REFERENCE

A Framework for Evaluating Material Management Performance in Jordanian Concrete Building Projects

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Volume I

DEDICATION

I dedicate this thesis to

Almighty ALLAH,

My great father (Gasim Alzohbi), my beloved mother (Aisha Alzoubi),

my dear wife (Khawla Alzuabi), and my sons (Little Gasim, Almoatasambillah, and

Ahmed) for their patience, encouragement, and waiting for me.

ABSTRACT:

The rapid growth of the construction sector in the Arab region of the Middle East, particular in Jordan, is expected to attract investments worth 21 billion U.S. dollars over the next five years (2012 – 2017). This growth has contributed to the increasing number and types of large-scale projects currently being undertaken, and also increased the use of building materials and the requirement for effective and efficient materials management services to ensure overall construction process performance. Studies have indicated that materials in building projects constitute about 60% of total project cost and control 80% of the project schedule. Inefficient materials management may therefore lead to an increase of 50% in work hours. Hence, there is a pressing need for measuring the effectiveness of the Construction Materials Management (CMM) process to provide a basis for the follow-up, and for evaluating and analysing the current performance of processes. The literature review of previous work, and pilot studies carried out to date, confirm that the effectiveness of the construction materials management process, and extent to which it meets the needs and expectations of construction operations has not been adequately defined or measured within building projects.

The primary aim of this research is therefore to establish a set of uniform measures for evaluating the Effectiveness of Construction Materials Management Performance (ECMMP), and to develop a framework for use within large-scale concrete building projects in Jordan.

The work adopts a mixed research methodological approach involving literature review and both qualitative and quantitative data collection techniques. The literature review process essentially explored the theory, and typical workflow diagram(s), to establish a set of measures that assess the effectiveness of material management performance in typical building construction projects.

Within the research main investigation, a case study project was also introduced where site visits and semi-structured interviews were carried out to establish a practical workflow diagram to reflect real-life CMM processes within Jordanian large-scale concrete building projects. This also included the identification of a set of measures to be used for evaluating the ECMMP on those building projects (Practical Effectiveness-Measures; P.E.Ms).

Based on the data collection and cross-cases analysis, a framework was developed to integrate practical effectiveness-measures within the practical workflow diagram of the CMM process, allowing an operational mechanism to communicate and operationalize those uniform measures within the workflow process (E.CMM.P Framework). This was followed by a framework validation designed to evaluate the functionality and appropriateness of the developed ECMMP through two techniques of formative and summative evaluations.

The E.CMM.P framework provides a new approach and methodology for evaluating, periodically and systematically, the effectiveness of the materials management performance. The framework not only brings about improvements in managing materials within Jordanian large-scale concrete building projects, but establishes a basis for unified standard benchmarking of performance for the materials management process in the Arab Construction Industry.

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TABLE OF CONTENTS:

DEDICATION I
ABSTRACT II
ACKNOWLEDGEMENTS III
TABLE OF CONTENTS IV
LIST OF TABLES XI
LIST OF FIGURES XIV
LIST OF ABBREVIATIONS XVI

CHAPTER I: INTRODUCTION:

1.0 INTRODUCTION OF THE CHAPTER 01
1.1 THE HISTORY AND DEVELOPMENT OF THE RESEARCH 01
1.2 RESEARCH STATEMENTS, QUESTION, AND PURPOSE 05
1.3 THE RESEARCH AIM AND OBJECTIVES 08
1.4 PREVIOUS STUDIES AND NECESSITY OF THE RESEARCH 09
1.5 RESEARCH METHODS ADOPTED 10
1.6 STRUCTURE OF THE THESIS 14
1.7 SUMMARY OF THE CHAPTER 17

CHAPTER II: SUPPLY CHAIN MANAGEMENT & LOGISTICS MANAGEMENT:

2.0 INTRODUCTION TO THE CHAPTER 18
2.1 SUPPLY CHAIN MANAGEMENT DEFINITION 18
2.2 DEVELOPMENT OF THE CONCEPT OF SCM 24
2.3 SUPPLY CHAIN MANAGEMENT IN CONSTRUCTION 26
2.3.1 Definition of Supply Chain Management in Construction Context 26
2.3.2 Roles of Supply Chain Management in Construction 29
2.4 SUPPLY CHAIN MANAGEMENT & LOGISTICS RELATIONSHIP 31
2.5 LOGISTICS DEFINITION 32
2.6 LOGISTICS MANAGEMENT 35
2.6.1 Logistics Management Role 35
2.7 LOGISTICS MANAGEMENT IN CONSTRUCTION 36
2.7.1 Logistics Functions in Construction 37
2.8 LOGISTICS AND MATERIALS MANAGEMENT 39
2.9 SUMMARY OF THE CHAPTER 42

CHAPTER III: CONSTRUCTION MATERIALS MANAGEMENT PROCESS:

3.0 INTRODUCTION TO THE CHAPTER 43

3.1 INTRODUCTION TO MATERIALS MANAGEMENT 43

3.1.1 What Are Materials? 43

3.1.2 Jordan Construction Materials 46

3.1.3 Construction Materials Addressed 47

3.2 MATERIALS MANAGEMENT IN CONSTRUCTION (CMM) 48

3.2.1 Definition of Materials Management 48

3.2.2 The Importance of Materials Management and Challenges Faced within the Construction Industry 50

3.2.3 Roles of the CMM Parties and Responsibilities 53

3.3 CONSTRUCTION MATERIAL MANAGEMENT PROCESS 57

3.3.1 Integration Functions 58

3.3.2 The CMM Process Boundaries and the Integrated Functions Adopted 64

3.4 IDENTIFYING THE TYPICAL CMM WORKFLOW DIAGRAM 66

3.4.1 Process Workflow-Diagram 67

3.4.2 Functional Workflow-Diagrams 69

3.5 SUMMARY OF THE CHAPTER 78

CHAPTER IV: EVALUATION APPROACHES AND MEASURES OF THE EFFECTIVENESS OF PERFORMANCE OF THE CMM PROCESS:

4.0 INTRODUCTION TO THE CHAPTER 79

4.1 EVALUATION MATERIALS MANAGEMENT PROCESS 80

4.1.1 Performance as an Evaluation Criterion 84

4.1.2 Effectiveness as a Process Measure 86

4.2 MEASUREMENT OF SUPPLY CHAIN MANAGEMENT (SCM) PERFORMANCE 88

4.2.1 SCM Performance Measures in Manufacturing Industry (MI) 88

4.2.2 SCM Performance Measures in Construction Industry (CI) 95

4.3 MEASUREMENT OF THE EFFECTIVENESS OF THE CMM PERFORMANCE IN INDUSTRIAL PROJECTS 99

4.4 ESTABLISHING A SET OF PROPOSED EFFECTIVENESS MEASURES TO EVALUATE THE PERFORMANCE OF THE CMM PROCESS 105

4.4.1 Flexibility as a Measure of SCM Performance 108

4.4.2 Definitions of the Attributes of the Proposed Effectiveness Measures Established 115

4.5 BENCHMARKING 124
4.5.1 Benchmarking Types 125
4.5.2 Benchmarking Models 130
4.5.3 Benchmarking in Construction Industry 135
4.6 SUMMARY OF THE CHAPTER 139

CHAPTER V: RESEARCH METHODOLOGY AND METHODS:

5.0 INTRODUCTION TO THE CHAPTER 141
5.1 RESEARCH METHODOLOGY 141
5.1.1 Types of Research 142
5.1.1.1 The Research Types according to their Purpose 142
5.1.1.2 The Research Types Classified on the Basis of Logic 142
5.1.1.3 The Research Types according to their Outcome 145
5.1.1.4 The Research Types Classified on the Basis of Process 146
5.2 RESEARCH PHILOSOPHY 146
5.2.1 Ontology 149
5.2.2 Epistemology 150
5.2.3 Choosing a Philosophy of Research 154
5.3 RESEARCH APPROACHES 157
5.3.1 Qualitative Research 158
5.3.2 Quantitative Research 159
5.3.3 The Mixed Research (Triangulation) Method 162
5.4 RESEARCH TECHNIQUES 165
5.5 RESEARCH STRATEGY DECISION & SELECTION METHODS 166
5.5.1 Selection of the Research Philosophy and Methodology 167
5.5.2 Selection of Case Studies Strategy/Approach 170
5.5.2.1 The Case study Research Design 171
5.5.2.2 Case Study Protocol 174
5.5.2.3 Framework for Designing, Collecting and Analysing Data 179
5.5.3 Selection of Data Collection Techniques 181
5.5.3.1 The Interview Selection 181
5.5.3.2 The Questionnaire Selection 184
5.5.3.3 The Questionnaire Sampling Size for this research 185
5.6 RESEARCH DESIGN AND ADOPTED RESEARCH METHOD 187
5.6.1 The Research Data Collection Process 188
5.6.1.1 Literature review 188

5.6.1.2 The Main Investigation 191
5.6.1.3 The Questionnaire Survey 195
5.6.2 Developing the E.CMM.P Framework 197
5.6.3 Validity of the Research and the Framework 199
5.6.3.1 Research Validity and Reliability 199
5.6.3.2 Assurance of Research Validity and Reliability 200
5.6.3.3 Framework Validation 201
5.6.4 The Research Pilot Studies 202
5.6.5.1 Pilot Studies Conducted in the research project 202
5.7 ETHICAL CONSIDERATIONS 206
5.8 SUMMARY OF THE CHAPTER 207

CHAPTER VI: QUALITATIVE DATA ANALYSIS AND DISCUSSION:

6.0 INTRODUCTION TO THE CHAPTER 208
6.1 AN OVERVIEW ON JORDANIAN CONSTRUCTION IDUSTRY 208
6.1.1 Jordan Location 209
6.1.2 Jordan Construction Industry (J.C.I) 210
6.1.3 Construction Management in the J.C.I 211
6.1.4 Jordanian Construction Materials Management in Literature 212
6.1.5 Construction Projects and Contractors in Jordan 214
6.2 CASE STUDY DATA COLLECTION METHODS 215
6.3 CASE STUDY DATA ANALYSIS METHODS 217
6.4 A CASE STUDY REPORT 218
6.5 CASE STUDY PROJECTS 221
6.5.1 CASE C: Military Hospital Project 223
6.5.1.1 Project Description/Background 223
6.5.1.2 Organisation Profile 225
6.5.1.3 Data Collection Process Conducted 225
6.5.1.4 The Process of CMM Practiced 225
6.5.1.5 Evaluation Approaches and Measures of the CMM Performance 234
6.5.1.6 Terminology 237
6.6 ANALYSIS OF THE CASE STUDIES' OUTPUT 240
6.6.1 The Process of CMM Practiced within the J.C.I 240
6.6.1.1 The Characteristics of the CMM Process within the J.C.I 240
6.6.1.2 The Functions that form the CMM Process in the JCI 245
6.6.1.3 Developing Practical Workflow Diagram of CMM process Practiced within the J.C.I 260

6.6.2 The Measures of the Effectiveness of CMM Performance within the J.C.I 264
6.6.2.1 An Overview of Mechanisms of Monitoring and Evaluating of the CMM Process Practiced within the J.C.I 264
6.6.2.2 Practical Effectiveness Measures of the Performance of CMM process Practiced within the J.C.I 267
6.6.2.3 Establishing a Set of Practical Effectiveness Measures (P.E.M) that is and/or can be implemented in J.C.I 296
6.7 SUMMARY OF THE CHAPTER 315

CHAPTER VII: QUANTITATIVE DATA ANALYSIS AND DISCUSSION:

7.0 INTRODUCTION TO THE CHAPTER 317
7.1 ANALYSIS METHODS AND TECHNIQUES 317
7.2 ANALYSIS OF THE QUESTIONNAIRE'S OUTPUTS 320
7.2.1 Section 1 Analysis: Respondents Background Information 321
7.2.2 Section 2 Analysis: Evaluation of Effectiveness Measures 326
7.2.2.1 Evaluation of Measures' Utilization 326
7.2.2.2 Evaluation of Measures' Importance 331
7.2.2.3 Evaluation of Measures' Practicality 338
7.2.2.4 Barriers of Measures' Implementation 352
7.2.3 Section 3 Analysis: Additional Measures 356
7.2.4 Section 4 Analysis: Evaluation the Developed Practical Workflow Diagram of the CMM Process 359
7.3 SUMMARY OF THE CHAPTER 365

CHAPTER VIII: DEVELOPMENT OF THE E.CMM.P FRAMEWORK:

8.0 INTRODUCTION TO THE CHAPTER 366
8.1 STRUCTURE OF THE FRAMEWORK & SOURCE OF DATA 366
8.2 PHASE I: DEVELOPING THE PRACTICAL WORKFLOW DIAGRAM OF CMM PROCESS IN THE J.C.I 370
8.3 PHASE II: ESTABLISHING A SET OF PRACTICAL EFFECTIVENESS MEASURES (P.E.MS) 381
8.4 PHASE III: SETTING OUT AN OPERATIONAL MECHANISM AND DESIGNING THE FINAL E.CMM.P FRAMEWORK 389
8.4.1 Setting up the Operational Mechanism 389
8.4.2 Designing the E.CMM.P Framework 394
8.4.3 An Explanatory Scenario for the E.CMM.P Framework Application 398
8.5 SUMMARY OF THE CHAPTER 403

CHAPTER IX: THE E.CMM.P FRAMEWORK VALIDATION:

9.0 INTRODUCTION TO THE CHAPTER 404
9.1 THE VALIDATION AIM AND OBJECTIVES 404
9.2 THE E.CMM.P FRAMEWORK VALIDATION PROCESS 405
9.2.1 The Framework Formative Evaluation 405
9.2.2 The Framework Summative Evaluation 408
9.2.2.1 Feedback and Analysis 410
9.2.2.2 Summary of the findings of the Framework Summative Evaluation 425
9.2.2.3: Some Actions related to Research Validation 425
9.3 SUMMARY OF THE CHAPTER 427

CHAPTER X: CONCLUSION:

10.0 INTRODUCTION TO THE CHAPTER 429
10.1 KEY CONCLUSIONS 429
10.2 THE SIGNIFICANCE AND CONTRIBUTION TO KNOWLEDGE 439
10.3 LIMITATIONS OF THE RESEARCH 442
10.4 RECOMMENDATIONS FOR FURTHER RESEARCH 443
10.5 CONCLUDING REMARKS 444

REFERENCES 446

APPENDICES:

APPENDIX A: LITERATURE REVIEW PROCESS PLAN DIAGRAM A-1
APPENDIX B: PLEMMONS'S CMM PROCESS DIAGRAM B-1
APPENDIX C: THE SPSS CODE BOOK C1-C2
APPENDIX D: THE RESEARCH KEYS-OF-CONTACT D-1
APPENDIX E: PICTURES THAT DOCUMENT CASE STUDIES SITE VISITS E1-E3
APPENDIX F: THE MAIN SUBJECTS AND QUESTIONS OF THE INTERVIEW F1-F2
APPENDIX G: THE QUESTIONNAIRE SURVEY G1-G11
APPENDIX H: PICTURES THAT DOCUMENT THE PILOT STUDY I H-1
APPENDIX I: PICTURES THAT DOCUMENT THE PILOT STUDY II I-1
APPENDIX J: CASE STUDIES' REPORTS: PRESENTING THE CASE STUDIES OUTCOMES:
CASE A: THE CANCER CENTRE BUILDING PROJECT J1-J21
CASE B: PRESIDENTIAL RESORT & FIVE STAR HOTELS J22-J34

CASE D: HUGE IKEA STORE PROJECT J35-J48
CASE E: THE HOTEL-TOWER PROJECT J49-J63
CASE F: MODERN RURAL VILLAGE J64-J78
APPENDIX K: NODE SCREEN DISPLAY (NVIVO) K-1
APPENDIX L: THE DETAILED E.CMM.P FRAMEWORK L-1
APPENDIX M: THE ANNUAL CONFERENCE OF THE JORDANIAN CONSTRUCTION CONTRACTORS ASSOCIATION (JCCA) M-1
APPENDIX N: PUBLICATION ABSTRACT N-1
APPENDIX O: PUBLISHED POSTER O-1
APPENDIX P: THE PARTIES, FUNCTIONS, AND ACTIVITIES INVOLVED IN THE CMM PROCESS P1-P15
APPENDIX Q: DESCRIPTIONS OF THE PROPOSED EFFECTIVENESS MEASURES OF THE CMM PERFORMANCE Q1-Q15

LIST OF TABLES:

Table 1.1: A Summary of the Role of Methods Adopted for achieving the Research Objectives 11

Table 2.1: Different Terminologies of SCM 20

Table 2.2: A sample of SCM definitions 21

Table 2.3: A Sample of the Recent Definitions of SCM 22

Table 2.4: A Classification of SCM 22

Table 2.5: Comparison of Manufacturing and Construction Supply Chain 26

Table 2.6: Defining the SCM in the context of Construction Industry 28

Table 2.7: Logistics Definitions 33

Table 3.1: Classification of Construction Materials 45

Table 3.2: The Importance of Materials Management in Construction 52

Table 3.3: Parties Involved in the Construction Materials Management (CMM) 53

Table 3.4: Summary of the Theoretical Studies on the Process of the CMM 60

Table 4.1: Summary of the literature that highlights the limitation of studies related to evaluating or measuring material management performance in construction industry 81

Table 4.2: Measures of Supply Chain Performance Reported in the Literature 89

Table 4.3: Measures of SCM Performance 90

Table 4.4: A framework of the metrics for the performance evaluation of a Supply Chain 91

Table 4.5: A framework for Measuring SCM Performance 92

Table 4.6: Performance Metrics of SCM based on the Six Measurement Perspectives 93

Table 4.7: A Framework for Measuring the Supply Chain Management Practices 94

Table 4.8: Assessment Efforts of Construction Supply Chains 96

Table 4.9: Project Supply Chain Performance Metrics 98

Table 4.10: The Key Measures of Material-Management Effectiveness and Those for Benchmarking 100

Table 4.11: The Key Effectiveness Measures in Industrial Construction Projects (ICPs) 102

Table 4.12: The Importance Rank of the Performance Effectiveness-Measures in Industrial Construction Projects (ICPs) 103

Table 4.13: The Rank of the CMM Effectiveness-Measures in terms of their Practicality in Industrial Construction Projects (ICPs) 104

Table 4.14: The Proposed Measures for Assessing the Effectiveness of Building Materials Management with Six Attributes 107

Table 4.15: Summary of some Types of Flexibility related to SC/SCM; They are specified by the Literature 109

Table 4.16: The Proposed Effectiveness-Measures for assessing the Performance of the Building Materials Management Process with Seven Attributes 120

Table 4.17: Some Definitions for Benchmarking that have been found in the Literature 124
Table 4.18: Taxonomy for Benchmarking Models 131
Table 5.1: The Research Types 142
Table 5.2: Categorization of Research Methods based on the research purpose 143
Table 5.3: A Summary of Some Philosophical Considerations 153
Table 5.4: Summary of the Characteristics of the Qualitative and Quantitative Methods 161
Table 5.5: Four types of triangulation 164
Table 6.1: Describing the Data Collection Techniques Used 216
Table 6.2: List of Projects Involved in the Case Studies 223
Table 6.3: Responsibility Matrix for Managing Materials in the Case Study C 239
Table 6.4: Matrix: A Summary of Practical Measures, Approaches, and Techniques of Evaluating the CMM Performance Practiced within the Case Studies 269
Table 6.5: Classification of the Practical Measures, Approaches, and Techniques of Evaluating the CMM Performance Practiced within the Case Studies 298
Table 6.5.1: The New Practical Measures, Approaches and Techniques Practiced in the Case Studies 299
Table 6.6: The Set of Practical Effectiveness Measures (P.E.Ms) that Can be Used for Evaluating (E.CMM.P) in the Large-scale Concrete Building Projects within the J.C.I 312
Table 7.1: Frequency Analysis of Respondents' Position Title 321
Table 7.2: Frequency Respondents for the Perspective that has been Chosen to answer the Questionnaire's Questions 322
Table 7.3: Respondents' Years of Experience 323
Table 7.4: Estimated Cost of the Case Projects and the Size of these Projects 325
Table 7.4a: Reliability Analysis for the Estimated Cost of the Projects and the Size of these Projects 325
Table 7.5: Types of the Projects Contracts 326
Table 7.6: The Positive Responses' Frequency and Percentage of the Utilization of Proposed Effectiveness Measures 328
Table 7.7: Descriptive Analysis (Scores and Median) and Validity and Reliability Analysis of Scales for the Importance of the Proposed Effectiveness Measures 332
Table 7.8: The Importance-Rank of the Proposed Effectiveness Measures by Means Scores ... 336
Table 7.9: Descriptive Analysis (Scores and Median) and Validity and Reliability Analysis of Scales for the Practicality of the Proposed Effectiveness Measures 340
Table 7.10: The Practicality-Rank of the Proposed Effectiveness Measures by Mean Score 344
Table 7.11: A Comparison between the Importance and Practicality of the Effectiveness-Measures and the Values of the Association's Tests 347
Table 7.12: A Comparison of the Importance Ranking with the Practicality Ranking of the Proposed Effectiveness Measures by the Means Scores 350
Table 7.13: Barriers that can hinder the Implementation of the Proposed Effectiveness

Measures within the J.C.I 354

Table 7.14: The Evaluation of the Practical Construction Materials Management Process (PCMMP) Workflow Diagram Developed 363

Table 8.1: The description of the Practical Effectiveness Measures (P.E.Ms) that can be used for Evaluating (E.CMM.P) within the Jordanian Large-scale Concrete Building Projects 385

Table 9.1: Details of Evaluators who participated in Summative Evaluation 410

LIST OF FIGURES:

Figure 2.1: The Simple Structure of the Supply Chain 19

Figure 2.2: Integrated Logistics Management and Developing the Concept of SCM 25

Figure 2.3: The Four Major Roles of the Supply Chain Management in Construction 30

Figure 2.4: The Four Perspectives concerning the Relationship between SCM and Logistics ... 32

Figure 2.5: The System of Logistics in A Construction Organization 38

Figure 2.6: Logistics Activities divided into Materials Management and Physical Distribution 41

Figure 2.7: The Materials Management within the Logistics 42

Figure 3.1: The Responsibility Matrix of CMM Process 55

Figure 3.2: Responsibilities Flowchart for CMM process 56

Figure 3.3: Flowchart Construction Materials Management System 58

Figure 3.4: The System's Theory: Basic System Components 67

Figure 3.5: Process Hierarchy: The Hierarchy of Integrated Functions and Basic Activities within a Process 68

Figure 3.6: The Typical Workflow Diagram of Materials Management Process in the Construction Industry 71

Figure 3.6.1: Typical Planning Function Diagram 73

Figure 3.6.2: Typical Material Take-off & Design Interface Function Diagram 73

Figure 3.6.3: Typical Vendor Inquiry & Evaluation Function Diagram 74

Figure 3.6.4: Typical Purchasing Function Diagram 74

Figure 3.6.5: Typical Expediting & Transportation Function Diagram 75

Figure 3.6.6: Typical Quality Management Function Diagram 76

Figure 3.6.7: Typical Field Control and Warehousing Functions Diagram 77

Figure 4.1: Dimension of Performance Measurement System 97

Figure 4.2: the Basic Classification Scheme for Benchmarking 129

Figure 4.3: Benchmarking Process Compared to Deming Cycle 132

Figure 4.4: Five-Step Benchmarking Model 132

Figure 4.5: Xerox Benchmarking Model: Benchmarking Process Steps 134

Figure 4.6: Integration of Clearinghouse and Benchmarking Procedures 138

Figure 4.7: Integration of Clearinghouse and Benchmarking Procedures – CIAG Clearinghouse Model 139

Figure 5.1: Research Types on the Logic Basis (Deductive and Inductive) 145

Figure 5.2: A Nested Research Methodology 148

Figure 5.3: The Research Onion 148

Figure 5.4: Triangulation of Qualitative and Quantitative Data 162
Figure 5.5: Breadth and Depth in Question-based Studies 166
Figure 5.6: Selection of the Research Methodology 167
Figure 5.7: The Components and Steps of the case study design 172
Figure 5.8: The Geographical Distribution of the Case Studies Selected in Jordan 178
Figure 5.9: The Case Study Protocol Framework: Designing and conducting the case studies .. 180
Figure 5.10: Flowchart of the Research Process 189
Figure 6.1: Jordan's Map: The International Boundary 209
Figure 6.2: Collection of Some Pictures for the Case Study C 224
Figure 6.3: The Project Team Structure as Related to CMM Process in Case Study C 227
Figure 6.4: The Practical Workflow Diagram of the CMM Process within Case Study C 233
Figure 6.5: A Summary for the Workflow Diagrams of the CMM Processes Practiced within the Six Case Studies 247
Figure 6.6: The Practical Workflow Diagram of the CMM Process Practiced in the J.C.I 262
Figure 7.1: The Percentages of the Type of Projects 324
Figure 7.2: The Percentages of the Type of Organisations 324
Figure 7.3: Venn diagram of Positive Responses Group1 (in Current Use) and Group2 (Potential Use) 330
Figure 7.4: Graphically, Ranking of the Importance of the Proposed Effectiveness Measures by Means Scores 337
Figure 7.5: Graphically, Practicality Ranking of the Proposed Effectiveness Measures by Means Scores 345
Figure 7.6: Graphically, a Comparison of the Importance Ranking and the Practicality Ranking of the Proposed Effectiveness Measures by 'Mean Scores' 351
Figure 7.7: Graphically, the Evaluation of the Developed Practical Workflow Diagram of the Construction Materials Management Process (PCMMP Workflow Diagram) 364
Figure 8.1: Figure 8.1: The Phases and Stages of the process of the Development of the E.CMM.P Framework, and the Data Sources employed 369
Figure 8.2: Developed Practical Integrated Workflow Diagram for the Functions that form the Practical CMM Process within the J.C.I 372
Figure 8.2.1: Developed Practical Planning Function Diagram 376
Figure 8.2.2: Developed Practical Material Take-off & Design Interface Function Diagram ... 377
Figure 8.2.3: Developed Practical Material Procurement & Transportation Function Diagram . 378
Figure 8.2.4: Developed Practical Field Control & Warehousing Functions Diagram 379
Figure 8.2.5: Developed Practical Quality Management Function Diagram 380
Figure 8.3: Operational Mechanism of Operationalizing the Practical Effectiveness-Measures within the E.CMM.P Framework 393
Figure 8.4: The Developed E.CMM.P Framework 397

LIST OF ABBREVIATIONS:

A.C.I	Arab Construction Industry
AICI	Arab Industrial Construction Industry
BBS	Bar Bending Schedule
BEC	Bid, Evaluate, and Commit
BOQ	Bill Of Quantity
CI	Construction Industry
CMM	Construction Materials Management
CSM	Construction Site Manager
E.CMM.P	Effectiveness of Construction Materials Management Performance
EDI	Electronic Data Interchange
E.M.R Form	External Material Request Form
ESD	Early Start Date
F.L	Field Level
FND	Field Need Date
I.C.I	Industrial Construction Industry
ICPs	Industrial Construction Projects
I.M.R Form	Internal Material Request Form
JCCA	Jordanian Construction Contractors Association
J.C.I	Jordanian Construction Industry
JEA	Jordanian Engineers Association
JISM	Jordanian Institution for Standards and Metrology
K.E.M	Key Effectiveness-Measures
K/P.E.Ms	Key Effectiveness Measures or Practical Effectiveness Measures
LCI	Libyan Construction Industry
LM	Logistics Management
M.D.S Report	Material Delivery Status S Report
MHR	Ministry of Housing and Reconstruction
MI	Manufacturing Industry
M.I.R	Materials Inspection Request
MM	Material Management
SCM	Supply Chain Management
MPWH	Ministry of Public Works and Housing
M.S.L	Material Submittal Log
NDW Form	Notification of Delivery to Warehouse (NDW) Form
O.L	Organisational Level

O.S&D List/Report	Over, Short and Damaged List/Report
(OS&D) status	Over, Short, and Damage status
P.CMM.P	Practical Construction Materials Management Process
P.E.M	Practical Effectiveness-Measures
PM	Project Manager
PO(s)	purchase order(s)
QA	Quality Assurance
QC	Quality Control
RFQ(s)	Requisitions/Request For Quotation(s)
R.M.A Form	Request for Material Approving Form
R.M.S Form	Request Material from Site-Store Form
R.M.W Form	Request Material from warehouse Form
R.Q.C Report	Receiving Quality Control Receiving Quality Control Report
R.S.B Sheet	Reinforcement Steel Bars Sheet
Variation Order	VO

CHAPTER I:

INTRODUCTION

1.0 INTRODUCTION OF THE CHAPTER:

Chapter one is intended to familiarise the reader with the background, purpose and subject area of the research. The chapter starts with an overview of the history of this research and the evolution of the study. It briefly presents the previous studies that have been conducted on the subject in order to shed light on the necessity and the significance of the research to bridge the gap in those studies and to make contribution to knowledge and society. The purpose, aims, and objectives of this research are also outlined. The chapter also presents an overview of the research methodology clarifying the methods and procedures that were applied to develop this research. Lastly, the chapter describes the structure of the thesis.

1.1 THE HISTORY AND DEVELOPMENT OF THE RESEARCH:

The thesis of this research is originally based on feedback obtained from the researcher`s previous experience of working in the construction projects and their related processes and operations in Libya over the past fifteen years. The researcher has carried out various tasks and held different posts from being an engineer, a construction site manager, a construction supervisor to a project manager and he has observed many problems facing the construction's participants during the implementation stages; they dramatically influenced the completion of projects, especially within the large-scale concrete projects. The primary analysis of these problems has revealed that mostly they are associated with poor materials management. The researcher, therefore, dedicated his master's study to "investigate the problematic issues associated with construction site management conducting a case study on the Great Man-made River Project in Libya. The findings of the MSc research revealed that the lack of proper materials management was the most frequent problem facing construction site management and the third most important problem, in terms of their effect on managing the construction site (Alzohbi, 2008).
This finding prompted the researcher to consider the issue of Construction Materials Management (CMM) in his PhD study two years later. However, formulating the PhD topic requires an intensive study and an in-depth investigation for identifying the specific research area, the main research statement and question, the study's purpose, and its significance and contribution to knowledge. For this purpose, a primary work plan was developed to manage a course of actions for accomplishing this purpose, which included the following actions:

➢ **Desk-top Review:** Determining a specific topic or a problem in the context of Construction Materials Management (CMM) required, at the first stage, performing a desk-top review. This process included reviewing dozens of the previous theses, associated papers, related studies, and some selected books. As a result, the subject of material management within the construction industry was found to be one of the most interesting current issues. Furthermore, it has many aspects that are still ambiguous and need further investigation. The findings of the researcher's MSc study demonstrated that the lack of proper materials management was the most frequent problem facing the construction site managers; it was also inferred that construction material management, for a long time, has been an obsession for the project engineers and managers. According to Saad (1996), Kornelius and Wamelink (1998), Vrijhoef and Koskela (2000), Al-Khalil *et al.*, (2004), Alzohbi (2008), and Najmi (2011), the major part of the construction processes' problems regarding delays, budget overruns, quality, controllability, waste, and others, are associated with the problems of supplying construction materials. In order to reduce time and money consumed for procuring, managing and using materials, many attempts have been made by the contractors and employees in the construction area, including performing a number of intentional changes and modifications, installing computerized applications and updated technologies, and implementing new strategies and systems. However, during the desktop review process, a significant question was raised, and no answer has been found: "how the impact of these changes and applications can be checked and evaluated in order to identify the extent of their effectiveness, suitability, and the need for more improvement or replacement. With this question in his mind, the researcher moved to the next stage.

➢ **Site Visits (Pilot Study I):** Based on the knowledge that has been derived from the previous step, a decision was made to pay informal visits to the construction sites in the researcher's home country (Libya), in order to expand the researcher's knowledge about the CMM issues and to specify the pivotal points which need to be addressed in the research. This stage was named, later as 'the First' Pilot Study'. Unofficial and unstructured personal interviews formed the central technique utilized for obtaining the required information from the site visits. The key stages that were involved in this pilot study were the following:

1- Interviewing the previous General Director of the Research Centre for Construction Materials in Libya, who was interested in the topic. Within the interview that was held in his office in Tripoli, many vital issues regarding construction management in Libya, in particular, materials management, were discussed, and the sites that would be visited along with the people who would be interviewed during the visits were determined.

2- Visiting three types of large-scale construction projects: a Public Housing Project and a Semi-Public International Investment project in Tripoli, and a State Project in town of Sirte. Upon visiting these construction sites, many interviews were conducted with project managers, construction site managers, materials managers, and consultants; they were questioned about the issue of managing the building materials, with a slight focus on the extent of the effectiveness of the current used approaches or strategies of construction materials management.

3- Conducting interviews with some decision makers in the Libyan Construction Industry; among them are the Secretary-General People's Committee for Housing and Facilities – the Central Zone, the General Projects Manager at the General People's Committee for Housing and Facilities and the Senior Manager of Technical Affairs and Planning Department in the Great Man-made River, the Water Utilization Authority – Central Zone.

Generally, among the most significant findings obtained from these interviews and discussions, were:

- Poor construction materials management system was one of the most important problems facing the site managers; the extent of the effectiveness of the currently used approach of managing the construction materials is still unclear and unquantified.
- The lack of specific parameters for evaluating the extent of the effectiveness of any change or strategy that might be applied on the materials management process to improve its performance.
- The use of the cost and benefit approach (at the end of a financial year) is the only traditional method employed to evaluate the effectiveness of any new strategy that might be implemented on the materials management system.

- Although there are some general regulations, there is no a Libyan standard or a specific regulation for managing materials within the construction site.

It can be concluded that the subject of construction materials management is very important and that it has a significant effect on carrying out the construction projects successfully. Moreover, the lack of a specific mechanism to evaluate the effectiveness of materials management performance confirms the need for further investigations in this field. It is interesting to know that during the visits, one of the interviewees was asking, with astonishment, "*Is it possible to create a machine that can give an indication whether or not the materials management system or strategy used is on the right track? I mean, whether or not it is effective*".

➢ **Formulating the PhD Topic:** Based on the previous desk-top study and the first Pilot Study that were performed, it was decided that the performance of construction materials management would be the focal area of the study and that it was necessary to perform in-depth review of the CMM-related literature. Therefore, the review of literature on materials management has been conducted, with more emphasis on the topic of evaluating the effectiveness of materials management performance. As a result, it was found out that there is a pressing need for measuring the performance of the materials management process to provide a basis for assessing and analysing the impact of any improvements or changes on the materials management process and upon the overall construction industry (James *et al*., 1995; Hoyle, 1995; Plemmons and Bell, 1995; Rolstands, 1995; Waggoner, Neely and Kennerley, 1999; Gunasekaran, Patel and Tirtiroglu, 2001; Al-Khalil *et al*., 2004; Öztaş, Güzelsoy and Tekinkuş, 2007; Hotmoko, 2008, among others). However, throughout the extensive search of the literature on quantifying the effectiveness of materials management process, no relevant references can be found within the building construction projects (see **Table 4.1**). Although the issue of measuring the performance is the focus of many academics and professional's attention recently, it is still very limited in the construction industry, and it might be absent in the area of building materials management. Consequently, the primary aim of the research was to develop a uniform set of measures to evaluate the effectiveness of the construction materials management performance. However, there are different types of construction projects and a huge number of construction materials types.

➢ **Identifying the Scope of the Study:** moving from generality to specificity; delimiting the research area and specifying the type of projects and the type of construction materials, which would be addressed in the research, was thought to be necessary. A number of authors and researchers such as, Ibn-Homaid (2002), Shakantu (2004), and Al-Haddad (2006) believe that the material management process of small projects does not have particular criteria or standardized procedures, and that it is dependent on the person's behaviour and talents. For more reliable and valid research findings, it was decided to conduct this study on Large-Scale Projects.

With regard to the types of the construction projects; the projects can be categorized into '*Building*' projects (Concrete/ Steel residential/ non-residential), '*infrastructure*' projects (highways, roads, dams, harbours, etc.) and '*Supply Drinking Water and Discharge of Sewage*' projects (Harris and McCaffer, 2001). However, Grifa (2006, p392) in his study on the Libyan Construction Industry pointed out the following:

> *"It is observed throughout the visual and the empirical survey that cement, steel, sand, aggregate and water are the most important construction materials in the Arab construction projects,....., in particular, skeleton stage where the majority of these materials are used ....Also, it is recognized that the current operations of the LCI is cement-based. Thus, construction skills, knowledge, and technology in Libya are generally related to the concrete industry."*

This inspired the researcher to focus on 'the Construction Concrete Building Projects – the Skeleton Stage' as the main case of study.

In the light of the above discussion, the research primary title, aim, and objectives, which reflect the main job intended to be implemented, were agreed on, and the uniqueness of the research was crystallized. The initial research title was "*Investigating and evaluating the Effectiveness of Construction Materials Management Performance in the Large-scale Concrete Building Projects in the Jordan*" (see **Section 5.5.2.2**, the rationale of selecting Jordan). During the PhD research progress, the aim and objectives have been slightly modified until they have reached the current status as illustrated in **Section 1.3**.

1.2 RESEARCH STATEMENTS, QUESTION, AND PURPOSE:

The initial idea and the main question of the research and then its aim and objectives were based on some statements that were realized through the initial literature review. Previous published researches and statements by prominent construction leaders and experts over the past three decades have emphasised the need for uniform measures and a benchmarking mechanism for assessing and analysing the impact of technology, change and other improvements upon the overall construction industry, and in particular, the process of materials management. The Construction Industry Cost Effectiveness (CICE) Report, which was issued by the Business Roundtable in 1982, recommended that the contractors and owners should "*develop standards of performance for materials management activities*". Referring to this situation, Stukhart and Bell (1985) stated:

> "*To justify the expenditures, there has to be some means of measuring comparative performance; that is, some set of attributes or standards for industry.*"

Fisher, Miertschin and Pollock (1995) make reference to Oswald and Burati (1992) when discussing the connection among continuous improvements, measures, and benchmarking;

> *"The continuous improvements and changes, to be verifiable, must be measurable. This is accomplished by the use of "metrics": measureable outcomes that indicate degree of success in achieving some continuous improvements (Oswald and Burati, 1992). "To determine the degree of success, one must compare between things. The process of determining the value of metrics, which process measurements are to be compared against, is known as benchmarking (Fisher, Miertschin and Pollock, 1995)"*

With regard to the status of benchmarking activities within the construction industry, Fisher, Miertschin and Pollock (1995) concluded;

> *"...currently there are no available benchmarked standards for the construction industry, nor is there a non-profit organisation established for the purpose of collecting data and information in the industry for benchmarking"*

In response to this, Turker (1995) believes that apart from 'benchmarked standards', there are actions that project managers can take to assess improvements and to increase the chances of success. He addressed the issue by making a suggestion included within this comment;

> *"...use data to prove that the new approaches work. Compare old projects and old ways to the new ideas and the projects planned and executed using new ideas. Compile lessons learned and project databases that can be used for*

benchmarking and other quality measurements. Such metrics are a necessity in tracking progress (Turker, 1995)."

Stukhart (1995) confirmed this approach, which can be called comparison technique or self-benchmarking. Stukhart views, in his book that was published in 1995, that the lack of a standardised benchmark can be compensated by using the comparison technique through comparing the effectiveness of a current or a new system to the previous one:

> "*One materials system can be analyzed for its overall effectiveness and compared with other alternatives. For example, an existing materials system that does not use automatic identification could be compared with one that does, or a manual system could be compared with a computerized system. Ideally, there must be a way to measure the system's performance (Stukhart, 1995)*".

More recent statements and studies still stress the necessity for developing uniform effectiveness measures and measurement mechanisms for assessing and tracking the CMM process improvements in different construction industries. Al-Khalil *et al.* (2004) refers to Plemmons and Bell (1995) to confirm the need of the Arab Industrial Construction Industry (A.I.C.I) for effectiveness measures:

> "*A need exists within the industrial construction industry to measure the effectiveness of the materials management process to provide a basis for analysing the impact of process changes on the process performance (Plemmons and Bell, 1995). A measurement of the effectiveness of the materials management process is needed because, without measurement, documenting and benchmarking the impact of intentional changes is limited (Al-Khalil et al., 2004).*"

Based on the above statements along with the initial investigation processes (the desk-top study and the first Pilot Study) that were performed earlier in the research, the main question and the purpose of the research are crystallized.

The Research Main Question: 'how the impact of any strategies, systems, or applications, which are currently applied on the CMM process, can be evaluated in order to identify the extent of their effectiveness, suitability, and the need for extra improvement or replacement?'

The Research Main Purpose: 'to develop or propose a mechanism or a framework for measuring the effectiveness of the performance of CMM process in order to provide a basis for analysing and evaluating the impact of the continuous improvements that can be made on this process'.

In order to answer the research question and to achieve the research purpose, the aim and the objectives that guide the accomplishment of this study have been developed as stated in the next section.

1.3 THE RESEARCH AIM AND OBJECTIVES:

The primary aim of this research is "*to establish a set of uniform measures for evaluating the effectiveness of construction materials management performance and to develop a framework for their use within the large-scale concrete building projects in the Jordanian Construction Industry*". To achieve this aim, the following objectives and sub-objectives have been formulated:

1- To critically review the existing literature on materials management processes and to identify, theoretically, the typical workflow diagram(s) of the material management process in the construction industry.

2- To identify and assess the material-related measures used within the construction industry (or may be other industries) and to establish a proposed set of measures to evaluate the effectiveness of the performance of the Construction Materials Management (CMM) process in construction projects,

3- To develop a practical workflow diagram for communicating the integrated functions and activities that form the CMM process within the large-scale concrete building projects in the Jordanian Construction Industry (J.C.I); this involves:
   - Investigating the current practices of CMM process,
   - Re-shaping the typical workflow diagram of the CMM process to reflect the real-life CMM processes that are practiced within the large-scale concrete building projects in the J.C.I.

4- To evaluate the proposed set of measures, and to determine the Practical Effectiveness-Measures (P.E.Ms) that can be applied within CMM process in the Jordanian large-scale concrete building projects; this includes:
   - Examining the current measures, mechanisms, or approaches that are used for evaluating the performance of the CMM process,

- Reformatting and/or reformulating the measures and approaches to reflect the effectiveness ratio, and identify the P.E.Ms,
- Determining the barriers that hinder the implementation of proposed measures.

5- To develop and validate a framework for operationalize the P.E.Ms for evaluating the Effectiveness of the CMM Performance (E.CMM.P Framework) within the large-scale concrete building projects in Jordan.

1.4 PREVIOUS STUDIES AND NECESSITY OF THE RESEARCH:

Various research studies have demonstrated how materials management can be improved; these include studies conducted by Stukhart and Bell (1985), Bell and Stukhart (1986), Dodd et al., (1987), the Construction Industry Institute (1988), Muya (1999), Shakantu (2004), Binti Kasim (2008) and many others. However, the evaluation of the impact of these improvements and the extent of their effectiveness has still been a subject of controversy. Based on the in-depth review of the related literatures, it was found out that the issue of the performance measurement of the supply chain management is a contemporary issue in academic and applied studies in manufacturing industry. These studies are carried out by Dixon, Nanni and Vollmann (1990), Das (1996), Yuthas and Young (1998), Beamon (1999), Gunasekaran, Patel and Tirtiroglu (2001), Ibn-Homaid (2002), Otto and Kotzab (2003), Bhatnagar and Sohal (2005), Gunasekaran, Patel and McCaughey (2004), Wu and Liu (2008) and Jabbour et al., (2011); however, they are still very limited to the construction industry (see **Section 4.1** and **Table 4.1**). Though some attempts have been made to measure the supply chain management performance in construction industry such as those by Love and Holt (2000), Wegelius-Lehtonen (2001), Venkataraman (2004), Nudurupati (2007) and Hatmoko (2008), it is worth pointing out that most (if not all) of those attempts have focused on measuring the performance of the supply chain process or the supply chain management in the construction industry, but not on a particular materials management process, which is the main issue of this research.

With regard to the measurement performance of the materials management process in construction industry, very limited empirical studies have been conducted (see **Sections 4.2.2** and **4.3**). The Business Roundtable study team in 1982 made the first effort to define the measures of the performance of materials management. The performance standards, which were to be used to plan and control materials management for construction projects, were evaluated on the basis of the cost benefit or work hours. Moreover, it was revealed that "*a single measure, comparable across all projects, was not feasible but that certain guidelines, based on historical data, could provide reasonable criteria for evaluation*" (Stukhart, 1995). That effort was followed by attempts made by Plemmons in 1994 and 1995 to identify the effectiveness measures of the materials management process that was applied in the American industrial projects. After that, few studies were undertaken in the Kingdom of Saudi Arabia on the possibility of using some of these measures in the Saudi oil industries projects, by Al-Darweesh (1999), Al-Khalil (2004), Al-Juaid (2005), and Al-Alawi, Al-Ghazwi and Al-Saeed (2007). It is worth noting that all of these studies utilized empirical approaches, which have been increasingly applied by scholars on the operation and supply chain management research in the past several years (Boyer and Swink, 2008). Furthermore, these studies were conducted on the industrial construction projects and manufacturing industries in limited areas of the world (the United States of America and the Kingdom of Saudi Arabia), and they, largely, used the same measures that were developed by Plemmons in 1995.

Based on the in-depth review of the related literatures and critically examine the previous studies that are cited above, besides the importance of materials management process in determining the project success in construction as it does in manufacturing (see **Section 3.2**), one can realize the significance and necessity of developing a framework for measuring the effectiveness of the CMM performance to provide a basis for evaluating the impact of the continuous improvements that can be made on the material management process'. This was demanded by many authors and scholars such as, Stukhart (1995).

Accordingly, one can envisage and realize the extent of the significance of this research and its essential contribution to knowledge; as highlighted in **Chapter X**.

1.5 RESEARCH METHODS ADOPTED:

In order to achieve the research aim and objectives, an eclectic approach was adopted. The adopted research methods mainly comprise the literature review, main investigation (case studies), the questionnaire survey, and validation, as illustrated diagrammatically in **Figure 5.10** (flowchart of the research process of this study) and discussed in **Section 5.6.** The matrix in **Table 1.1** below illustrates the mechanism of using the research methods adopted to achieve the research objectives. The table summarises the role of each method in accomplishing each research objective. Within this section, a briefly summary for the research methods adopted is presented, and the full details of the research methods used and justifications for their use are provided in **Chapter V**.

Table 1.1: A Summary of the Role of Methods Adopted for achieving the Research Objectives

The Research Objective	*Literature Review*	*Interview/ Site Visits*	*Questionnaire*	*Evaluation /Validation*
(1) To critically review the existing literature on materials management process and to identify, theoretically, the typical workflow diagram(s) of the material management process in construction industry.	×			
(2) To identify and assess the material-related measures used within the construction industry (or may be other industries) and to establish a proposed set of measures to evaluate the effectiveness of construction materials management performance in construction projects.	×			
(3) To develop a practical workflow diagram for communicating the integrated functions and activities that form the CMM process within the large-scale concrete building projects in the J.C.I		×	×	
(4) To evaluate the proposed set of measures, and to determine the Practical Effectiveness-Measures (P.E.Ms) that can be applied within CMM process in the Jordanian large-scale concrete building projects		×	×	
(5) To develop and validate a framework for operationalize the P.E.Ms for evaluating the Effectiveness of the CMM Performance (E.CMM.P Framework) within the large-scale concrete building projects in Jordan.	×	×	×	×

(a) The Literature Review Process:

At the outset of the research, a review of literature was made. The review focused on uncovering the current relevant literature on materials management in the construction industry, in particular, the development of the process of the CMM and its performance within the construction projects. Also, the development of the performance measurement approaches in different industries were explored and reviewed. The literature review process essentially aims to achieve the first and second objectives of the study, including understanding the practice of the construction material management (CMM) process, identifying the typical workflow diagram of material management process, and defining the measurement mechanisms that have been offered theoretically to evaluate the performance of material management process in different industries and projects (Manufacturing Industry-M.I, Construction Industry-C.I and Industrial Projects), and then developing a theoretical set of proposed measures for evaluating Effectiveness of Construction Materials Management Performance (E.CMM.P). The literature review process is designed to achieve the first and second stages of developing the framework (see **Figure 8.1**).

However, the limitations of the related literature on building materials management process, as stated earlier, in particular, the lack of measures for quantifying the effectiveness of its performance, have led the researcher to explore relevant books, articles, research studies, theses and case studies related to manufacturing industrial projects and services industries (in combination with CI related background information) for developing the research subject. In order to overcome the lack of related literature on construction industry and to satisfy the researcher's conviction that "understanding any idea properly, implies understanding its roots first", it was essential to set out a plan to organise the literature review process (**see Appendix A**). The plan of the literature review process, graphically depicts the stages of reviewing the related literature. It is intended to review and interpret the relationship between the Supply Chain Management (SCM), Logistics Management (LM), and Construction Materials Management (CMM), and to explain the evolution of the CMM; the focal point of the study. This also helps in clarifying the confusion, which occurs within the A.C.I, between the terminology of SCM, LM, and CMM; whereby each one is considered as synonymous to the other.

(b) The Main Investigation:

To meet the purpose of the research in developing a framework for monitoring, analysing and evaluating the performance of the CMM process within the J.C.I, the main investigation was designed to accomplish, partly, the third and fourth objectives. It is intended to achieve the third and fourth stages of developing the framework (see **Figure 8.1**). A case study technique, including site visits and semi-structured interviews, was undertaken to investigate the current practices of the CMM process in the Jordanian building projects, and to examine the current measures, mechanisms, or approaches that were used to evaluate the performance of CMM process, and those that can be possibly used in the J.C.I. An analysis of the data obtained from the case studies was used as a foundation to: 1) develop a practical workflow diagram that can depict the real-life of the CMM process that is practiced within the large-scale concrete building projects in the J.C.I; and 2) identify the set of Practical Effectiveness-Measures (**P.E.Ms**) that can be practically used for evaluating the Effectiveness of the Construction Materials Management Performance (**E.CMM.P**) in the Large-scale Concrete Building Projects in the J.C.I .

(c) The Questionnaire Survey:

The questionnaire survey was based on the outcomes of the two previous phases: the literature review and the case study technique. The technique of 'a group administrated questionnaire survey' was adopted to gain a wider response from the functional experts in the J.C.I. The survey is intended to assess the proposed set of the measures of the Effectiveness of the CMM Performance (ECMMP) that has been developed from the literature review, and to evaluate the Practical Construction Materials Management Process (PCMMP) workflow diagram that has resulted from the analysis case studies' data. This comes at the context of performing the first stage of the validation process 'formative evaluation', which has been designed to evaluate the basic structure and the main components of the developed Framework. The questionnaire survey was also essential to identify the barriers for implementing the ECMMP measures and to determine the Key Effectiveness Measures (**K.E.Ms**) for evaluating the E.CMM.P in the J.C.I.

(d) Developing the E.CMM.P Framework:

This phase aims to develop an operational framework for communicating the integrated CMM functions and operationalize their practical effectiveness measures. The development of the framework is based on the main outputs obtained from the literature review and the main investigation process. These findings shape the main body (Practical CMM Process workflow diagram) and the main elements (Practical Effectiveness Measures) of the E.CMM.P Framework. However, in order to run this framework, it was necessary to find out and to set an operational mechanism for linking its components and employing them within its body. Therefore, an operational mechanism built on the benchmarking techniques has been proposed to operationalize the P.E.Ms within the practical CMM process diagram.

As a result of integrating the P.E.Ms and placing them at the point of measurment within the practical workflow diagram of the CMM process, and then applying the operational mechanism for communicating those measures within the practical diagram, the framework for evaluating the E.CMM.P has been developed (ECMMP Framework).

(e) Validation Process:

The validation process was designed to evaluate the applicability and appropriateness of the developed framework to monitor and evaluate the effectiveness of the performance of the CMM process. The validation session consisted of two evaluation techniques:

1- Formative Evaluation: it was carried out during the development stages and before the final actual development takes place. The evaluation feedback was derived from the results of the questionnaire survey through evaluating the proposed set of effectiveness measures, and the practical CMM process workflow diagram within the large-scale concrete building projects in the J.C.I.

2- Summative Evaluation: it is the evaluation of the actual final developed framework. This approach mainly aims to test the applicability of the developed framework to monitor and evaluate the effectiveness of CMM performance within the J.C.I. This evaluation technique is established through the feedback from the highly experienced professionals and functional experts in the construction industry in the Kingdom of Jordan. It includes obtaining their opinions on the developed framework, in terms of its effectiveness, applicability, and usability, in addition to the availability of documents necessary for the operation of this framework.

1.6 STRUCTURE OF THE THESIS:

The thesis consists of ten chapters, followed by a list of references and appendices. A brief summary for each of these chapters is provided below;

Chapter I: Introduction: the first chapter is intended to introduce briefly the history of the evolution of the thesis: the underlying ideas, the question, and the purpose; it explains the gap in the previous studies and the necessity of the research, aim, and objectives, and it provides the structure of the thesis.

Chapter II: Supply Chain Management and Logistics Management: chapter two is mainly designed to interpret the relationship between the concept of Supply Chain Management (SCM) and the Logistics Management (LM), and to explain the evolution of the Construction Materials Management (CMM) concept on the basis of the SCM and LM. This includes defining the SCM and LM in manufacturing and construction context, and exploring the evolution of their concepts and the relationship between them.

Chapter III: Construction Materials Management Process: this chapter provides a critical review through analysing the existing literature on materials management context, with more concentration on studying the materials management process in construction (CMM). It seeks to explore, theoretically, the typical workflow diagram(s) depicting the functions and activities that shape the construction materials management process.

Chapter IV: Evaluation Approaches and Measures of the Effectiveness of Performance of the CMM Process: chapter four defines and assesses the material-related measures and mechanisms that have been accepted or adopted by different industries and projects including manufacturing industry and industrial projects. The chapter also explains the development of a set of measures that are proposed to assess the effectiveness of materials management performance in the building construction projects, in addition to present an overview of the benchmarking processes that have been used within the manufacturing, construction, and service-related industries.

Chapter V: Research Methodology and Methods: the chapter begins with giving an overview of the existing research methodology, philosophy, approaches, and techniques found in the literature. It then continues by defining and explaining in detail the research methods adopted and employed in this study, and presenting the structure of data collection and analysis processes of this project study. Moreover, the chapter outlines the selection criteria for the projects and the interviewees that are involved in the case study investigation, and the techniques and tools used for collecting and analysing the data. Additionally, it presents the sample size and the process of conducting the questionnaire.

Chapter VI: Qualitative Data Analysis and Discussion: it reports the analysis of the data collected and the discussion of the outcomes of the case study research (the main investigation). This chapter begins with presenting the findings revealed and lessons learnt from one of the six selected case studies as example. This chapter then proceeds to report a discussion of the outcomes obtained. Based on the data discussion, Chapter Seven explains the development of the Practical Workflow Diagram of the CMM Process (PCMMP Workflow Diagram) and the establishment of the set of the Practical Effectiveness Measures (PEMs) that can be practiced in the J.C.I.

Chapter VII: Quantitative Data Analysis and Discussion: it reports the last phase of the data collection process using a questionnaire survey. Here, the results of the questionnaire survey are analysed and discussed. The survey is mainly intended to perform the first stage of the validation process 'formative evaluation', which is designed to assess the basic structure and the main elements of the Developed E.CMM.P Framework (the practical workflow diagram of the CMM process, and the proposed set of effectiveness-measures).

Chapter VIII: The Development of the E.CMM.P Framework: it presents the phases and stages for developing of a framework for Evaluating the Effectiveness of the Construction Materials Management Process Performance (E.CMM.P Framework) within the large-scale concrete building projects in the J.C.I. Developing the E.CMM.P framework accomplishes the fifth objective of the study.

Chapter IX: The E.CMM.P Framework Validation: Chapter nine reports the validation process of the developed E.CMM.P framework. It starts with an introduction to the evaluation aim and objectives. It then presents the validation process and the outcomes obtained. Finally, the summary of the chapter is presented; it includes the main suggestions and recommendations concerning the implementation process received from the evaluators.

Chapter X: Conclusion: it is the last chapter of the thesis. Chapter ten draws the key conclusions of this research and proposes the recommendations for the further research. The chapter sheds light on the significance of the research and its contribution to knowledge and society. It also outlines the major limitations of this research work.

1.7 SUMMARY OF THE CHAPTER:

This chapter provided a brief introduction to the research project. The overview covered the history and emergence of the thesis concept, and the evolution of the statements regarding evaluating the CMM process. This chapter presented the purpose, aim, and objectives of this study. It also reviewed the previous relevant studies and determined the necessity of the study, followed by an outline of the research methodology and the methods adopted. It concludes with the structure of the thesis. The next chapter, which represents the first part of the literature process, defines the concept of Supply Chain Management and Logistics Management and interprets the evolution of the Construction Material Management Concept.

CHAPTER II:

SUPPLY CHAIN MANAGEMENT (SCM)
&
LOGISTICS MANAGEMENT (LM)

2.0 INTRODUCTION TO THE CHAPTER:

As mentioned in chapter one, the plan of literature review process (see **Appendix A**) was developed to address and overcome the deficiencies of the related literature on building materials management, and also to satisfy the researcher's conviction that "understanding any idea properly, implies understanding its roots first". Therefore, the first step of the literature review process is the review of literatures related to Supply Chain Management (SCM), Logistics Management (LM) in manufacturing and construction industries, the relationship between them, and their relation with the Construction Materials Management (CMM).

Chapter II reviews a number of relevant literatures on supply chain management (SCM) and logistics management (LM). The chapter starts with presenting definitions for the SCM and LM and the development of their concepts in manufacturing and construction contexts.

It then discusses the main roles and the activities of the SCM and the LM within the construction industry. Chapter two is, in fact, intended to clarify the confusion, which occurs within Arabic Construction Industry, between the terminology of SCM, LM, and CMM, whereby each one is considered as synonymous to the other. This has been achieved through explaining the relationship between the concepts of the SCM and the LM from one hand and the relationship between them and CMM from other hand. This, in turn, interprets the evolution of the Construction Materials Management (CMM: the focal point of the study) concept on the basis of the SCM and LM.

2.1 SUPPLY CHAIN MANAGEMENT DEFINITION:

According to La Londe and Masters (1994), Christopher (1998), Handfield and Nichols (1999), Chen and Paulraj (2004), Langley, et al. (2008), and Kietzman, et al. (2011), supply chain is a process that consists of a series of activities and a network of firms that materials, services and information move through on their journey from the initial suppliers to the ultimate customers. The simplest structure of a supply chain consists of a single product, material, or service moving through a set of organisations; the activities that in front of each organisation including the moving materials inwards from the original supplier are called upstream activities; those which after the organisation including moving materials outward to the ultimate customer are called downstream activities (Mentzer et al., 2001; Ganeshan and Harrison, 2002; Waters, 2009), as illustrated in **Figure 2.1**.

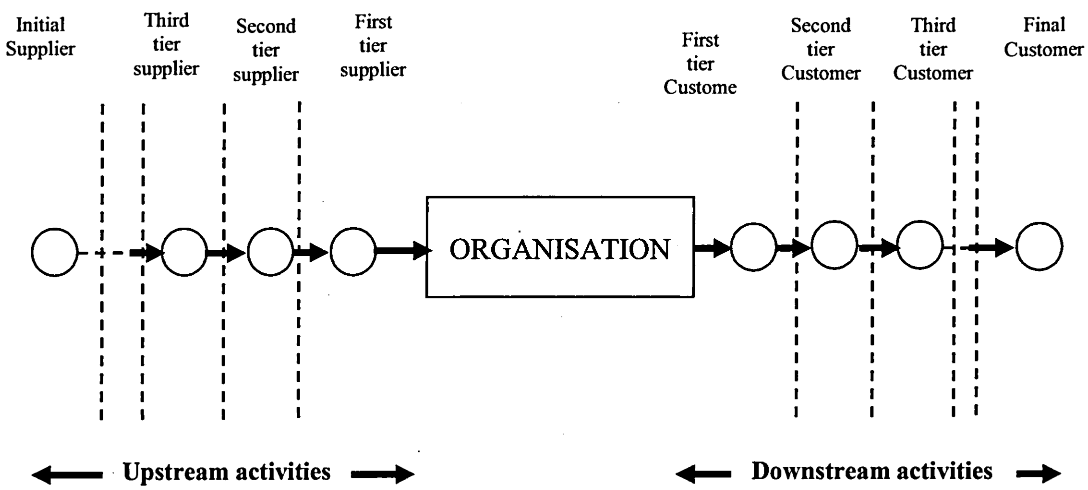


Figure 2.1: the Simple Structure of the Supply Chain (Waters, 2009)

Supply chain management (SCM) is not a new concept (Longley et al., 2008); however, in recent years, the term of supply chain management and its synonyms such as, supply pipeline management, value stream management, demand flow management, demand chain management and network scouring, have attracted the attention of consultants, academics and business management (Hines, 1994; Saunders, 1995; Lamming, 1996; Croom, Romano and Giannakis, 2000; Longley et *al.*, 2008). They have recurred, in the majority of the literature including Macbeth and Ferguson (1994); Cox (1997) and Croom, Romano and Giannakis, 2000, as the central unit of competitive analysis.

Supply chain management has been recognized since early 1980. However, many authors and researchers in supply chain management fields, such as New (1995); Cooper, Lambert and Pagh (1997); Sanders (1998) and Croom, Romano and Giannakis (2000) believe that because of the multidisciplinary origin and evolution of its concept, conceptually supply chain management is not well-understood and it does not have a universal definition. Furthermore, they stressed the importance of a clear definition and a conceptual framework on supply chain management.

Supply chain management has been defined in various ways, which demonstrate the fact that the SCM concept is viewed from different angles in the different bodies of the literature. As a consequence, within the SCM literature, many terms can be found; they refer to SCM (Croom, Romano and Giannakis, 2000; Mentzeret et al., 2001; Hatmoko, 2008). This variety may create unavoidable confusion of overlapping meanings and terminology. This could be further supported by a warning made by Saunders (1995) "*... attempts to pursue to universal definitions may lead to unnecessary frustration and conflict*". With the aim of highlighting some of the contrasting approaches to the SCM existing in literature, **Tables 2.1** and **2.2** below present a sample of the definitions and terms associated with the concept of SCM, which has been found in the literature analysed.

Table 2.1: Different Terminologies of SCM (Developed by Croom, Romano and Giannakis (2000); Hatmoko, 2008)

Authors	*Different Terminologies of SCM*
Burt (1984)	An integrated purchasing strategy
Farmer and Van Amstel (1990)	A supply pipeline management
Lee and Billington (1992)	A value-added chain
Lamming (1993)	A buyer-supplier partnership
Nishiguchi (1994)	A supply network
Jones (1995)	A value stream
New and Ramsay (1995)	A lean chain approach
Lewis (1995)	A supply base management, strategic supplier alliances
Tan et at. (1998)	A supply chain synchronisation
Nassimbeni (1998)	A network supply chain
Dyer et at. (1998)	A supplier integration

Croom, Romano and Giannakis (2000) collected different definitions from the early 1980s, when the SCM started receiving attention, and through the ten years after, as shown in **Table 2.2**.

Table 2.2: A sample of SCM definitions (Croom, Romano and Giannakis, 2000)

Authors	*Definitions*
Jones and Riley (1985)	An integrative approach to dealing with the planning and control of the materials flow from suppliers to end-users.
Ellram (1991)	A network of firms interacting to deliver product or service to the end customer, linking flows from raw material supply to final delivery.
Christopher (1992)	Network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer.
Lee and Billington (1992)	Networks of manufacturing and distribution sites that procure raw materials, transform them into intermediate and finished products, and distribute the finished products to customers.
Berry et at. (1994)	Supply chain management aims at building trust, exchanging information on market needs, developing new products, and reducing the supplier base to a particular OEM (original equipment manufacturer) so as to release management resources for developing meaningful, long term relationship.
Saunders (1995)	External Chain is the total chain of exchange from original source of raw material, through the various firms involved in extracting and processing raw materials, manufacturing, assembling, distributing and retailing to ultimate end customers.
Harland (1996)	Supply chain management (SCM) is the management of a network of interconnected businesses involved in the ultimate provision of product and service packages required by end customers
Lee and Ng (1997)	A network of entities that starts with the suppliers' supplier and ends with the customers' custom the production and delivery of goods and services.
Tan et at. (1998)	Supply chain management encompasses materials/supply management from the supply of basic raw materials to final product (and possible recycling and re-use). Supply chain management focuses on how firms utilise their suppliers' processes, technology and capability to enhance competitive advantage. It is a management philosophy that extends traditional intra enterprise activities by bringing trading partners together with the common goal of optimisation and efficiency.

From the recent definitions of SCM over the last decade, as shown in **Table 2.3** below, one can clearly note that SCM definitions have become increasingly associated with the effectiveness of the supply chain performance. This could call the attention of researchers, academics and professionals to measure the effectiveness of SCM in their organizations in order to assess the SCM process constantly.

Table 2.3: A Sample of the Recent Definitions of SCM

Authors	*Definitions*
Mentzer et al. (2001, p18)	*Supply chain management is the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole.*
Chen and Paulraj (2004)	The term SCM has been used to explain the planning and control of materials and information flows as well as the logistics activities internally and externally.
Hines (2004, p76)	*"Supply chain management requires a total systems view of the linkages in the chain that work together efficiently to create customer satisfaction at the end point of delivery to the consumer."*
CSX World Terminals (2004); Gibson, Mentzer and Cook (2005, p17)	*"'SCM is the management and control of all materials and information in the logistics process from acquisition of raw materials to delivery to end user"* (Gihson, Mentzer and Cook , 2005, p17)
LOGIC (2006)	"Supply Chain Management is about managing the flow of information, materials, services and money across any activity, in a way which maximises the effectiveness of the process."
Lambert, (2008); Lambert, Garcia-Dastugue and Croxton (2008)	supply chain management is the integration of key business processes across the supply chain for the purpose of creating value for customers and stakeholders
Langley et al., (2008, p17); Venus (2011)	Supply chain management is a process used by companies to ensure that their supply chain is efficient and cost-effective.

Different perspectives in defining the supply chain management have been expressed by many researchers and authors. Based on this, Mentzer et al., (2001) and Hatmoko (2008) classified the definitions of SCM into three categories: category 1 views SCM as a management philosophy, category 2 views SCM as the implementation of management philosophy and category 3 sees SCM as a set of management process. Therefore, from this point of view, defining SCM depends on the way in which the SCM is classified, as shown in **Table 2.4** below.

Table 2.4: A Classification of SCM developed from Mentzer et al., (2001), and Hatmoko (2008)

Categories of SCM	*Definition*	*Characteristics*
As a management philosophy Ellram and Cooper (1990), Houlihan (1985), Ellram (1990), Jones and Riley (1985), Cooper et al., (1997),	*"a set of beliefs that each firm in the supply chain directly and indirectly affects the performance of all the other supply members, as well as ultimate, overall channel*	Adopts a system approach to viewing the channels as a single entity, rather than as a series of fragmented parts performing Individually system approach, and to managing the total flow of goods inventory from the initial supplier to the final customer.

Categories of SCM	Definition	Characteristics
Ross (1998), Langley and Holcomb (1992) members, ultimate,	*performance"*	*"a strategic orientation toward cooperative efforts to synchronize and converge intrafirm operational and strategic capabilities into a unified whole, a customer to create unique and individualized source of customer value, leading to customer satisfaction"*
As the implementation of management philosophy Cooper and Ellram (1993), Cooper et al., (1997), Ellram and Cooper (1990), Novack et al., (1995)	A series of activities to implement the philosophy of SCM	*"Integrated behaviour* *Mutually sharing information* *Mutually sharing channel risk and rewards* *Cooperation* *The same goal and the same focus of serving customers* *Integration of processes* *Partners to build and maintain long-term relationship"*
As a set of management processes La Londe (1997), Ross (1998), Cooper et al., (1997), Lambert et al., (1998)	A method and process of managing relationships, information and materials flow across enterprise boundaries for the purpose of meet customer needs	The entire functions within a supply chain are reorganized as key processes, including customer relationship management, customer service management, demand management, order fulfillment, manufacturing flow management, procurement, and product development and commercialization.

As a result of reviewing the various definitions and terminologies of the SCM, it is evident that there is a lack of SCM definition consensus, which may produce obscurity or misunderstanding concerning the research and practice of SCM. Thus, from this point of view and in contrast with Saunders (1995), Cooper, Lambert and Pagh (1997); Mentzer et al., (2001); Gibson, Mentzer and Cook (2005), Hatmoko (2008) highlight the necessity of drawing a clear single definition for SCM, since it is significantly needed for understanding the concept, and for agreeing on the key elemental functions, and applying SCM in research and practice. Based on reviewing and integrating different SCM aspects, they proposed their definition, which is adopted by the Council of Logistics Management (CLM) in 1998 and 2000, as "*Supply chain management is the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole.*"

To further understand CSM, one may refer to the development of the SCM concept in coming section.

2.2 DEVELOPMENT OF THE CONCEPT OF SCM:

Although the concept of supply chain management is not a new brand (as stated before), Croom, Romano and Giannakis (2000) and Langley, *et al.* (2008) observe that its roots are unclear. They agreed with Rushton, Oxley and Croucher (2000) that the initial development of the SCM concept started in the 1950s and early 1960s along with the development of the 'physical distribution' and the transport concept that concentrate on the outbound side of an organisation's logistics system. This approach only focused on a single element in the chain, which can not guarantee the effectiveness of the system (Croom, Romano and Giannakis, 2000). During the period of the technology boom in the 1980s, a number of organisations developed the concept of 'integrated logistics management' by adding inbound logistics to the outbound logistics of physical distribution. Coyle, Bardi and Langley (1996), Muya (1999) and Langley *et* al., (2008) noticed that this addition was very logical since international suppliers and materials sourcing were growing in importance, and the coordination between the inbound and outbound logistics systems was needed for increasing the supply chain efficiency and improving the customer service. Throughout the 1980s, many other concepts had been developed such as the 'total cost' concept, 'value chain' concept, 'integrated logistics system' and 'materials management' concept. The organisations have become aware of the fact that greater operational efficiencies could be resulted, if the whole product and material flow was viewed as a continuum. As a consequence, 'the logistics management' concept developed, in the early 1990s, to include the entire organisations, manufactures, raw materials suppliers, and the final customer within the 'total logistics system'. The 1990s witnessed the birth of new concept that is based on alliances among the trading partners, and it is called the 'supply chain management', which continues to be the focal point for making companies more competitive in the international marketplace. The contemporary supply chain management can be seen as "*a pipeline or conduit for the efficient and effective flow of products/materials, services, information, and financials from the supplier's suppliers through the various intermediate organisations/companies out to the customer's customers*" (Langley, et al., 2008). **Figure 2.2** below summaries the stages of the development of the contemporary SCM concept.

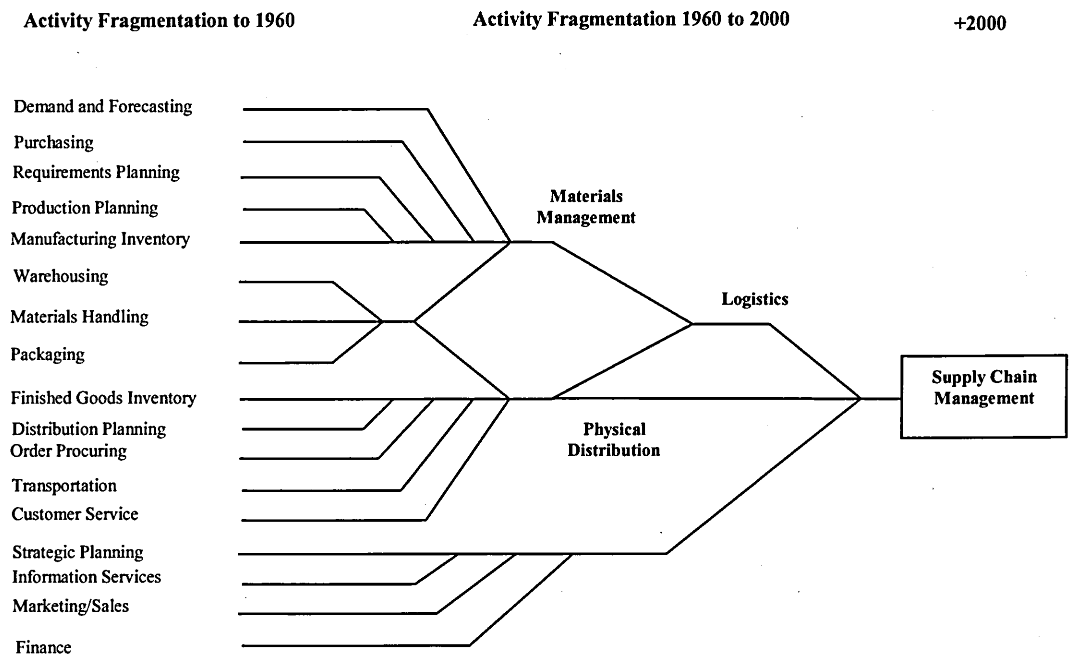


Figure 2.2: Integrated Logistics Management and Developing the Concept of Supply Chain Management developed from; Coyle, Bardi and Langley (1996); Muya (1999: p16); Langley et al., (2008: p6)

Having different perspectives in defining SCM, as noted earlier, has led to different perspectives in describing the history of the evolution of SCM. Hatmoko (2008) summarises two main perspectives to describe the development of SCM: *first* describing SCM evolution from the perspective of logistics and distribution (from point of view of 'Rushton, Oxley and Croucher (2000)') and *second* describing SCM evolution from the perspective of production's management (Point of view of 'Tan (2001)'); see Hatmoko (2008, p11-12).

Croom, Romano and Giannakis (2000) argue that

> "*such a multidisciplinary origin and evolution is reflected in the lack of robust conceptual frameworks for the development of theory on supply chain management. As a consequence, the schemes of interpretation of supply chain management are mostly partial or anecdotal with a relatively poor supply of empirically validated models explaining the scope and form of supply chain management, its costs and its benefits*" (Hatmoko (2008, p12)

2.3 SUPPLY CHAIN MANAGEMENT IN CONSTRUCTION:

2.3.1 Definition of Supply Chain Management in Construction Context:

The concept of SCM was originated and flourished in the manufacturing industry, particularly in the Japanese and Western automotive industry. Many practitioners and academic writers in the construction industry, such as Luhtala, Kilpinen and Anttila (1994) and Vrijhoef and Koskela (2000), remark that the use of the traditional approach in the construction industry to control the supply chain is not adequate any more, and a shift of approaches for managing the supply chain is needed. They suppose that the same principles and methods of SCM that have been applied in the manufacturing industry can be translated and used in construction industry. However, in contrast to those, Cox, Ireland and Towsend (2006) and Hatmoko (2008) argue that the nature of the construction industry is different in several ways from the nature of the manufacturing industry. According to Ghurka (2003) and Venkataraman (2004), the most significant differences between the manufacturing supply chain and the construction supply chain can be summarised in **Table 2.5** below.

It can be evident that there are considerable differences between the manufacturing and construction supply chains, and these differences should be taken into account by the researchers when applying supply chain management techniques they come across in manufacturing industry to the construction context. Copying SCM ideas and methods from manufacturing and applying them to construction are simplistic: furthermore, such copying fails to understand the nature of construction supply chain management (Muya, 1999; Fearne and Fowler, 2006; Hatmoko, 2008; Research Paper Centre, 2009). As a consequence, it is essential to place the framework of SCM in the context of construction.

Table 2.5: Comparison of Manufacturing and Construction Supply Chain developed from Ghurka (2003) and Venkataraman (2004)

Manufacturing Supply Chain (Make-to-stoke)	***Construction Supply Chain (Make-to-order)***
The inbound supply chain is usually shorter than the outbound.	The inbound supply chain is usually longer than the outbound.
Make-to-stock is generally a used model.	Build-to- order is the widely used
The product is wider and less specific	The product is defined and specific

Manufacturing Supply Chain (Make-to-stoke)	*Construction Supply Chain (Make-to-order)*
High level of standardization with repeatability	Project–unique design and material specifications with slight or without repeatability
Planning can be carried out on the bases of reliable demand forecast	Uncertain demand forecast and inadequate tools
Normally only one company is responsible for the production process	The production process includes multiple companies with different objectives
Distribution network predefined	Distribution network and project-specific suppliers
Many suppliers supply a wide range of ultimate customers.	Many suppliers supply specific ultimate customers.

Vrijhoef and Koskela (2000) and Shin *et al.*, (2010) insist on the necessity of a clear definition of SCM in the construction context in order to eliminate uncertainties in the construction supply chain. However, as SCM in construction is an emerging concept and it is still in its infancy (Akintoye, McIntosh and Fitzgerald, 2000; Saad, Jones and James, 2002; Love, Irani and Edwards, 2004; Hatmoko, 2008), few studies have defined what SCM is within the construction process, as exhibited in **Table 2.6**. These efforts aim to define the limitation of SCM to suit the context of construction industry. Dedicated efforts were exerted by Vijhoef (1998); they aimed to set up holistic definition of construction SCM by means of summing up 35 definitions made by various writers and researchers, some of which are provided in Hatmoko (2008, p17) . He then offers his own definition of SCM *"....the establishment, co-ordination and maintenance of an optimised supply chain that operates effectively, fulfilling all its preconditions and goals optimally, and involving all its stakeholders*".

Although the definition that is offered by O'Brien is the most straightforward definition, Hatmoko (2008) proposes a more detailed definition, whereby he defines SCM in construction as "*the system where suppliers, contractors and client/architect work together under the coordination of the main contractor to produce, deliver, install and utilise information, materials, plant, temporary work, equipment and labour and other resources for construction projects."* For this research, the definition of Hatmoko is adopted with some minor changes as follows; the construction SCM is the system where suppliers, contractors and client/architect work together effectively under the coordination of the main contractor to produce, deliver, install and utilise information, materials, plant, temporary work, equipment and labour (through upstream activities and organistations) in order to deliver quality construction products and services to the customer (through the downstream activities and organisations).

Table 2.6: Defining the SCM in the context of Construction Industry

Authors	*Definition of the Construction Supply Chain Management*
O' Brien and Fisher (1993)	*"Supply chain management is the system of suppliers and contractors producing, delivering, and installing materials for construction projects."*
Vrijhoef (1998)	*"....the establishment, co-ordination and maintenance of an optimised supply chain that operates effectively, fulfilling all its preconditions and goals optimally, and involving all its stakeholders"*
Akintoye, McIntosh and Fitzgerald (2000)	*Construction SCM may be regarded as the process of strategic management of information flow, activities, tasks and processes, involving various networks of organisations and linkages (upstream and downstream) involved in the delivery of quality construction products and services through the firms, and to the customer, in an efficient manner."*
Arbulu and Tommelein (2002)	*"Construction supply chains are networks of interrelated processes designed to satisfy end customer needs".*
Elfving (2003)	*"Supply chain management is the management of all the processes that are required to deliver a service or a product for a customer through a network of organizations with minimum waste and maximum value ".*
Tommelein, Riley and Hershauer (2003)	*"The practice of a group of companies and individuals working collaboratively in a network of interrelated processes structured to best satisfy end customer needs while rewarding all members of the chain ".*
Hatmoko (2008)	*"supply chain management is the system where suppliers, contractors and client/architect work together under the coordination of the main contractor to produce, deliver, install and utilise information, materials, plant, temporary work, equipment and labour and other resources for construction projects."*
Shin et al. (2010)	SCM in construction is the system of management that aims to *"improve efficiency in time and money by increasing prefabrication of building components and materials, and to build an integrated system between supply chain and the construction site to react to design changes more effectively and efficiently."*

In this research, the upstream within the construction SCM consists of the all tasks and activities leading to the preparation of the production on a site and involves construction clients and design team with relation to the main contactor; the downstream consists of all the activities and tasks involved in delivering the construction product; they are the subcontractors, construction suppliers and specialist contractors who work collaboratively, under the main contractor (Akintoye, McIntosh and Fitzgerald, 2000).

As stated earlier, there is an urgent need for a shift in managing the supply chain. The reason for this need together with the importance of SCM in construction is outside the scope of this research. However, the next section briefly clarifies the characteristics and roles of SCM in the construction industry.

2.3.2 Roles of Supply Chain Management in Construction:

To recognize the function of SCM in construction, the characteristics of the construction supply chain should be highlighted. Vrijhoef and Koskela (2000) and Hatmoko (2008) argue that the construction supply chain is characterized by three main elements:

- It is a converging supply chain whereby all materials and sources are delivered, assembled on a site and set up around a single product by the subcontractors and suppliers under the coordination of the main contractor, in contrast to the manufacturing supply chain whereby multiple products pass through factory, and are distributed to many customers.
- It is a temporary supply chain as the nature of the construction is project-based and the construction supply chain is typified by fragmentation, instability, fluctuation of productivity and separation between the construction and the design of the product.
- It is a make-to-order supply chain; most construction projects are customer driven, whereby the process of a construction project starts and ends with the customer. Therefore, each construction project creates a new prototype or product with very little repetition.

Vrijhoef and Koskela (2000) observe that these characteristics influence the management of the supply chains. They have specified four major roles for SCM in construction, which depend on the area of focus, whereby the focus can be on the construction site, the supply chain itself, or both, as shown in **Figure 2.3** and clarified below;

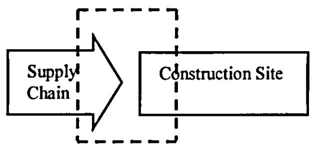
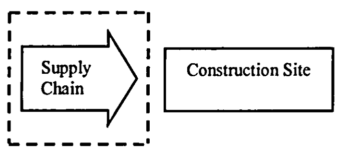
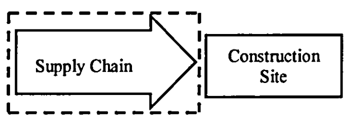
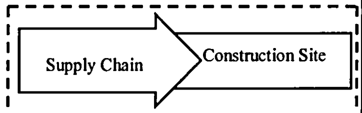
Roles	Focus	Goals	Who may adopt/initiate this focus?
1 	The importance of the supply chain on site activities	To reduce costs and duration of site activities	The contractor
2 	The supply chain itself	Reducing costs related to logistics, lead time and inventory	Material and component supplies
3 	Transferring activities from the site to earlier stages of the supply chain	To reduce total costs and durations	Suppliers or contractors
4 	The integrated management and improvement of the supply chain and the site production	Site production is subsumed into SCM	Clients, suppliers or subcontractors

Figure 2.3: The four major roles of the supply chain management in construction (developed by Vrijhoef and Koskela (2000))

1- The first role is that when the focus is placed on the impact of the supply chains on the site activities; in this case, the main concern is to ensure dependable materials and labour flow to the site to avoid disruption to the workflow. The aim of this focus is to reduce the duration and cost of site activities and the best person to adopt it is the main contractor.

2- The second role is that when the emphasis is laid on the supply chain itself; in this case, the focus aim is to reduce the costs related to lead-time, logistics and inventory. This focus might be initiated by the suppliers of materials and components.

3- The third role is that when the focus is placed on transferring activities from the site to earlier stages of the supply chain. This role aims to reduce the total duration and costs. The contractor or suppliers may adopt this focus.

4- The fourth role is that when the emphasis is laid on integrated management and on improvement of the supply chain and the site production. This focus may be initiated by contractors, suppliers or clients.

Practically, the four SCM roles are usually used jointly and they are simultaneously applied in order to improve both the effectiveness and efficiency of the supply chain (Vrijhoef and Koskela, 2000).

2.4 SUPPLY CHAIN MANAGEMENT & LOGISTICS RELATIONSHIP:

The analysis of the development of the SCM concepts, which has been conducted in previous section, obviously indicates the expansion of the area of SCM and the overlap of the fields that are involved in it. Among these fields, logistics has been selected to be discussed in more details in the next section, since it is the most closely related one to SCM, and it often causes some confusion and debate (Lummus, Krumwiede and Vokurka 2001; Hatmoko, 2008; Decker, 2011).

Christopher (2005) argues that SCM is a wider concept than logistics. However, many other researchers and authors such as, Lummus, Krumwiede and Vokurka, (2001) stated that "*Over the past few years, there has been confusion and disagreement among general business practitioners and operations professionals concerning the terms "logistics" and "supply chain management"*". They believe that although SCM and logistics are part of the same solution set (Strahan and Bodegraven, 2011), the relation between the two terms is still confusing and controversial. In 2004, a study was conducted by Larson and Halldorsson; it aimed to determine what the relationship between SCM and logistics is. They proposed four unique perspectives of SCM in relation to logistics; Relabelling, Traditionalists, Unionists and Inter-sectionisst (See **Figure 2.4**).

The *Relabelling* perspective perceives no difference between SCM and logistics, only the name logistics has changed to SCM; the *Traditionalists* consider SCM as a small element of logistics, whereas logistics is viewed as the overarching discipline, while SCM is described as just a process of moving materials; the *Unionists* contradict the traditionalists' view and treat logistics as a small part of SCM, whereas SCM encompasses in addition to logistics all aspects of production, marketing, purchasing and operations management; the

Inter-sectionists conceive SCM and logistics as related fields. Even thought they are not totally united, they overlap in some areas.

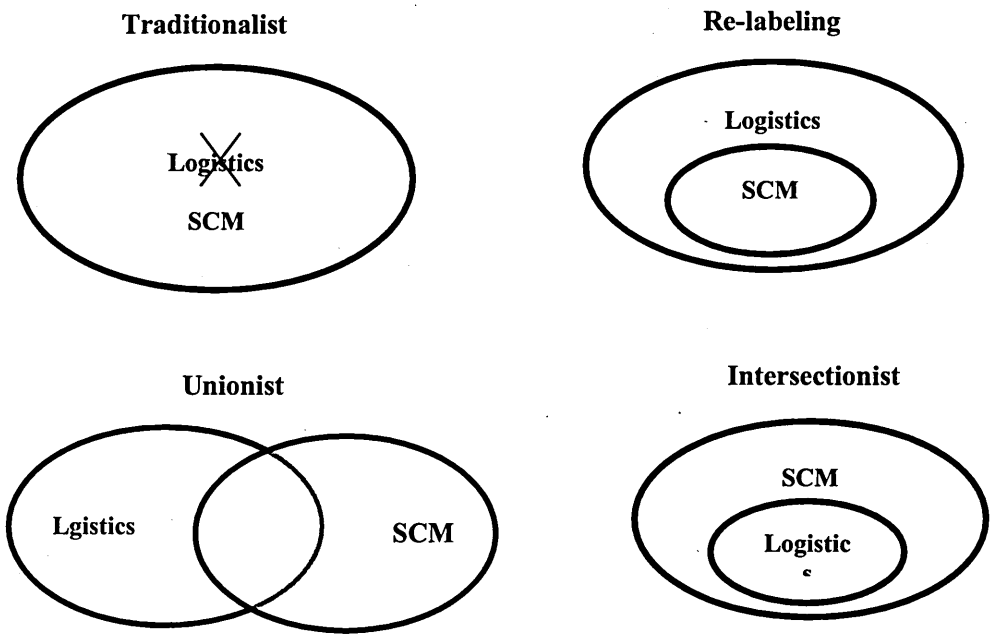


Figure 2.4: The Four Perspectives concerning the Relationship between SCM and Logistics (Larson and Halldorsson, 2004)

In this research, the Unionist perspective is adopted, since it is the most realistic, practical and popular view (Decker, 2011). This selection was further supported by the Council of Logistics Management (CLM) (2004), Christopher (2005) and Hatmoko (2008), who look at logistics as a single process of SCM.

2.5 LOGISTICS DEFINITION:

Similarly to SCM, logistics has a number of definitions that depend on its roles and responsibilities. A general definition of logistics can be found in the Concise Oxford Dictionary in 1995, where it is defined as "*the organisation of moving, lodging, and supplying troops and equipment*". The definition indicates that the logistics as a term came out from military practice (Hatmoko, 2008), whereby the term became a part of the military lexicon in Europe in the 18th century (Langley et al., 2008). However, logistics has been defined by a variety of angles and from different perspectives as demonstrated in **Table 2.7**.

Table 2.7: Logistics Definitions (Adopted from Russell, 2000; Langley et al., 2008)

PERSPECTIVE	*DEFINITION*
Inventory	Management of materials in motion and rest
Customer	Getting the right product, to the right customer, in the right quantity, in the right condition, at the right place, at the right time, and at the right cost (Seven Rs Logistics)
Dictionary	The branch of military since having to do with procuring, maintaining, and transporting material, personnel, and facilities
International Society of Logistics	The art and science of management, engineering, and technical activities concerned with requirements, design, and supplying and maintaining resources to support objectives, plans, and operations
Utility/Value	Providing time and place utility/value of materials and products in support of organization objectives
Council of Supply Chain Management Professionals	That part of supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from point of origin to point of consumption in order to meet customer requirements
Component Support	Supply management for the plant (inbound logistics) and distribution management for the firm's customers (outbound Logistics)
Functional management	Materials requirements determination, purchasing, transportation, inventory management, warehousing, materials handling, industrial packaging, facility location analysis, distribution, return goods handling, information management, customer service, and all other activities concerned with supporting the internal customer (manufacturing) with materials and external customer (retail stores) with product
Common culture	Handling the detail of activity

In the last 20 years, the term of logistics has been gradually developed and become more widely recognized by the general public and individuals. Among the most recent definitions of logistics is one originated by Quayle and Jones in 1999 and updated by Waters in (2009, p4), which described the logistics as "*the function that is responsible for all aspects of the movement and storage of materials on their journey from original suppliers through to final customers*" whereas Langley et al. (2008, p36) defined in more detail and identified it as *"the process of anticipating customer needs and wants; acquiring the capital, materials, people, technologies, and information necessary to meet those needs and wants; optimizing the goods- or service-producing network to fulfil customer requests; and utilizing the network to fulfil customer requests in a timely manner*". The fact that many views are expressed to describe logistics is part of the definition problem, exactly as it has been the case with the definition of supply chain management.

Logistics is a broad term which covers a wide set of related activities (Waters, 2009) dedicated to the transformation and distribution of goods, as they converted from raw materials into finished products and then distributed to market, in addition to the related information flows (Ballou, 2004; Rodrigue and Hesse, 2009). The various activities which may make up total logistics' functions vary from one organisation to another, depending on different aspects, such as particular organisational structure of a firm, the constituents of the supply chain management of its business, and the significance of individual activities to its operations (Sutton, 1993; Ballou, 2004). However, according to the various literatures, such as Tersine (1985), Prabu and Baker (1986), Lambert and Stock (1993), Magad and Amos (1995), Payne, Cliclsoin and Rcavill (1996), Agapiou et al. (1998), Muya (1999), the Council of Logistics Management CLM (2004), Langley et al. (2008), Waters (2009) and Blanchard (2010), the most common activities that form the logistics includes; Procurement/ Purchasing, Transportation and Physical Destruction, Receiving, Warehousing/ Storage, Stock/ Inventory Control, Material Handling, Order Picking, Packaging, Location, Recycling Returns and Waste Disposal, and Communication.

Additionally, there are other activities that might be considered as a part of logistics, such as customer services, demand forecasting, and production planning. Ballou (2004) classifies these activities into two categories: *Key Activities* including customer service, transportation and inventory management; *Support Activities* includes Warehousing, materials handling, purchasing, packaging, co-operating, and Information maintenance. Muya (1999, p16) notes that *"Efficiency and cost effectiveness in logistics systems are determined by how well these activities are managed and co-ordinated"*.

The Council of Supply Chain Management Professionals defines the combination of materials and information flow as logistics management, which is discussed in the next section.

2.6 LOGISTICS MANAGEMENT:

The term logistics has a huge number of definitions and meanings that creates confusion to the users (Ballou, 2004; Langley et al., 2008). For example, all the terms in the following list refer to what has been described as logistics:

- Distribution.
- Marketing management.
- Materials management.
- Supply management.
- Physical distribution management.
- Business logistics management.
- Logistics management.
- Integrated logistics management.
- Industrial logistics.

These and a series of other terms are usually alternatives for the more general word of 'logistics'; however, the term be used carefully as it sometimes refers to slightly different activities or particular aspects of supply chain (Waters, 2009). Langley et al. (2008) and Asnaashri et al. (2010) believe that the most widely accepted use of the logistics term is 'Logistics Management'; it is used not only in the non-profit and government sectors but also in private and service sectors. They agree with Magad and Amos (1995) and Hatmoko (2008) that the most unambiguous definition of logistics management has been introduced by the Council of Logistics Management (CLM) that defines logistics management as "*that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements*".

2.6.1 Logistics Management Role:

Generally, twenty years ago, logistics management has greatly influenced forming and designing the internal operations sequences of different businesses and industries (Christopher, 1998). Logistics can provide competitive advantages by reducing the ultimate time and cost of the production (Christopher, 1998) and increasing productivity of the projects (Blanchard, 1998). Simchi-Levi, Chen and Bramel (2005), Rushton, Croucher and Baker (2006), Asnaashari, Hurst and Knight (2008) and Asnaashri et al. (2010) argue that logistics management is a means which ensures logistics system efficiency. Even though it has the lowest proportions of total logistics costs, it still plays a considerable role in saving the logistics cost. They surmise its function into two roles; the *first* role is to provide a cost-effective system from supplying raw materials to distributing finished products; the *second* role is to appraise services and matters which might impact the logistics cost and make the product match the requirements of customers.

Beside those roles, Knill (1992), Rushton, Croucher and Baker (2006) and Asnaashri et al. (2010) argue that in addition to the distribution and procurement tasks, the field of logistics management can include activities, such as equipment testing, supply support, and asset tracking, transportation, material handling and storage. They conclude that an effective logistics management can be defined as the efficient transfer of materials, equipment, goods or services from the supply's source through the place of manufacture to the consumption's point with acceptable service to the consumer in a cost-effective manner. In construction firms, implementing an effective logistics management to their construction projects can save 15 percent of their labour and materials (Fairs, 2002) and 10 to 30 percent of the total logistics cost (Strategic Forum for Construction (SFfC), 2005). This is further indicator that supports the importance of logistics management roles.

2.7 LOGISTICS MANAGEMENT IN CONSTRUCTION:

In spite of the efforts that have been exerted for building up the concept of effective logistics management in different industries such as food, manufacturing and retail (Harrison and Hoek, 2005; Daugherty, Stank and Rogers, 2006), it is still difficult to apply these concepts properly in construction (Hill and Ballard, 2001; Hatmoko, 2008; Sullivan, Barthorpe and Robbins, 2010). Woudhysen and Abley (2004) and Asnaashri et al. (2010) believe that the main reason behind that might be the fact that construction always has been behind other fields and industries in terms of innovation and knowledge development. While Muya (1999), Cox, Ireland, and Towsend (2006) and Sullivan, Barthorpe and Robbins (2010) maintain that owing to the culture, environment and nature of construction industry (fragmented supply chain, uniqueness in design, temporary organisation, matchless project, and site and single production), a logistics management model that is designed for other industries cannot be implemented in construction appropriately. Hence, as in supply chain management, there is a significant need for understanding of logistics in construction context (Shakantu, 2004). Logistics management needs to develop a new framework that respects and simulates the features of construction industry and suits its context (Hatmoko, 2008; Asnaashri et al., 2010).

Koskela (1992), the Council of Logistics Management (CLM 1992) and Hill and Ballard (2001) argue that the focal point of attention in construction logistics management are materials and information flow. Material flow, which involves efficient and continuous movement of resources, aims to ensure that the required materials and components are delivered at the right time, in proper sequences and to the right required (Knill, 1992). The logistical information includes flow of necessary information, such as delivery and order status, the time that a material needed, inventory, availability of cash and site condition (Hill and Ballard, 2001). It can be understood that logistics in construction is a multidisciplinary process that involves a number of functions (Silva and Cardoso, 1999).

2.7.1 Logistics Functions in Construction:

Construction logistics is the heartbeat of a project (Sullivan, Barthorpe and Robbins, 2010, p225). Based on numerous explanations and definitions that are presented in literature, in research studies conducted by Silva and Cardoso (1999), Hill and Ballord (2001), Cox, Ireland, and Towsend (2006), Ebel and Clausen (2007) and Asnaashri et al (2010), twelve functions of construction logistics management can be recognised as the following: (1) Identifying supply sources, (2) Acquisition of materials, (3) Planning and schedule control, (4) Designing site layout, (5) Site infrastructure and equipment location (site preparation), (6) Transportation, (7) Testing materials and checking components' quality, (8) Storage, inventory and warehousing, (9) Processing and handling materials, (10) Site physical flow management, (11) Monitoring and control, and (12) Management of information related to all physical and service flows. These functions or activities are carried out before and during construction works.

The logistics functions in a construction organisation can be divided roughly into supply logistics, site logistics and disposal logistics (Muya, 1999; Silva and Cardoso, 1999; Ebel and Clausen, 2007, p24 ; Hatmoko, 2008), as displayed in **Figure 2.5.**

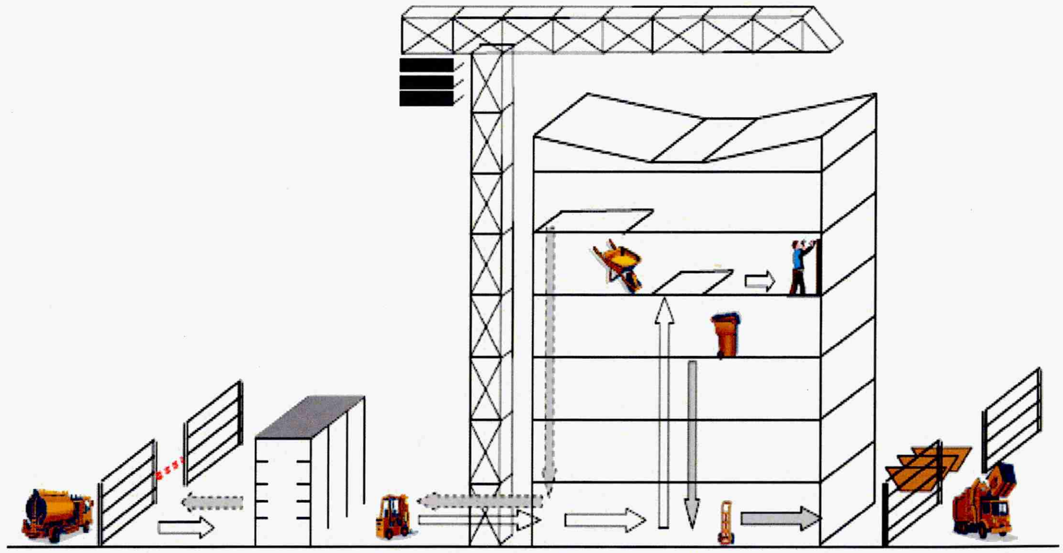


Figure 2.5: The System of Logistics in A Construction Organization (Ebel and Clausen, 2007:248)

Supply Logistics: It is a field related to activities that are built in the production system; it includes supply planning, supply resources (materials, equipment and manpower) specification, acquisition of resources, delivery to site, and storage control (Silva and Cardoso, 1999). Ebel and Clausen (2007) assert that the essential prerequisite for continuous working processes is a trouble-free supply of the site with construction materials, labourer, and building equipments. That commences with traffic control in the surroundings of the construction site to permit the supply of construction resources in time. They also stress the importance of the trouble-free process at the materials' receipt using automated transfer systems for optimizing the supply processes.

Site logistics: According to Johnston (1981), Kirby (1995) and Muya (1999), Logistics activities which affect the flow of construction materials are usually executed by head office and site management. All the activities from receiving the construction materials on site to their final use in site are called site logistics. Site logistics includes the functions that are more related to the physical flow planning, directing, organising, and controlling of materials on site. Among the site logistics activities are expediting, receiving, management of handling system, site layout, site warehousing, safety equipment, definition of activity sequence and decision of interference between production teams' activities on-site (Silva and Cardoso, 1999; Hatmoko, 2008). As Ebel and Clausen (2007), point out the correct storage of the materials on a construction site, the preparation of storage areas in a site, materials handling and inventory management are very important functions in site logistics.

Disposal logistics: Leite (2003), Schneider (2003) and Nunes, Mahler and Valle (2009) define reverse logistics as the stages and means through which the excess or surplus resources return to the productive cycle re-acquiring value in secondary markets by recycling or reusing of their constituent materials. If the return of these materials is not economically viable, the materials alternatively end at the final disposal, such as waste dumps and landfills, as law prescribes (Muya, 1999). The disposal function in construction sites is a significant cost factor, especially when construction site is located in crowded area buildings Ebel and Clausen (2007). Therefore, the selection of suitable collection system and transport are indispensable tasks in disposal logistics.

In short, it can be concluded that "*The main objectives of a logistics system are to maximize customer service level and to minimize total cost in its activities. In other words, the objectives are to generate value to the customer and to reduce cost in the production pro*cess." (Silva and Cardoso, 1999, p149).

2.8 LOGISTICS AND MATERIALS MANAGEMENT:

"*Logistics activities provide the bridge between production and market locations that are separated by time and distance*" Ballou (2004). Despite the fact that a few literatures see that materials management process includes physical distribution (Bell and Stukhart, 1986) and logistics (Binti Kasim, 2008), the majority of the scholars believe that logistics functions involve the physical distribution and materials management (Muya 1999; Ballou 2004; Rodrigue and Hesse, 2009). However, to clarify the real contemporary relationship between logistics and material management, the reference to the history of the evolution of logistics is essential.

Although, logistics called the attention of academic researchers in the early 1900s (Lambert and Stock, 1993), its development as a field more associated with marketing came into sight after World War II (Coyle, Bardi and Langley, 1996). Owing to the mass production that followed World War II, the capacity to distribute products speeded up; the need emerged for more efficient physical distribution system to reach new markets. In the early 1960s, the logistics concept began to appear in the business-related activities under the label of physical distribution (Langley et al, 2008). In the beginning, the whole activities of physical distribution were managed as separate elements; however, the total cost of reaching new markets by this manner required economic considerations to be bear in mind (Muya, 1999). In the mid of 1960s and with the aim of reducing the total cost of logistics, the organisations began placing all distribution activities: transportation, materials handling, warehousing and inventory control in one management function, namely physical distribution, which focuses on the outbound side of the logistics system (Langley et al, 2008). Within the same period 1960-1970, organisations whose businesses had complex inbound logistics were similarly managing the all upstream activities together with one function, namely materials management (Muya, 1999).

Since the 1970s, organisations have become aware that integrating materials management with physical distribution and flowing the all materials and products continuously offers a good opportunity for future cost saving and for greater operational efficiencies. The 1980s and 1990s witnessed the development of logistics perspective to encompass all companies within the total logistics system from raw materials suppliers to ultimate customer (Coyle, Bardi and Langley, 1996; Muya, 1999; Ballou, 2004), as exhibited in **Figure 2.6**;

By referring to the logistics development history and reviewing a number of literature, such as Sutton (1993), Coyle, Bardi and Langley (1996), Muya (1999), Tan (2001), Ballou (2004), Shakantu, 2004, Langley et al (2008), Rodrigue and Hesse, (2009), and Waters (2009), one can concluded that the logistics management at the organisation level involves two main parts of *materials management* and *physical distribution* as illustrated in the figure above. This provides further support for the equation that was presented by Rushton and Oxley (1989) and that displayed the relationship between logistics and material management:

Material Management + Physical Distribution = Logistics

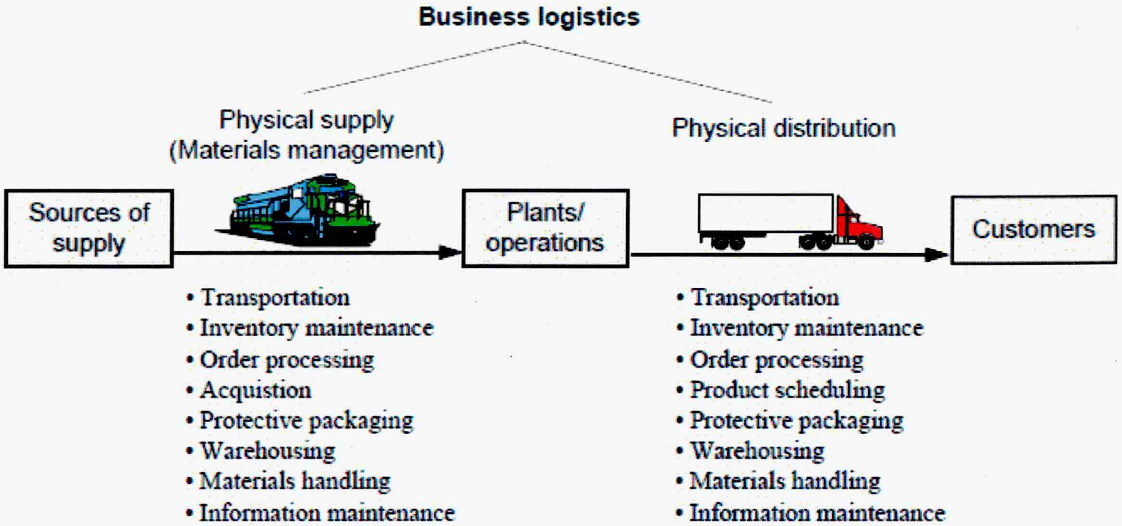


Figure 2.6: Logistics Activities divided into Materials Management and Physical Distribution (Ballou, 2004)

In construction industry, Waters (2009, p5) observes that *"the logistics manages the flow of inputs from suppliers, the movement of materials through different operations within the organisation, and the flow of materials out to customer"*. Waters (2009, p5) broke down the structure of the logistics management into three sections; 1- *Inbound/Inward Logistics*: Moving materials into an organisation from suppliers; 2- *Outbound/outward Logistics*: Moving materials from an organisation out to customers; 3- *Materials Management*: Controlling the movement of materials within an organisation (from internal suppliers and delivering to internal customers), as illustrated in **Figure 2.7** below.

Based on the fact of that managing the construction materials successfully within an organisation means managing the whole logistics process successfully (Venkataraman, 2004; Binti Kasim, 2008), and the results that was derived from the survey that conducted by Alzohbi (2008) and found that construction material management (CMM) is the most frequent problem in construction projects and the third most important problem in terms of their effect on managing the construction projects in Libya, the **Construction Material Management** (CMM) has been adopted in this research to be the focal area of study.

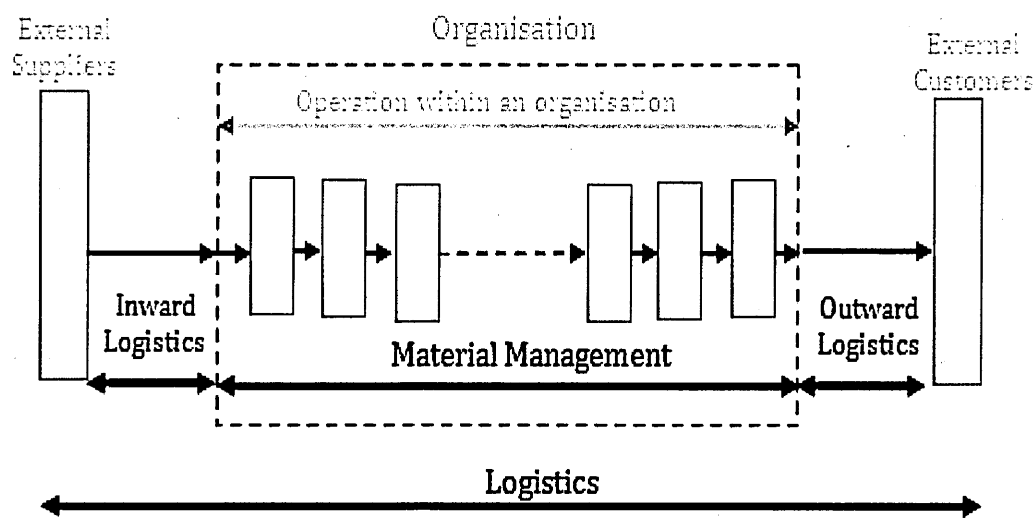


Figure 2.7: The Materials Management within the Logistics (Waters, 2009)

2.9 SUMMARY OF THE CHAPTER

In addition to presenting the definitions of supply chain management (SCM) and logistics management (LM) from different perspectives, chapter II interpreted the evolution of the Construction Materials Management (CMM) concept, and provides clarification the common misconception within the majority of Arab construction projects; 'terminology of SCM and LM are synonymous to CMM'. Since, the chapter explains the different between the concepts and the roles of SCM, LM, and CMM, and how this concept has been generated from the SCM and the LM notions. The chapter also illustrates the focus and the limitation of this project study, where, the study concentrates on the process of the CMM that is practiced within a contractor organisation, as discussed in the next chapter.

CHAPTER III:

CONSTRUCTION MATERIALS MANAGEMENT PROCESS:

3.0 INTRODUCTION TO THE CHAPTER:

Based on what has been pointed out in the previous chapter (Chapter II), the roots of the materials management process have become apparent; materials management is a part of logistics management which in turn is a part of supply chain management. Chapter III focuses on studying the materials management process in construction (CMM), which represents the focal point of the current research. The chapter is designed to achieve the first objective of the research through providing a critical review built on analysing the existing literature on materials management context, with more concentration on studying the materials management process in construction (CMM). It seeks to explore, theoretically, the typical workflow diagram(s) depicting the main functions and activities that shape the construction materials management process.

This chapter reviews the research efforts in materials management on construction projects. It starts with defining the different types of construction materials together with materials management from different perspectives. Then the efforts concentrate on reviewing the existing studies on processing materials management and determining the main and typical components that form the materials management process within the construction projects. The results of the research efforts made on construction materials management process are synthesized and the main functions that are adopted to shape the CMM process are identified. In the last part of this chapter, the typical workflow diagram(s) of the CMM process is/are explored. The development of CMM process workflow diagram would be helpful to understand the adopted materials management process and to provide the basis for building the Practical Workflow Diagram of the CMM Process (PCMMP Workflow Diagram), which in turn represents the basic structure of the framework of measuring the Effectiveness of the Construction Materials Management Performance (E.CMM.P Framework).

3.1 INTRODUCTION TO MATERIALS MANAGEMENT:

3.1.1 What Are Materials?

The term "materials" has different definitions that vary according to the descriptive and perspective viewpoints in terms of location, use, classification, and other perspectives. This term is defined by *Webster's Dictionary* as "*the elements, constituents, or substances of* *which something is composed or can be made.*" (the *Webster's Dictionary*) whereas, Ballot (1971) defines materials, physically, as the items and parts that are purchased and used to produce the final product, but he does not imply that the materials are the final product. In line with this definition, Bailey and Farmer (1982), Stukhart (1995) and Al-Haddad (2006) define materials as the goods and items purchased from sources not related to the organisation, and they are used to create a product; these can include raw materials, supplies, parts, and equipments.

With regard to defining materials in terms of classification and place to be used, Perdomo-Rivera (2004) provides a comparative classification for materials within the manufacturing and construction industries; Dobler and Burt (1996) classify materials within manufacturing industry into five main categories of manufacturing materials, as follows;

- Raw Materials: materials that the company converts into processed parts. This might include parts specifically produced for company and parts bought directly off the shelf (i.e. bolts, nuts).
- Purchased Parts: parts that the company buys from outside sources (i.e. rubber parts, plastic parts).
- Manufactured parts: parts produced by the company (i.e. a tower case for a computer).
- Work in Process: these are semi-finished products found at various stages in the production process (i.e. assemble motherboard).
- MOR Supplies: Maintenance, Repairing, and Operating Supplies used in the manufacturing process but are not part of the final products (i.e. soap, lubricating oil).

Chandler (1978) classifies materials within the construction industry, construction materials, into different five categories depending on their fabrication and on the manner that they can be handled on site;

- Bulk materials: materials that are delivered in mass and are deposited in a container.
- Bagged materials: materials delivered in bags for ease of handling and controlled use.
- Palleted materials: bagged materials that are placed in pallets for delivery.

- Packaged materials: materials that are packaged together to prevent damage during transportation and deterioration when they are stored.
- Loose materials: materials that are partially fabricated and that should be handled individually.

Table 3.1 below displays examples of the classification of some commonly used materials in construction.

Table 3.1: Classification of Construction Materials (Adopted from Chandler, 1978 and Perdomo-Rivera, 2004)

Material	*Bulk*	*Bagged*	*Palleted*	*Packaged*	*Loose*
Sand	×				
Gravel	×				
Topsoil	×				
Paving Slabs					×
Structural Timber					×
Cement	×	×	×		
Concrete	×				
Pipes				×	×
Tiles				×	
Doors			×		
Electrical Fittings				×	

However, many of the recent studies and researches, such as those conducted by Perdomo-Rivera (2004), Al Haddad (2006), and Nasir (2008), prefer the classification of construction materials that is introduced by Stukhart (1995) and approved by the Construction Industry Institute (CII) (1999). He classified materials that are encountered in a construction project into three main categories: engineered materials, bulk materials, and fabricated materials.

- ***Engineered materials:*** these materials are specifically fabricated for a particular project or are manufactured to an industry specification in a shop away from the site. They are uniquely identified on drawings and they have a uniquely assigned number (or tag) so that they can be uniquely referred to and identified throughout the entire life of the facility. They are considered as the most visible, costly, complex, and quality-critical. Nasir (2008) further divides the engineered materials into:

- Major Equipment: items which are engineered and fabricated specially for the project (e.g., tanks, heat exchangers, pumps, major instrumentation systems),
- Minor Equipment: items that are manufactured to an industry specification and are often stocked by the manufacturer or the distributor. They are also uniquely tagged for identification purposes (e.g., minor instrumentation items, thermo wells, transmitters, specialty items).

- ***Bulk materials:*** materials manufactured to industry standards and are usually purchased in large quantities. They are more difficult to plan because of uncertainty in quantities needed; moreover, the design evolution requires continual updating of the bulk requirements. Examples of such materials include concrete (ready mixed and site manufactured), pipes, wiring, cables, stone, gravel, and sand; brickwork and block-work and related products.

- ***Fabricated materials:*** materials and items that are typically engineered and fabricated in compliance with the engineering specifications in a fabrication shop or site which is separated from the construction site. Depending on the strategies or the contract's type of project, the component materials which constitute the fabricated items may be quantified, procured, and delivered to the fabricator by the engineer or constructor (Nasir, 2008). Fabricated materials may include modules and preassemblies, platforms, structural reinforcement steel, steel beams with holes, pipe spools, control stations, and precast concrete items, wall panels, columns or beams.

3.1.2 Jordan Construction Materials:

Jordanian buildings, as those in the majority of the Arab region, are mainly constructed from limestone, different forms of concrete, aggregate, bricks, cement plaster, and steel (Sharaf and Hamideen, 2013). According to Najmi (2011), Jordan has a self-sufficiency of most of the resources and the raw materials that are used in the majority of the Jordanian construction projects; among those resources are ornamental stones and marble, cement, sand, gravel, crushed stone and other materials. He added that "Jordan also has a good reputation regionally when it comes to working with metal and producing metal structures for various construction purposes". (Najmi, 2011, p45). This provides a major benefit to the construction industry and encourages the investment in the different construction sectors in Jordan.

3.1.3 Construction Materials Addressed:

Each category of materials requires a different approach during the planning and execution stages of the project. Tommelein (1998) observes that "*engineered items are available at higher costs in smaller quantities and with more unique properties than long-lead bulk materials and off-the-shelf items, thus implying longer lead-time and requiring more front-end planning*" (on Nair, 2008, p14). On the other hand, Nasir (2008, p14) believes that "*the availability of long lead-bulks and off-the shelf items is of concern to short-range planning and execution of the work at the crew level*". This can cause complexity in understanding and identifying the functions and activities that form the process of materials management. This confirms the necessity to determine the scope of this research regarding the type of projects, the stage of implementation and the type of construction materials which would be addressed in the study.

As mentioned in Chapter One, the majority of the construction projects in the Arab regions are concrete based, and accordingly, cement, steel, sand, aggregate and water are the most important construction materials within the Arab Construction Industry (Grifa, 2006). Therefore, the term "materials" in this study refers to raw materials, component parts, consumables, packing and packaging and equipment used for implementing Construction Concrete Building Projects within Skeleton Stage. Generally, the term "equipment" means permanent equipment including minor equipment, parts, and special tools, but it excludes construction (movable) equipment and related pats. In this study, more emphasis is placed on the next materials, which according to Grifa (2006) and Al-Haddad (2006), are selected to represent the main types of construction materials used within a skeleton stage in the Arab building projects; 'Concrete' represents the bulk materials, 'Reinforcement Structural Steel' represents fabricated materials, and 'Insulation/Isolation Boards represents engineered materials. This customization could help in avoiding the complexity in managing various types of materials and facilitating the development of a typical and unified workflow diagram for the process of the CMM.

3.2 MATERIALS MANAGEMENT IN CONSTRUCTION (CMM):

3.2.1 Definition of Materials Management:

Managing materials successfully can play a key role in the construction project success. In order to understand the maritals management process, one needs to review and identify exact definitions (Al-Darweesh, 1999). Various definitions for materials management are presented; the most common of which is the one presented by the Business Roundtable (1982). It is considered by a number of authors as the best one so far. Materials management is defined as; "*planning and controlling all the necessary efforts to ensure that the correct quality and quantity of materials and installed equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed*" (Plemmons, 1995, p14). On the other hand, Bell and Stukhart (1986) and Bell and Stukhart (1987) define it in more details as

> "*the process of planning, controlling, and integrated of materials takeoff, purchasing, economic, expediting, transportation, warehousing, and issue functions in order to achieve a smooth, timely, efficient flow of materials to the project in the required quantity, the required time, and at an acceptable price and required quality, and the planning and controlling of these functions*" (Al-Darweesh, 1999, p4).

Al-Haddad (2006) is consistent with respect to the conceptions of the Chandler (1978), Ammer (1980), Bailey and Farmer (1982), Gossom (1983), and Arnold (1991) that defined materials management as the process whereby an organisation obtains the required materials for achieving its objectives. They believe that his process is responsible for the planning and controlling of materials flow, beginning from the time of developing a plan, requisition of materials from the supplier, purchasing, receiving, storage, quality control, and inventory control, until the material is used and converted into a final product. They stress that these activities that compose the material management process should be interrelated.

Concerning the construction context, Muehlhausen (1991), who focussed on the construction context, defined materials management as;

> "*planning, executing, and controlling of all activities influencing the flow of materials to and through the jobsite. These activities include the design of the structure, materials requirements and project planning, requisitioning of materials, purchasing materials, expediting shop drawing approval and materials fabrication and delivery, shipping the materials, receiving the*

materials at site or other storage location, and sorting and handling the materials" (Al-Darweesh, 1999, p4).

Additionally, with more relevance to the construction projects, Stukhart (1995) adopts the definition provided by Plemmons and Bell (1995) that considers materials management as the plan and control of all activities involved to purchase, expedite, transport, store, and issue in order to achieve an efficient flow of materials and to ensure that the required materials are bought in the required quantities, at the required time, with the required quality, at an acceptable price, and that they are available when needed.

Many other definitions of materials management can be found; however, the majority of the authors of contemporary literature such as, Al-Darweesh (1999), Yang and Mahdjoubi (2000), Yang, Edwards and Nicholas (2003), Al-Khalil, et al. (2004), Al-Juaid (2005), Al-Quriesha, Bello and Fallatah (2006), and Al-Alawi, Al-Ghazwi and Al-Saeed (2007) preferred the first definition of materials management that was provided by the Business Roundtable (1982). Nevertheless, they all agree with Plemmons (1995), Stukhart (1995) and Formoso and Revelo (1999) that materials management is a process rather than an organisation, which encompasses activities that go beyond the organisational boundaries to embrace the outside organisations such as those of vendors and subcontractors.

In short, one can note that materials management is a system for planning, organising, and controlling all those activities that are primarily concerned with the flow of materials into an organisation. In the context of construction, materials management is an approach for planning to secure the availability of the construction materials whenever and wherever they are needed and to ensure that the right quality and quantity of materials are appropriately selected, purchased, delivered, and handled onsite in a timely manner and at a reasonable cost (Al-Alawi, Al-Ghazwi and Al-Saeed, 2007). In general, the construction materials are expensive and bulky; furthermore, they are supplied in large quantities to the construction sites; therefore, there is an urgent need for a unique system for managing the construction materials.

3.2.2 The Importance of Materials Management and Challenges Faced within the Construction Industry (CI):

The World Bank (1988), Beardsworth *et al.* (1988), Fellows *et al.* (2002), Hassan (2005), and Cook and Williams (2009) believe that Construction Industry (CI) is the economic sector which converts a variety of resources into constructed social and economic infrastructure and facilities. Construction is the process of physically erecting the project and positioning the construction equipment, materials, supervision, supplies, and management necessary to accomplish the job (Clough, Sears and Sears, 2000). Construction activity within the industry is a civil engineering; it involves building everything from house repair to large and sophisticated civil engineering projects such as the Great Man-made River project in Libya and the Millennium Dome project in the UK. The construction industry is a project-oriented industry (Wegelius-Lethtonen, 2001). Although a similar set of process stages can be implemented on every road, building, bridge, industrial, or process plant construction project, each project is regarded as unique (Newcomb, Langford and Fellows, 1993; Wegelius-Lethtonen, 2001; Fryer, 2004 and Griffith and Watson, 2004). A conception can be crystallized; it implies that each construction project is characterised by its temporary nature particularly with respect to the fragmentation and the geographical dispersion of the production sites (Newcomb, Langford and Fellows, 1993; Beatham et al., 2004; Fryer, 2004; Griffith and Watson, 2004; Nudurupati, Arshad, and Turner, 2007). This makes construction projects complex in that they involve many organisations and participants, such as owners/clients (employers, accountants and financers), architects (designers, planners and supervisors), contractors (executive managers, engineers, professionals and construction workers), insurers, materials suppliers and vendors. Although Hassan (2005) conceives that relationships within the parties in construction projects are more stable, continuous and enduring than those in manufacturing, Walker (2007) and Cook and Williams (2009) point to the interrelationships that undergo in the construction projects between the parties concerned; they are the most complex relationships (Walker, 2007; Cook and Williams, 2009). This complexity includes "*the heterogeneous and often complex process of producing unique, large and immovable products with a supply of the resources (money, equipment, material, and labour)*" (Binti-Kasim, 2008, p47).

The uniqueness of the majority of construction projects makes the management of materials a challenge that has continued to cause a major obstacle to the success and profitability of these projects. As projects grow in size and complexity, materials management becomes more difficult and the need for excellent materials management techniques becomes essential. Construction materials management (CMM) particularly in large and major projects is a complex and important function that requires substantial improvements (Ibn-Homaid, 2002). Construction Materials Management can be defined as a system that comprises all the functions required for acquiring and internally distributing the materials and equipment to support construction. Perdomo-Rivera (2004, p39) argues that "*the basic idea behind construction materials management is that the materials and/or equipment needed, in the quantities needed, meeting the standards of the quality specified, are obtained at a reasonable cost and are available when needed on the construction site*". CMM aims, amongst other things, to gain the best value for the purchased materials, to reduce inventory to the lowest amount required, to ensure that supplies are at hand whenever and wherever needed, to guarantee that the quality requirements are met, and to provide low cost transport, security and storage of materials at the construction sites (CII Handbook, 1987; Construction Institution Industry (CII) Handbook, 1988; Plemmons, 1995; Al-Darweesh, 1999).

Typically, in the construction projects, the cost of materials and equipment used represents around 50-60 percent of the total cost of these projects (Construction Institution Industry (CII) Handbook, 1987; Plemmons, 1995). Consequently, the lack of construction materials when required at the job site is, normally, the single most frequent problem that occurs in a construction site and that causes the construction delays (Construction Institution Industry (CII) Handbook, 1987, Plemmons, 1995; Alzohbi, 2008; Alzohbi, Stephenson and Griffith, 2011). According to the findings that were reached from the survey conducted by Bell and Stukhart (1987), an effective materials management system could reduce bulk materials surplus from a range of 5-10% of bulk materials purchased to about 1-3%. Their research also concluded that efficient materials management can reduce man hours needed for materials management; that's where the construction projects that suffer from poor materials management system; craft foremen spend up to 20% of their time searching for materials and another 10% tracking purchase orders (POs) and expediting. Moreover, Dey (2000) found out that the delays in supplying materials are a major case of time overrun.

Additionally, the importance of materials management in construction can be demonstrated from various perspectives in the majority of the literature related to materials management as shown in **Table 3.2**.

Table 3.2: The Importance of Materials Management in Construction

The Author	*The Importance*
Marsh (1985)	*"Effective materials management will result in 6 to 8% improvement in labour productivity, improved cash flow, reduced bulk materials surplus, reduced materials management human resources, improved vendor performance, reduced requirement for physical warehouse facilities, quantity purchasing discounts, minimized cost impact of change orders and fewer project delays"*
Silver (1988)	Materials management can make a significant contribution to the cost effectiveness of projects and it is important in the planning and execution of large scale construction projects.
Ogunlana, Pronikuntong and Jeark-jirm (1996)	"...... *the main reasons for project delays on housing projects in Thailand were incomplete drawings, materials management problems, organisation deficiencies, shortage of construction materials, and inefficiencies in site workers*".
Opfer (1998)	Properly executed material management strategies in a construction project can improve the project's cost structure and client service.
Formoso and Revelo, (1999)	*"The lack of materials is one of the most common causes of delays in construction"*
Al-Darweesh (1999)	"*.....the need to implement an Effective Material Management System in construction is highly desirable*".
Ibn-Homaid (2002)	*"The importance of proper management of materials is highlighted by the fact that they account for substantial portions of project cost and time."*
Perdomo-Rivera (2004, p39)	*"A well managed materials management system can contribute to the cost effectiveness of a project"*
Al Haddad (2006, p9)	*"Materials management is an important element in project planning and control".*
Binti Kasim (2008)	Materials management is an important function for improving productivity in construction projects.
Alzohbi, Stephenson and Griffith (2011)	Lack of materials management in construction projects represents the most frequent problem in managing the construction site and the third most important problem of the construction sites, in terms of their effect on managing the construction site, after problems of planning and design.

The statements above further illustrate that improper management and handling of materials during the construction process can dramatically influence the total project time, cost, and quality. Given the impact on cost, schedule, and quality, it can be concluded that materials management in complex and large construction projects needs adequate consideration, and the effectiveness of its performance needs to be measured.

3.2.3 Roles of the CMM Parties and Responsibilities:

Edum-Fotwe, Thorpe and McCaffer (1999) and (Hatmoko, 2008) argue that the parties involved in the construction materials management (CMM) may vary according to the stage of the construction, and they proposed classification for the parties of CMM as summarized in **Table 3.3** below.

Table 3.3: Parties Involved in the Construction Materials Management (CMM) (Edum-Fotwe, Thorpe and McCaffer, 1999)

Conceptual	*Construction*	*Maintenance*	*Replacement*	*De - commission*
Client Project Manager Safety Consultant Architecture designers Civil Designer Structural Designer Mechanical Designer Electronic Designers Cost Consultant Financial Institution Insurance agency Regulatory bodies	Main Contractor Domestic subcontractors Nominated subcontractors Project manager Material suppliers Plant/equipment suppliers Designer Financial Institution Insurance agency Regulatory bodies	Client In-house management Maintenance contractors Facilities consultant Insurance agency	Client Project manager Safety/quality consultant Architectural designers Civil designers Electronically designers Specialities designers Cost consultant Regulatory bodies Main Contractor Domestic subcontractors Nominated subcontractors Material suppliers Plan/equipment suppliers	Demotion contractor

However, among many construction related researchers and authors, Muya (1999), Perdomo-Rivera (2004) and Hatmoko (2008) believe that the key parties within construction materials management process include clients, main contractors, subcontractors, materials suppliers, and/or vendors. All these provide input of one form or another which goes towards the realisation of projects. In order to have a common perception and understanding of the key parties in the process of CMM, the definitions and roles of client, main contractor, subcontractors, supplier, and vendor, which have been provided by Muya (1999), Perdomo-Rivera (2004), and Hatmoko (2008), are introduced briefly in **Appendix P**.

Responsibilities for Construction Materials Management Process:

Overall, the discussion of the roles of the CMM parties (see **Appendix P**) demonstrates that clients, main contractors, subcontractors, and suppliers/vendors play important roles in the success of construction materials management process as they occupy strategic positions in the process. However, their roles and responsibilities should be identified from the earlier time of project planning or may be before signing a contract. Each construction company has its particular materials management system where the responsibilities for various functions and activities are spread between engineering, purchasing, and construction (Al-Haddad, 2006; Najmi, 2011). Stukhart (1995) and Nasir (2008) stress that the organisation plan, particularly for large-scale projects, should develop responsibilities for materials from a sequential flow chart, where the procurement process starts with identifying the purchasing responsibility.

Based on the fact that among the essentials for getting people to function well in such an organizational arrangement is that "people want recognition for their work" Stukhart (1995). Many of the construction companies, thus, manage materials in the large projects through an informal team, using responsibilities matrices such as the one in **Figure 3.1** or sequential flow charts, similar to that in **Figure 3.2**. The role and responsibilities matrix and flow chart, which are usually represented within the materials management organization, represent the responsibilities of several people from different departments (Perdomo-Rivera, 2004).

Stukhart (1995, p71) believes that "*a detailed system flow chart and matrix should be developed with input from all key project participants, because each key person will then have a clear understanding of materials management responsibilities*". He added that the responsibility and position of all key personnel for each corporate or project participants are best illustrated on organization charts that promote better understanding of the different organizational groups participating in the work and allow a clear understanding of the authority of key personnel, showing the flow of information through the line of authority. It can be noted that the flow chart can include a material coordinator, who may be a person in the home office, or a material group, that might include the range of activities associated with procurement. However, the coordination of activities operating within the context of matrix and the flowchart of responsibilities require considerable skill and experiences.

	Materials Management Plan	Reorder Status	Requisition control/processing	Expediting/traffic	inspection	Shop fabrication control	Inventory control	Field requisition	Field buying	Change order evaluation	Surplus disposition
PROJECT MANAGEMENT	A		A	A	A					A	A
ENGINEERING					I E						
PROJECT CONTROLS										E	
MATERIALS GROUP										E	E
MATERIALS COORDINATOR	I E C	I E C	I E C	C	C	I E C	C	C	C	I C	I C
CONSTRUCTION				E	E		I E	I E	I E	E	E

I: INITIATE A: APPROVE E: EXECUTE/PREPAR C: COORDINATE

Figure 3.1: The Responsibility Matrix for CMM Process (Stukhart, 1995, p74)

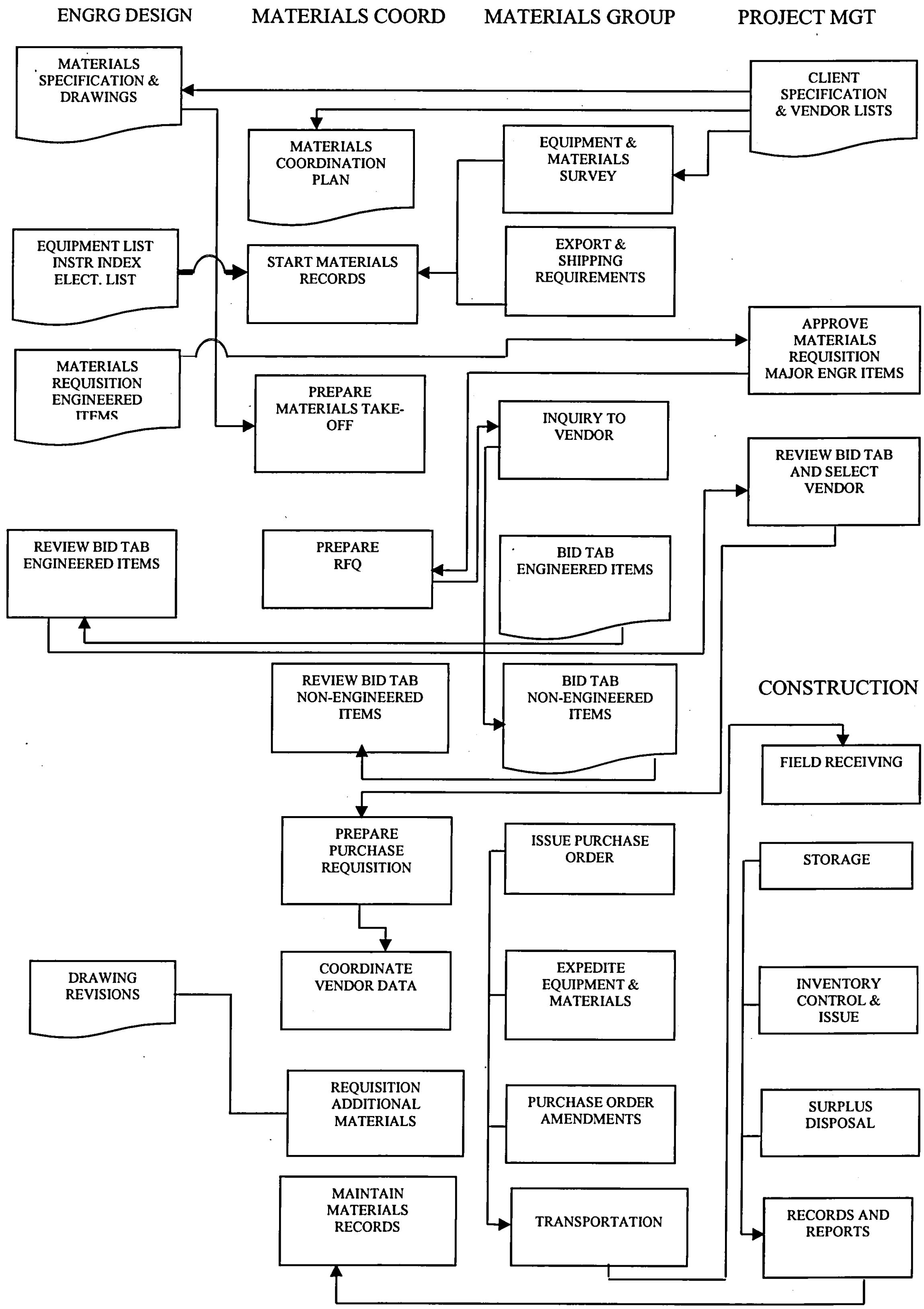


Figure 3.2: Responsibilities Flowchart for CMM process (Stukhart, 1995, p72)

3.3 CONSTRUCTION MATERIAL MANAGEMENT PROCESS:

It can be concluded from the research studies presented earlier that the management of construction materials is a process that includes various activities which exceed the organizational boundaries of a construction project. This supports the perspective of Construction Industry Institution (CII) that was introduced in the Project Materials Planning Guide in 1987; it stipulates that;

> "*Project materials management should be thought of as a process rather than an organisation. In fact, the activities of materials cycle cross all organisational lines of the project and begin with specification of the material which is primarily the responsibility of the owner and engineer*".

The CMM process crosses the organisation boundary to reach outside organisations such as those of subcontractors and vendors (Al-Darweesh, 1999). There are several CMM-related researchers and professionals who have suggested the vision of recognizing the Construction Materials Management as a process. For instance, Stukhart (1995, p29) justified the necessity for this vision; "*it is very important that materials management be recognized as a **system** or **process**, rather than a function or organisation, because systems and processes imply a common set of goals, as distinct from just some commonality in activities*". He added that the use of this approach (a system or process) to construction materials management provides a means of looking at assumptions that govern existing techniques and enable one to think in terms of innovations that affect the entire system. Plemmons (1995), Ul-Asad (2005), Al-Quriesha, Bello and Fallatah (2006) among others agree with Bell and Stukhart (1987) that "*Construction professionals are recognizing the need to focus on the materials management process as a proactive, identifiable entity that has a significant impact on the cost of construction*".

However, according to Stukhart (1995, p34) "*The difficulty in considering materials management as a process is that it must be a measured set of activities*". Formoso and Revelo (1999) observe that in construction projects, the number of materials is very large and that there is a wide variety of suppliers, which makes the process of supplying materials to the building sites difficult to manage, even for a moderate construction project. Therefore, the materials supply process in building projects involves many functions and activities, carried out on several different departments; moreover, managing the construction materials requires comprehensive knowledge of these functions and activities and identification of their roles and boundaries.

According to Construction Industry Institution (CII) (1988), the materials management process includes the key functions for identifying, acquiring, distributing, and disposing of materials required for a construction project. **Figure 3.3** displays the logical components of a construction materials management system that is developed by the Construction Industry Institute (CII)-Materials Management Task Force Publication 7-2 in 1988; and it is adopted by Stukhart, (1995), Oswal (2007), and Nasir (2008).

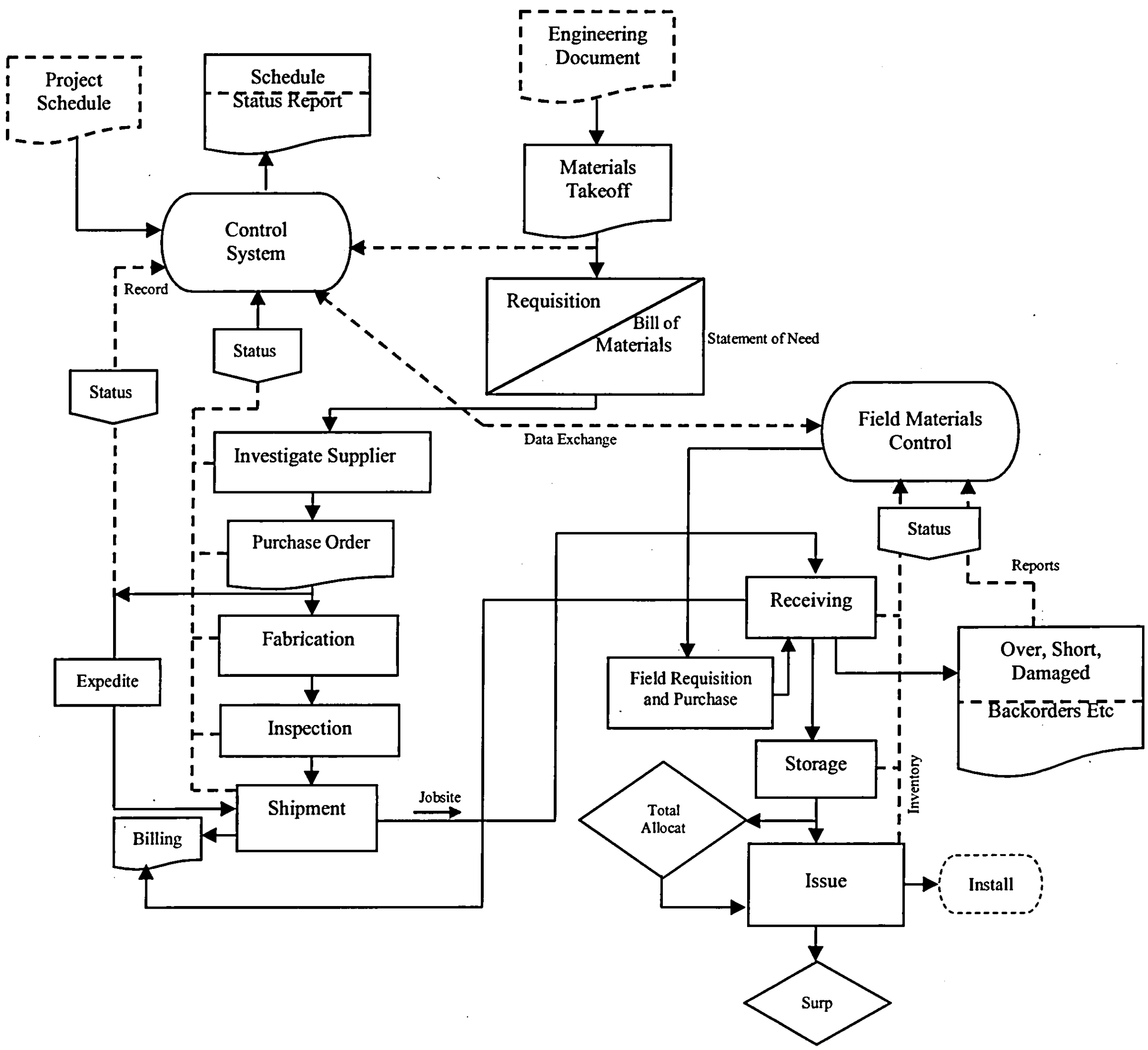


Figure 3.3: Flowchart Construction Materials Management System (Generated by (CII), Materials Management Task Force Publication 7-2, 1988, p2; Adopted by Stukhart, 1995, p28; Nasir, 2008, p2)

The integration of these functions, which will be discussed in the following sections, aims at achieving the subsequent objectives;

- Ensuring that quality materials are on hand whenever and wherever required.
- Obtaining the best value for the purchased materials.
- Providing efficient, low cost transport, security, and storage of materials within the construction sites.
- Reducing the surplus to the lowest level possible (CII, 1988).

3.3.1 Integration Functions:

The functions of construction materials management are often performed on a fragmented basis with minimal communication and no clearly established responsibilities among the parties involved. This fragmentation creates gaps in information flow, which does not help in implementing the collaboration required among departments, and in turn leads to project delays (Perdomo-Rivera, 2004). In contrast, the Construction Industry Institution (Construction Institution Industry (CII), 1988) declares that in certain instances, particularly on large projects, the whole scope of materials functions may be combined into one unit. Pannell (2006) in the ICMM newsletter confirms what was argued by CII (1987), CII (1988), Plemmons (1995), and Al-Quriesha, Bello and Fallatah (2005) that a proactive integrated system approach is the only successful means to ensure that materials are considered in project planning, controlling and directing activities. CII (1988) suggests that the integration system must satisfy the control and reporting requirements for each function of the process exposed in **Figure 3.3**. It further stresses the flexibility of the system to allow the entry and tracking of materials by a work package, consistent with the total project work planning. Stukhart and Marsh (1986), Plemmons (1995) and Al-Quriesha, Bello and Fallatah (2005) argued for the necessity of involving the material management personnel in the different phases of project management to achieve a proactive integrated materials management. They confirm what was stated by Construction Industry Institution (CII) (1988 p5);

> "*Materials management personnel must be able to operate in the project environment, to anticipate the requirements of other organizations, to administer their program within a complex set of organizational arrangements, and to communicate the importance of materials management*".

With regard to the application of an integrated computer system, CII (1987) and CII (1988) point out that to achieve coordination of the individual functions of construction materials management (CMM), a computer system is usually needed. A well designed one can assist in generating materials requirements and then tracking the materials requisitions and purchase orders through purchasing, expediting, and warehouse functions to their final destination ending with their instalment in a construction site. However, building an integrated computerized system needs determining clearly the integrated functions that form the process of managing construction materials, in order to identify many issues; the material-related data needs of the project, the specific functions to be integrated, and the identity and location of the various participating entities (CII, 1988). The identification of the integrated functions is the primary step of developing a construction materials management process.

In recent years, the contractors involved in the construction projects have developed integrated (Total Concept) materials management systems that combine and integrate a number of functions and activities (Bell1 and Stukhart, 1987). Nevertheless, due to the differences in the type, size, and location of the construction projects, some differences in the functions and activities that form the integrated system of CMM can be pinpointed. Therefore, in order to understand and define the integrated functions involved in the construction materials management process, it was vital to conduct a survey of the literature (Literature Review) related to materials management in the construction projects. The detailed examination of the literature on construction materials management reveals different forms of the construction materials management process that involves various integrated functions, as summarised in **Table 3.4**.

Table 3.4: Summary of the Theoretical Studies on the Process of the CMM

The Author(s)	*The Integrated Functions Form the CMM Process*
Bell and Stukhart (1986)	• Project Planning • Material Take-off • Vendor Inquiry and Evaluation • Purchasing • Expediting and Transportation • Field Material Control • Warehousing
CII (1987)	• Material Specifications and Take off

The Author(s)	*The Integrated Functions Form the CMM Process*
	• Vendor Selection • Order • Approval and Quality management • Expediting and Transportation • Fabrication and Delivery • Installation
CII (1988)	• Material Requirements Planning and Control • Purchasing • Expediting • Quality Assurance and Quality Control • Transportation • Site Materials Management • Surplus Materials
Plemmons (1995) & Plemmons and Bill (1995)	• Planning • Material Takeoff and Design Interface • Vendor Inquiry and Evaluation • Purchasing • Expediting and Transportation • Warehousing • Field Control • Issue of materials
Stukhart (1995)	• Planning and Communication • Materials Requirements and Engineering Interface • Vendor Inquiry and Evaluation • Purchasing • Quality Assurance and Control • Warehousing, Receiving, and distribution • Field Material Control
Al-Darweesh (1999)	• Materials takeoff and Vendor Selection • Purchasing • Quality management • Expediting • Shipping • Receiving • Warehousing • Issues of materials
Kini (1999)	• Vendor Enquiry and purchasing • expediting and • controlling the progress of the vendor
Muya (1999)	• Purchasing policy • Construction phase o The buying schedule o The materials schedule • Site logistics activities o Expediting o Deliveries and receiving of materials

The Author(s)	*The Integrated Functions Form the CMM Process*
	o Receiving o Quality control at receiving o Off-loading o Materials handling on site o Inventory management o Warehousing and issue of materials o Issue of materials
Developed from Coyle, Bardi and Langley (1996) and Ballou (2004),	• Requirements Planning • Purchasing • Warehousing • Co-operate with production/operations • Shipping • Receiving • Information maintenance • Issues of materials
Al-Juaid (2005)	• Materials takeoff • Purchasing concerns o Establishment of forms and procedures to purchase materials; o Developing standards terms and conditions; o Issuing request for quotations; o Evaluating bids; o Price and contract negotiations; o Preparing and administrating purchase orders; o executing close outer activities, • Quality management • Expediting • Shipping • Warehousing
UL-Asad (2005)	• Planning • Materials Take-off • Vendor Enquiry • Purchasing • Material Control • Warehousing • Expediting and Shipping
Al-Haddad (2006) adopted from Perdomo-Rivera (2004)	• Procurement and purchasing • Expediting • .Materials planning • .Materials handling • Distribution • Cost control • Inventory management / Receiving/ Warehousing • Transportation
Al-Alawi, Al-Ghazwi and Al-Saeed (2007)	• Planning • Materials Take-off • Vendor Enquiry • Purchasing

The Author(s)	*The Integrated Functions Form the CMM Process*
	• Material Control • Warehousing • Expediting and Shipping
Binti-Kasim (2008)	• Planning • Procurement • Logistics • Handling • Stock and Waste Control
Nasir (2008)	• Materials takeoff, • Purchasing, • Expediting, • Receiving, • Warehousing and • Distribution

Although there are relative differences between the CMM functions that form the CMM process and their order (as illustrated in **Table 3.4** above), one can not see major differences between these integrated functions within the twenty years, and there are essential commonalities that can be discerned. It can be derived from **Table 3.4** that the most common integrated functions that are used by various construction contractors and that can be considered as commonalities among the CMM processes are;

1- Project planning,
2- Material take-off,
3- Vendor enquiry and evaluation,
4- Purchasing,
5- Expediting and transportation,
6- Field control,
7- Warehousing,
8- Material Issues,
9- Surplus Materials, and
10- Quality management (Quality Assurance and Quality Control).

One can argue that certain sub-functions or activities can be incorporated within the main functions. For example, functions like receiving, quality control for receiving and handling materials on a site can be included within the field control or/and warehousing functions;

warehousing can refer to inventory management, receiving, and distribution; procurement could subsume vendor enquiry, evaluation and selection, and the entire purchasing functions (including the establishment of forms and procedures for purchasing materials, the development of standards terms and conditions, the issuance of request for quotations, the evaluation of bids, prices and contract negotiations, etc.); transportation could encompass packaging, shipping and whole delivery operations and documents. It can be observed that the CMM process can comprise a wide range of functions and activities.

Therefore, in order to identify the exact functions and activities involved in the CMM process and addressed in this study, the boundaries of the CMM process or system (may be the boundaries of the study) should be identified. The CMM Process Boundaries and the Integrated Functions that are adopted in this study will be discussed and identified in the next section.

3.3.2 The CMM Process Boundaries and the Integrated Functions Adopted:

As opposed to the advantages and the importance of using a system approach to construction materials management that has been stated above, the vision of recognizing the Construction Materials Management (CMM) as a process has more than one disadvantage. The most tangible disadvantage of this approach is that;

> "*one must determine where the system starts and stops; that is, its boundaries. Unless management specifically defines materials management, there is a likelihood that the system will be defined differently in each organization. As a result, some functions and personnel will not believe that their goal is the same as that of the materials management system*" (Stukhart, 1995, p30)

In order to name the specific functions that form the CMM process in this research, the boundaries of the construction materials management process should be identified, and their complexity should be disintegrated into manageable and logical pieces (Plemmos, 1995). For this purpose, it is necessary to limit the materials management process to those functions primarily associated with materials and materials-related data. The functions, which are considered "*to be a customer of material management data and information and to have no direct influence on the primary outputs of the materials management process*" (Plemmons, 1995, p10), are not considered among the integrated functions of the materials management system. For instance, the function or organisation associated with the accounts payable or the accounting activities.

To facilitate identifying the CMM process boundaries, Broeke *et al.*, (1989) suggest using a process model to communicate the transportation of input into output. In other words, "*inputs enter into the process, and the process converts these inputs into outputs*" (Plemmons, 1995, p16). In our case, the model includes input consisting of the capital, labour, raw materials and information that are transformed into output embodied by the performance indicators of price, time, quality, quantity and place. Stukhart and Bell (1985, p74) state that "*the materials management process actually begins with a materials management plan incorporated into the project plan*". This means that the first function of the model of the CMM process is planning including the reception of the primary process input in the form of materials-related information from the team of a project. It acts on those early communications between the contractor and the owner, and it defines those responsibilities, considerations, constraints, and requirements that are considered necessary for the successful achievement of a construction project (Plemmons, 1995).

The CII handbook (1987) states that "*the main purpose of the site materials organisation is to get the right material...... in the hands of the construction personnel who are responsible for installing it*", and this view further supports that expressed by Plemmons (1995) and Al-Darweesh (1999) who define the end process boundary by the primary process output that is associated with issuing construction materials to the craft worker. The interface with construction has been recognised by CII handbook (1987) in the following statement; "*the materials management activities performed at the jobsite are the final stage of a process that can have a significant effect on the cost and schedule of a project*". Furthermore, Barba (1986) and Plemmons (1995) view the recognised interface between the jobsite activities, represented by the warehousing and field control functions and the customer process (construction or issuing materials to the craft worker), as the end boundary of the materials management process.

Considering the ten common integrated functions that are regarded as commonalities between the CMM processes reported in **Table 3.4**, and based on addressing the statements above through the life cycle of a construction project as depicted in **Figure 3.3**, one can detect the main integrated functions that can form a typical process of construction materials management. <u>**Eight** integrated functions</u> are identified as applicable to a typical building construction project; these functions begin with **1)** Planning as the first function and then followed by **2)** Material Take-off, **3)** Vendor Inquiry and Evaluation, **4)** Purchasing, **5)** Expediting and Transportation, **6)** Quality management (Quality Control), **7)** Warehousing, and **8)** Field Control. With the exception of the **sixth** function (Quality management), the other seven integrated functions were further selected by CII (1986), Bell and stukhart (1986), Plemmons (1995), Plemmons and Bell (1995), Ul-Asad (2005) and Al-Alawi, Al-Ghazwi and Al-Saeed, (2007) to form their proposed CMM processes.

For the purpose of understanding these functions and exploring their roles, responsibilities, limitations, and the activities that form these functions, the functions will be discussed, with some details, in **Appendix P**.

Perdomo-Rivera (2004) agrees with Bell and Stukhart (1986) that the integration of these functions needs a technique or system for communicating the process inputs, functions, activities and outputs, and for achieving the expected level of coordination of the CMM process. In order to comprehend and communicate the process inputs, attributes, functions and outputs, one of the most common techniques used is the process workflow diagram (Harrington, 1991; Plemmons, 1995), which will be discussed in the following section.

<u>3.4 IDENTIFYING THE TYPICAL CMM WORKFLOW DIAGRAM:</u>

A workflow diagram is one of the seven basic tools used in Total Quality Management (TQM) concepts (Walton, 1986; Brassard, 1989). A Workflow diagram, which is also known as a flowchart, can be defined as a technique for the graphical depiction of an existing process or a suggested future process by using symbols, icons, words and lines to provide a detailed overview of the activities and their sequence in the process (Harrington, 1991; Business Dictionary, 2011). Harrington (1991) describes flowcharting as "*an invaluable tool for understanding the inner workings of and the relationships between, business processes*"; he further added that when the flowcharts are applied to an entire process, they become "*the basis for analysing and improving the process*" (Plemmons, 1995, 70-71).

The workflow diagrams' application ranges from an outline view of process to a very detailed series of functions and activities so they can be developed for any level of organisational detail. Thus, Harrington (1991) and Plemmons (1995) classify this level of details into two categories of business processes that typically coexist within an organisation: the simple processes that are normally considered as sub-processes are organised along departmental responsibility lines and the more complex processes that are considered as cross-functional business processes flow horizontally across a number of organisational department lines including functions or activities.

3.4.1 Process Workflow-Diagram:

Based on what was stated above and what was clarified by Harrington (1991); the flowcharting of an entire process "*is the basis for analysing and improving the process*", the typical workflow diagram(s) of the CMM process and its functions will be developed to facilitate observing "*the rippling effect of improving any activity and the consequential impact on the external customer (the output)*" (Plemmons, 1995). Considering materials management as a complex process and the **eight** integrated functions adopted as sub-processes provides the basis for developing the CMM process diagram(s).

As alluded to earlier and adopted from the systems theory, input(s), Process(es) and output(s) are the basic components of any system or process, as demonstrated in **Figure 3.4.**

Figure 3.4: The System's Theory: Basic System Components

Based on what presented earlier, the construction materials management process, within the workflow diagram(s), can be broken into its components by tracing the information or materials from input, through the system, to output. This actually provides an understanding of the CMM process and its integrated functions and activities. Harrington (1991) offers a figure that demonstrates the hierarchy of the integrated functions and the basic activities within a process, as exhibited in **Figure 3.5.**

From **Figure 3.5**, it can be clearly illustrated that a process is bounded by the primary and secondary process inputs and outputs. Harrington (1991) and Plemmons (1995) explain the process hierarchy stating that the primary process input is passed to the first function through the beginning boundary, while the output from the end boundary is the primary output of the process and it goes to the end primary customer of the process. Similarly, **Figure 3.5** reveals that any other sub-process or function can be entered by the secondary inputs through the *upper* boundary, and the secondary outputs go to the end secondary customers through the *lower* boundary at any point of process.

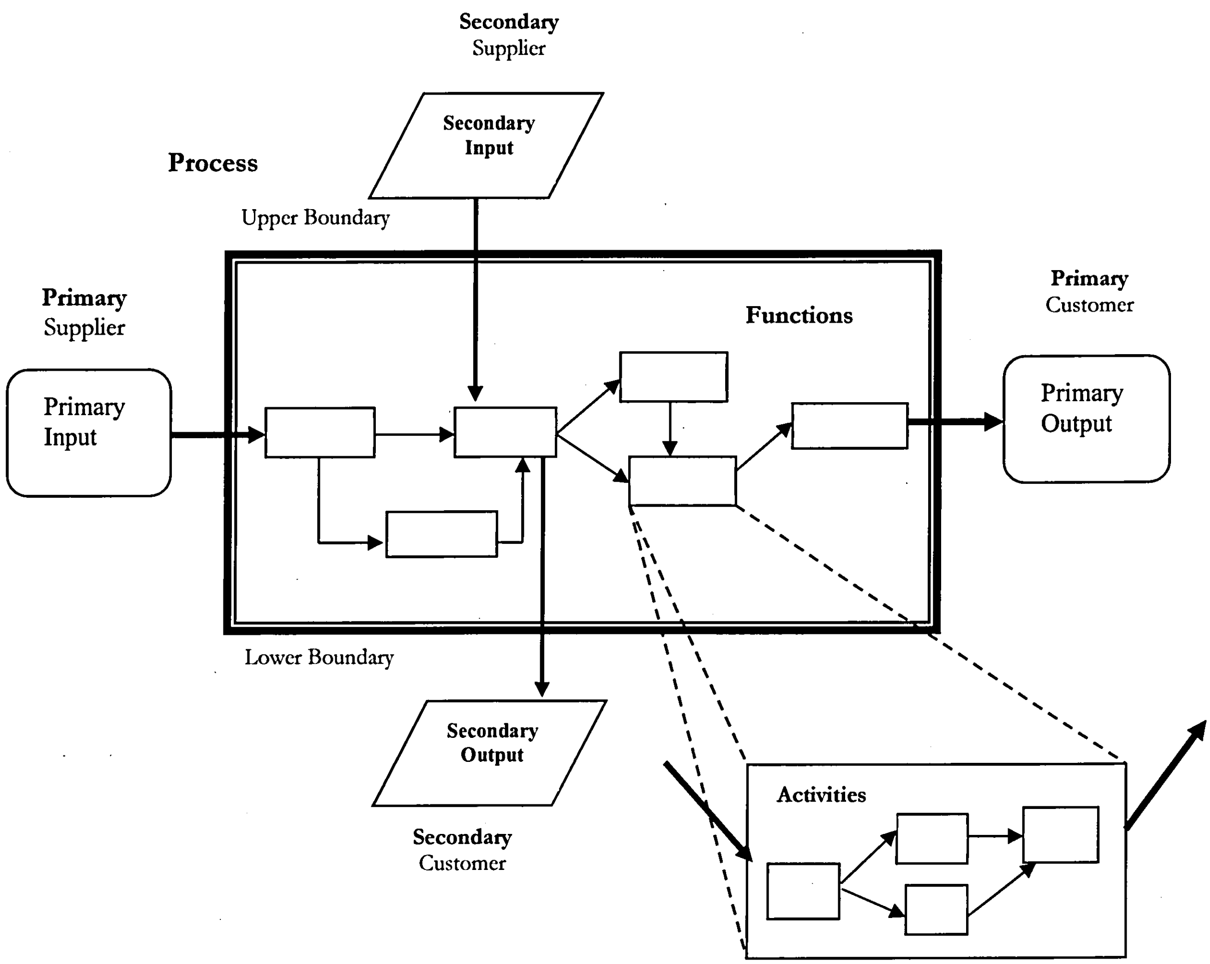


Figure 3.5: Process Hierarchy: The Hierarchy of Integrated Functions and Basic Activities within a Process (Adopted from Harrington, 1991; Plemmons, 1995)

3.4.2 Functional Workflow-Diagrams:

A functional diagram is the depiction of the process within the functional boundaries; it involves the use of arrows and samples to represent the transportation between primary and secondary suppliers on the one hand and the customers on the other hand and also among the integrated functions associated with the process. These transactions/ transportations comprise those associated with materials, information and data considered essential by the participants to produce the expected results (Plemmons, 1995).

Based on the next three actions, the workflows diagram has been developed to represent the typical materials management process for a typical construction project; these actions involve:

1. ***using*** the essential construction materials management workflow diagrams that were provided by CII Handbook, pub 7-1, (1986), CII Guidebook (1987), CII Handbook, pub 7-2, (1988) and Plemmons (1995) (See ***Appendix B***) as a basic references,
2. ***applying*** the flowcharting techniques and the concept of a process hierarchy that were identified and discussed earlier, and
3. ***putting*** into practice the identified typical **eight** integrated functions (Planning, Material Take-off, Vendor Inquiry and Evaluation, Purchasing, Expediting and Transportation, Quality management, Warehousing, and Field Control) and their boundaries and activities that have been identified from the literaturr (CII Handbook, pub 7-1, 1986; CII Guidebook, 1987; and Plemmons, 1995), as explained above and in **Appendix P**.

Figure 3.6 illustrates the overall workflow diagram of the CMM process which is considered in this research as the basic framework for communicating the integrated typical functions and activities that shape the materials management process in the construction industry.

By applying the boundaries of the CMM process, which are identified earlier, in the diagram, one can note that project planning is nominated as the first function in the CMM diagram and that it has received the primary process input in the form of material related information from the project team. The end process boundary is defined by the primary process output that is linked to issuing materials to the primary customer who is involved in construction operations and who represents those craft-workers to whom the materials are issued.

This diagram is somewhat similar to the one which was developed by Plemmons and Bell in 1995 in the USA; it was built up on seven integrated functions (see **Appendix B**). However, the CMM workflow diagram, in this study as illustrated in **Figure 3.6,** is based on eight integration functions, whereby the quality management function and its activities and relationships with the adjoining functions have been added to the previous seven integrated functions. In fact, there is no depiction for the function of quality management within the CMM workflow diagram has been found in the recent literature. In this research, the quality management function and its activities and relationships with the adjoining functions have been detected through reviewing the literature, as discussed in **Appendix P**. Therefore, the reposition, the activities involved, and the feedbacks of the quality management function will be explored practically throughout the data collection process.

Moreover, during the discussion of the integrated functions of the CMM Process and their boundaries that are presented in **Sections 3.3.2**, **3.4**, and **Appendix P**, it was found out that some feedbacks are sent from and to the project team such as;

- The Vendor Inquiry and Evaluation Function submits the vendor performance report to the project team;
- The Expediting and Transportation Function sends vendor data and material and transportation status reports to the project team.

Besides those additions, the position of the Field Control function has been modified as clarified in **Figure 3.6.** This modification was conducted to meet its updated role and relationships with the adjoining functions that were illustrated in the literature review (**Section 3.3.2** and **Appendix P**). These include, for instance, rejected or surplus materials, returned tools, and trial allocations that should be reported to the field control team before conveying them to the warehouse.

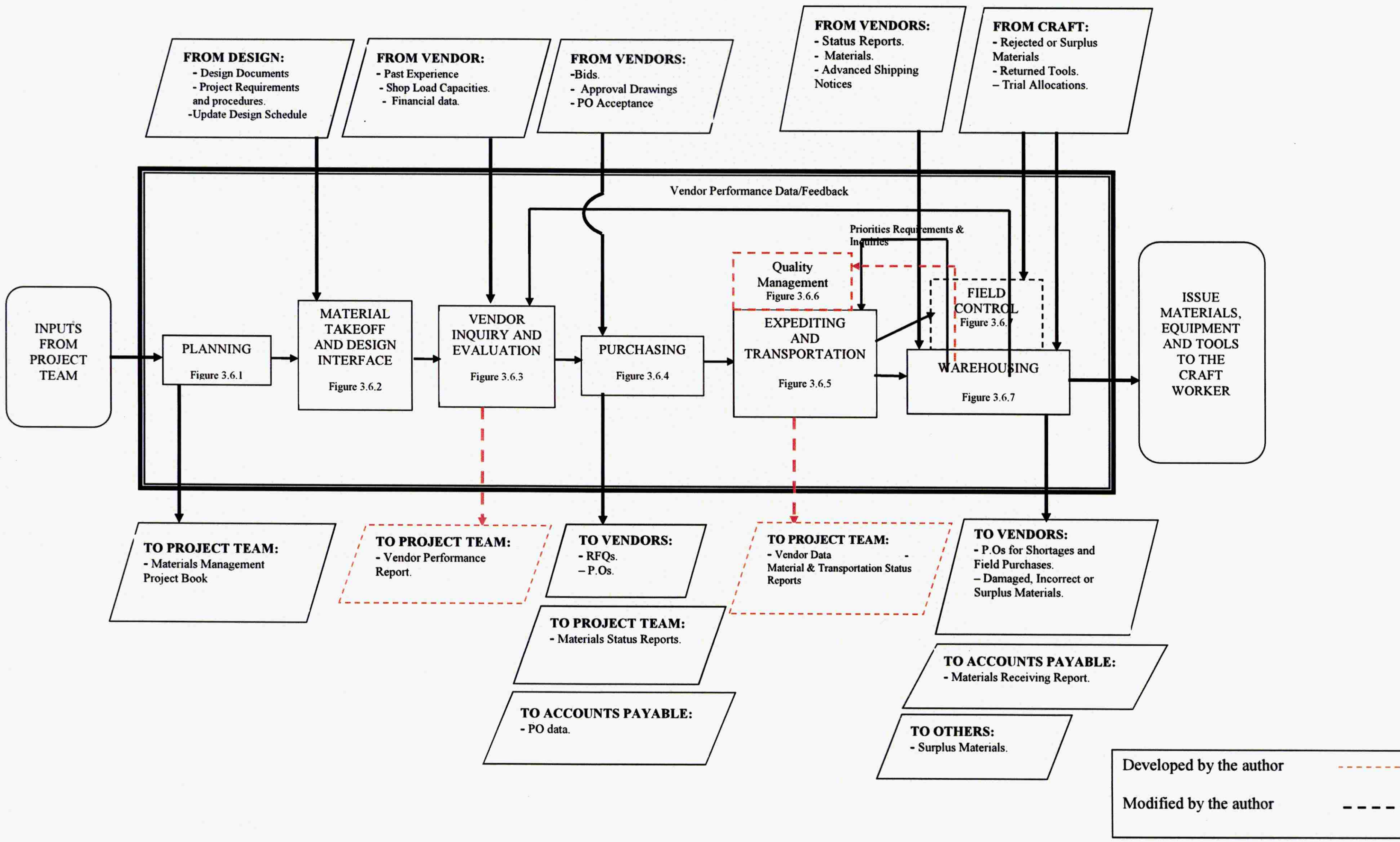


Figure 3.6: The Typical Workflow Diagram of Materials Management Process in the Construction Industry (Developed from CII, 1986; CII, 1987; CII, 1988; Plemmons, 1995; Plemmons and Bell, 1995)

As a result of the discussion of the CMM functions that was based on the literature review covering CII (1986), CII (1987), McConville (1993), Back and Bell (1994), Plemmons (1995), Muya (1999), Perdomo-Rivera (2004), Al Haddad (2006), Oswal (2007), Binti Kasim (2008), Rojas (2009), *Legacy Site Services* (2011), and TeamGrowth (2013) among others, the secondary workflow diagrams for each of the **eight** integrated CMM functions can be identified. These secondary workflow diagrams are illustrated throughout the **Figures from 3.6.1 to 3.6.7**. The secondary workflow diagrams are intended to depict graphically the typical key activities that form each of the eight functions of CMM process, and to portray the inputs and outputs that embody the relationship and the feedbacks between the eight functions of the CMM process and the external-participants. The secondary diagrams provide a view of an integrated process and represent a basic framework for effective and efficient communication between individuals who are generally familiar with the terms and workflow of materials management.

The typical CMM Process workflow diagram(s) represents the first step in developing the framework of evaluating the effectiveness of CMM performance. These diagrams will be used as basic comparative workflow diagrams for developing the practical workflow diagram of the CMM process that can be practiced in the real life of a building project in the JCI, through comparing these diagrams with the data collected from the case studies.

Many of the CMM-related scholars and researchers argue that the performance of functions and activities that involved in the CMM process varies from one system to another and from one organisation to another. They, therefore, emphasize the need for evaluating and measuring the effectiveness of the performance of the these functions and activities. The next chapter defines and explains, in details, the measurement of the effectiveness of the performance of the construction material management process.

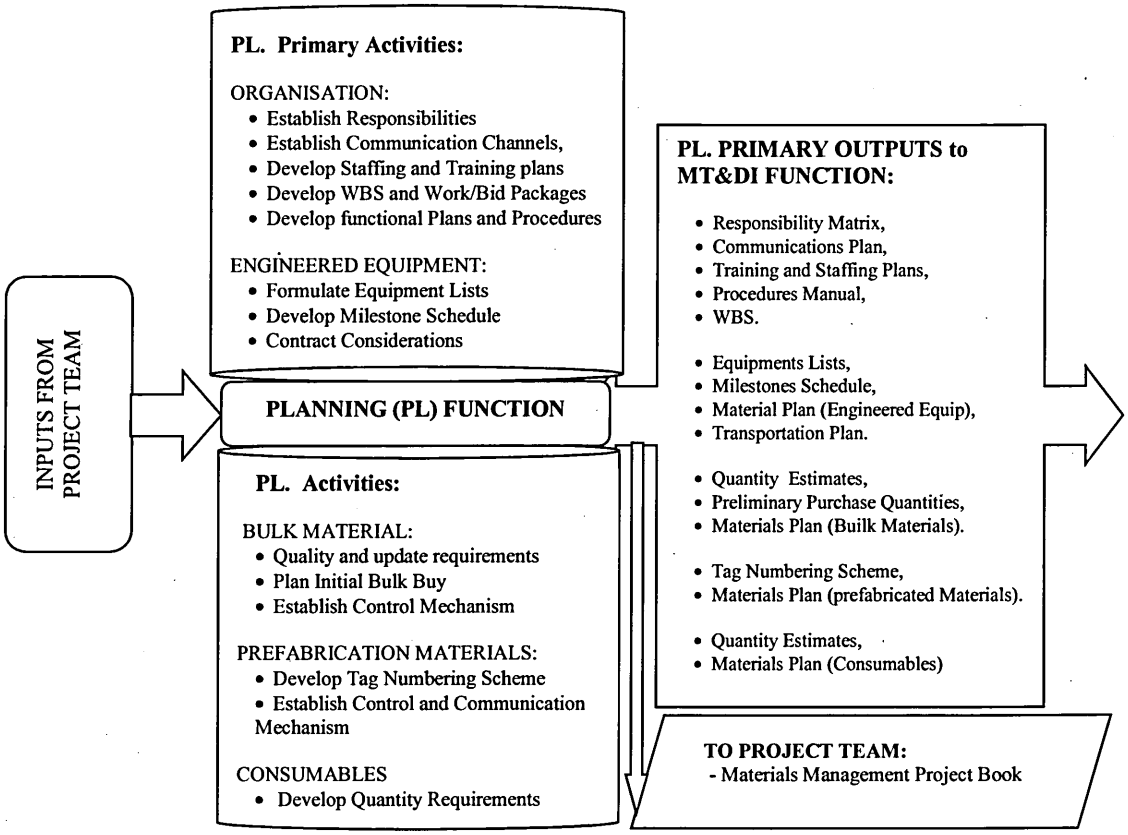


Figure 3.6.1: Typical Planning Function Diagram

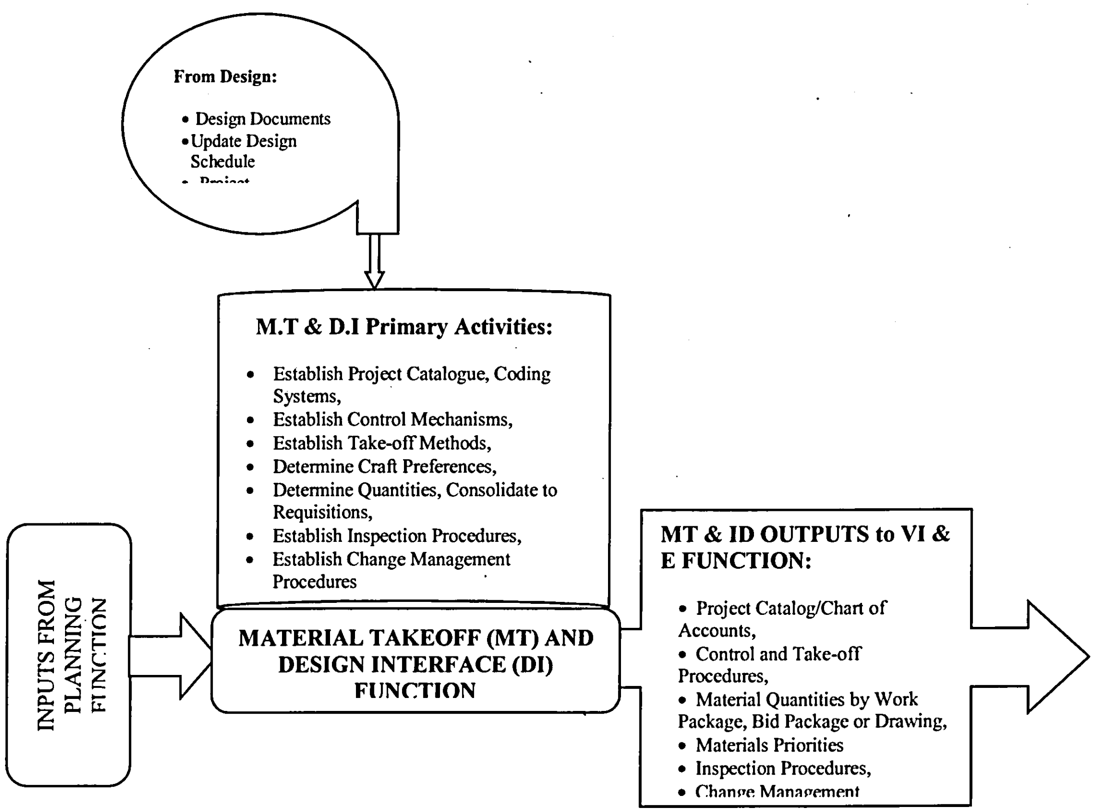


Figure 3.6.2: Typical Material Take-off & Design Interface Function Diagram

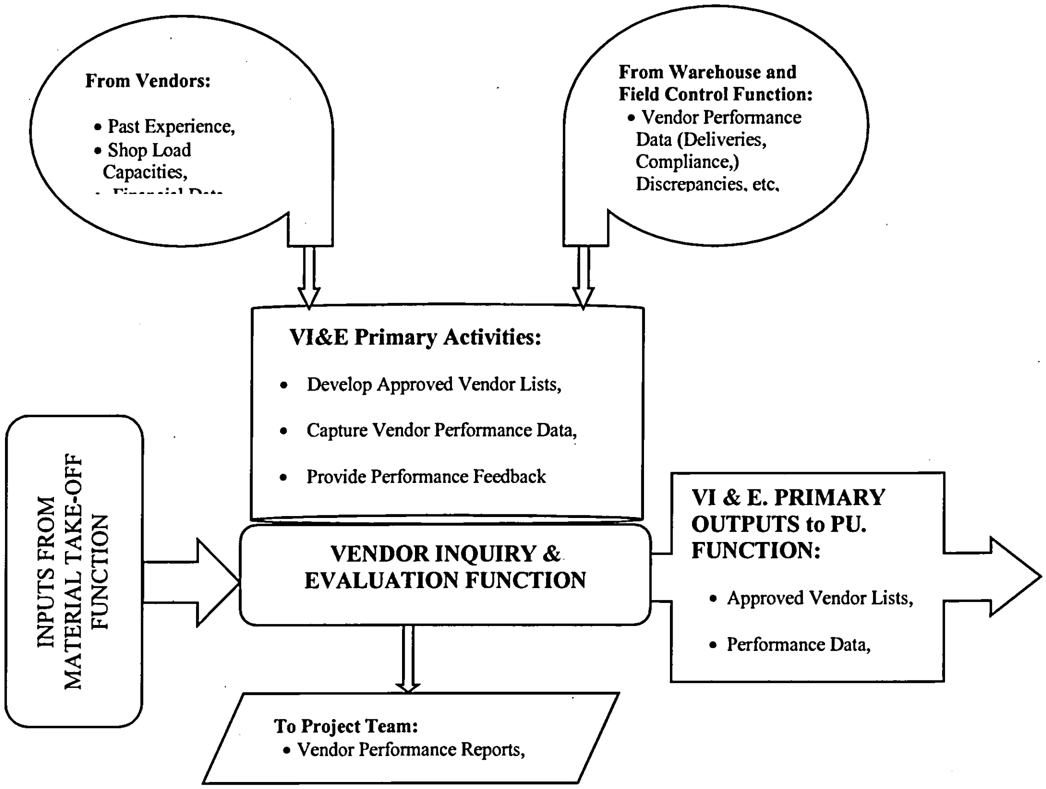


Figure 3.6.3: Typical Vendor Inquiry & Evaluation Function Diagram

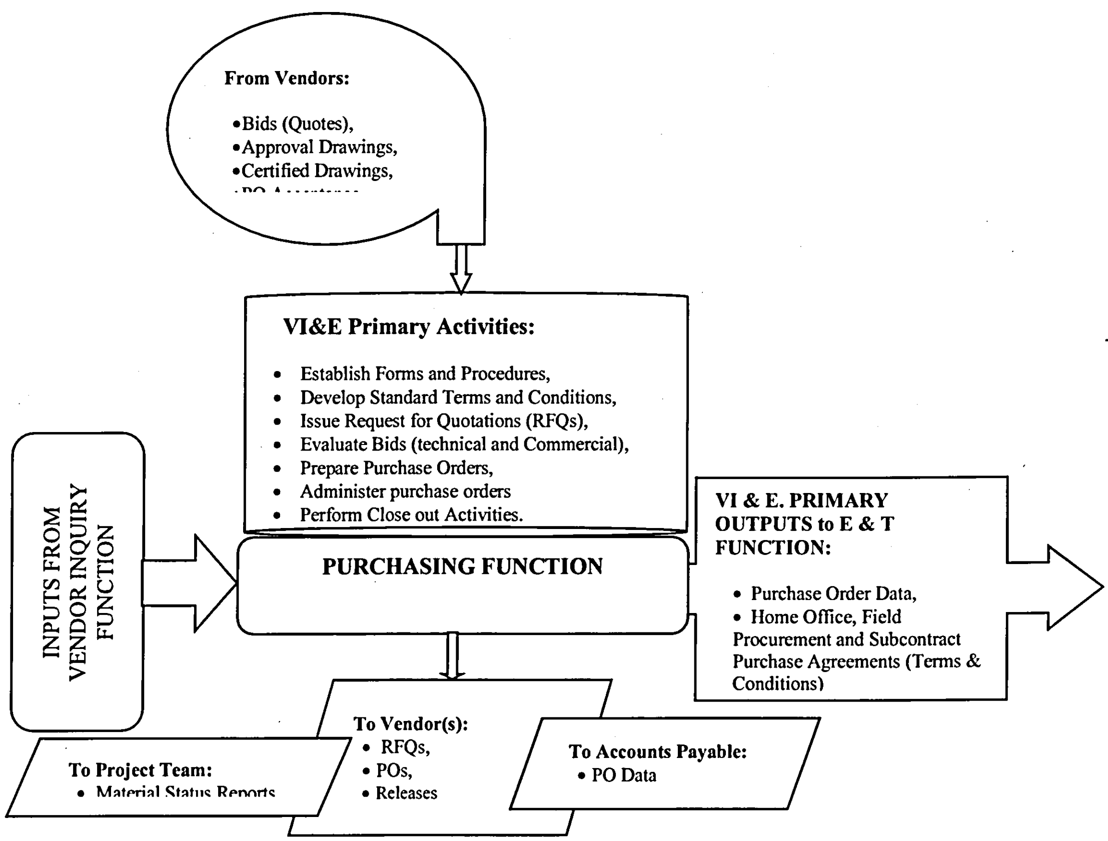


Figure 3.6.4: Typical Purchasing Function Diagram

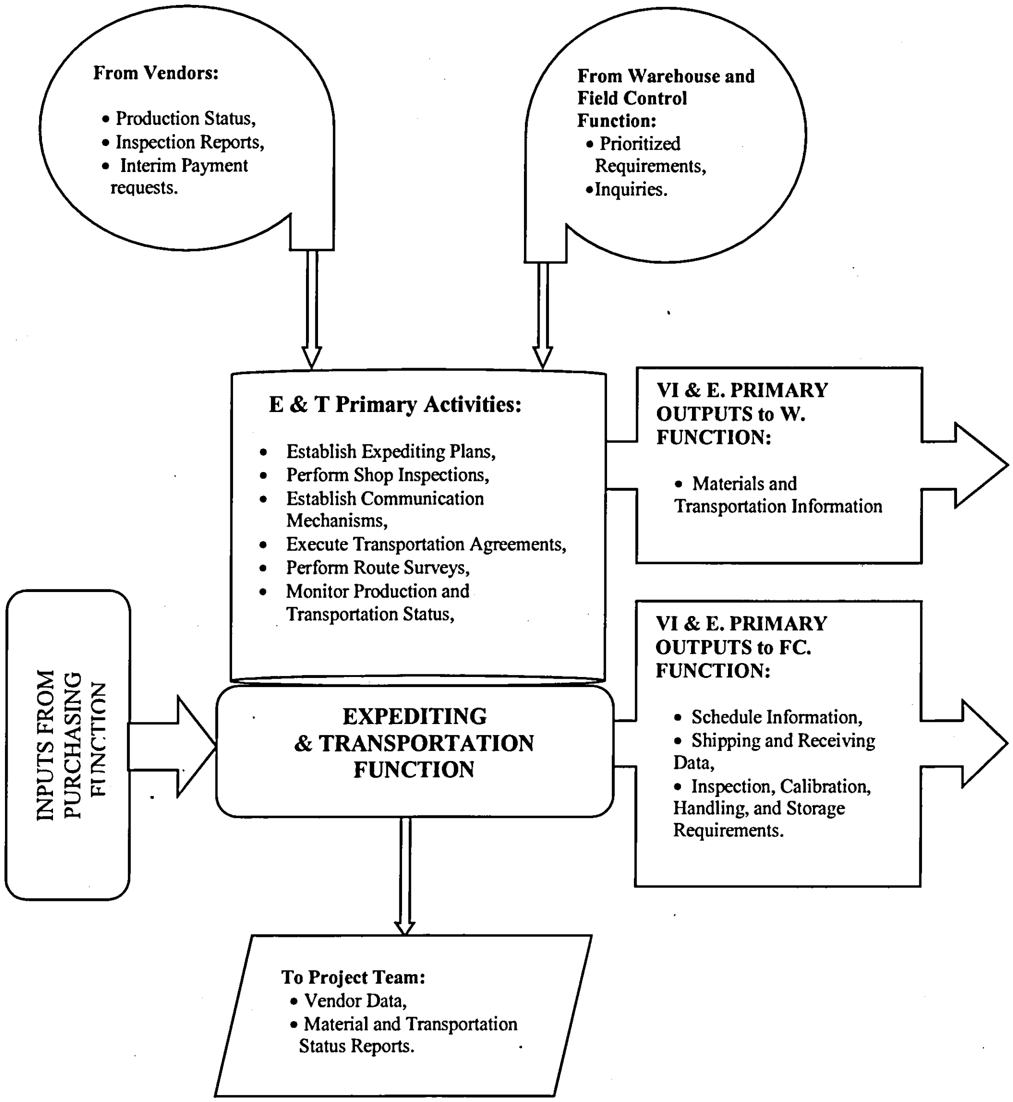


Figure 3.6.5: Expediting & Transportation Function Diagram

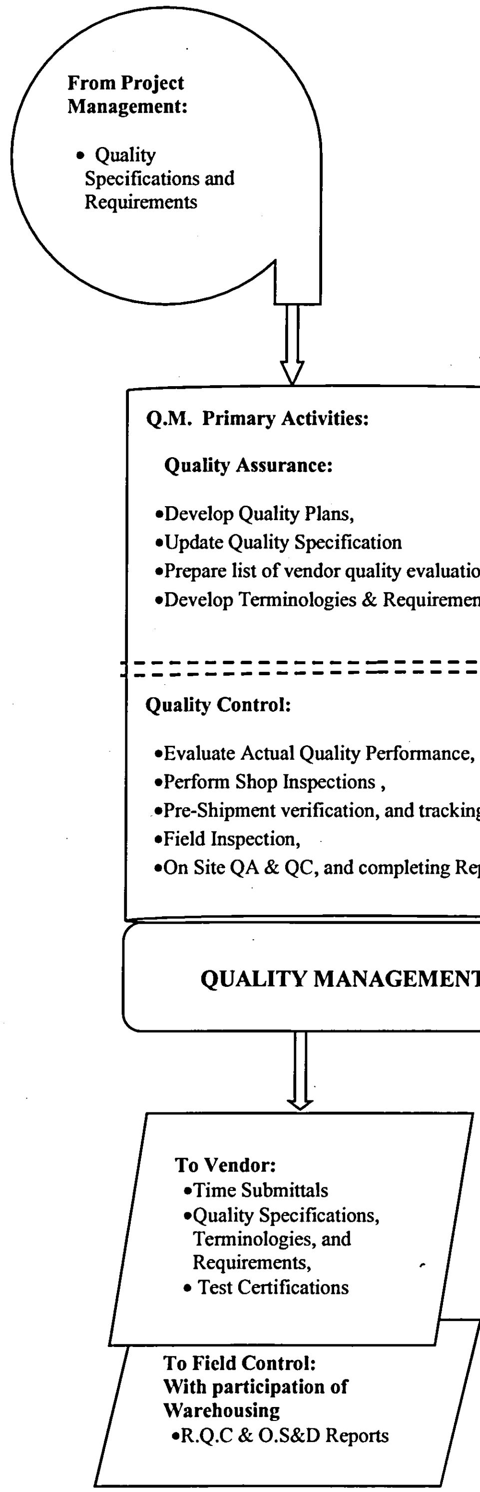


Figure 3.6.6: Typical Quality Management Function Diagram

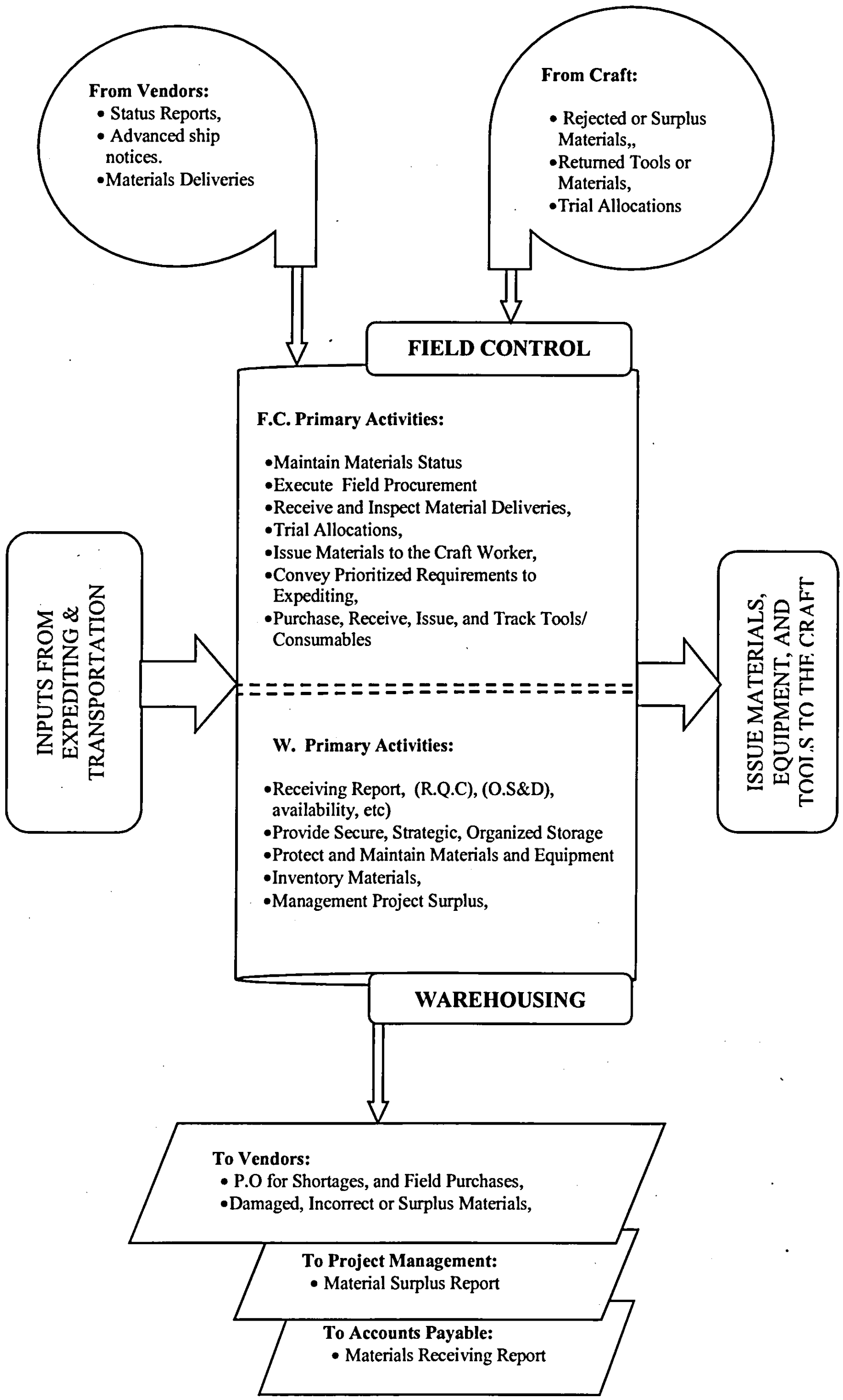


Figure 3.6.7: Typical Field Control and Warehousing Functions Diagram

3.5 SUMMARY OF THE CHAPTER:

As stated in the introduction above, this chapter serves to realize the first objective of the research. For this purpose, the first step in this part of research was the comprehensive review and analysis of the existing literature that is related to materials management issues, in order to understand the theory of materials management and the materials management process in construction. The basic functions and activities, which form the construction material management process, have been defined from different perspectives and the typical 'Eight Integrated Functions' have been identified and adopted within the boundaries of the characteristic CMM process. These integrated functions and activities, within the followed step, have been graphically depicted by using the workflow diagram technique. As a result of reviewing and understanding the design of the workflow diagram (process and functional diagrams) and of using a number of references related to the CMM process as basic references, the Typical Workflow Diagram of Material Management Process in the Construction Management has been identified.

The next chapter (Chapter IV) is planned to realize objective number two in this research which is intended to "identify and assess the material-related measures used within the construction industry (or may be within other industries) and to establish a proposed set of measures to evaluate the Effectiveness of Construction Materials Management Performance (E.CMM.P) in the building projects".

CHAPTER IV:

EVALUATION APPROACHES AND MEASURES OF THE EFFECTIVENESS OF PERFORMANCE OF THE CMM PROCESS

4.0 INTRODUCTION TO THE CHAPTER:

Several CMM-related scholars and researchers argue that on the basis of the assumption that there are varying degrees of performance of the CMM process, top management is always confronted with decisions regarding the need for improving the current CMM system/process. A need arises to determine where to allocate funds to improve one system other than another and to pinpoint the extent of the effectiveness of these improvements. This can give an indication for an urgent need to evaluate the performance of materials management process/systems, and to explore a mechanism for measuring the effectiveness of the performance of the CMM process. For this purpose, among other purposes, chapter IV is designed to realize objective number two in this research project; "To identify and assess the material-related measures used within the construction industry (or may be with other industries) and to establish a proposed set of measures to evaluate the Effectiveness of the Construction Materials Management Process Performance (E.CMM.P) in construction projects".

In this chapter, efforts are exerted to focus on developing a proposed set of effectiveness measures for evaluating the performance of the CMM process. In order to adopt the most suitable measures, in-depth research has been carried out to justify the adoption of these measures. Owing to the lack of literature that is related to the construction materials management process, in particular, to evaluating the effectiveness of its performance, relevant books, articles, and previous studies related to the manufacturing industry and industrial projects have been consulted. Based on the in-depth investigation and analysing the different materials management-related measures and metrics that have been specified during the review of literature, a set of proposed measures for evaluating the effectiveness of the performance of the construction materials management process has been developed.

Moreover, the chapter presents an overview of the benchmarking processes that have been developed by various researchers, academics, consultants, professionals, and experts, and they were used within the manufacturing, construction and service-related industries. This overview includes definitions, types, steps, and models of the benchmarking process, as well as the development of the benchmarking concept in construction industry and some examples of its implementation.

4.1 EVALUATION MATERIALS MANAGEMENT PROCESS:

Materials management, for a long time, has been an obsession for the project engineers. Many attempts have always been made by employees in the construction area to reduce time and save money consumed for procuring, managing, and using materials. With the aim of improving the materials management process, a number of intentional changes, modifications, computerized applications, new strategies, technologies, and new systems have been implemented. However, the impact of these changes and applications should be checked and evaluated in order to identify the extent of their effectiveness, suitability and to define the need for more improvement or replacement (Al-Juid, 2005 and Öztaş, Güzelsoy and Tekinkuş, 2007). To evaluate and analyze the impact of the changes, applications and technologies applied to the overall industry, especially the materials management process, a uniform performance measurement and a benchmarking mechanism are fundamentally needed (Hoyle, 1995; Plemmons and Bell, 1995; Rolstands, 1995; Waggoner, Neely and Kennerley, 1999; Gunasekaran, Patel and Tirtiroglu, 2001; Al-Khalil et al., 2004; Öztaş, Güzelsoy and Tekinkuş, 2007; Hotmoko, 2008 among others).

Plemmons and Bell (1995), Waggoner, Neely and Kennerley (1999), Proverbs and Holt (2000), Wegelius-Lehtonen (2001), and Nudurupati, Arshad and Turner (2007) consider performance evaluation and measurement as a key to control, manage, and improve any work process. They assert that measuring performance provides basic assistance for performance improvement in pursuit of the supply chain excellence and provide important feedback information that enable managers to follow progress, monitor performance, diagnose problems, enhance communication, reveal the effectiveness of strategies, and identify success and potential opportunities. Therefore, several countries at various levels of socio-economic development have recognized the need and significance of adopting measures to improve the performance of their construction industry in order to meet the aspirations of its developmental goals (Gwaya, Masu and Oyawa, 2014).

Measuring performance, in particular in construction industry, is a complicated, frustrating, challenging, misused, and difficult process (Stukhart and Bell, 1985; Dixon, Nanni and Vollmann, 1990; Early, 1991; Proverbs and Holt, 2000; Al-Juid, 2005, Öztaş, Güzelsoy and Tekinkuş, 2007). Additionally, very few researchers have focussed their attention on measuring supply materials performance (Stewart, 1995; Al-Darweesh, 1999; Proverbs and Holt, 2000; Wegelius-Lehtonen, 2001; Al-Khalil et al., 2004; Nudurupati, Arshad and Turner, 2007). Hatmoko, (2008) maintained that 'there is no study on measuring the effectiveness of CMM in building projects'.

Table 4.1 summarises the efforts that were made to review the literatures to find out studies related to the measurement of materials management. The table also includes some statements that were found in the literatures and confirms the limitation of studies that are related to evaluating or measuring materials management performance in construction industry.

Table 4.1: Summary of the literature that highlights the limitation of studies related to evaluating or measuring material management performance in construction industry

The Author	***Statements Adopted from the Literature***
Dixon, Nanni and Vollmann, 1990	Hence a number of academics and practitioners recognised the need to count the effectiveness of materials management systems currently in use to accommodate more suitable and new dimensions or processes.
Mentzer and Konrad (1991, p33)	*The evaluation of performance is a vital management function. However, refined measures to be used in the evaluation of logistics have not been rigorously developed.* "On the other hand, few corporations accurately measure their performance levels in terms of the resources used against the goals achieved"
Sink (1991)	"*Measurement is complex, frustrating, difficult, challenging, important, abused and misused*".
Fisher, Miertschin and Pollock (1995)	Construction Industry survey concluded that there were neither available benchmarked standards for the construction industry, nor a non-profit organisation established for the purpose of collecting data and information in the Industry for benchmarking
Neely et at. (1995)	The quantification of an action is necessary since we cannot manage what we cannot measure
Plemmons and Bell (1995, p26)	"*The benchmarking of materials management process performance cannot be executed due to the lack of effectiveness measures*".
Plemmons and Bell (1995)	A challenge facing the Construction Industry (CI) is the ability to measure and compare performance across project and organisational boundaries
Stukhart (1995, p34)	Ideally, there must be a means that measures the CMM systems

The Author	***Statements Adopted from the Literature***
	performance ....*"The difficulty in considering materials management as a process is that it must be a measured set of activities. Attempts have been made to measure the components of materials management, but there is no comprehensive set of tools now in existence"*.
Al-Darweesh (1999)	To date, no study has been conducted in the Kingdom to assess the effectiveness of the material management process. Hence, the proposed study is of paramount importance
Love and Holt (2000, p408, p410)	Many companies in the construction industry to-date rely on *"traditional (bottom-line) performance measures, such as efficiency, return on capital employed, and profitability",......, Yet, performance measurement research in construction has previously adopted a narrow focus*
Proverbs and Holt (2000)	*"...there have been few researchers who have focussed their research specifically on measuring supply chain performance in the construction industry...."*
Gunasekaran, Patel and Tirtiroglu (2001, p71)	*"While there are many ongoing research efforts on various aspects and areas of SCM, so far little attention has been given to the performance evaluation, and hence, to the measures and metrics of supply chains"*.
Wegelius-Lehtonen (2001)	Performance measurement is a current issue in academia, as well as in business community. However, in the construction industry, its usage as a tool for improvement and control of logistics has so far been limited.
Al-Khalil *et al.*, (2004, p82)	*"A measurement of the effectiveness of the material management process is needed because, without measurement, documenting and benchmarking the impact of intentional changes is limited"*
Gunasekaran, Patel and Mccaughey (2004, p334)	*"....there is a lack of empirical analysis and case studies on performance metrics and measurements in a supply chain environment.*
Bhatnagar and Sohal (2005, p445)	*"there is not a stable set of measures that can be used for assessing performance of supply chain in all contexts"*
Nudurupati, Arshad and Turner (2007, p667)	*"There has been a lot of research focused on performance measurement in general...........However, very few studies were reported on performance measurement in businesses operating in construction* industry"......*"Appropriate measures are required to control the complex supply chains' relationships. However, performance measurement remains unexplored in construction sector".*
Öztaş, Güzelsoy and Tekinkuş (2007, p1220)	*"Measurement of effectiveness seems to come more required in apparently less objective of area services such as construction."*
Hatmoko (2008, p38)	*"Despite an extensive search of the literature on the quantification of the impact of supply chain management practice on project performance, no relevant references could be found"*; .... And there is no study on measuring the effectiveness of CMM in building projects.
Ali, Al-Sulaihi and Al-Gahtani (2013)	In Saudi Arabia, as in the most Arab countries, a few previous efforts have been done to identify indicators or measures that can be used to evaluate the performance of the functions in construction projects.

The Author	Statements Adopted from the Literature
Alsubeh (2013)	There is a strong need for a framework for evaluating the performance of the processes and systems implemented in the Jordanian construction projects.
Gwaya, Masu and Oyawa (2014)	Despite the agreement of respondents on the necessity of developing a basis of organizations measuring and comparing performance of projects, the application of competitive benchmarking is still limited in the majority of the construction processes.
Sweis et at. (2014); Sweis et at. (2008)	Few studies addressing the effect of the material management process on construction delays.

From **Table 4.1**, it can be inferred that, although measuring performance is recently the focus of many academics and professional's attention, it is still very limited in construction industry, and it might be absent from the area of building materials management.

Based on the above, it can be concluded that there is a pressing need for measuring the performance of the materials management process to provide a basis for assessing and analysing the impact of any process changes in the materials management process and the overall construction industry. Accordingly, in-depth research studies for the measurement of materials management performance in construction industry should be conducted, and a set of uniform measures, an evaluating framework, computerised systems or mechanisms for measuring the effectiveness of the CMM process should be developed. For this purpose, the main aims of this research are to identify effectiveness-measures and to develop a framework for assessing the construction materials management performance within the large-scale concrete building projects in the Construction Industry.

Despite the extensive review of the literature on the quantification of the effectiveness of materials management process, no relevant references could be specified within the building construction projects; moreover, there is a limited amount of literature that is directly related to materials management in construction industry. Because of this limitation, relevant books, articles, studies, theses and case studies related to manufacturing, industrial construction, and service industries (in combination with the Construction Industry (CI)-related background information) are consulted to develop this study.

4.1.1 Performance as an Evaluation Criterion:

According to Kenneth (1984), Kearney (1985) and Mentzer and Konrad (1991), logistics functions can be evaluated by three criteria; *utilization*, *productivity* and *performance*. They define *utilization* as the ratio of the capacity used to the available capacity, *productivity* as the ratio of the real output to the real input, and *performance* as the ratio of the actual output to the standard output. Performance has been defined by Mentzer and Konrad (1991) as "*a function of both resources utilized and the results compared to a standard (goal)*". However, the fact that these evaluation measures/criteria, with other different evaluation criteria like profitability, are commonly used interchangeably by both academics and practitioners (Tangen, 2005; Pekuri, Haapasalo and Herrala, 2011).

In general, measurement is a tool to manage, improve and control any work process since performance can be defined as a function of both effectiveness and efficiency (Mentzer and Konrad, 1991; Neely et at., 1995). Performance measurement, in essence, is a set of metrics used to quantify and analyze both effectiveness and efficiency of actions in achieving the task required (Plemmons and Bell, 1994 & 1995; Neely et at., 1995; Al-Darweesh, 1999; Al-Juaid, 2005; Hatmoko, 2008; Pekuri, Haapasalo and Herrala, 2011).
Rolstandas (1995), Waggoner, Neely and Kennerley, (1999) and Nudurupati, Arshad and Turner (2007) argue that performance measurement in different businesses often provides feedback information that helps managers to monitor performance, identify the areas that need more attention, improve communication, enhance motivation and strengthen accountability. They further support Lynch and Cross (1991) and Wegelius-Lehtonen (2001) in that two simple questions should be answered by the performance management systems; these are: 1- Are functions and departments doing the right thing? 2- Are they doing them well? Thus, it can be concluded that "*Performance measures are used to measure and improve the efficiency, effectiveness and the quality of the business processes, and identify opportunities for progressive improvements in process performance*" (Wegelius-Lehtonen, 2001, p108).

In comparison with the other criteria of evaluation exist, one can recognize the appropriateness of the performance for evaluation a process. In discussing the evaluation of a construction organisation, Pekuri, Haapasalo, and Herrala (2011, p39) state that the results of the theoretical review of the performance measure in the construction industry indicate that productivity an ambiguous concept... and *"it is an inadequate measure for identifying improvement targets and control activities"*. They agreed with Rojas and Aramvareekul (2003) and O'Mahony & Timmer (2009) in that; various problems have been identified with productivity measurements that have led to doubts about the reliability and validity of measuring productivity at the macro level.

With regard to profitability, authors such as Miller (1984), Tangen (2005) and Pekuri, Haapasalo and Herrala (2011, p39) believe that; in spite of profitability is a crucial indicator for a company because it shows whether the company is making money with its business, in the long run, productivity is considered more suitable than profitability as a measure for monitoring manufacturing excellence since profits are influenced by many factors over the short term that can give a misleading indication of long-term success. In line with the above discussion, Plemmons (1995) and Al-Draweesh (1999) agreed with what Maloney (1990) stated:

> *"Many people operate with an extremely limited view of performance and consider the productivity of the firm's work force and the profitability of the firm as the only criteria of process evaluation. However, an examination of the productivity provides a very narrow perspective on evaluation a process or functions in a construction organization, while focusing on profitability does not ensure long-term survival of the firm. Profitability and productivity are necessary, but not sufficient, consideration for survival" Maloney (1990).*

They assert that by viewing performance from a wide perspective, performance can be considered a better criterion for evaluating the materials management process. This was supported by Haapasalo and Herrala (2011, p54) who concluded that "*Process-oriented performance indicators suit well with the project nature of the construction business and help to ensure that the requirements set by customers are met*". Moreover, Nudurupati, Arshad and Turner (2007) maintain that "*Performance measurement is a well-matured topic in literature*". Research conducted by Neely (1999) revealed that between early 1994 and late 1996, more than 3600 articles were published on performance measurement, which was described as the most used criterion for assessing businesses.

Based on the above discussion, this research, focuses on the use of performance measurement to evaluate materials management process.

4.1.2 Effectiveness as a Process Measure:

Three major process measures have been identified (Harrington 1991; Mentzer and Konrad 1991; Plemmons 1995; Al-Darweesh 1999; Ul-Asad 2005; Al-Juaid 2005; Fearne and Fowler 2006). These are *efficiency*, *adaptability*, and *effectiveness*. Plemmons, (1995) defined *Efficiency* as the extent to which resources are minimised and the waste eliminated in the pursuit of effectiveness. In construction, the term efficiency usually refers to the utilization of materials, equipment, tools, and fuel. Moreover, Van der Meulen and Spijkerman (1985) and Mentzer and Konrad (1991) defined *efficiency* mathematically as the ratio of the normal input level to the real input level; they view efficiency as the answer to the question of how well the expanded resources are utilized.
Adaptability is the flexibility of a process to handle the changing customer expectations and the special customer requests or the future demands (Harrington, 1991). This could be evident in engineering, procurement and construction industry (EPC) when the owner, contractor, engineer or supplier uses the established change control procedures to accommodate the client-driven changes that frequently occur during a typical construction project (Plemmons, 1995).
Effectiveness, as defined by the Business Dictionary (2011), is "*the degree to which objectives are achieved and the extent to which targeted problems are solved*". In contrast to efficiency, effectiveness is determined without reference to the costs. Whereas *efficiency* is defined as "doing the thing right", *effectiveness* means "doing the right thing". With regard to materials management, Maloney (1990) Fraser (1994), Plemmons and Bell, (1995), and Al-Khalil *et al.*, (2004) believe that effectiveness represents the degree of obtaining the right output at the right place, the right time and at the right price. They view it as the measure that weighs up the performance process by building a comparison between actual outputs and planned or targeted outputs. Mathematically, Van der Meulen and Spijkerman (1985) and Mentzer and Konrad (1991) view effectiveness as the ratio of the real outputs to the normal or standard outputs.

Although efficiency and adaptability are important and interesting matters, they will be excluded from the present research study for the reasons specified below; only effectiveness will be adopted as the process measure for evaluating the performance of the material management process because:

- of the ability to utilize the existing project data to measure the performance of the materials management process, (Harrington, 1991),
- depending on measuring efficiency to evaluate the materials management process is not sufficient (Mentzer and Konrad 1991),
- effectiveness measure must be an integral part of any measurement process (Kaplan and Norton, 1992),
- of the ability to benchmark uniformly defined effectiveness or ratio measures across projects and corporate (Plemmons, 1995),
- of the possibility of adding process performance measures to traditional project management and control systems (Plemmons, 1995),
- of the need for performance measures to manage multifunctional processes, like materials management (Plemmons and Bell, 1995),
- effectiveness is a ratio between the actual and planned results; it is ideal to use the existing project data to benchmark materials management performance across project and corporate boundaries.
- measuring the effectiveness is the most direct approach to assess the effects of the system on materials management performance outcomes such as inventory costs, turnover, and fill rates (Yuthas and Young, 1998),
- of the need for result-oriented measures to quantify the impact of process changes, like applied technology, supplier partnering and reengineering (Al-Darweesh, 1999), and
- the effectiveness of the construction process can be the best measure to how well the project is able to deliver against the objectives of building to budget, programme and quality (Fearne and Fowler, 2006).

It can be concluded that defining the customer expectations and needs is necessary to ensure that a process is effective. Defining these expectations and needs provides tangible yardsticks for those companies which intend to evaluate process performance and to compare the goals (Harrington, 1991). Concerning the materials management process, effectiveness means the ability to do the actions that need to be done; thus, meeting the expectations and needs of the customers. The attributes which represent the customer's expectations and needs concerning a materials management process and the measures required will be discussed in depth in the following sections and provided in **Appendix Q**.

4.2 MEASUREMENT OF SUPPLY CHAIN MANAGEMENT (SCM) PERFORMANCE:

Based on the argument above and the related-literature survey that is summarised in **Table 4.1,** it can be demonstrated that there is a dire need to develop a set of uniform measures for the effectiveness of the materials management process and for a mechanism for communicating and comparing these measures across projects and organisational boundaries. However, the different approaches of materials management lead to different interpretations of what should be measured to evaluate performance (Otto and Kotzab, 2003). In addition, the uniqueness of the construction projects results in difficulties related to measuring the performance (Ibn-Homaid, 2002). These provide further support to what was remarked by Sink (1991) and Fisher, Miertschin and Pollock (1995) that the ability to measure and compare materials management performance across projects and organisational boundaries is one of the biggest challenges facing the construction industry. Accordingly, in order to reveal a real insight of the materials management performance in construction projects, the appropriate performance measures that best suit materials management in the construction context are required.

Owing to the lack of related literature on building materials management, as stated earlier, in particular for measuring the effectiveness of performance, relevant sources (books, articles, previous theses and studies) that are related to manufacturing are consulted. Likewise, certain measures that have been used to evaluate the supply chain management (SCM) in manufacturing industry (MI) and industrial projects can be adopted in the construction context, taking into consideration the gap in the supply material practices among the construction and manufacturing industries, as mentioned in **Section 2.3.1.**

4.2.1 SCM Performance Measures in Manufacturing Industry (MI):

Although the revolution of performance measurement started in manufacturing industry in the late 1970s and early 1980s (Skinner, 1974; Johnson and Kaplan, 1987; Dixon, Nanni and Vollmann, 1990; Kaplan and Norton, 1992), the virtual performance measures remained unexplored in the Supply Chain performance till the early 1990s (Dixon, Nanni and Vollmann, 1990; Neely *et al.*, 1995; Nudurupati, Arshad and Turner, 2007). According to Bhatnagar and Sohal (2004) and Hatmoko (2008), the first appearance of the usable performance measures was in the late 1990s. Among those measures, are some of the important supply chain performance measures that have been recognised in the literature of Mentzer and Konrad (1991), Bhatnagar and Sohal (2004), and Hatmoko (2008) as revealed in **Table 4.2**.

Table 4.2: Measures of Supply Chain Performance Reported in the Literature (adopted from Mentzer and Konrad, 1991; Bhatnagar and Sohal, 2004; Hatmoko, 2008)

The Author	*Measures of Performance*
Cohen and Lee (1990)	• Work in the process inventor • Material inventory • Finished goods inventory • Fill rates • Stock out frequencies • Lead time
Lambert and Sharman (1990)	• Delivery performance • Lead time • Level of defects • Responsiveness
Mentzer and Konrad (1991)	• Transportation, • Warehousing, • Inventory control, • Order processing, • Logistics administration.
Christopher (1992)	• Order cycle time • Order completeness • Delivery reliability
Lee and Billington (1992)	• Inventory turns • Line item fill rate • Order item fill rate • Total order cycle time • Total response time to an order • Average backorder levels • Average variability in delivery
Levy (1995)	• Average finished goods inventory • Demand fulfilment

At the time when they were developing these performance measures, Bhatnagar and Sohal (2004) concluded that "*there is no a stable set of measures that can be used for assessing the performance of supply chain in all contexts*". The performance measures listed in **Table 4.2** mainly relate to the operational level of SCM, and tend to evaluate the customer service, quality, lead time, inventory and flexibility. The list above covers the period from 1990 to 1995; for the purpose of updating this list, some examples of the recent supply chain performance measures, which were reported in literature, are discussed below.

Research conducted by Beamon in 1999 placed emphasis on three main types of performance measures; Resources (R), Output (O), and Flexibility (F). The research concluded that a supply chain performance measurement system is useless if it does not address these three types (R, O, and F). From Beamon's point of view, the reason behind that is that "*each type is vital to the overall performance success of the supply chain, and each of the three types of measures has important characteristics and the measure of each of these affects the others*". Where efficient resource management is critical to profitability (R), customers will turn to other supply chains without acceptable output (O), and in an uncertain environment, supply chains must be able to respond to change (F). **Table 4.3** illustrates the components involved into the three types of measures.

Table 4.3: Measures of SCM Performance (Developed from: Beamon, 1999)

Resources	***Output***	***Flexibility***
• Inventory levels • Personnel requirement • Equipment utilization • Energy usage • Cost	• Sales • Profit • Fill rate • One-time deliveries • Backorder/Stock-out • Customer response time • Manufacturing lead time • Shipping errors • Customer complaints.	• Volume flexibility • Delivery flexibility • Mix flexibility • New product flexibility.

Gunasekaran, Patel and Tirtiroglu (2001) developed a framework illustrating the performance measures and metrics for the evaluation of a supply chain performance. Within this framework, the metrics are classified into strategic, tactical, and operational levels of management, as displayed in **Table 4.4**. The framework facilitates assigning the metrics whereby they can best deal with the appropriate management level for fair decisions to be made. Furthermore, the metrics are classified into financial and non-financial so that a suitable costing method based on activity analysis can be applied.

Table 4.4: A framework of the metrics for the performance evaluation of a Supply Chain (Gunasekaran, Patel and Tirtiroglu, 2001)

Level	*Performance metrics*	*Financial*	*Non-financial*
Strategic	• Total supply chain cycle time		£
	• Total cash flow time	£	£
	• Customer query time	£	£
	• Level of customer perceived value of product		£
	• Net profit vs. productivity ratio	£	
	• Rate of return on investment	£	
	• Range of product and services		£
	• Variations against budget	£	
	• Order lead time		£
	• Flexibility of service systems to meet particular Customer needs		£
	• Buyer-supplier partnership level	£	£
	• Supplier lead time against industry norm		£
	• Level of supplier's defect free deliveries		£
	• Delivery lead time		£
	• Delivery performance	£	£
Tactical	• Accuracy of forecasting techniques		£
	• Product development cycle time		£
	• Order entry methods		£
	• Effectiveness of delivery invoice methods		£
	• Purchase order cycle time		£
	• Planned process cycle time		£
	• Effectiveness of master production schedule		£
	• Supplier assistance in solving technical problems		£
	• Supplier ability to respond to quality problems		£
	• Supplier cost saving initiatives	£	
	• Supplier's booking in procedures		£
	• Delivery reliability	£	£
	• Responsiveness to urgent deliveries		£
	• Effectiveness of distribution planning schedule		£
Operational	• Cost per operation hour	£	
	• Information carrying cost	£	£
	• Capacity utilisation		£
	• Total inventory	£	
	• Supplier rejection rate	£	£
	• Quality of delivery documentation		£
	• Efficiency of purchase order cycle time		£
	• Frequency of delivery		£
	• Driver reliability for performance		£
	• Quality of delivered goods		£
	• Achievement of defect free deliveries		£

One can see that the emphasis, in the framework, is on the performance measures dealing with suppliers, delivery performance, customer-service, and inventory and logistics costs in a supply chain management.

Three years later, Gunasekaran, Patel and Mccaughey (2004) developed a wider performance measurement framework for measuring SCM performance. This new framework concentrates on the extensive and complete performance measurement of the supply chains which should be cross functional and intra-organisational. They (2004, p346) argue that "*a performance measurement program for a supply chain should be complete—important aspects of performance in any link are not ignored—and they must be tailored to varying needs of participants*". The framework aims to evaluate five areas of the supply chain performance; the order planning, production level, supply link, delivery link, service and customer satisfaction and supply chain and logistics cost, as illustrated in **Table 4.5.**

Table 4.5: A framework for Measuring SCM Performance (Gunasekaran, Patel and Mccaughey, 2004)

Metrics for order planning	***Evaluation of supply link***	***Measures and metrics at production level***	***Evaluation of delivery link***	***Measuring customer service and satisfaction***	***Supply chain and logistics cost***
• The order entry method • Order lead time • The customer path	• Evaluation of suppliers • Strategic level measures • Tactical level measures • Operation level measures	• Range of product and services • Capacity utilization • Effectiveness of scheduling techniques	• Measures for delivery performance evaluation • Total distribution cost	• Flexibility • Customer query time • Post transaction measures of customer service	• Cost associated with assets and return on investment • Information processing cost

Based on the different views of measurement, Otto and Kotzab (2003) proposed a set of performance metrics of supply chain management grouped under six perspectives. Within the six perspectives, which are: system dynamics, logistics, operation research, marketing, organisation and strategy, it is said that a set of comprehensive and holistic metrics for evaluating the SCM may be established. **Table 4.6** exhibits the performance metrics of SCM which were developed by Otto and Kotzab (2003), based on the six measurement perspectives.

Table 4.6: Performance Metrics of SCM based on the Six Measurement Perspectives (Adopted from Otto and Kotzab, 2003)

System Dynamics	*Operations Research*	*Logistics*	*Marketing*	*Organization*	*Strategy*
• Capacity utilization • Cumulative inventory level • stock-outs • Time lags • Time to adapt • Phantom ordering	• Logistics costs per unit • Service level • Time to deliver	• Integration • Lead times • Order cycle time • Inventory level • Flexibility	• Customer satisfaction • Distribution costs per unit • Market share/channel costs	• Transaction costs • Time to network • Flexibility • Density of relationships	• Time to network • Time to market • ROI of focal organisation

The most recent study in this area was carried out by Jabbour *et al.*, (2011). This piece of work is based on a survey that was conducted on 107 Brazilian companies. In this research, a framework was developed for measuring the supply chain management practices. The framework is built on six structures, namely: the supply chain integration, information sharing, customer service management, customer relationship, supplier relationship and postponement. Each structure includes a set of indicators, which are said to be good validated and reliable measures for the SCM practice in its area, as shown in **Table 4.7**.

In short, from the different examples that have been provided above and others, it can be inferred that performance measures may differ among authors or researches depending on the scope, area, level, and goal of these measures or studies. Otto and Kotzab (2003, p316) observe that performance measures should be tailored to what they are designed to measure as "*different approaches to SCM (*Supply Chain Management*) lead to different awareness of what should be measured to assess performance*". Hatmoko (2008) also agrees with them in that performance measures which are used in an organisation might not be appropriate to others. Consequently, the construct of the appropriate performance measures that suit SCM and MM (Materials Management) context is crucial.

Table 4.7: A Framework for Measuring the Supply Chain Management Practices (Jabbour et al., 2011)

Structures	*Indicators*	*Code*
Supply chain integration	• Customer integration	V1
	• Supplier integration	V2
	• Customer involvement in the plans	V3
	• Supplier involvement in the plans	V4
	• Supplier collaboration demand forecasting	V5
	• Customer collaboration demand forecasting	V6
	• Supplier collaboration stock planning	V7
	• Customer collaboration stock planning	V8
	• Supplier collaboration production planning	V9
	• Customer collaboration production planning	V10
	• Creation of multifunctional teams	V11
Information sharing	• Cost information sharing customer	V12
	• Information sharing product launching supplier	V13
	• Participation in customer marketing	V14
	• Customer future needs	V15
	• Supplier communication future strategy	V16
Customer service Management	• Customer feedback	V17
Customer relationship	• Customer support new product decision	V18
	• Consultation customer production programming	V19
Supplier relationship	• Consultation supplier production programming	V20
	• Supplier support product development	V21
Postponement	• Assembly near customer	V22

The performance measures discussed above are mainly used to evaluate the supply chain management in the context of the manufacturing industry, where the SCM theories were initially originated. However, as there is a gap in the supply chain practice between the manufacturing and the construction industries (Naim, 1997), the question to be raised is the following, "*Could the performance measures be used in the manufacturing work for the construction environment?*". The answer to this question can be clarified in the following section which reviews the literature that reported measures of the supply chain management or materials management performance in the construction industry and industrial projects.

4.2.2 SCM Performance Measures in Construction Industry (CI):

The majority of the reported cases and the literature developed on performance measurement are from the non-construction industrial sector (Love and Holt, 2000; Nudurupati, Arshad and Turner, 2007; Jabbour *et al.*, 2011). Performance measurement in construction was said to be a difficult, complicated, and important process (Mentzer and Konrad, 1991; Sink, 1991; Proverbs and Holt, 2000; Ul-Asad, 2005). However, as alluded to earlier, there have been few researchers and authors who have focused their study on measuring SCM performance in the construction industry (Gunasekaran, Patel and Tirtiroglu, 2001; Wegelius-Lehtonen, 2001; Öztaş, Güzelsoy and Tekinkuş, 2007; Nudurupati, Arshad and Turner, 2007; Hatmoko, 2008). Moreover, there is a small number of those who study the effectiveness performance measurement in the construction materials management area (Plemmons, 1995; Al-Darweesh, 1999, Ibn-Homaid, 2002; Al-Juaid, 2005). To the best of the researcher`s knowledge, no study has been conducted to measure the effectiveness of the materials management process in the building projects. This indicates the significance of the contribution of the research project to the knowledge.

In order to develop a set measures of the CMM process, one should first introduce and discuss the attempts that were reported in the literature to measure the SCM performance and in particular the materials management process in the construction industry. **Table 4.8** presents some attempts that were found in the previous literature reviews; they were reported by Virjhoef (1998) and Hatmoko (2008). It can be noted that the assessment method listed below relates to materials management effectiveness, productivity, logistic and the supply chain processes.

Table 4.8: Assessment Efforts of Construction Supply Chains (Developed from Vrijhoef, 1998; Hatmoko, 2008)

Author(s)	***Assessment Method***	***Performance Measures/Metrics***
Plemmons and Bell (1995)	Benchmarking process effectiveness	• Materials Management effectiveness
Wegelius-Lehtonen (1995)	Analysis of logistic process	• Time • Costs • Accuracy • Delivery Times
Smith and Lin (1996)	Analysis of Variations	• Variation • Interruptions • Disruptions of Productivity
Formoso and Revelo (1996)	Identification of Deviations	• Deviation in the supply chain process
Lewis and Atherley (1996)	Definition and classification of delays	• Delays along the supply chain process
O'Brien (1997)	Integrated cost and performance analysis	• Lead times • Deliveries • Production Costs • Uncertainty
Formoso and Revelo (1999)	Average cycle time and processing time for each task	• Materials order • Checking stocks • Price survey • Purchase approval • Acquisition • Transport and delivery • Receiving materials from depot • Receiving materials from suppliers • Payment
	Cost Process	• Percentage of the total cost of the process in relation to the monthly amount of purchases.

To update this list, some more recent studies on the performance measurement of the supply chain management in construction, which are found in the literature, will be reported here. From the literature presented above, it is evident that performance measures can be classified in several ways. Measures can be grouped, for example, into finance and non-finance (Fisher, 1992; Gunasekaran, Patel and Tirtiroglu, 2001), soft and hard (Ijiri, 1975), or process and output (Beamon, 1999).

Another type of classification is introduced by Wegelius-Lehtonen (2001) within a new framework for measuring performance in construction logistics whereby using the two-dimensional model, the performance measures have been classified into '*use of measures*' and '*focus of measure*'. The first dimension of the classification, *use of measures*, reveals the application area where the measures are to be used, and includes two types of measures: '*improvement measures*' and '*monitoring measures*'. The first measures, *improvement measures*, are mainly used during the development projects; they help the construction projects to find out the present logistical performance level and to identify the problems within the current practices and the improvement potential. The second measures, *the monitoring measures*, are needed for continuous monitoring and for controlling the day-to-day operations of an organisation. These measures are vital as they provide continuous feedback on the operational level activities to both organisations' top management and operational managers. The second dimension of the framework is called the *focus of measures*. This dimension demonstrates the organisational level where the measures can be applied, i.e. at the '*general company*' or '*the project level*', as well as at the '*specific subcontractor*' or '*material supplier level*'. The rationale for this type of classification is the fact that different levels of organisation require different measures (Hatmoko, 2008). **Figure 4.1** depicts the two-dimensional framework of performance measurement in construction Logistics.

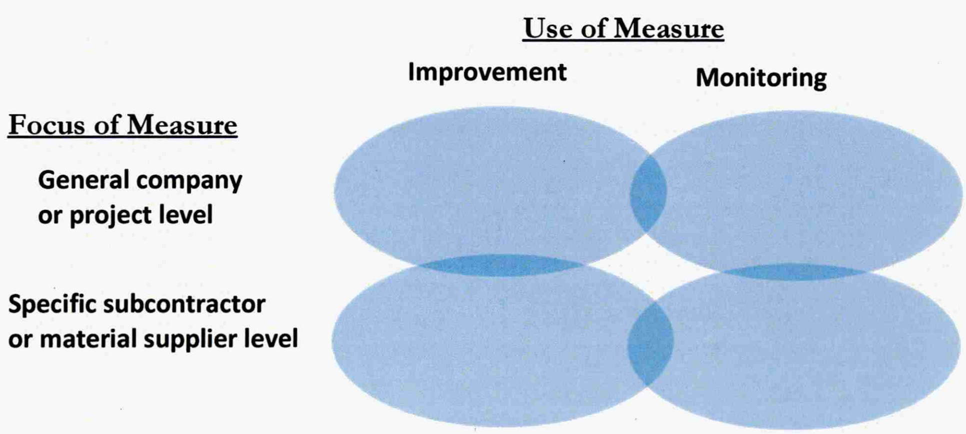


Figure 4.1: Dimension of Performance Measurement System (Adopted from Wegelius-Lethtonen, 2001)

Another piece of research in this area was carried out by Venkataraman (2004). He proposed some metrics for the project supply chain performance. These metrics are classified into four categories; Time, Cost, Quality and flexibility, as listed in **Table 4.9.**

Table 4.9: Project Supply Chain Performance Metrics (Venkataraman, 2004)

Performance Category	*Performance Measures/Metrics*
Time	1. the project completed and delivered on time? 2. What is the potential variability in project completion times? 3. Was the completed project operationalised on time to the satisfaction of the customer? 4. Were the purchased materials and manufactured components delivered on time by the upstream suppliers? 5. What is the potential variability in procurement lead times'?
Cost	1. Was the completed project within budget for each of the project supply chain member? 2. How much did the total project supply chain cost? • Procurement cost of the purchased materials • Manufacturing cost • Inventory-related cost • Transportation cost • Project acceleration costs • Cost of liquidated damages • Other relevant costs: administrative, etc
Quality	1. Did the project meet the technical specifications and did it provide the functionality desired by customer'? 2. Was the customer satisfied with the service provided during start-up, implementation, and final project transfer'? 3. Were the purchased raw materials and the manufactured components defected freely? 4. Was the completed project's product reliable and durable during its life?
Flexibility	1. Was the customer accorded reasonable freedom within a reasonable time frame to make changes to the project scope, design or specification'? 2. Were the upstream suppliers responsive to the reasonable needs of their downstream partners in terms of delivery time and quality issues'?

It is worth mentioning that some of the measures described above are adopted from the literature on manufacturing, and they were then transferred and tested on SCM in the construction industry. This supports what was revealed by Nudurupati, Arshad and Turner (2007, p668) that *"the construction sector is facing the same problems that the manufacturing sector faced in the 1980s,* and *"a lot of literature already developed in performance measurement (especially manufacturing industry) can also be adapted to businesses operating in the construction industry"* (Nudurupati, Arshad and Turner, 2007, p675). This could be the answer to the question posed above on the possibility of using measures in manufacturing for measuring the SCM in the construction sector.

It is also important to point out that most of the measures stated above have been used to assess the supply chain or the supply chain management performance in construction industry, but not in particular the materials management process, which is the main issue in this research. However, due to the lack of the relevant studies reported in the literature that aim to measure the effectiveness of the CMM performance in the building projects, some of the above studies will be used as basis for developing the measures of the effectiveness materials management performance in building construction industry in this research. The section below provides more measures related, in particular, to the performance of the CMM process.

4.3 MEASUREMENT OF THE EFFECTIVENESS OF THE CMM PERFORMANCE IN INDUSTRIAL PROJECTS:

The basic study in this area is the research that was conducted by **Plemmons in 1995**; it has then become the basis for other relevant studies reported in the literature on the industrial construction projects, especially on the petroleum companies in the Arab Gulf. Consequently, this study will be used as a reference and bookmark study in this research project as well. In his research, Plemmons (1995) conducted a survey on functional experts within six engineering companies that worked on behalf of the chemical and petroleum refining organisations in the United States. The main purpose of this research was to identify the measures, currently in use, that can best communicate the effectiveness of the construction materials management process in the industrial projects, and to identify the measures which might be benchmarked between projects and companies.

Based on the results of their study, Plemmons and Bell (1995) reported the **ten (10)** key effectiveness measures that were judged to be the best to communicate the effectiveness of materials management process in the Industrial Construction Projects (ICPs). They, furthermore, identified the best 10 measures for benchmarking between projects within an organisation (internal), and further the best 10 measures for benchmarking between organisations within the Industrial Construction Industry-ICI (external). **Table 4.10** demonstrates the key measures of materials management effectiveness and the effectiveness measures for benchmarking.

Table 4.10: The Key Measures of Material-Management Effectiveness and Those for Benchmarking. (Developed from Plemmons, 1995 and Plemmons and Bell, 1995)

Attributes	*Key Measures of Materials-Management Effectiveness*	*The Effectiveness Measures for Benchmarking*	
		Between Projects within an Organisation (internal)	*Between Organisations within the Industrial Construction Industry (external)*
Accuracy	• Material Receipt Problems • Warehouse Inventory Accuracy		• Material Receipt Problems
Quality	• Jobsite Rejections of Tagged Equipment	• Piping Spool Rework	• Jobsite Rejections of Tagged Equipment
Quantity		• Electronic Data Interchange (EDI) Purchases	• Electronic Data Interchange (EDI) Purchases • Minority Suppliers
Timelines	• Procurement Lead Time • Purchase Orders (PO) to Material Receipt Duration • Commodity Vendor Timeliness • Commodity Timeliness	• Procurement Lead Time • Commodity Vendor Timeliness • Commodity Timeliness	• Procurement Lead Time • Bid/Evaluate/Commit Lead Time • Commodity Vendor Timeliness • Commodity Timeliness
Cost	• Construction Time Lost) • Total Surplus	• Average Man-hour/Work hour per Purchase Order (PO) • Construction Time Lost • Warehouse Safety Incident Rate • Total Surplus	• Warehouse Safety Incident Rate • Total Surplus
Availability	• Material Availability	• Material Availability	

Six attributes of performance for materials management were used by Plemmons to classify these key effectiveness measures, i.e. *quality*, *quantity*, *timelines*, *cost*, *availability*, and *accuracy*. The first five attributes evolved from the Business Roundtable (BRT, 1982), and the sixth one, accuracy, was developed via discussion with the Construction Industry Action Group (CIAG) members (Plemmons, 1995).

It can be noted that apart from the flexibility attribute, the attributes used by Venkataraman (2004); time, cost, and quality, are similar to those used by Plemmons (1995). Despite the differences in the measure titles, it can easily be seen that some of these measures are adopted from the manufacturing industry such as, Procurement Lead-time, Purchasing Order to Material Receipt Duration (PO cycle time), Jobsite Rejections of Tagged Equipment (rejection Rate), etc.

Al-Khalil et al. (2004) reported the findings of a study conducted by Al-Draweesh (1999). It was considered the first study that implements the key effectiveness measures, which were mainly initiated by Plemmons (1995), to assess the effectiveness of the materials management process practically. Al-Draweesh (1999) adopted 12 key measures for evaluating the effectiveness of the performance of the materials management process of 17 industrial projects which were executed by the construction companies in Saudi Arabia. These 12 measures are shown in **Table 4.11**. It is evident that there is no measure among them for evaluating the quantity attribute; furthermore, there are two other measures that are not listed among the Plemmons's key measures or benchmarking measures. These are: 'Material Receiving Processing Time' and 'Materials Withdrawal Request (MWR) Lead-Time' measures.

In this study, the 12 measures were implemented on 17 ongoing industrial projects (8 projects were petrochemicals, 7 were oil and gas, 1 was a refinery and 1 was an industry project), and they were calculated for each project. The overall effectiveness performance value/amount for each project was calculated. Based on the results, the performance of each project was evaluated. By comparing the performance of each project with that of the others, the projects' ranking was identified. Finally, the results were retained, in order to be used as a basis for benchmarking future projects or organisations.

Table 4.11: The Key Effectiveness Measures in Industrial Construction Projects (ICPs); (Adopted from; Al-Khalil et al., 2004)

Attributes	*Key Measures of Materials-Management Effectiveness*
Accuracy	• Material Receipt Problems • Warehouse Inventory Accuracy
Quality	• Jobsite Rejections of Tagged Equipment
Timelines	• Procurement Lead Time • Bid/Evaluate/Commit Lead Time • Purchase Orders (PO) to Material Receipt Duration • Material Receiving Processing Time • Commodity Vendor Timeliness • Materials Withdraw Request (MWR) Lead-time
Cost	• Construction Time Lost • Total Surplus
Availability	• Material Availability

A similar study, but on different industrial projects, was undertaken by Al-Juaid (2005) using the same measures adopted by Al-Draweesh (1999) for assessing the effectiveness of materials management performance. Similarly, in this study, the effectiveness of materials management performance was also measured for different industrial projects in Saudi Arabia, and the project ranking was identified. The results were also preserved to be used as a basis for benchmarking future projects.

Ul-Asad (2005) made an attempt to determine the importance of the performance measures in assessing the effectiveness of the materials management process in the industrial projects in Saudi Arabia. In his research, the specific measures were ranked in terms of their importance in evaluating the effectiveness of material management performance. **Table 4.12** lists the most important **10** measures for evaluating the effectiveness of the materials management performance in the industrial projects in Saudi Arabia. It can be noted that the measures listed in **Table 4.12** are among those related to availability, time lines, cost and accuracy attributes.

Table 4.12: The Importance Rank of the Performance Effectiveness-Measures in Industrial Construction Projects (ICPs); (Adopted from; Ul-Asad, 2005)

The Rank	*Attributes*	*Measures of Materials-Management Effectiveness*
1	Availability	Material availability
2	Timelines	Procurement lead time
3	Cost	Construction time lost
4	Cost	Express deliveries percent
5	Accuracy	Materials Receipt Problems-internal
6	Accuracy	Materials Receipt Problems
7	Availability	Stock out analysis
8	Timelines	PO to materials receipt duration
9	Cost	Freight cost percent
10	Accuracy	Warehouse inventory accuracy

In addition to the importance-rank, Al-Alawi, Al-Ghazwi and Al-Saeed (2007) identified the practicality of the implementation of performance measures in the industrial projects in Saudi Arabia. Similarly, the measures proposed have been ranked, in terms of their practicality of implementation. **Table 4.13** demonstrates the rank of the measures in terms of their practicality.

Among the most recent studies in this area was the one conducted by Al-Quriesha, Bello and Fallatah (2006). This study aimed to evaluate the usage of the performance measures that were identified in the industrial construction projects of SABIC and the Saudi ARAMCO companies in the Eastern Province of Saudi Arabia. Probably, because of implementing them in the same country, the results of this study were fairly similar to those obtained by the above-stated studies. However, in this study, the concentration was on measures related to quantity attributes, which were considered the most frequently employed by those companies. These measures were; 1) Home Office Requisition ratio, 2) Quantity of Purchase Order-home Office, 3) Average Line Items per Release, 4) Equipment/Material Commitment-home Office and Field, 5) Sole Source Purchase. Again, it can be noted that some of these measures were adopted from the manufacturing industry.

Table 4.13: The Rank of the CMM Effectiveness-Measures in terms of their Practicality in Industrial Construction Projects (ICPs); (Adopted from Al-Alawi, Al-Ghazwi and Al-Saeed, 2007)

The Rank	*Attributes*	*Measures of Materials-Management Effectiveness*
1	Quantity	Commitment – Field
2	Cost	Construction time lost
3	Accuracy	Warehouse inventory accuracy
4	Accuracy	Materials Receipt Problems
5	Cost	Average Man-hour/Work hour per Material Take-off (MTO)
6	Quantity	Electronic Data Interchange (EDI) Purchases
7	Timelines	Material Receiving Processing Time
8	Timelines	PO to materials receipt duration
9	Quantity	Average Line Items Per Release
10	Cost	Payment Discounts

It is worth noting that the majority of the above authors and researchers ranked the evaluation measures, whether in terms of importance, practicality, or utilization, between 8-12. This is totally consistent with the logic put forward by Ali, Al-Sulaihi and Al-Gahtani (2013), who argue that the organizational performance of the building companies is measured in terms of Key Performance Indicators (KPIs). They confirms what was concluded by Swan and Kyng (2004) that; "*Since too many KPIs can be unmanageable, management must select appropriate KPIs, the suitable number of KPIs should be 8–12, based on the value of the Relative Importance Index (RII)*" (Ali, Al-Sulaihi and Al-Gahtani, 2013, p130), or *'based on the value of the mean'* (Swan and Kyng, 2004; Takim and Adnan, 2008; Ali, 2011) of the indictors' importance.

In the next section, the measures that have been presented above along with others will be analysed and modified to fit the building construction context, and then, in turn, a set of measures that have been proposed to assess the effectiveness of the performance of the construction material management process will be developed.

4.4 ESTABLISHING A SET OF PROPOSED EFFECTIVENESS MEASURES TO EVALUATE THE PERFORMANCE OF THE CMM PROCESS:

The process of establishing a set of proposed effectiveness measures for evaluating the CMM performance is mainly based on analysing and adopting a number of measures that were used in manufacturing SCM, construction SCM and industrial construction projects, which were presented in the previous sections. The process focuses on modifying these measures to fit the building construction text. The analysis (filtration) process embodies removing the duplications and the organisational measures that were not directly associated with the materials management, such as '*Workforce Diversity*' and '*Warehouse Overtime*', '*Schedule Milestone Attainment*' as well as eliminating the measures related to the general supply chain process but not specified to the supply chain management or to the materials management process, such as 'Buyer-Supplier Partnership Level', 'R*ange of Product and Services*', '*Accuracy of Forecasting* Techniques' among others.

Although some of the measures above have already been reported in the effectiveness format (ratio or percentage), others need re-formatting into a ratio format of effectiveness. Therefore, the process of developing the set of effectiveness-measures includes also reformatting some measures into the effectiveness format. For example, a measure entitled as '*Quantity of Purchase orders-home office*' has been converted to an effectiveness format to be '*Home Office Ratio*'. In addition to that, within the process of analysing the measures, some combined measures have been converted (separated) for the purpose of facilitating their calculation; for instance, a measure entitled '*Equipment/Materials Commitment-Home Office and Filed*' was broken up and re-classified (separated) into '*Commitment-Home Office*' and '*Commitment-Field*'.

The development of the set of effectiveness measures also involves modifying some measures, which were adopted form other sectors or industries, to fit the building construction sector. For example, a measure entitled '*Piping Spool Rework*' that is used to report the piping spools was identified as requiring rework in industrial projects. This measure is designed to evaluate the ability of the materials management process to react to design changes (or any another reason) without impacting the construction operation in the industrial construction projects (petrochemicals, oil and gas, and refinery), whereby installing pipes is the main activity (Plemmons, 1995). However, as the case of this research is building construction projects, where installing equipments is the main activity rather than installing pipe, this measure has been converted into an '*Installing Equipment Rework*'.

The main result of the process of analysing and modifying the previous sets of measures that were reported in the literature is a set of **30** measures proposed to assess the effectiveness of materials management in the building projects, as shown in **Table 4.14**. These measures have been considered by the most of the previous studies as the key measures, the best that can communicate effectiveness, the most important, the most practical and the most frequent measures used in industrial projects. The meaning and usage of each measure are described and explained in **Section 4.4.2 and Appendix Q**.

In fact, in order to maintain consistency with what exists in the field of CMM-related literature and to work in similar environment, the **30** proposed effectiveness measures were subsumed under the same six main attributes that have already been used by the previous related researches and studies for categorizing the supply chain management and material management measures or metrics. The six attributes: '*Accuracy*', '*Quality*', '*Quantity*', '*Timeline*', '*Cost*', and '*Availability*', represent a customer's needs and expectations concerning a materials management process and its information system (Plemmons, 1995).

In order to organise these measures, it is necessary to label them in a descriptive and logical manner. The technique that is adopted in this research project is the one used by Plemmons (1995), Al-Draweesh (1999), Al-Khalil et al. (2004), Al-Alawi, Al-Ghazwi and Al-Saeed (2007), and others. The adopted technique is based on grouping the measures under the attributes of performance, whereby each measure was classified according to whether it communicates Accuracy (AC), Quality (Q), Quantity (QN), Timelines (T), Cost (C), or Availability (AV). Along with this technique, the measures in each group were numbered in no particular order as exposed in **Table 4.14**. These attributes are defined and discussed in **Section 4.4.2**.

Table 4.14: The Proposed Measures for Assessing the Effectiveness of CMM with Six Attributes

Attribute	*Label*	*Measures*
ACCURACY	AC1	Materials Receipt Problems
	AC2	Materials Receipt Problems—internal
	AC3	Warehouse inventory Accuracy
QUALITY	Q1	Installing Equipments Rework
	Q2	Jobsite Rejections of Tagged Equipment
QUANTITY	QN1	Home Office Requisition Ratio
	QN2	Home Office PO Ratio
	QN3	Average Line Items Per Release
	QN4	Commitment—Home Office
	QN5	Commitment—Field
	QN6	Electronic Data Interchange (EDI) Purchases
	QN7	Sole Source Purchases
	QN8	Minority Suppliers
TIMELINES	T1	Procurement Lead Time
	T2	Bid/Evaluate/Commit Lead-time
	T3	Purchase Orders (PO) to Material Receipt Duration
	T4	Material Receiving Processing Time
	T5	Commodity Vendor Timeliness
	T6	Commodity Timeliness
	T7	Materials Withdrawal Request (MWR) Lead-time
COST	C1	Average Man-hour /Work hour Per Material Take-off (MTO)
	C2	Average Man-hour /Work hour Per PO
	C3	Freight Cost Percent
	C4	Express Deliveries Percent
	C5	Construction Time Lost
	C6	Payment Discounts
	C7	Warehouse Safety Incident Rate
	C8	Total Surplus
AVAILABILITY	AV1	Material Availability
	AV2	Stock out Analysis

It is worth pointing out that there is no single measure communicating flexibility has been reported in the materials management-related literature, at the time of conducting this research; neither in the construction industry nor in the industrial projects. In manufacturing industry, very few studies considered flexibility from a supply chain perspective (Duclos, Vokurka and Lummus, 2003). The next section sheds light on flexibility as a tool for evaluating the performance of the supply chain management (SM) process.

4.4.1 Flexibility as a Measure of SCM Performance:

Beamon (1999) believes that owing to several factors, such as the demand fluctuations, delivery delays, equipment breakdowns, and production yield fluctuations, the supply chains operate in an uncertain environment. Hence, he views flexibility as the key to enabling supply chains to continue to operate efficiently and effectively in the face of uncertainty.

Although numerous flexibility measures for the flexible manufacturing systems on the level of machine and plants exist in many research papers such as those of Slack (1983), Gupta and Goyal (1989), Sethi and Sethi (1990), Slack (1991) and Beamon (1999), the measurement of SCM flexibility has rarely been addressed, and a limited number of authors and researchers has developed measures for assessing the flexibility of SCM performance (Beamon, 1999; Duclos, Vokurka and Lummus, 2003; Wu and Liu, 2008).

Flexibility measurement in the supply chain (SC) can be defined as the measure of the system ability to accommodate schedule and volume fluctuations of the customers, manufactures, and suppliers. Supply chain flexibility measurement is important for evaluating the manufacturing SC performance (Slack, 1983). Wu and Liu (2008) argue that the importance of flexibility in estimating the SCM performance can be attributed to four main reasons;

1- Recent trends such as mass customization, require supply chains to meet the individual customer requirements without adding a significant cost,
2- In many innovative product categories, such as the fashion apparel and electronic devices, uncertainty of demand is a fact of life; creating a responsive supply chain is one method of avoiding uncertainty, and
3- In the ever-changing environment, companies are required to introduce rapid new products and quick response to the customer demands in all parts of the world.

The survey that was conducted by Das (1996) indicated that "*since every manufacturing facility experiences different changes to different degrees, and the diversity of these possible changes is large, several different types of flexibilities may be appropriate*". Two basic categories of flexibility were identified by Slack (1991): 'range flexibility' and 'response flexibility'. While *range flexibility* means the extent to which an operation can be changed, *response flexibility* can be defined as the ease (in terms of time, cost, or both) with which the operation can be changed (Beamon, 1999). Although many of the flexibility types have been identified during the review of literature, the majority of them were grouped under *range flexibility*, *response flexibility*, or *both*.

Table 4.15 summarizes some types of SCM flexibility that were reported in the literature, and the perspectives which are classified on the basis of these types.

Table 4.15: Summary of some Types of Flexibility related to SC/SCM; They are specified by the Literature

Author	*Perspective*	*Flexibility Types*	*Definition*
Slack (1991)	*Supply Chain*	*Volume flexibility*	The ability to change the output level of products produced
		Delivery flexibility	The ability to change planned delivery dates.
		Mix flexibility	The ability to change the variety of products produced
Beamon (1999)	*Measuring Supply Chain Performance*	*Volume flexibility*	The ability to change the output level of products produced (Variable demand)
		Delivery flexibility	The ability to change planned delivery dates (Delivery dates change regularly and costs are associated without meeting new delivery dates)
		Mix flexibility	The ability to change the variety of products produced (Stationary demand for multiple product types)
		New product flexibility	The ability of the material management system to procure any new materials or products with short life cycle.

Author	*Perspective*	*Flexibility Types*	*Definition*
Vicker,Calantone and Droge (1999)	*Customer-oriented*	*Product flexibility*	The ability to customize product to meet specific customer demands.
		Volume flexibility	The ability to adjust capacity to meet changes in the customer quantities
		New product flexibility	The ability to launch new or revised products.
		Distribution flexibility	The ability to provide widespread access to products.
		Responsiveness flexibility	The ability to respond to target market needs.
Sabri and Beamon (2000	*supply chain flexibility measurement*	*production flexibility*	The ability to customize product to meet specific customer demand.
		distribution flexibility	The ability to provide widespread access to products.
Vokurka and O'Leary-Kelly (2000)	*Measurement of supply chain flexibility*	*Production flexibility*	The ability to customize products to meet specific customer demands.
		Output flexibility	No clear definition
		Variety flexibility	No clear definition
De Toni and Tonchia (2001)	*Performance Measurement System*	*volume flexibility*	The ability to adjust capacity to meet changes in customer quantities
		mix flexibility	The ability to change the variety of products produced (Stationary demand for multiple product types)
		product modification flexibility	The ability to customize products to meet specific customer demands.
		process modification flexibility	No definition found
		expansion flexibility	No definition found
Das and Abdel-Malek (2003)	*Estimation Supply chain flexibility*	*Order Quantity*	No clear definition

Author	*Perspective*	*Flexibility Types*	*Definition*
		Lead Time	No clear definition
Duclos, Vokurka and Lummus (2003)	*Components of supply chain flexibility*	*Operation System flexibility*	The ability to configure assets and operations to react to emerging customer trends (Product changes, volume, mix) at each node of the supply chain)
		Market flexibility	The ability to mass customize and build close relationships with customers, including designing and modifying new and existing products.
		Logistics flexibility	The ability to cost effectively receive and deliver products as sources of supply and customers changes
		Supply flexibility	The ability to reconfigure the supply chain, altering the supply of a product in line with the customer demand.
		Organisational flexibility	The ability to align labour force skills to the needs of the supply chain to meet customer service/demand requirements
		Information systems flexibility	The ability to align information system architectures and systems with the changing information needs of the organisation as they respond to changing customer demands
S'anchez and P'erez (2005)	*Flexibility dimension*	*Product flexibility*	No specific definition found within this perspective
		Volume flexibility	No specific definition found within this perspective
		Routing flexibility	No definition found
		Delivery flexibility	No specific definition found within this perspective
		Transhipment flexibility	No clear definition found
		Postponement flexibility	No definition found
		Access flexibility	No definition found

Author	*Perspective*	*Flexibility Types*	*Definition*
		Launch flexibility	No definition found
		Response to market flexibility	No specific definition found within this perspective
		Sourcing flexibility	No clear definition
		System flexibility	No specific definition found within this perspective
		Basic flexibility (construct)	No definition found
		Aggregate flexibility (construct)	No specific definition found within this perspective
Slack, and Chambers, and Johnston (2007)	*Production Tasks and Flexibility*	*New Product flexibility*	The ability of the material management system to procure any new materials or products with a short life cycle
		Product Mix flexibility	Product mix flexibility is the ability to manufacture a particular mix of products within the minimum planning period used by the company.
		Quality flexibility	The ability of the system to change the quality level of one or more of its products.
		Volume flexibility	The range of possible changes in a production system's aggregate volume of output which is, in the short term exclusively determined by its level of operating capacity.
		Delivery flexibility	The ability of the system to shorten or lengthen its delivery time, that is to bring forward or put back production.
Wu and Liu (2008)	*Index System of Supply Chain flexibility measurement*	*Structured flexibility*	No definition found
		Procurement flexibility	No clear definition found
		Manufacture	No definition found

Author	*Perspective*	*Flexibility Types*	*Definition*
		flexibility	
		Logistics flexibility	No specific definition found within this perspective
		Information system flexibility	No specific definition found within this perspective

As it can be displayed from **Table 4.15** above, many of the flexibility types have been classified on the basis of how they can be measured. Beamon (1999), Duclos, Vokurka and Lummus (2003), Shen (2006) and Wu and Liu (2008) argue that the measurement of the supply chain management flexibility should emphasize the entire supply chain flexibility. Based on their survey, however, Wu and Liu (2008, p2222) found out that "*current researches of flexibility estimation rarely review flexibility as a whole*". Besides, Beamon (1999) and Wu and Liu (2008) confirmed what was concluded by Slack (1983, p12) that "*flexibility measures potential behaviour, whereas other operational objectives are actually demonstrated by the system's operating behaviour (performance)*". On the other hand, Wu and Liu (2008, p2227) observe that flexibility "*is not kind of system behaviour but the ability to respond to variety environment*". Generally, the difficulty of measuring the flexibility of supply chain management as a whole can be evident from many relevant studies. Slack (1983) maintains that the difficulty in measuring the flexibility of a production system as a whole is attributed to three factors;

a) It is a measure of potential rather than performance,
b) It is not a single concept, but it needs to be applied to the other production objectives of product specification, quality, volume and delivery,
c) It has three dimensions: range (which may itself consist of several elements), cost and time.

Therefore, in order to simplify measuring flexibility in SCM, researchers have not measured the entire SCM flexibility; rather, they only concentrate on measuring the flexibility of operations or objectives considered to be the key strategies in their organisation, as presented in **Table 4.15**.

Flexibility is, in theory, an ability to change something (for example, the production, volume or the mix) in relation to all the three performances of *cost*, *time* and *quality* (De

Toni and Tonchia, 1998; and De Toni and Tonchia, 2001). Slack (1983) contends that the *time* and *cost* elements are the dominant elements of measuring flexibility such as 'volume flexibility' and 'delivery flexibility'. Beamon (1999) used a quantitative approach to measure the flexibility of SCM performance in manufacturing. He provides equations to calculate the 'volume flexibility', 'delivery flexibility' and 'mix flexibility'. He believes that although many different types of flexibility measures for the flexible manufacturing systems have been identified in the literature and many of these types may have some application to specific supply chain systems, given the universality of the uncertain environment in which supply chain systems exist, '**Volume Flexibility**' is commonly the most desirable measure.

According to Slack (1983), flexibility measurement must be applied to production objectives, such as volume or delivery. In order to study this perspective, Beamon conducted an investigation in 1999 on measuring the supply chain performance. Based on this study, it was concluded that among the three types of performance measures (resource, output and flexibility) for the supply chain system, 'volume flexibility' and 'delivery flexibility' are necessary measures in any supply chain performance measurement system. In line with this, S'anchez and P'erez (2005) ranked '**Delivery Flexibility**' and '**Volume Flexibility**' as the most important supply chain flexibility dimensions, in terms of their effect on the firm's overall performance.

As concluded previously, due to some similarities between manufacturing and construction industries in adopting the same solutions for facing similar problems (Nudurupati, Arshad and Turner, 2007), and since SCM is considered as the root of CMM, it is possible to adopt some SCM approaches from the manufacturing industry and implement them within CMM in the construction industry. Accordingly, the '**Volume Flexibility**' and '**Delivery Flexibility**' measures will be adopted in this research; they are considered measures to assess the effectiveness of the material management performance in building projects.

Fayek, Dissanayake and Campero (2003) carried out a pilot study on a mega project performed under Engineering, Procurement, and Construction (EPC) arrangement in Alberta. The pilot study, which was a result of the collective efforts of the Field Rework Measurement Subcommittee and the Pilot Study Steering Committee of the Construction

Owners Association of Alberta, aims to 'Measuring and Classifying Construction Field Rework'. Its main objectives were to develop a standard methodology for identifying rework in the field and measuring or quantifying the amount of rework on the basis of cost, schedule, and other impacts. Besides, the pilot study aimed to identify the major factors and sub-factors causing rework, and develop a standard methodology for quantifying the impact of each cause on the rework amount.

Among the major factors that can cause the construction field rework was 'Materials and Equipment Supply' including changes in design, materials specifications, and/or customer needs. Therefore, the researcher decided to adopt the measurement of the ability of the construction materials management system to react to any changes without influencing the cost of the field construction phase, to be used for evaluating the effectiveness of the performance of the CMM process in this research. This measure, which will be called the **Changes Flexibility**, will also be added to the list of the set measures that are proposed to assess the effectiveness of materials management in building projects.

As a result of the above discussion in this section, the three flexibility measures, **Delivery Flexibility**, **Change Flexibility,** and **Volume Flexibility**, will be added to the proposed list of the 30 effectiveness measures to become 33 measures. As these measures communicate flexibility, similarly they have been grouped under flexibility attribute, and they have been labelled by **F1**, **F2** and **F3** for Delivery Flexibility, Change Flexibility, and Volume Flexibility respectively, as illustrated in **Table 4.16**. The definition of the flexibility attribute is introduced in the next section (**Section 4.4.2**), and the description of its measures are detailed in **Appendix Q**. In Fact, this might be the first attempt that uses the flexibility attribute as an effectiveness measure to evaluate the CMM performance in the construction projects, which can represent another contribution of this research.

4.4.2 Definitions of the Attributes of the Proposed Effectiveness Measures Established:

The main result of this part of the research effort is a set of **33** measures within seven attributes that are proposed to measure the effectiveness of materials management in the building projects, as listed in **Table 4.16**. This section presents the definitions of the seven attributes; Accuracy, Quality, Quantity, Timelines, Cost, Availability, and Flexibility. The detailed descriptions of these **33** measures that form the proposed set of effectiveness measures that have been developed from the literature review process are presented in **Appendix Q**; The description of each effectiveness measure includes the measures' name, measurement attributes, measures' code/label, point of measurement (Measure's Location), and the definitions the measure. Mainly, the descriptions of these effectiveness-measures and their attributes are developed from the descriptions and definitions provided by **Plemmons** (1995), Plemmons and Bell (1994), Swanson (1994), Plemmons and Bell (1995), Al-Draweesh (1999), Beamon (1999), Al-Khalil et al. (2004), Ul Asad (2005), and Al-Juaid (2005).

1- Accuracy Attribute (AC):

Accuracy is an attribute of the information that adds to relevant knowledge; reduces uncertainty and supports the decision-making process in an organization (Senn 1990). It is the degree to which an item of information is true or false. Without verification of each item of information, a user may treat inaccurate information as if it were accurate. A materials management computer system should provide current and reliable data to a wide spectrum of project personnel (CII Handbook, 1987). Three effectiveness measures are grouped under this attribute; '*AC1: Material Receipt Problems*', '*AC2: Material Receipt Problems-Internal*', and '*AC3: Warehouse Inventory Accuracy*'; see **Appendix Q** for detailed definitions and descriptions of the 'Accuracy Measures'.

2- Quality Attribute (Q):

Quality is the degree to which a system conforms to the requirements, specifications, or expectations and it is considered an outcome of an organizational system (Sink, 1985). As a key aspect of logistical performance measurement, Bowersox et al., (1992) classify quality "*one of the most popular ways of assessing logistical performance...The notion is simply...do what you told the customer you were capable of doing. Taken to the extreme, zero defects means doing the right things in the right way every time*".

Related to the materials management process, quality manifests itself in physical characteristics of the materials. A critical activity of the site or field control function is the receiving of materials. One factor in receiving materials at the work site is the necessity for a prompt, thorough inspection by warehouse personnel to identify "defective components, especially those which are likely to impact the start-up and operational availability of the plant", in order to prevent costly, last minute delays and disruptions (CII Handbook, 1987). Thus, for the purpose of this study, materials management process quality manifests itself in the physical characteristics associated with the materials in terms of damage resulting from the processes and problems affecting usability. The best quality is that which can be purchased at the lowest cost to fulfil the need for the intended function for which the material is being purchased. Two examples of materials management process quality have been adopted together with the set of the proposed effectiveness measures; '*Q1: Installing Equipments Rework*' and '*Q2: Jobsite Rejections of Tagged Equipment*'; see **Appendix Q** for detailed definitions and descriptions of the 'Quality Measures'.

3- Quantity Attribute (QN):

It is an attribute of observable outputs that result from worker or work-group performance (Swanson, 1994). The purpose of quantity measures is to quantify the volume of transactions or throughput of materials management process. The proposed measures that are categorized into this attribute are; '*QN1: Home Office Requisition Ratio*', '*QN2: Home Office Purchase Order Ratio*', '*QN3: Average Line Items Per Release*', '*QN4: Commitment – Home Office*', '*QN5: Commitment – Field*', '*QN6: Electronic Data Interchange (EDI) Purchases*', '*QN7: Sole Source Purchases*', and '*QN8: Minority Suppliers*'. These quantity measures evaluate the process flow or throughput in terms of volume or quantities related to planned accomplishment; see **Appendix Q** for detailed definitions and descriptions of the 'Quantity Measures'.

4- Timeliness (T):

Timeliness is defined as the measurable interval between two events or the period during which some activity occurs (Swanson, 1994). Measures of this characteristic report duration aspects of the materials management process. The timing of purchase is a factor that must be given due consideration. When considering the timing of purchases, buyers are interested first in assuring their firms an adequate supply of materials and second in acquiring the materials at an optimal price, considering quality and service requirements. Timing is a much more important matter when a purchase is made in a market that tends to be unstable. Seven effectiveness measures have been proposed to be involved in developing a set of effectiveness measures that are intended to evaluate the effectiveness of the performance of the CMM process; '*T1: Procurement Lead Time*', '*T2: Bid/Evaluate/Commit Lead Time*', '*T3: Purchase Orders (PO) to Material Receipt Duration*', '*T4: Material Receiving Processing Time*', '*T5: Commodity Vendor Timeliness*', '*T6: Commodity Timeliness*', and '*T7: Materials Withdraw Request (MWR) Lead-time*'; see **Appendix Q** for detailed definitions and descriptions of the 'Timeliness Measures'.

5- Cost (C):

Cost characteristics define the process in terms of meeting planned cost and labour targets. The focus is on the efficient use of labour, the introduction of labour-saving technology, and the avoidance of "unreasonable" or unnecessary expenses. In addition to the direct costs, acquisition costs comprise a different set of indirect costs related to materials management. These costs contribute to the cost of generating, processing, handling and order, along with its related paperwork. Eight examples of cost related effectiveness measures that have been adopted to be listed with the set of the proposed effectiveness measures are: '*C1: Average Manhour/Workhour per Material Takeoff (MTO)*', '*C2: Average Manhour/Workhour per Purchase Order (PO)*', '*C3: Freight Cost Percent*', '*C4: Express Deliveries Percent*', '*C5: Construction Time Lost*', '*C6: Payment Discounts*', '*C7: Warehouse Safety Incident*', and '*C8: Total Surplus*'; see **Appendix Q** for detailed definitions and descriptions of the 'Cost Measures'.

6- Availability (A):

Availability characterizes the ability of the materials management process to fill requests for materials at the agreed time and place. It is a major element of customer service (Firth et al., 1988) and it reflects the degree to which the process made the materials available when construction operations are planned to withdraw or receive them. If materials required on site are not available, it may cost additional labour charges and loss of productivity. '*AV1: Material Availability*' and '*AV2: Stockout Analysis*' are the main two measures adopted in this work project to represent availability attribute in the set of proposed measures that is developed to assess the effectiveness of the CMM performance; see **Appendix Q** for detailed definitions and descriptions of the 'Availability Measures'.

7- Flexibility (F):

Flexibility has been defined from many perspectives in many studies regarding the supply chain management (SCM) process (See **Table 4.15**). This study adopts the most common definition of flexibility that has been proposed in studies such those of: Slack (1983), Gupta and Goyal (1989), Sethi and Sethi (1990), Slack (1991) and Beamon (1999); Flexibility measurement can be defined as the measurement of the system ability to accommodate schedule and velum fluctuations of the customers, manufactures, and suppliers. Supply chain flexibility measurement is important for evaluating the manufacturing Supply Chain (SC) performance (Slack, 1983), and thus it is very important for assessing the performance of the CMM process as well. The involvement of flexibility attribute in evaluating the effectiveness of the CMM performance might be the first attempt so far; three effectiveness measures have been grouped under this attribute as it was a result of the development process previously stated in **Section 4.4.1**; '*F1: Delivery Flexibility*', '*F2: Changes Flexibility*' and '*F3: Volume Flexibility*'; see **Appendix Q** for detailed definitions and descriptions of the 'Cost Measures'.

The definitions and descriptions of measures which have been proposed for evaluating the effectiveness of CMM process (the set of proposed effectiveness-measures) is detailed in **Appendix Q**, and it is summarised in **Table 4.16**. The measures description in **Table 4.16** includes the measures' name, measurement attributes, measures' code/label, point of measurement (Measure's Location), measure's definition, and a brief description of the measure's meaning and related issues.

In fact, these measures have been established to continuously measure and evaluate the effectiveness of the performance of the construction materials management process. The objective is to collect information that helps an organisation to take action that improves its performance, and to search for the best practices that lead to the superior performance of an organisation through internal comparison (within an organisation) or to search for the best industry practices through external comparison (between the industry's organisations). However, According to Camp (1989), Lema and Price (1995), Anand and Kodali (2008), among others, this process can be defined as a benchmarking. The definitions, types, steps, and applications of benchmarking will be explored, in details, in the next section.

Table 4.16: The Proposed Effectiveness-Measures for assessing the Performance of

CATEGORIES ATTRIBUTES	CODE	MEASUREMENT TITLE	AREA/POINT OF MEASUREMENT	
ACCURACY	AC1	**Material Receipt Problems**	The interface between vendor and warehouse function	➢ **AC1** asso corr man ➢ This disc
	AC2	**Material Receipt Problems - Internal**	At the interface of the Vendor with the Warehouse Function.	➢ **AC2** relat ➢ AC2 inter
	AC3	**Warehouse Inventory Accuracy**	Within the Warehouse functions	➢ This **stati the** area ➢ AC3 accu that
QUALITY	Q1	**Installing Equipments Rework**	At the interface of Construction with the field control Function.	➢ **Q1** insta mod Q1 mea ➢ **Q1** iden the t to pr
	Q2	**Jobsite Rejections of Tagged Equipment**	At the interface of Construction operation with the field control Function.	➢ **Q2** equi ➢ **Q2** tagg equi
QUANTITY	QN1	**Home Office Requisition Ratio**	At the interface of the Purchasing Function with the Vendor.	➢ **QN1** (RF num time
	QN2	**Home Office Purchase Order Ratio**	At the interface of the Purchasing Function with the Vendor.	➢ **QN2** perf

CATEGORIES ATTRIBUTES	CODE	MEASUREMENT TITLE	AREA/POINT OF MEASUREMENT	
				of P
	QN3	**Average Line Items Per Release**	At the interface of the Purchasing Function with the Vendor.	➢ **QN** plan ➢ The com
	QN4	**Commitment – Home Office**	At the interface of the Purchasing Function with the Vendor.	➢ **QN** tagg to th peri
	QN5	**Commitment – Field**	At the interface of the Purchasing Function with the Vendor.	➢ **QN** tagg total
	QN6	**Electronic Data Interchange (EDI) Purchases**	At the interface of the Purchasing Function with the Vendor.	➢ **QN data** purc
	QN7	**Sole Source Purchases**	At the interface of the Purchasing Function with the Vendor.	➢ **QN** the t
	QN8	**Minority Suppliers**	At the interface of the Purchasing Function with the Vendor.	➢ **QN** purc
TIMELINESS	T1	**Procurement Lead Time**	The interface between vendor and of purchasing function	➢ **T1** i in da ➢ **T1** u valu
	T2	**Bid/Evaluate/Commit Lead Time**	The first measure **T2a** is at the interface of the Vendor with the Purchasing Function. The second measure **T2b** is taken at the interface of the Purchasing Function with the Vendor.	➢ **T2** i and ➢ **T2** u durat
	T3	**Purchase Orders (PO) to Material Receipt Duration**	The first measure location **T3a** is at the interface of the Purchasing Function with the Vendors. The second location **T3b** is at the interface of the Vendor with the Warehouse Function.	➢ **T3** i the r ➢ **T3** u and t
	T4	**Material Receiving Processing Time**	Within the Warehouse and the Field Control functions.	➢ **T4** r ware **day'**
	T5	**Commodity Vendor Timeliness**	At the interface of the Vendors with the Warehouse Function.	➢ **T5** is deliv and t

CATEGORIES ATTRIBUTES	CODE	MEASUREMENT TITLE	AREA/POINT OF MEASUREMENT	
				➢ **Cal** time spec
	T6	**Commodity Timeliness**	At the interface of the Vendors with the Warehouse Function.	➢ **T6** i 'act **deli** ➢ **Cal** deli and of ti
	T7	**Materials Withdraw Request (MWR) Lead-time**	At the interface of Construction with the Warehouse Function.	➢ **T7** r deli ➢ **T7** i requ ➢ The lead
COST	C1	**Average Manhour/Workhour per Material Takeoff (MTO)**	Within the Material Takeoff and Design Interface Function	➢ C1 r gene shee ➢ The worl ➢ The iden prod
	C2	**Average Manhour/Workhour per Purchase Order (PO)**	Within the Purchasing Function	➢ **C2** r gene ➢ The work gene
	C3	**Freight Cost Percent**	Within the Expediting and Transportation function.	➢ **C3** r mate
	C4	**Express Deliveries Percent**	At the interface Between the Vendor and the Warehouse Function.	➢ **C4** r proje deliv time
	C5	**Construction Time Lost**	Between Construction Operations and the Field Control Function.	➢ **C5** i impa supe ➢ To **c** of m time
	C6	**Payment Discounts**	Within the Purchasing Function	➢ **C6** r taken
	C7	**Warehouse Safety Incident**	Within the Warehouse function.	➢ **C7** r funct
	C8	**Total Surplus**	Within the Warehouse and Field Control Functions.	➢ **C8** r relati

CATEGORIES ATTRIBUTES	CODE	MEASUREMENT TITLE	AREA/POINT OF MEASUREMENT	
AVAILABILITY	AV1	**Material Availability**	At the interface of the Warehouse Function with Construction Operations.	➢ **AV** ma lin
	AV2	**Stockout Analysis**	Within the Warehouse function.	➢ **AV** **wa** by
Flexibility	F1	**Delivery Flexibility** Beamon (1999) (Measuring Flexibility)	The first measure location **F1a** is at the interface of the Vendor with the Warehouse. The second location **F1b** is at the interface of Warehouse Function with Construction Operations	➢ **Del** slac ➢ Del exc
	F2	**Changes Flexibility**	At the interface of Construction with the field control Function.	➢ The **ave** the nee
	F3	**Volume Flexibility**	The first measure location F3a is at the interface of the Purchasing Function with Vendor. The second location F3b is at the interface of Warehouse Function with Construction Operations	➢ The prop man ➢ This **aver** man the r

4.5 BENCHMARKING:

"performance measurement is the heart of ceaseless improvement" (Luu, Kim and Huynh, 2008, p759), as a general rule, *"benchmarking is the next step to improve contractors' efficiency and effectiveness of products and processes"* (Ali, Al-Sulaihi and Al-Gahtani, 2013, p125). Benchmarking is defined differently in the literature. According to Nandi and Banwet (2000) and Anand and Kodali (2008), 49 definitions were given for benchmarking. **Table 4.17** below provides some diverse definitions for benchmarking.

Table 4.17: Some Definitions for benchmarking that have been found in the Literature

Author	*Definition*
Camp (1989)	*"Benchmarking is the search for the best industry practices which will lead to exceptional performance through the implementation of these best practices"*
Rothman (1992)	*"Benchmarking is the continuous process of measuring products, services, and practices against the toughest competitors or those organisations as industry leaders"*
Longmire (1993) Plemmons (1995) Plemmons and Bell (1995)	Benchmarking is the process of continuously comparing and measuring an organisation with the business leaders anywhere in the world to gain information that will help the organisation take action to improve its performance
The International Benchmarking Clearinghouse (IBH, 1993)	*"The Practice of being humble enough to admit that someone else is better at something and being wise enough to try to learn how to mach and surpass them at it"*
Al-Darweesh (1999)	Benchmarking quantities measures present management with comparative information to justify new technologies and to measure the success or failure of implementation
Kumar, Antony and Dhakar (2006) Anand and Kodali (2008),	Benchmarking is the process of identifying, understanding, and adapting outstanding practices from organizations anywhere in the world to help an organization improve its performance. It is an activity that looks outward to find best practice and high performance and then measures actual business operations against those goals
Gwaya, Masu and Oyawa (2014)	Benchmarking is a tool that applied by companies and organizations to comparing their practices and performance in key activities.

In addition, more definitions are provided during the evolution of benchmarking, such as those given by Bemowski (1991) Vaziri (1992), the International Benchmarking Clearing House Design Committee (Lema and Price, 1995), Epper (1999), American Productivity &

Quality Centre (1993), Dervitsiotis (2000), Freytag and Hollensen (2001), Sarkis (2001), Maire (2002), Maire, Bronet and France (2005), Anand and Kodali (2008), and many others. However, the majority of these definitions have been generated from the definition that was developed on the basis of a survey that was conducted by the International Benchmarking Centre in 1993; it represents a consensus among 100 companies;

> "*Benchmarking is a systematic and continuous measurement process; a process of continuously measuring and comparing an organisation's business process against business leaders anywhere in the world to gain information which will help the organisation to take action to improve its performance*" (Lema and Price, 1995, p29).

This definition was also adopted by many institutions, such as, Construction Industry Institution, International Benchmarking Clearing House Design Committee, and American Productivity & Quality Centre, and by many authors, such as El-Mashaleh, Minchin and O'Brien (2007), Stapenhurst (2009), and Ali, Al-Sulaihi and Al-Gahtani (2013), who believe that:

> "*Benchmarking can be applied by an organization to measure and compare its performance against results from recognized leaders for the purpose of identifying the strengths and weaknesses in performance, then using lessons learned from the best ones to determine the best practices that can lead to superior performance when adapted and implemented*" (cited in Ali, Al-Sulaihi and Al-Gahtani, 2013, p125)

4.5.1 Benchmarking Types:

The literature review process reveals that there are several methods to categorise the types of benchmarking. Nevertheless, there is clear evidence which indicates that there is still a lack of consensus on the classification of benchmarking. On the basis of what benchmarking focuses on, the benchmarking techniques are classified into three types (Luu, Kim and Huynh, 2008);

1- *Performance Benchmarking*: it depends on the comparison between one company and another (Garnett and Pickrell, 2000). It involves a comparison with the established standards or performance data of other organizations in order to improve the organization's own performance,

2- *Process Benchmarking*: it is the comparison of methods and practices for performing business processes so as to learn the best practice and to improve one's own processes,

3- *Strategic Benchmarking*: it is based on the comparison of the strategic choices and dispositions which are made by other organizations for the purpose of collecting information so that they would be able to improve their own strategic planning and positioning (Isˇoraite˙, 2004).

Regarding the environment against benchmarking, benchmarking can be classified into two types;

1- *Internal Benchmarking*: with this type of benchmarking, an organization collects data on its own performance and assessment so as to make improvements through comparing its performance with that of the past years (Kozak, 2006; Gwaya, Masu and Oyawa, 2014),
2- *External Benchmarking*: whereas the comparison between one organization and its competitors in the same industry is external to benchmarking (Kozak and Rimmington, 1998; Gwaya, Masu and Oyawa, 2014). When dealing with external benchmarking, the organizations focus on the identification of performance gaps and learn the best practice of the competitors.

Moreover, based on the application level of benchmarking, Ali, Al-Sulaihi and Al-Gahtani (2013) broke the benchmarking down into five levels: 1) task (e.g. project specific activities such as placement of steel or concrete); 2) project (e.g. cost of the project or phases in the project life cycle, times for design or construction, cost and time predictability, health and safety issues, and client satisfaction); 3) organization (e.g. profitability of the company, productivity, training, human resources, ability to innovate); 4) industry: (e.g. industry productivity, ability to innovate, image, human resources); and 5) economy (e.g. international competitiveness, financial capacity, and productivity.

In addition, there are different classification schemes and types of benchmarking that are provided by Codling (1992), Spendolini (1992), Watson (1993), Jackson, Safford and Swart (1994), Partovi (1994), Malec (1994), Lema and Price (1995), Fong, Cheng and Ho (1998), Le Vie (1998), Maas and Flake (2001), among others, (see Anand and Kodali, 2008). Although the literature does not arrive at a consensus on the types of benchmarking, a number of authors seem to agree on the four basic types of benchmarking (Lema and Price, 1995), which are based mainly on the approaches or perspectives that an organisation heads toward uncovering comparative information (Plemmons, 1995); Internal Benchmarking, Competitive Benchmarking, Functional Benchmarking, and Generic Benchmarking. Despite the agreement of many authors on the classification of the four types of benchmarking, there is no agreement on the meaning and definitions of each type (Lema and Price, 1995). However, most of the definitions that were offered by these authors, such as Lema and Price (1995), Plemmons (1995), Al-Darweesh (1999), Swan and Kyng (2004), Watson (2007), Anand and Kodali (2008), and Ali, Al-Sulaihi and Al-Gahtani (2013), are in agreement with Camp (1989), Zairi (1992), and Watson (1993). Below are the definitions of these four types of benchmarking as presented by Plemmons (1995, p29-32);

1- *Internal Benchmarking:* it is performed within an organisation by comparing the performance of similar business units or business processes. Internal benchmarking is used to compare similar activities in different locations, departments, or operating units within an organisation. Besides, it can be used to compare the parallel or same activities in similar departments within an organisation at different times. For the construction industry, the differences between projects within a company might be compared to identify internal performance standards. Readily available data and information and the lack of problems associated with confidentiality or the nondisclosure of data makes internal benchmarking the easiest to perform. As a result, many companies through benchmarking their internal activities (internal benchmarking) introduce the basic benchmarking concepts and procedures to their staff. The result of internal benchmarking is the development of a baseline of knowledge and experience. From this baseline, benchmarking activities can be expanded to involve external benchmarking partners. This progress into external benchmarking helps overcome the disadvantages of internal benchmarking which concern the limited focus on the subject being benchmarked and the organisational bias that might affect the findings.

2- *Competitive Benchmarking:* it is a measure of an organisation's performance compared with the other competing organisations; studies that target specific product designs, process capabilities, or administrative methods used by a company's direct competitors; and practices or services compared with direct competitors. Competitive benchmarking involves product-oriented comparisons between direct competitors selling to the same customer base (Spendolini, 1992). This comparison of direct product competitors characterizes the difference between competitive and other benchmarking classifications. It adopts the obvious approach of comparing direct competitors. Competitive benchmarking is of considerable value when operations are comparable in terms of size, practice, and technology. While comparability may be a concern, the difficulty of collecting proprietary information, along with the ethical issues and antagonistic attitudes, can be overcome by exchanging information through a third party that provides confidentiality and possible anonymity (Camp, 1989).

3- *Functional Benchmarking:* it is an application of the benchmarking process that compares a particular business function in two or more organisations. The functional benchmarking study compares similar functions within an industry. The difference between functional and competitive benchmarking studies is the limitation on the functional competitors or the industry leader firms. For the construction industry, this would involve identifying those companies with superior procurement or logistics wherever they exist. Another example could be the attributes of companies with superior materials-related processes that might be identified and benchmarked. Functional benchmarking is often used to compare organisational performance of industry leaders or to a select group of companies that ordinarily sign nondisclosure agreements to maintain the confidentiality of results. The process studies are usually conducted by an independent third party, who removes competitive information, nominalises performance to a common base measures, and reports company approved or generic case study information. This third party action removes the potential of unapproved information becoming available to direct competitors while presenting a major opportunity for promoting significant process improvement (Longmire, 1993).

4- *Generic Benchmarking:* it is an application of functional benchmarking that compares a particular business function in two or more organisations. Generic benchmarking searches for best practices irrespective of industry. It often reveals practices and methods that with further development and adaption are transferable regardless of industry (Camp, 1989). The aim is to remove the limitations of industry comparisons and to identify the best of the best. While the definitions for generic and functional benchmarking are overlapping, this removal of limitations distinguishes generic benchmarking from the other classifications. It also makes generic benchmarking the most difficult benchmarking concept to gain formal acceptance and use but probably has the highest long-term reward (Camp, 1989).

Based on their domain knowledge and experience, Lema and Price (1995), Luu, Kim and Huynh (2008), and Anand and Kodali (2008) assert that benchmarking should mainly be classified as internal and external. All other types like strategic, product, process, functional, etc. can be listed under these two basic categories, as revealed in **Figure 4.2**. The reason behind this scheme of classification is that conducting benchmarking needs to take a decision on the benchmarking subject, which can be a function, product, strategy, performance, process, or even a standard. Regardless of the subject identified, a suitable benchmarking partner has to be found. "*The partner may be from internal sources or an external organization, which may be another plant or branch of an organization or it can be a direct competitor or an organization from completely different industry*" (Anand and Kodali, 2008, p266). This classification scheme for benchmarking might be simple and can reduce the confusion among the practitioners.

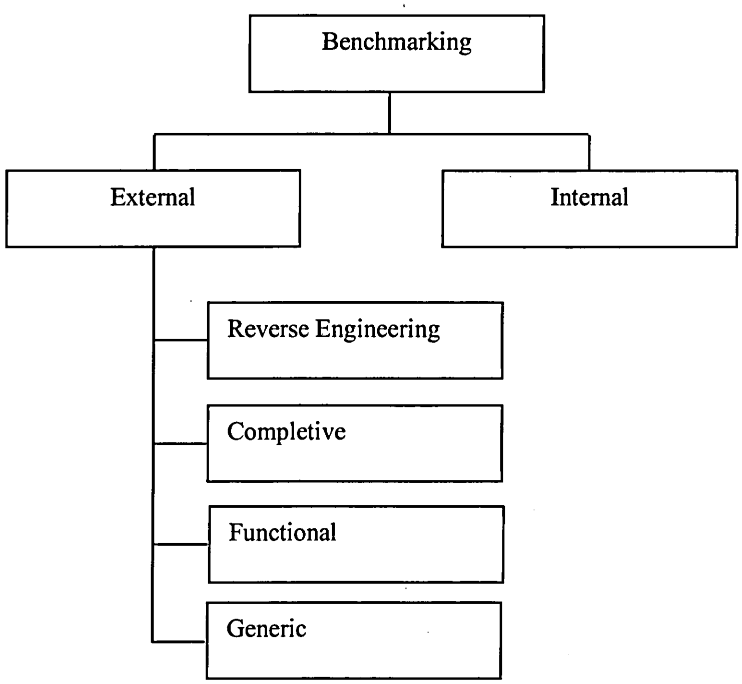


Figure 4.2: the Basic Classification Scheme for Benchmarking (Adopted from Lema and Price, 1995)

Whatever may the benchmarking type, Fong, Cheng and Ho (1998) stressed that while selecting a particular benchmarking type, the "*organizations should adopt a contingency approach for the selection of benchmarking types*". Anand and Kodali (2008, p260) added that such organisations "*should consider some major factors or conditions, such as the extent of the interdependence, number of benchmarking partners, degree of mutual trust, and strategic activities, that guide the choice*".

4.5.2 Benchmarking Models:

Plemmons (1995) and Elmuti and Kathawala (1997) have recommended that the process of benchmarking should be applied through a model, a framework for action, or formal set of procedures, with flexibility for modification to meet individual needs. A benchmark model depicts those steps or procedures that together describe the functionality of benchmarking process and the steps that should be carried out while performing benchmarking (Partovi, 1994; Plemmons, 1995).

A survey conducted by the American Productivity and Quality Centre (APQC) on 87 of its organisations found out that 81 per cent of the companies reported using a formal benchmarking process (Longmire, 1993; Plemmons, 1995). Several benchmarking models have been developed or adopted for use primarily within the manufacturing and service-related industries. Despite the fact that the core of the different benchmarking models is similar, most of the authors have tailored their approaches or models based on their own practices and experience (Partovi, 1994).

Anderson and Moen (1999) have reviewed and identified 60 different existing models proposed by various researchers, academics, consultants, professionals, and experts in the service industry. These models and frameworks were classified by Deros, Yusof and Salleh (2006) into academic/research-based models, consultant/expert-based models, and organization-based models; and they were exposed by Anand and Kodali (2008), as shown in **Table 4.18**. According to Bhutta and Huq (1999), each benchmarking model can be implemented in many steps; some companies have used up to 33 steps while others have used only four. Watson (1993) used the four step approach to quality management, which is commonly known as the 'Deming Cycle', for developing his benchmarking models. The activities of this model were integrated with Deming Cycle functions: 'Plan', 'Do', 'Check' and 'Act', as illustrated in **Figure 4.3**.

Table 4.18: Taxonomy for Benchmarking Models (Adopted from Anand and Kodali, 2008)

Taxonomy	Benchmarking Models
Consultant/expert-based models	Camp (1989) Codling (1992) Vaziri (1992) Boxwell (1994) Spendolini (1992) Watson (1993) Sole and Bist (1995) Blam (1992) Harrington and Harrington (1996) Macdonald and Tanner (1996) Matters and Evans (1997) Pulat (1994) Tutcher (1994) Leibfried and McNair (1992) Maas and Flake (2001) Keehley and MacBride (1997) Finnigan (1996)
Academic/research-based models	Anderson and Moen (1999) Anderson and Pettersen (1996) Fong, Cheng and Ho (1998) Yasin and Zimmerer (1995) Freytage and Hollensen (2001) Drew's model (Carpintti and De Melo, 2002) Longbottom (2000) Shetty's modle (Lema and Price, 1995)
Organisation-based models	Xerox (Finnigan, 1996) NPC India (Nandi, 1995) AT&T (Bemowski, 1991) ALCOA (Bemowski, 1991) Society of Manfucturing Enginners (Fridley et al., 1997) Corning Company (Sweeney, 1994) Yellow Pages (Simpson and Kondouli, 2000) The Employment Service (Simpson and Kondouli, 2000) Avon Product's Benchmarking (Leibfried and McNair, 1992)

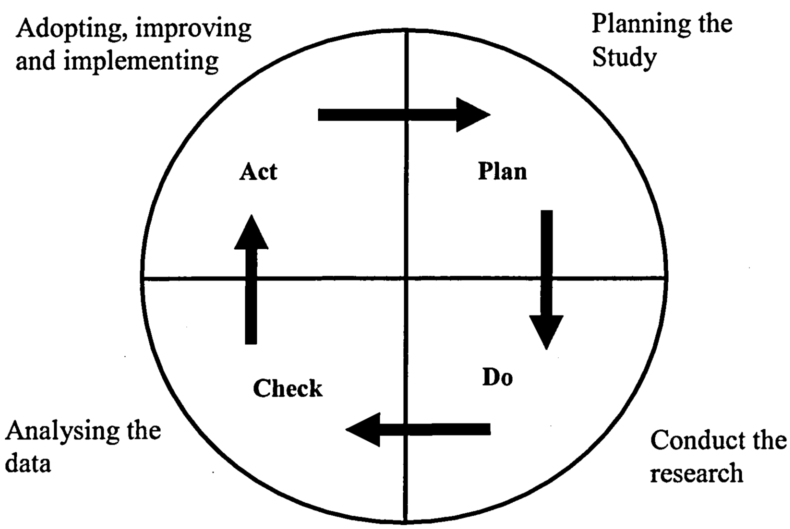


Figure 4.3: Benchmarking Process Compared to Deming Cycle (Adopted from Watson, 1993, and found in Lema and Price, 1995)

Although different organisations have adopted different models to benchmark, the majority of these generally conform to Watson's model, with some modification to meet their individual needs. Based on the model proposed by Watson, Shetty suggested a more detailed benchmarking model that consists of five basic steps, as shown in **Figure 4.4**.

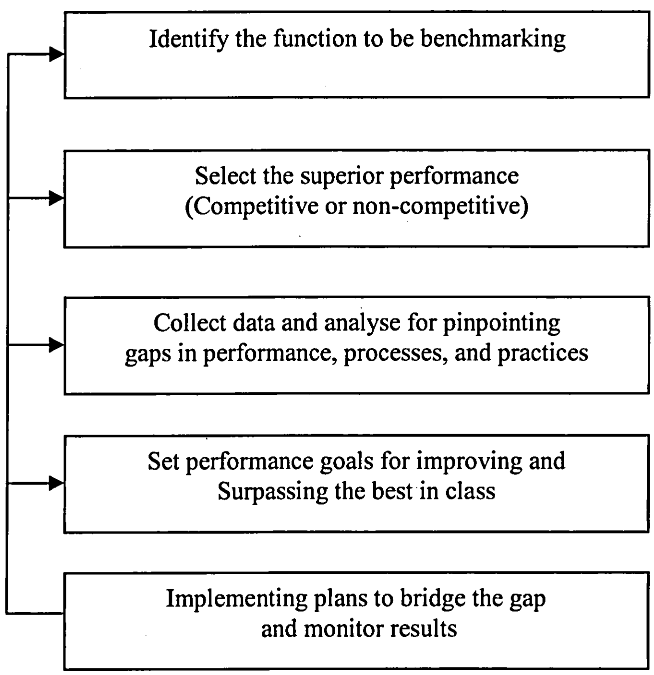


Figure 4.4: Five-Step Benchmarking Model suggested by Shetty, 1993 (Found in Lema and Price, 1995)

The model above may give deceptive impression about the ease of the process; however, practically, benchmarking needs several iterations, and it is a judgmental process (Shetty, 1993); it may be difficult to identify the functions and firms to be benchmarked. Note that the feedback loops are required to provide data for setting new performance goals for continuous improvement (Lema and Price, 1995). In addition to these models, Anand and Kodali (2008) provided many examples on the benchmarking process models; Filer et al. (1988) identified seven-step process, Spendolini's (1992) specified five-step process, IBM classified five phase/14-stepprocess (Eyrich, 1991), Alcoa's defined six-step benchmarking, AT&T's presented 12-step benchmarking process (Bemowski, 1991) and many academicians too have proposed their own models, which were even later modified and adapted for different benchmarking situations, for example, Boxwell (1994), Nath and Mrinalini (1995), and Sole and Bist (1995).

One of the most (if not the most) evident example of the successful benchmarking models is the one that initiated by Xerox Corporation to encounter the Japanese competitive challenge of the 1970s; it was reported by Camp (1989) (Lankford, 2000; Isoraite˙, 2004). The Camp benchmarking model, which is exemplified in **Figure 4.5**, is presented to illustrate the steps normally followed by a benchmarking team (Plemmons, 1995). The benchmarking model uses a ten-step approach (Camp, 1989). These ten steps were superimposed on four primary steps. These common steps are: '*Planning*', '*Analysis*', '*Integration*' and '*Action*, which closely resemble the four-step of Deming cycle model (Plan, Do, Check and Act).

According to Lema and Price (1995), Xerox is widely publicized as one of the first successful pioneers of benchmarking as part of its TQM initiative; Xerox was one of the early winners of the prestigious Malcolm Baldidge National Award, which is awarded to those companies that on the basis of their statutes, have been the most successful in pursuing their quality programs. Anand and Kodali (2008, p269) provide the three main reasons behind the wide use of the Xerox model for benchmarking;

- *In the earlier study, Zairi and Leonard (1994) highly rated Camp's model (which they identify as the "Xerox" methodology)....They concluded that "most, if not all, of the methodological approaches (i.e. models) are preaching the same basic rules of benchmarking, but using different languages", and that "most methodological approaches are based on the*

Xerox approach, which is considered to be an effective and generic way of conducting benchmarking projects".

- *The literature review also revealed that the Xerox benchmarking process model has been highly cited and quoted in the literature. Hence, it is assumed that it is the most commonly used models by the practitioners.*

- *Further, the Xerox model has been used for quite a long time without any modifications. Hence, it was felt that it should be improved and evolved incorporating the best practices within this model.*

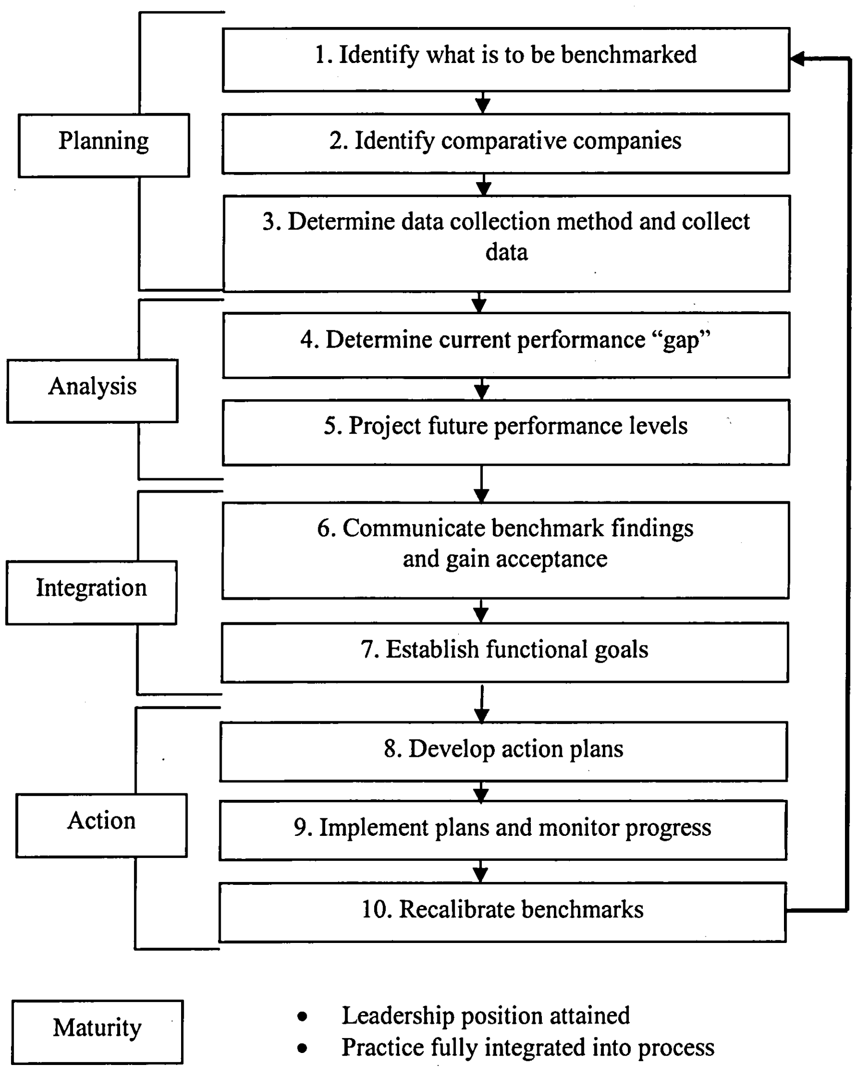


Figure 4.5: Xerox Benchmarking Model: Benchmarking Process Steps (Adopted from Camp, 1989; Found in Lema and Price, 199; Plemmons, 1995; Al-Darweesh, 1999; Anand and Kodali (2008)

The Xerox Benchmarking model has been adopted and modified for application in many different manufacturing and service-related companies. In addition to Xerox, companies like Du Pont, IBM, AT & T, Eastman Kodak, Motorola, Ford, and Miliken, are reported to use this benchmarking model as a standard tool (Lema and Price, 1995). A report conducted by the Massachusetts Institute of Technology in the state of American Industry concluded that most successful companies shared an emphasis on Xerox benchmarking process (First find your bench, 1991).

4.5.3 Benchmarking in Construction Industry:

Benchmarking is "*the means by which company performance can be measured, or by which a company can be judged, and to be effective, standards must be made available*" (Stukhart, 1995, p188); for this reason, many firms in the construction industry find performing a benchmarking process as difficult because companies rarely reveal their detailed data (Stukhart, 1995). Lema and Price (1995) adopt this concept and argue that in contrast to the manufacturing industry, formal benchmarking activities are not widely applied within the construction industry. A study conducted by Plemmons 1995 reveals that there are no any scholarly references to benchmarking or the existence of benchmarked data that have been found within the construction industry. This further supports what was concluded by Fisher, Miertschin and Pollock (1995) that "*there was neither available benchmarked standard for the construction industry, nor was there a non-profit organisation established for the purpose of collecting data information in the industry for benchmarking*" (Plemmons, 1995, p34).

Despite the lack of benchmarking standards in the construction industry (Ali, Al-Sulaihi and Al-Gahtani, 2013), comparing performance information is not unique to the manufacturing and service industries. Construction-related literature indicates that information is available for firms and individuals to compare their organisational and project performance (Plemmons, 1995). Gwaya, Masu and Oyawa (2014) confirm that benchmarking can be applied in construction to both the product and the process with reference to time, quality and cost and any other appropriate variables. Through engaging in activities closely resembling those found in the definition of benchmarking, the construction industry makes extensive use of comparative measures. An example of comparative measures is the Experience Modification Rating (EMR), which is used by owners for selecting and prequalifying construction contractors. The EMR is a tool for measuring a company's safety record, and it is considered as an indicator of a construction contractor's insurance cost of accidents (Levitt, 1987). Another example of comparisons that are related to the construction industry reports and articles is found in the Engineering-News Record (ENR). Moreover, several task forces in the Construction Industry Institution (CII) have produced research findings of comparative value for the construction industry; for example, the investigation, which was conducted by Anderson and Tucker (1990), to study the potential for construction industry improvement. The findings of this investigation determined the factors of the project performance that were measured from the owner's, architect/engineer's, and contractor's perspective.

The most important and CMM-related study that has been carried out for developing the performance benchmarking process in the construction industry is the one that was conducted by Plemmons (1995) in the United States of America. This research is a good attempt to benchmark the materials management process using a series of measures that can be collected (Stukhart, 1995). The majority of the studies and researches concerning measuring the performance of the CMM process rely on Plemmons (1995); similarly, this work project is built on the Plemmons's study.

Based on a careful examination of benchmarking models utilized in manufacturing and service industries, Plemmons (1995) presented a proposed benchmarking model for construction industry. Central to the proposed model is a third-party benchmarking mechanism to support the collection and dissemination of performance data and best practices. This mechanism is called, in Plemmons's study, the Benchmarking Clearinghouse. The selection of Clearinghouse approach was based on the relative absence of industry-specific benchmarking resources available to the construction-related managers and manufacturing and services orientation of other clearinghouse organisations. The proposed purpose of Clearinghouse, in Plemmons's model, is the efficient and effective collection and dissemination of comparative performance data and information for the construction materials management process. Plemmons (1995) suggests the role of Clearinghouse, in his benchmarking model, to be the reduction of the cost, time, and effort associated with benchmarking projects by simplifying the information planning, gathering, analysis, and reporting procedures. The function of Clearinghouse was proposed to benchmark key effectiveness measures while surmounting the critical ethical and expense questions related to competitive benchmarking. The Clearinghouse concept can be defined within relatively narrow range of activities. Plemmons and Bell (1995) established a mechanism for integrating Clearinghouse within the typical companies' benchmarking procedures, as illustrated in **Figure 4.6** and **Figure 4.7**. The diagram in **Figure 4.7** depicts how the Construction Industry Action Group (CIAG) clearinghouse would interface with a company's routine benchmarking procedures; the participating organisations would initiate or continue their own benchmarking procedures with the inclusion of the Clearinghouse as a mechanism for collecting and communicating information. For the purpose of safeguarding proprietary data and producing trustworthy and timely benchmarking reports and best-practice studies, Plemmons and Bell (1995) proposed an independent and impartial administrative function that would be established under criteria approved by the Clearinghouse membership; it was called the Clearinghouse Administrator.

The benchmarking procedures, which were developed from the previous benchmarking processes found in literature, primarily reflect actions associated with the four common steps outlined by the most benchmarking models, in particular the Xerox Benchmarking model. These four steps, which on the basis of which the majority of the companies' routine benchmarking activities were superimposed, are: '*Planning*', '*Collect*', '*Analysis*', and '*Improve*'. According to Plemmons (1995), the sequence of the activities that ordinarily occur during these four phases (steps) characterizes the structured nature of a formal process model. Plemmons offers definitions for those four phases (activities/functions) as follows; **1)** ***Planning*** phase addresses the planning of a benchmarking project. Activities in this step include identifying the process to benchmark, understanding in detail the process flow and the process performance measures, and determining the data collecting method; **2)** the second step is '***Collecting***'; it involves those activities primarily associated with collecting of data. Benchmarking as related to the collection of process data within the company: the benchmarking team activities would include planning the external data collection procedures, gaining partners, collecting data, and possibly making on-site observations; **3)** in the third step, '***Analysis***'; comparative data are analysed for identifying performance gaps and enablers. Enablers are those processes, practices, or methods that produce the "best-in-class" performance. Activities of this step include organising the data to permit identification of performance gaps by comparing current performance against benchmarking, identifying the reason for these gaps, projecting performance three to five years into the future, isolating those enablers that correlate to process improvements, and determining the adaptability of enablers to the current processes; **4)** during the fourth or '***Improve***' step, the applicable process enablers and best practices are integrated into the company operations. The activities in this step include setting goals based on exceeding the performance gap, developing an action plan, committing resources, implementing the plan, monitoring and reporting progress toward the goal while regularly recalibrating the benchmarks. To ensure continuing improvement, there should be continuous looping process.

The company-specific benchmarking procedures are based on an empirical study of several benchmarking models (Camp, 1989; Spendolini, 1992; Longmire, 1993). The four steps are used to provide a framework for illustrating the corresponding activities between the company and the Clearinghouse. In general, the model chosen by the organisation should be clear and basic, emphasising logical planning and organisation and establishing a protocol of behaviour and outcomes.

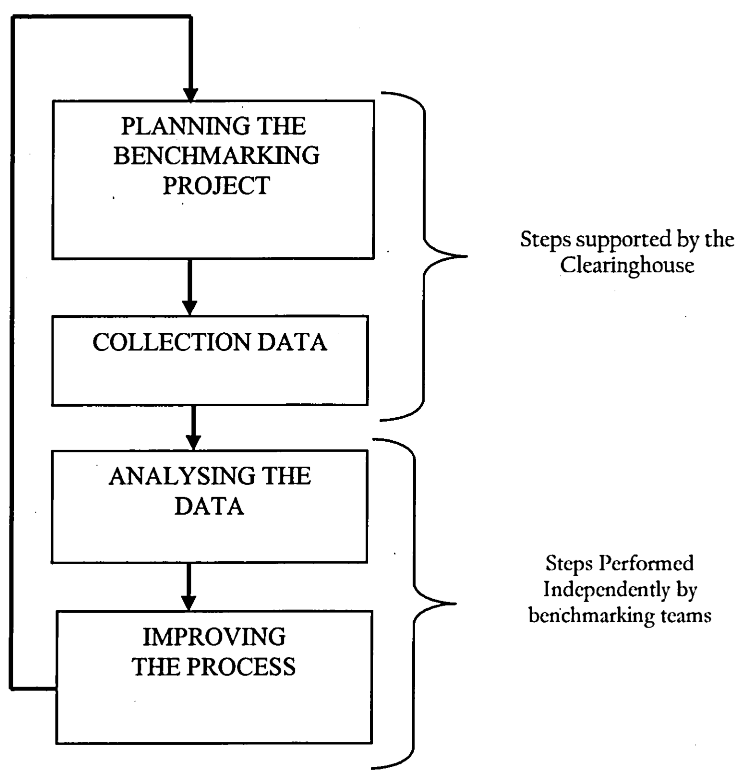
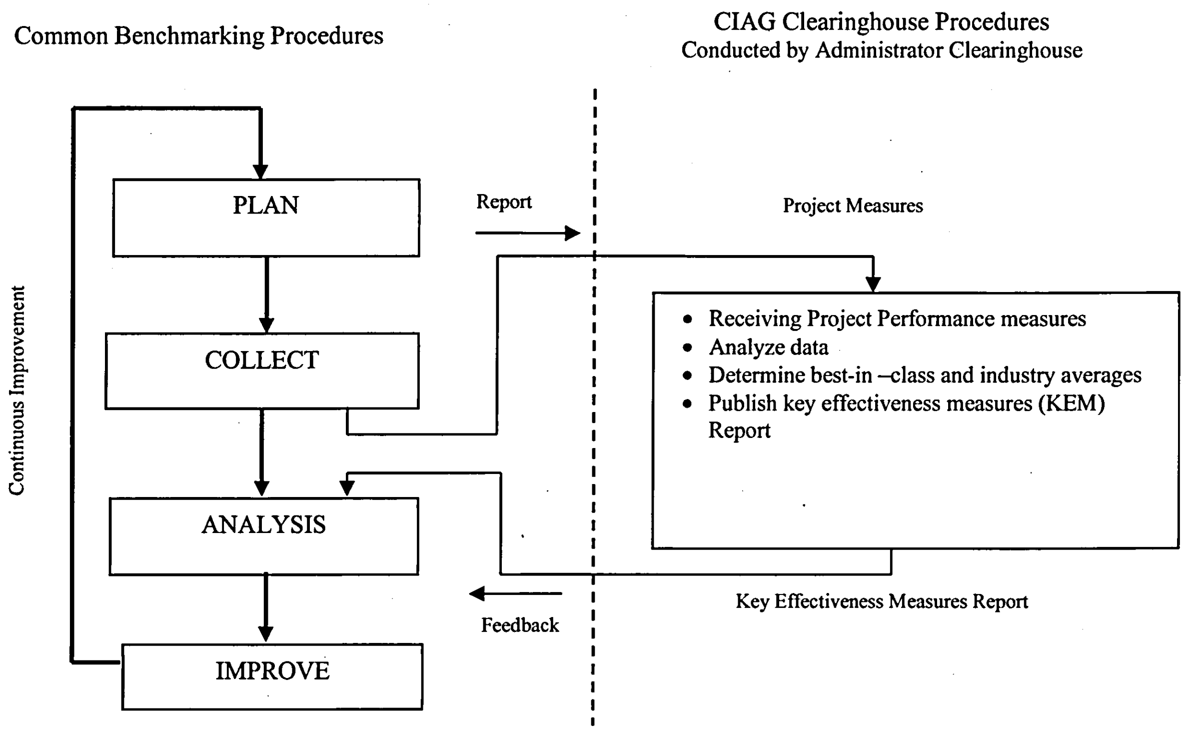


Figure 4.6: Integration of Clearinghouse and Benchmarking Procedures (Adopted from Plemmons and Bell, 1995)



"The Construction Industry Action Group (**CIAG**) is an organisation of approximately 60 owner, engineering, construction contractor, supplier, subcontractor, and technology vendor firms. The mission of CIAG is to promote the implementation of cost-effective data-related technologies, provide user-level implementation support for these technologies, and represent the construction industry in various national and international standards organisations" (Plemmons, 1995, p44).

Figure 4.7: Integration of Clearinghouse and Benchmarking Procedures – CIAG Clearinghouse Model (Adopted from Plemmons, 1995; Plemmons and Bell, 1995)

4.6 SUMMARY OF THE CHAPTER:

Chapter four achieved what it was designed for, which is the accomplishment of the second objective of the study.

Due to a lack in studies directly related to evaluating or measuring the CMM performance, an in-depth investigation has been conducted concerning the used measurements of the supply chain management and materials management processes within manufacturing and construction industries and industrial projects. A set of **33** effectiveness-measures was proposed to assess the performance of a materials management process in building construction projects as a result of analysing a number of measures that are identified in the literature related to different industries; this included removing duplicates and items not related to material management, re-formulating the measures into effectiveness format, and modifying some measures to fit the building construction sector. This set of proposed measures is considered as the basis for the comparison and developing the measures that will be aggregated during the data collection process (See **Chapter VI**).

Chapter four also includes the findings of an examination conducted on the benchmarking processes that have been used in different manufacturing and service-related organisations. In addition to the different definitions and types of benchmarking, the chapter offered different successful examples for the benchmarking processes that are used in different industries. Furthermore, it explored the development of the benchmarking concept in the construction industry. Based on these benchmarking models, the mechanism of operating the developed framework for evaluating the Effectiveness of CMM Performance (E.CMM.P) will be designed, as discussed in **Chapter VIII**.

CHAPTER V:

RESEARCH METHODOLOGY AND METHODS

5.0 INTRODUCTION TO THE CHAPTER:

Chapter five mainly aims to discuss and describe the research methodology adopted for the research project. The chapter starts with an overview of the research methodology and the research philosophy followed by a discussion on the research approaches and techniques. The chapter also explains the research strategy decision and provides justifications for the approaches adopted to conduct this research. Finally, the research techniques and procedures used for the data collection process and analysis are outlined through a critical analysis of the research design adopted, including the rationale for selecting these techniques, research sample, and the process of research validation.

5.1 RESEARCH METHODOLOGY:

Research methodology has been defined in different literatures and examined from various perspectives. One of the clearest and simplest definitions is the one that was introduced by Fellow and Liu (1999) and Klien and Myers (1999); it was also adopted by Binti-Kasim (2008). The definition considers research methodology as "*the principles and procedures of the logical thought process which are applied to a specific investigation*". Checkland (1981), Easterby-Smith, Thorpe and Lowe (1993), and Sherif (2010) view methodology as a combination of techniques used to enquire about a specific situation; it includes problem solving methods that aim to answer the question of how, and the philosophy to answer the question of what. In the literature, scholars use the terms of research methodology and the research method interchangeably, causing some confusing. However, Hussey and Hussey (1997) and Bell (2005) distinguish between them; they define research *methodology* as an overall approach to the research process; it involves identifying the research problem, establishing the theory and drawing conclusions under the umbrella of the research objectives, whereas the research *method* refers only to the instruments and techniques adopted to collect and analyse the research data.

According to Binti-Kasim (2008), a decision on choosing the appropriate research method to be adopted for a certain research project is paramount to reach realistic results and to produce good quality research. However, the answer to the question of how to choose a suitable methodology is still difficult and mysterious to many researchers (Walker, 1997; Fapohunda, 2009).

Fapohunda (2009) asserts that a critical evaluation of the research type and methodology to be used in the social scientific world is essential to identify and adopt the suitable research methods that will ensure valid and reliable research findings. Therefore, it is very useful to cast a quick look on the research types.

5.1.1 Types of Research:

Collis and Hussey (2003) identified four types of research along with its basis: the purpose, the process, the logic and the outcome as illustrated in **Table 5.1** and discussed below.

Table 5.1: The Research Types (Adopted from Collis and Hussey, 2003)

No	*Basis of Classification*	*Type of research*
1	Purpose of the research	Descriptive, Predictive, Exploratory or Analytical Research
2	Process of the research	Qualitative or Quantitative Research
3	Logic of the research	Inductive or Deductive Research
4	Outcome of the research	Basic or Applied Research

5.1.1.1 The Research Types according to their Purpose:

The purpose reveals the reason behind carrying out the research project. Based on purpose, the research can be classified as predictive, descriptive, exploratory and analytical (Collis and Hussey, 2003). According to Fellows and Lui (2008, p84) "*the distinctions among the classifications of types are not absolute and a research project may involve more than one type of research design, e.g. exploratory research may be an initial step followed by descriptive or explanatory research*". **Table 5.2** summarises some distinctions among the research methods that are classified on the basis of the research purpose.

5.1.1.2 The Research Types Classified on the Basis of Logic:

Logic illustrates whether the research moves from specific to general or the other way around. According to logic, the research can be classified as inductive or deductive, as exhibited in **Figure 5.1** and discussed below;

Table 5.2: Categorization of Research Methods based on the research purpose (developed from Ellram (1996), Collis and Hussey (2003), Zikmund (2003), Hatmoko (2008), and Naoum (2013))

Research Type (Purpose Basis)	Description	Aim	Example of Appropriate Methodologies	Appropriate Question Words
Exploratory	Suitable when there are few or no earlier studies and a researcher with limited knowledge about the topic to be investigated (Ellram, 1996)	To diagnosing a situation, screening alternatives and discovering new ideas (Zikmund, 2003). To look for pattern, Ideas or hypothesis, rather than testing or confirming a hypotheses	• **Qualitative:** o Experiment, o Case study o Participation observation o Historical analysis • **Quantitative:** o Survey o Secondary data analysis	How and Why How often, How much, How many, Who, What, Where
Descriptive	Describe phenomena as they exist	To describe phenomena as they exist by obtaining information and evaluating opinions towards a particular issue or problem (Naoum, 2013).	• **Qualitative:** o Experiment, o Case study o Participation observation o Grounded Theory o Ethnography • **Quantitative:** o Survey o Secondary data analysis o Longitudinal	Who, What, Where, Who, What, Where, How many, How much
Analytical or Explanatory	A continuation of descriptive research. Describe, analyse and explain why and how the characteristics happen (Hatmoko, 2008)	To understand phenomena by discovering and measuring casual relations among them	• **Qualitative:** o Experiment, o Case study o Participation observation o Grounded Theory o Ethnography o Case survey	How Why
Predictive	Forecast the likelihood of an occurrence	To generalise from analysis by predicting certain phenomena on the basis of hypothesised general relationships (Ellram, 1996)	• **Qualitative:** o Experiment, o Case study o Participation observation o Grounded Theory o Ethnography Case survey • **Quantitative:** o Survey o Secondary data analysis Longitudinal	Who, What, Where, Who, What, Where, How many, How much

- *Deductive research* was defined by Collis and Hussey (2003) as a "*study in which a conceptual and theoretical structure is developed and then tested by empirical observation where particular instances are deduced from general inferences*". Fellows and Liu (2008) and Ali (2011) argue that the deduction research (deductive approach) starts with an abstract framework based on ideas in the texts (books, articles etc.) and through communication with others (experts, professionals, colleagues etc.), it moves to more specific hypothesis or research questions that can be explored. These research questions or hypotheses will then be tested through the process of data collection or observation. Deductive logic "*is more narrow in nature and is concerned with testing or confirming hypotheses*" (Trochim, 2006).

- *Inductive research;* in this type of research, as Fapohunda (2009) observed "*a conclusion is drawn based on literature search and findings obtained through exploratory study*". In comparison with deductive logic, inductive reasoning does not start with any pre-established ideas or assumptions but it is more concerned with observation (Leedy and Ormrod, 2005; Ali, 2011). Inductive reasoning, by its nature, "is less restricted and more open-ended and exploratory, especially at the beginning as it involves a qualitative approach (Trochim, 2006; Ali, 2011). It enables the researcher to generate ideas and opinions straight from the data or observations and to move from a specific to a border generalisation or even universal theory (Frankfort-Nachmias and Nachmias, 1998; Ali, 2011).

Punch (2000) and Trochim (2006) assert that the two methods are based on different beliefs when conducting research. Though a particular study may look like purely deductive (or inductive), most social research involves both deductive and inductive reasoning approaches at the same time in some points in a project. Ali (2011) shares Gummesson's perspective that "*Initially research splits into deductive and inductive but after this early phase, all research becomes an interaction between the two approaches*" (Ali, 2011, p132).

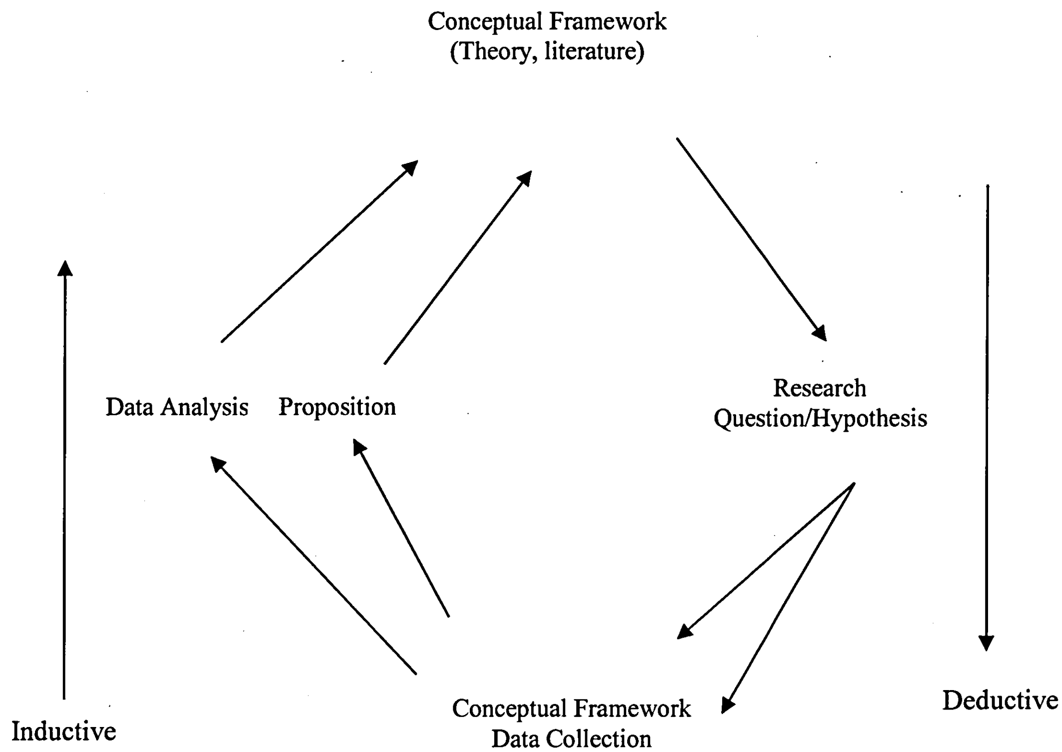


Figure 5.1: Research Types on the Logic Basis (Deductive and Inductive) (Adopted from Ali, 2011)

5.1.1.3 The Research Types according to their Outcome:

The outcome reveals whether the research findings are designed to solve a particular problem or to make a general contribution to knowledge. According to the outcome, the research can be classified as 'basic (pure)' or 'applied';

- *Basic (Pure)* research is conducted mainly to improve our understanding of general matters. The main principle of basic research is to make contribution to knowledge and to the body of a theory which exists to aid the research for 'truth'. Pure research, therefore, represents the most academic forms of research (Collis and Hussey, 2003; Fellows and Liu, 2008).

- *Applied research* seeks to address issues of applications (Fellows and Liu, 2008). It is, as Hatmoko (2008, p44) puts it "a *research whose findings are designed to solve a specific problem*". Thus, most practitioners and industrialists tend to pursue development work and applications (applied research). It can be noted that while the basic 'pure' research develops scientific knowledge and asks if it is true, applied research uses scientific knowledge and so asks if it works (Fellows and Liu, 2008).

In the construction context, the vast majority of research is a combination of 'pure' and 'applied' research (Fellows and Liu, 2008). Fellows and Liu (2008, p7) attributed that to the fact that "*development and applications cannot exist without the basic (pure) research, whilst pure research is unlikely to be of great benefit to society without development and applications*".

5.1.1.4 The Research Types Classified on the Basis of Process:

The process-basis illustrates the approach whereby data will be collected and analysed. This classification concerns the research methods adopted, and it broadly classifies researches as either qualitative or quantitative. The *quantitative research* adopts 'scientific method', and involves an experimental approach that includes testing a hypothesis and data collection that relies upon measurement and statistical techniques for analysis (Ali, 2011). On the other hand, Fellows and Liu (2008) argue that *qualitative research* is intended to gain understanding and to collect data and information in such manner that theories will emerge. Thus, qualitative research is a precursor to quantitative research. These types of researches and their merits and demerits are explained in the research approach section; **Sections 5.3.**

5.2 RESEARCH PHILOSOPHY:

Recently, a review of philosophy has become a vital aspect of the research process. Holden and Lynch (2004) attribute the importance of reviewing research philosophy to its role in opening the researchers' minds to other possibilities, which can lead to both an enhancement in their confidence that they are using the appropriate methodology and an enrichment of their research skills. Flowers (2009) argues that when undertaking a research, it is important to consider different paradigms and matters of the research philosophy as they can influence the way in which the research is undertaken, from design through to conclusions.

A number of researchers are usually concerned with the method of collecting data to answer your research question. According to Fellows (2010), Creswell (2013), and Higham (2014), however, the design of any research project includes number of interrelated levels of decision ranging from broad vision/strategy pertaining to the research philosophical position that should be adopted brought to the project down to more particular decisions about how to collect and analyse the data. In line with this view, Saunders, Lewis and Thornhill (2009, p106) state: "*You are not unusual if you begin thinking about your research by considering whether you should, for example, administer a questionnaire or conduct interviews*". They, among others, believe that initial thoughts should concentrate on the issues underlying the choice of data collection techniques and analysis procedures, which are usually related to the research philosophy approach adopted. This implies that the selection of research approaches and techniques is essentially based on the research philosophy adopted.

Kagioglou et al. (1998) developed a hierarchal model of research methodology, named "*nested research methodology*", which includes three main interrelated themes; research philosophy; research approaches and research techniques, as shown in **Figure 5.2**. Within the nested methodology, the research philosophy constitutes the outer pyramid guides and includes the inner research approaches; a process which guides and establishes the inner research techniques (Kagioglou et al., 1998; Kagioglou et al., 2000; Sexton, 2000; Thurairajah, Haigh and Amaratunga, 2006; Binti-Kasim, 2008). In the same context, (with some difference in the content), Saunders, Lewis and Thornhill (2009) depict the issues underlying the selection of the research approach and strategies and the data collection techniques using 'the *Research Onion*', as illustrated in **Figure 5.3** below. They argue that before coming to the research data collection and analysis, which is located in the central point, there are important layers of the onion that need to be peeled away.

The above perspectives further support what was argued by some writers, such as Guba and Lincoln (1994, p105), that "*questions of research methods are of secondary importance to the questions of which paradigm is applicable to your research*".

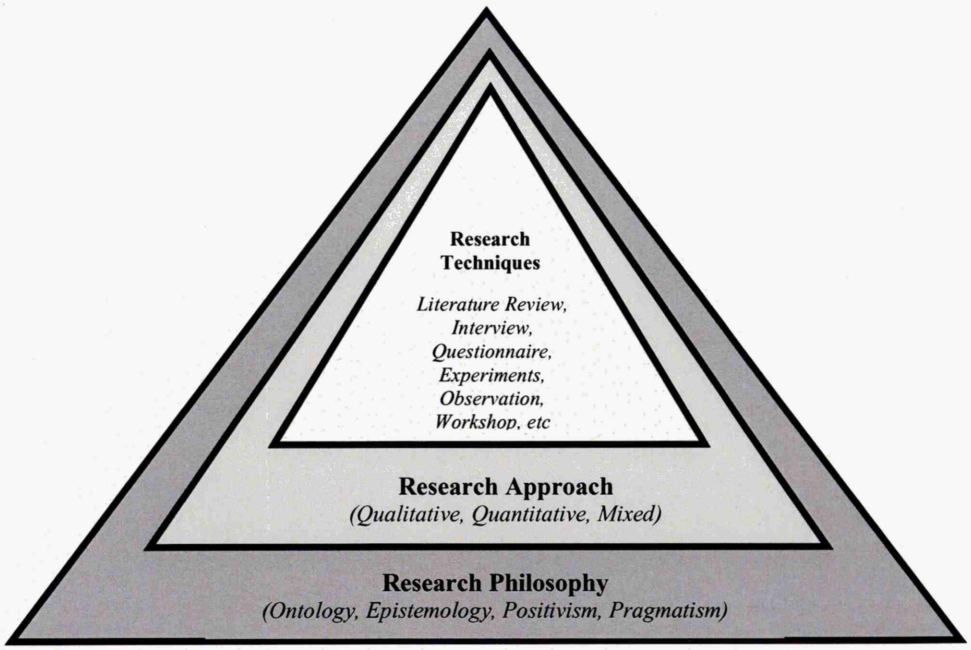


Figure 5.2: A Nested Research Methodology (Developed from Kagioglou et al., 2000)

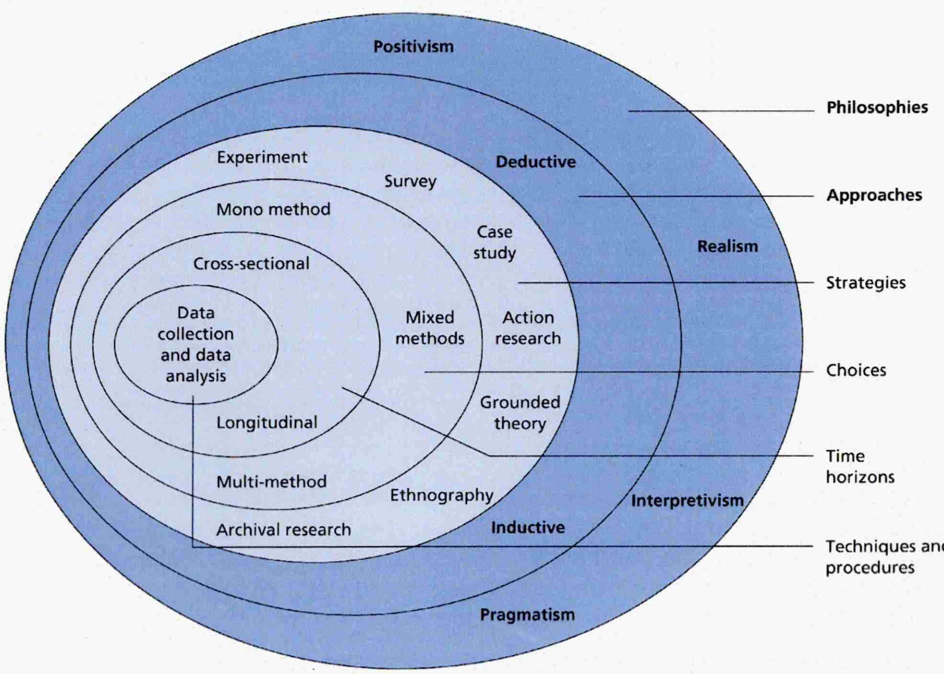


Figure 5.3: The Research Onion (Adopted from Saunders, Lewis and Thornhill, 2009)

Through reviewing the relevant literature, various dimensions and paradigms of research philosophy have been observed. Some authors such as Creswell (2003), Saunders, Lewis and Thornhill (2009), and Rubin and Rubin (2012) believe that, the three basic research philosophy dimensions are 'Positivists', 'Realism' and 'Naturalists (Interpretivism)'. While, the majority of authors and researchers such as, Kagioglou et al. (2000), Holden and Lynch (2004), Thurairajah, Haigh and Amaratunga (2006), Binti-Kasim (2008), Flowers (2009), Hesse-Biber and Leavy (2011) believe that 'Ontology' and 'Epistemology' are the two chief schools of the research philosophy in social research, and the other philosophy approaches: positivism, realism and interpretivism (phenomenology) are all included under those three philosophy schools.

The decision of the philosophical foundation to be adopted influences every aspect of the research process, including topic selection, question formulation, method selection, sampling, and research design (Hesse-Biber and Leavy (2011). This section, therefore, slightly sheds light on the concepts of some of the research philosophy approaches that are usually used in the social researches.

5.2.1 Ontology:

The root definition of ontology has been described by Blaikie (1993) as 'the science or study of being'. He develops this definition for the social sciences to cover 'claims about what exists, what it looks like, what units make it up and how these units interact with each other'. The ontological philosophy is concerned with the assumptions about the nature of the existence and the structure of social reality (Crotty, 1998; Binti Kasim, 2008; Saunders, Lewis and Thornhill, 2009). For example, "*is the social world patterned and predictable, or is the social world continually being constructed through human interactions and rituals?*" (Hesse-Biber and Leavy, 2011, p4). Flowers (2009) believes that ontology philosophy describes our views (claims or assumptions) on the nature of reality, 'is this an objective reality that really exists, or only a subjective reality that is created in our minds'. Hatch and Cunliffe (2006) extended the discussion as to how individuals (and groups) determine these realities – does the reality exist only through experiencing it (subjectivism), or does it exist independently of those who live it (objectivism). They provide an everyday example to illustrate that point; they use "*the* *example of a workplace report – asking one to question whether it describes what is really going on, or only what the author thinks is going on*".

According to researchers like Holden and Lynch (2004), Hatch and Cunliffe (2006), Saunders, Lewis and Thornhill (2009), the major philosophical approaches that are delineated by several core assumptions concerning ontology (reality) are 'Objectivism' and 'Subjectivism'. These two aspects of ontology have their devotees among business and management researchers, and both are likely to be accepted as producing valid knowledge by many researchers (Saunders, Lewis and Thornhill, 2009);

1- Objectivism: this "*portrays the position that social entities exist in reality external to social actors concerned with their existence*" (Saunders, Lewis and Thornhill, 2009, p110). Objectivists argue that reality is a concrete structure (Sausman, 2011). A good explanatory example on objectivism is provided by Saunders, Lewis and Thornhill (2009, p110) using the subject of the role of management in an organisation.

2- Subjectivism: the subjectivist view is that social phenomena are created from the perceptions and consequent actions of social actors through the continual process of social interaction (Saunders, Lewis and Thornhill, 2009). For the purpose of illustrating the concept of subjectivism, Saunders, Lewis and Thornhill (2009, p111) offer an example concerning the customer service.

Saunders, Lewis and Thornhill (2009) contend that the debate of objectivist- subjectivist is somewhat similar to the different methods whereby the theoretical and practical approaches to organisational culture have developed in recent years. When considering that different views exist regarding what constitutes reality, another question must be posed, according to Flowers (2009), and that is 'how is that reality measured, and what constitutes the knowledge of that reality'. This leads to questions of 'Epistemology'.

5.2.2 Epistemology:

Epistemology is explained and defined from different perspectives. Crotty (1998, p8) defines epistemology as "*how we know what we know*", while from the point of view of Guba and Lincoln (1998, p201), it is about "*the nature of the relationship between the knower or the would-be knower and what can be known*". It is concerned with providing a philosophical grounding for deciding what kinds of knowledge are possible and how we can ensure that they are both adequate and legitimate (Maynard, 1994; Crotty, 1998) among others. Epistemology considers views about the most appropriate ways of enquiring into the nature of the world (Easterby-Smith, Thorpe and Jackson, 2008; Flowers, 2009) and 'what is knowledge and what are the sources and limits of knowledge' (ibid). Blaikie (1993) defines epistemology as '*the theory or science of the method or grounds of knowledge*' and he expands this into a set of assumptions or claims about how it is possible to gain knowledge of reality, how what exists may be known, what can be known, and what criteria must be satisfied in order to be described as knowledge. On this basis, Flowers (2009) believes that the epistemology questions begin to consider the research method.

A number of authors (Hussey and Hussey, 1997; Tzortzopoulos, 2004; Flowers, 2009; Saunders, Lewis and Thornhill, 2009; Rubin and Rubin, 2012) argue that positivist and interpretivist (Phenomenology/Constructivist/Naturalist) are the two key approaches of thought that can shape the epistemology stance. Due to that similar paradigms being developed in parallel across the different disciplines of the social sciences, different names are often used to describe similar paradigms. The reason behind choosing these paradigms is not only their prevalence to management research, but also that they effectively form the 'poles' from which other paradigms are developed or derived (Flowers, 2009).

1- Positivism: this position is derived from "*that of natural science and is characterised by testing hypothesis developed from existing theory (hence deductive or theory testing) through measurement of observable social realities*" (Flowers, 2009, p3). There is a consensus among many authors such as, Blaikie (1993), Hatch and Cunliffe (2006), Saunders, Lewis and Thornhill (2007), Easterby-Smith, Thorpe and Jackson (2008), Eriksson and Kovalainen (2008), and Flowers (2009), that positivism focuses purely on facts that are gathered through experience and direct observation, and then measured empirically using quantitative methods; surveys, experiments and statistical analysis. On the organisational context, positivists hold that what truly happens in organisations can only be detected through categorisation and scientific measurement of the behaviour of people and systems and that language is truly representative of reality (Hatch and Cunliffe, 2006). Hesse-Biber and Leavy (2011), argue that the positivist science holds several basic beliefs about the nature of knowledge, which combined together form the cornerstone of the quantitative paradigm. Gill and Johnson (2002) observe that the positivist researcher will be likely to use a highly structured methodology, with more emphasis on quantifiable observations that lend themselves to statistical analysis, in order to facilitate replication.

2- Interpretivism (Naturalist/Phenomrnology): the Interpretivist position is described as anti-positivist (Hatch and Cunliffe, 2006), as post-positivist (Blaikie, 1993), and as naturalists (Rubin and Rubin, 2012). As mentioned above, this difference in terminology is attributed to the difference between the subject matters of natural and social sciences. Rubin and Rubin (2012) argue that whereas positivists assume that reality is fixed, directly measurable, and knowable and that there is just one truth and one external reality, interpretivists assume that reality constantly changes and can be known only indirectly, through the interpretations of people; they accept the possibility that there are multiple versions of reality. In the social world, social reality in which people act is created by multiple interpretations that resulted from constructing and (over time) constantly re-constructing meanings based on different individual experience, memories and expectations of individuals and groups (Flowers (2009).

> "*Since 'all knowledge is relative to the knower' interpretivists aim to work alongside others as they make sense of, draw meaning from and create their realities in order to understand their points of view, and to interpret these experiences in the context of the researchers academic experience, and hence is inductive or theory building*" (Flowers 2009, p3).

Saunders, Lewis and Thornhill (2007) summarise interpretivism as an epistemology paradigm that focuses on understanding the meanings and interpretations of 'social actors' in order to understand their world from their point of view; this can be carried out through analysing the data that is gathered by qualitative approaches (Eriksson and Kovalainen, 2008). Saunders, Lewis and Thornhill (2009) argue that an interpretivist position is very appropriate in the case of business and management research, in particular in fields like marketing, human resource management and organisational behaviour.

In order to facilitate the distinction between those two paradigms, Saunders, Lewis and Thornhill (2009) display an example that depicts the paradox between two cases of researchers; One is concerned with facts, such as the resources needed in a manufacturing process ('resources' researcher; positivist), and another research is concerned with the feelings and attitudes of the workers towards their managers in that same manufacturing process ('feelings' researcher; interpretivist), see Saunders, Lewis and Thornhill (2009, p112). Various examples are adduced by Rubin and Rubin (2012) that can in-depth explain the differences between positivist and interpretivist (Naturalist). In addition, a number of authors, such as, Easterby-Smith, Thorpe and Lowe (1991), Hussey and Hussey (1997), Fitzgerald and Howcroft (1998), Bryman (2004), and Binti-Kasim (2008), and Rubin and Rubin (2012) highlight various elements and features of these two philosophy paradigm alternatives. Among those, the philosophical considerations, which were summarised by Fitzgerald and Howcroft (1998), Bryman (2004), and Binti-Kasim (2008) that can facilitate the distinction between the different philosophical stances and approaches; as illustrated in **Table 5.3**.

Table 5.3: A Summary of Philosophical Considerations (Adopted from Fitzgerald and Howcroft, 1998; Bryman, 2004; Binti Kasim, 2008)

Ontological Considerations	
Realist (objectivist):	***Relativist: (Subjectivist):***
• External world comprises pre-existing hard and tangible structures	• Existence of multiple realities as subjective construction of the mind
• Structures exist independent of individual's ability to acquire knowledge	• Society-transmitting terms vary across different languages and culture
Epistemological Considerations	
Positivist:	***Interpretivist:***
• Application of natural science method to study social reality and beyond	• Absence of universal truth and emphasis on realism of context
• World conforms to the laws of causation and complex issues can be reduced through reductionism	• Understanding and interpretation come from the researcher's own frame of reference

5.2.3 Choosing a Philosophy of Research:

Dainty (2008) suggests that the selection of philosophy paradigm should consist of three essentials:

1. Ontology: What is the nature of reality
2. Epistemology: How do we know the world?
3. Methodology: How do we gain knowledge of the world?

Higham (2014) explained that as the selection of ontology (assumptions about how the world is made up and the nature of things) and epistemology (our beliefs about how one may discover knowledge) should be selected in sequences but Crotty (1998) avows that they should be considered together, as they are interdependent, whereas Bryman (2004) suggests that the philosophy "paradigm" is a cluster of beliefs and diktats, so it can be argued that the paradigm is a mix of how and why, both of which influence what should be studied and approach used. This may indicate a lack of consensus on the unified foundations of selecting a specific philosophy.

Saunders, Lewis and Thornhill (2009, 108), maintain that "*it would be easy to fall into the trap of thinking that one research approach is 'better' than another. This would miss the point*". Each approach is 'better' than others at doing different things, depending on the research question(s) you are seeking to answer. This perspective is further supported by Flowers (2009) who believes that selecting one position rather than another is practically unrealistic. This could be attributed to the strong interdependent relationship and overlapping between these philosophical positions, paradigms and approaches; epistemology is closely coupled with ontology (Flowers (2009), and they are related to each other, since the epistemological stance implies a particular ontological stance and vice versa.

The debate could also be framed in terms of a choice between the positivist paradigm and the interpretivist paradigm. This requires understanding the differences between these research paradigms. As mentioned above, several relevant writers and researchers have offered a variety of key elements and examples to distinguish between the positivist and the interpretivist. Among those are Rubin and Rubin (2012) who display different examples to illustrate the differences between these two research paradigms. However, in their study that is focused on the subject of 'choosing the research's philosophy', in particular, they investigated 'which philosophy approach is better and more appropriate?' They concluded that "*the answer to this question is usually probably that both are necessary and useful; they supplement each other, especially if the survey and the in-depth interviews were done separately, each following the assumptions of its own paradigm*". This confirms what was suggested by Saunders, Lewis and Thornhill (2009) that the researches within the business and management field are often a mixture between interpretivist and positivist.

This also supports the fact what has been noted by many researchers (Connell and Nord, 1996; Hughes and Sharrock, 1997; Holden and Lynch, 2004; Saunders, Lewis and Thornhill, 2009) that debating on ontology, epistemology, positivist, and interpretivist cannot lead to any philosophical solution; there is no right or wrong philosophical position or paradigm. Connell and Nord (1996, p1) among others note that "*Due to we do not know how to discover a correct position on the existence of, let alone the nature of reality", any philosophical debate is moot*" (Saunders, Lewis and Thornhill, 2009). In line with this perspective, Hughes and Sharrock (1997) were also unable to provide any guideline to an appropriate philosophical position or approach, they state that;

> "*Since the nature of philosophy, and its relationship to other forms of knowledge, is itself a major matter of philosophical dispute, there is, of course, no real basis for us to advocate any one view on these matters as the unequivocally correct conception of the relationship between philosophy and social research*" (Hughes and Sharrock, 1997, p13).

In line with the above perspective, yet within the construction context, Dainty (2008) argued that construction management does not yet have a clear theoretical or philosophical base which researchers can develop their design. This Dainty (2008) attests, leaves the researcher with the difficulty of deciphering the many conflicting theories of knowledge and paradigms within the literature from which the research can be potentially developed (Cited in Higham (2014, p97)).

The above has prompted some relevant academics to offer other alternatives. One of the most common and contemporary alternative, which is suggested by a number of authors (Murphy, 1990; Patton, 1990; Cherrholmes, 1992; Eastman and Bailey (1996); Hughes and Sharrock (1997); Tashakkori and Teddlie, 1998; Holden and Lynch, 2004; Saunders, Lewis and Thornhill, 2009), is a **pragmatic one**.

Pragmatism: advocates, "*applying methods that suit the problem rather than methods that suit Philosophy ontology or epistemology* (objectivism, subjectivism, positivism, or interpretivism) *concerns*" (Holden and Lynch, 2004, p13). 'Pragmatism', which is considered as one of the main epistemology perspectives by some authors, such as Creswell (2013), has its roots in the work of the American philosopher, Charles Peirce, who first proposed the pragmatic maxim, a philosophy which was then subjected to further advancement in the seminal works of William James and John Dewey (Aikin, 2008; Hammond and Wellington, 2013; Higham, 2014). Hughes and Sharrock (1997) argue that numerous contemporary empiricists and realists are pragmatic; they

> "*do not worry about epistemology and ontology but about the particular problems they confront from their theories and investigations...If all that matters is that scientists go about their business...using methods appropriate to the problems they have to deal with, then philosophical worries about ontology and epistemology are an irrelevance...There is certainly no reason to feel bound by stipulations about a unified method or a unified ontology for science, for on these arguments no such creature exists*" (Hughes and Sharrock, 1997, p94).

According to Higham (2014, p104), pragmatists continuing to assert that, "*in order to know the meaning of a concept, researches need to consider its practical consequences rather than adhere to preconceived, theoretical ideas*". It is this general thread which runs through the pragmatists' claim to knowledge, preventing any ontological and therefore particular epistemological perspective, with the pragmatism articulating the belief that the problem is sovereign not the methods used to understand the problem (Creswell, 2013). In other words, the researcher in a particular study should consider the philosophy adopted as a continuum rather than an opposite position (Tashakkori and Teddlie, 1998).

They, therefore, stress that "*pragmatism is intuitively appealing largely, because it avoids the researcher engaging in what they see as rather pointless debates about such concepts as truth and reality*" (Tashakkori and Teddlie, 1998, p30). Similarly, Holden and Lynch (2004) believe that it is more appropriate for the problem to be investigated with a method from an alternative philosophical stance, and they attribute this perspective to those researchers, for various reasons such as past training and skills; they "*may have unthinkingly slotted themselves into an objectivist or subjectivist position, not realising that the methods of an alternative philosophy may suit their research problem better*" (Holden and Lynch, 2004, p13).

In short, one can observe that a philosophy review has a double impact on the researchers including opening their mind for other possibilities and enhancing confidence in their research results. However, in many cases, choosing one philosophical stance is not vital to the proper utilisation of research methodology; therefore, applying mixed or different methods that suit the problem and that answer the research question is more appropriate and highly recommended than implementing methods that suit one philosophy concerns. In the view of Tashakkori and Teddlie (1998) among many others, a researcher should study what interests him/her and what is of value to his study in the different ways in which s/he deems appropriate and use the results in ways that can bring about positive consequences within his value system.

5.3 RESEARCH APPROACHES:

A research approach is a means of pointing out a particular technique and employing different methods for conducting research; nevertheless, the choice could be justified as the most appropriate available method that can achieve the research objectives and answer the research questions. In order to justify the methods selected for doing a research, it is significant to discuss and address the main approaches of managing research methodology (Sherif, 2010). Selecting the suitable research method, as stated earlier, is not an easy task and consequently some considerations need to be taken into account. The appropriate methodology is usually determined by the research topic and the problem emerging from reviewing the literature (Remenyi et al., 1998; Sherif, 2010). However, Yin (2003) and Binti-Kasim (2008) view that choosing an appropriate approach should be governed by the following basis; the nature of the enquiry and the type of question(s) being posed, the level of focus on existing events, and the extent of the researcher's control over the actual events.

The different research approaches concentrate on collecting and analysing the data rather than examining the theory and literature; they could influence the results, conclusions, values, validity, and reliability of the research (Fellows and Liu, 2008). Three main types of research methods have been recognised; *qualitative* method, *quantitative* method and *mixed* method (triangulation) (Fellows and Liu, 1999; Leedy and Ormrod (2001); Creswell, 2003; Neuman, 2006; Binti-Kasim, 2008) which are described in the following section.

5.3.1 Qualitative Research:

The word 'qualitative' is often used to describe research which emanates from the observation of participants (Oakley, 1994). The qualitative approach was defined by Hussey and Hussey (1997, p20) as "*a subjective approach which includes examining and reflecting on perceptions in order to gain understanding of social and human activities*". It seeks to understand people's (whether as individual or groups) perceptions, beliefs, opinions, understanding, views, etc. It produces descriptive data by the observable behaviour or the individuals' own written words in order to understand social and human activities (Collis and Hussey, 2003; Dainty, 2004; Binti-Kasim, 2008). In qualitative research, which is an inductive one, an exploration of a subject is undertaken without prior formulations. Fellows and Liu, (2008), Bryman and Bell (2003), Bryman (2004) and Neuman (2006) argue that a qualitative method is suitable for relatively new subjects or for topics that lack the necessary research data.

Qualitative research offers more real bases of interpretation and analysis, and provides solid ground on how and what; in addition, it helps the researcher to be alert to changes that may occur (Yin, 1994; Hussey and Hussey, 1997). However, there are some disadvantages for this approach identified by some researchers and authors. This research approach is criticised for being too subjective, difficult to replicate or analyse, and probably expensive and time consuming (Bryman and Bell, 2003; Sherif, 2010). They stress that in order to be able to interpret the participants' behaviour from their own perspective, the researcher ought to be 'value free', which is, defiantly, not easy. They add that to ensure the validity and the accuracy of the study; one must avoid bias.

Sources of qualitative data could be collected by various research techniques; documents and texts, interviews, observation, participant observation (fieldwork), and the impressions and reactions of the researcher. It can be argued that using the interview-case study technique is the most effective means in research for judging the respondent's views and ensuring the validity of data (Frankfort-Nachmias and Nachmias, 1996; Sherif, 2010) (see **Section 5.5.3.1**).

5.3.2 Quantitative Research:

It is defined as "*an inquiry into a social or human problem, based on testing a hypothesis or a theory composed of variables, measured with numbers, and analysed with statistical procedures in order to determine whether the hypothesis or theory holds true*" (Creswell, 1994). Unlike qualitative approach, this approach is built upon previous work (e.g. using data collected by others) which helps to decide the data requirements of a particular research project (Fellows and Liu, 2008). It is objective in nature and it uses statistical and mathematical techniques to measure the phenomena and to identify facts and casual relationships by collecting and analysing numerical data (Hussey and Hussey, 1997; Fitzgerald and Howcroft, 1998; Creswell, 2003). Yin (1994) and Hatmoko (2008) argue that a quantitative method is deductive and that it is more appropriate for question words like how and what. Bryman (2004) stated that in quantitative research, the samples collected are often large and representative, and the results obtained could be generalised to a wider population within acceptable limits of error. The validity of these results depends on the careful selection of measuring tools and accurate techniques for assessing the research targets (Pattaon, 2002).

There are many advantages for using the quantitative research method; the most distinguished advantages are: the reliability of the results gained and the provision of a wide range of situations, which is fast and economical (Leedy and Ormrod, 2001; Amaratunga et al. 2002; Abdullah, 2003; Binti-Kasim, 2008; Sherif, 2010). However, the quantitative approach has also received some criticism such as that it is built on instruments and procedures that can hinder the connection between research and the real life of the people and social institutions; it is also criticized for being not effective in understanding processes or creating theories (Bryman and Bell, 2003; Neuman, 2006). In addition, Fellows and Liu (2008) argue that although using data collected by others could shorten time and save money, it can be problematic, as the data and/or samples have not been tailored to the particular research question.

The two most commonly used quantitative research approaches are 'experimental research' and 'surveys'. Quantitative research can be conducted by employing one or more of the following three main approaches: asking the respondents questions by questionnaires and quantitative interviews, carrying out experiments and desk research using data collected by others (Fellows and Liu, 2008). The main and the most common technique used to collect data through the quantitative research method is the questionnaire survey (Naoum, 2007; Fapohunda, 2009; Sherif, 2010), which is described in **Section 5.5.3.2**.

Although defining the qualitative research characteristics and its distinctions from the quantitative research method could be a controversial issue, some authors and researchers have endeavoured to define the features of qualitative and qualitative research approaches, such as the one that was conducted by Binti-Kasim (2008, p27).

In brief, as shown in **Table 5.4**, qualitative and quantitative research approaches differ basically in some major areas: their analytical objectives, types of questions posed, of data collection methods used, and of data produced, besides, the degree of flexibility in study design. Quantitative research involves an experimental approach; testing a hypothesis, and data collection that relies upon measurement and statistical techniques for analysis (Ali, 2011). While the qualitative approach is intended to explore why things happen as they do; to determine the meanings which people attribute to events, processes, and structures (Fellows and Liu, 2008), the qualitative approach analyses and describes words rather than numbers. As qualitative can be undertaken without prior formulisations, it is precursor to quantitative researches. Several key aspects to differentiate between the qualitative and quantitative approaches can be found in literature, such as those published by Creswell (2003), Neuman (2006), Binti-Kasim (2008), Sherif (2010), Ali (2011), and many others. However, for the purpose of limiting the disadvantages of each approach and drawing its advantages, many recent researches use both approaches (multiple method/ Mixed approach) to answer the research questions and to meet the research objectives.

Table 5.4: Summary of the Characteristics of the Qualitative and Quantitative Methods (Developed from Leedy and Ormrod, 2001; Amaratunga et al., 2002; Abdullah, 2003; Neuman, 2006; Binti-Kasim, 2008)

Characteristics	*Qualitative Research*	*Quantitative Research*
Purpose	• To describe and explain • To explore and interpret • To built theory	• To explain and predict • To confirm and validate • To test theory
Objective	• Study issues in-depth and detail and seeks to gain insight and understand people's perceptions	• Gather factual data and study relationship between facts and relationships in accordance with theory
Theory	• Theory can be causal or non-causal and is often inductive-concerned with development of theory from specific instances	• Theory is largely casual and is deductive-associated with verification of the theory and hypothesis testing
Process	• Holistic • Unknown variables • Flexible guidelines • Emergent design • Context-bound • Personal view	• Focused • Known variables • Established guidelines • Statistic design • Context free • Detached view
Research Procedures	• Research procedure are particular, and replication is very rare	• Procedures are standard, and replication id frequent
Data Collection	• Informative, small sample • Observations, interviews, documents	• Representative, large sample • Standardized instruments – questionnaires, laboratory experiments, etc.
Data Characteristics	• Soft data, descriptive, less structures, analysed using non-statistical methods	• Hard data, structured, large sample size, analysed using statistical methods
Reporting Findings	• Words • Narrative, individual quotes • Personal voices, literary style	• Numbers • Statistics, aggregated data • Formal voice, scientific style
Outcome	• Exploratory and/or investigate and findings are contextual	• Conclusive findings used to recommend a course of action
Strengths	• Data gathering methods seen as natural than artificial • Ability to look at change process over time • Ability to understand people's meaning • Contribute to theory generation	• Provide wide coverage of the rang of situations • Fast and economical • Where statistics are generated from large samples, they may be considerable relevance to policy decisions
Weaknesses	• Data collection can be tedious and require more resources • Analysis and interpretation of data may be more difficult • Harder to control the pace, progress and end-points of research progress	• Tend to be rather inflexibility and artificial • Not very effective in understanding process • Not very helpful in generating theories

5.3.3 The Mixed Research (Triangulation) Method:

Hatmoko (2008) describes this approach as the one that "*employs strategies of inquiry that involve collecting data either simultaneously or sequentially, and using numeric as well as text based information*". As demonstrated in **Figure 5.4**, it is a method whereby both qualitative and quantitative research approaches can be adopted at the same time in a research project in order to cope with the potential bias and limitation of a single method approach (Creswell, 2003; Collis and Hussey, 2003). Sticking to a single methodology could affect the reliability of the research contribution; for that reason a broad application of combined approaches can be applied in academic research and literature. Denzin (1970), Love et al. (2002), Abdullah (2003) and Sherif (2010) believe that the use of a triangulation research method leads to enhancing the capability to transmit knowledge in a tangible form and to ensure better understanding of the phenomena under study, and greater validity and/or reliability of results than a single method. It is a common technique to improve research validity and underpin confidence in the findings (Ali, 2011).

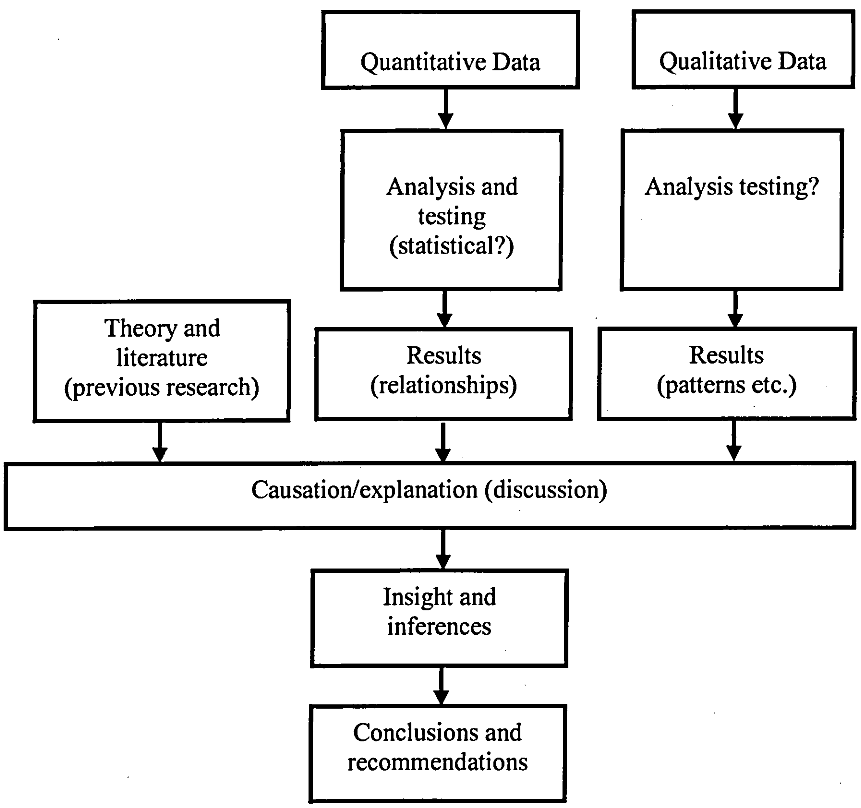


Figure 5.4: Triangulation of Qualitative and Quantitative Data (adopted from Fellows and Liu, 2008, p10)

The triangulation approach aims to eliminate or, at least, to reduce the demerits of each single approach, and to utilize the merits of each (Fellows and Liu, 1999); it allows for one approach to compensate the weakness in the others (Ali, 2011). Qualitative data can help the quantitative side of research at some stage in the design process by aiding with the conceptual development and instrumentation, while quantitative data can help with the qualitative side of research during design by selecting a representative sample and specifying the deviant samples (Amaratunga et al., 2002; Binti-Kasim, 2008). Punch (1998) cited in Fapohunda (2009, p66-67) summarizes the facts on the exploitation of a mixed method of research as follows;

- *The logic of triangulation:* it enables findings from one type of approach to be checkable against the findings derived from another type.
- *A research method facilitates other methods*: quantitative research helps to provide background information on the research concepts and to assist in the research interview question formulation and construction whereas qualitative research helps to bridge the deficiency of quantitative study.
- *The structure and process:* quantitative research is efficient in providing information about the structural features of social life while qualitative research is stronger in caring for the procedural aspects.
- *The problem of generality:* the inherent limitations of qualitative research lies in its inability to generalise its findings due to the limited geographical coverage, time, and cost; although its findings are significantly rich. To reduce this effect, quantitative research is explored to obtain information from a wider scope at a lower cost. Hence, the findings from the two approaches enhance the reliability and validity of this research work.
- *The interpretation and relationship variables*: quantitative research readily allows the easy establishment of relationships between variables but it is often weak in exploring the reasons for the relationships while, qualitative research helps to explain the factors underlying the broad relationships that were established by the quantitative method.
- *Development*: this is a case where results from one method can help in developing or informing another method.
- *Evaluation and Validation:* this is a case where findings that resulted from one approach are evaluated and validated through another approach.

Furthermore, Ali (2011) supports Fellows and Liu (2008) in that the triangulation is a very powerful approach, and he attributes this to the fact that this approach enables the researcher to investigate each objective from different perspective; it, thus, strengthens the validity and the reliability of data.

Although a distinction between the quantitative and qualitative approaches has been drawn, the advantages obtainable from the exploration of the eclectic method induce and encourage the researcher to adopt the *triangulation research method*: a combination of qualitative and quantitative research surveys to meet the objectives of *this research*.

According to Esterby-Smith et al. (1991) and Esterby-Smith et al. (2002), there are four types of triangulation involving *data triangulation*, *investigator triangulation*, *theoretical triangulation* and *methodology triangulation* as summarised in **Table 5.5**.

Table 5.5: Four types of triangulation (adopted from Esterby-Smith et al., (1991) and Esterby-Smith *et al.*, (2002) and Hatmoko, (2008)

No	*Type of Triangulation*	*Description*
1	Data Triangulation	Data is collected over different time frames or from different resources.
2	Investigator Triangulation	Different investigators gather the data independently on the same situation and the results are then compared.
3	Theoretical Triangulation	Borrowing a model or theory from one discipline and using it to explain a phenomenon in another discipline.
4	Methodological Triangulation	Using both qualitative and quantitative methods of data collection.

The research project proposed in this thesis can meet the descriptions of '*methodological triangulation*'; as both qualitative and quantitative methods of data collection and analysis are used; and '*data triangulation*'; as data is gathered from various construction organisations and sites and using different sources. The rationale for selecting data triangulation, which involves collecting data from different construction organisations and sites, is to avoid partiality which may appear while collecting data solely from an organisation or a site, to increase the level of the generalisability of the data, and to enrich, strengthen, and widen the range of data collection. As for the methodological triangulation, qualitative and quantitative methods of data collection are used at different levels of investigation in this research. Thus, the mixed method provides good evidence for using the (triangulation) method of data collection since it can upgrade the robustness of this research.

5.4 RESEARCH TECHNIQUES:

According to the hierarchal model of research methodology (the nested research methodology), as it is introduced above in **Figure 5.2**, the research approaches and strategies guide and constitute the inner research techniques, located in the central point. Fellows and Liu (2008) insist that the process of data collecting is a communication process. In order to ensure the reliability and accuracy of the data obtained, the data collection process should involve a chain of communication; it does not only involve the transfer of data from the provider (respondent) to the collector (researcher). Based on that aspect, they categorise the data collection techniques into two communication methods; 'One-way' communication (liner) methods include completely structured or unstructured interviews, postal questionnaires, scrutiny of archives/documents, diaries and observations by the researchers; 'two-way' communication (non-liner) methods include semi-structured interviews and participant observation.

Several types of research techniques have been distinguished and used in different research projects involving case study, qualitative interview, quantitative questionnaire, action research, grounded theory, ethnographic research, phenomenological study, and experimental research. The choice of a suitable research strategy or technique is dependent on many conditions such as, the research situation, type of research question, the type and size of the required data, accessing the required data, etc. (Yin, 2003; Binti-Kasim, 2008). Fellows and Liu (1999, 2008) believe that the consideration of the scope and depth required in a research project can influence the choice of a research strategy and its techniques as illustrated in **Figure 5.5** below. **Figure 5.5**, which is introduced by Fellows and Liu (2003), clearly demonstrates the choice made between a broad and shallow study, a narrow and deep study, or an intermediate position.

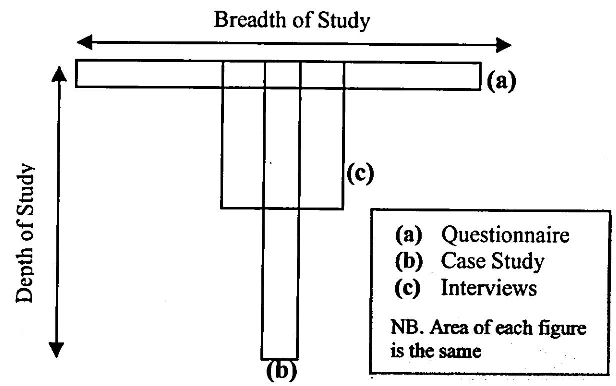


Figure 5.5: Breadth and Depth in Question-based Studies (Adopted from Fellow and Liu, 2003)

In order to avoid the repetition, an overview of the most common research techniques will be introduced, and the research techniques adopted will be detailed in **Section 5.5.3** and **5.6.1**.

5.5 RESEARCH STRATEGY DECISION & SELECTION METHODS:

A research project can be designed and executed based on the different philosophies, strategies, and methods; however, selecting the appropriate research strategies and methods is significant to produce good quality research (Kerlinger, 1979; Remeyi et al., 1998; Tzortzopoulos, 2004; Binti-Kasim, 2008). Consequently, a sensible decision should be made in order to choose an appropriate, proper and correct method, which can achieve the purpose of the study and answer the research question within the available resources (Roboson, 2002). Nevertheless, the majority of researchers still struggle with the difficult questions of 'what kind of research approach should be used?', 'how to choose an appropriate methodology for answering the research problem?', and 'what kind of technique will be effective for collecting the data needed' (Walker, 1997; Binti-Kasim, 2008; Ali, 2011).

As stated earlier in the methodology section, a decision for selecting a suitable technique for data collection and analysis is not an easy task and it is dependent on various factors and situations (research position, type and size of the data needed, the required data availability). The decision or choice, thus, may affect the whole research process and results. Therefore, a critical assessment of the different research techniques and the rationale for using specific technique(s) is needed. The selection of the research methodology and strategies, and the adoption of particular research technique(s) are justified; they are discussed in the following sections.

5.5.1 Selection of the Research Philosophy and Methodology:

Research strategy and methodology should be chosen as a function of the research situation (Yin, 2003). The guide for developing any research methodology is that it must completely address the research aim(s) and/or questions (Creswell, 1994), and that it must consider the complexity of the subject and kinds of data; an investigation of the problem requires feasible means of collecting data (Leedy and Ormrod, 2001; Binti-Kasim, 2008).

As this research project aims "to establish a set of uniform measures for evaluating the effectiveness of the construction materials management performance, and to develop a framework for their use within the large-scale concrete building projects in the Kingdom of Jordan", the decision on research methodology adoption is as depicted in **Figure 5.6**.

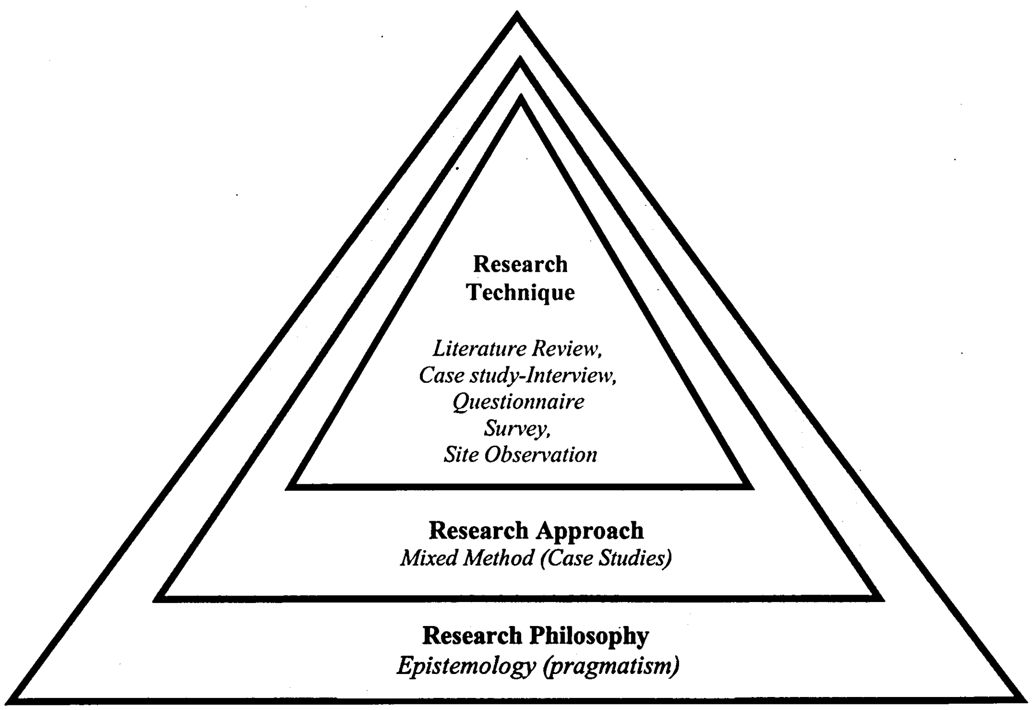


Figure 5.6: Selection of the Research Methodology

In the literature review discussions, it was discovered that the subject of materials management within the construction industry is complex and its evaluation and improvement involves complex procedures, actions and parties. Jessop (2008) argues that, epistemologically, "*the real world is infinitely complex and, for this reason, it cannot be exhausted analytically*" (Jessop, 2008, p229, cited in Daniel, 2014, p155). In view of this epistemological reality, it is appropriate, when studying any complex phenomenon or subject, "*that we select simplifying entry points into that complexity and recognise that all knowledge is partial, provisional, and incompletable*" (ibid). Furthermore to this, epistemology considers views about the most appropriate ways of enquiring into the nature of the world (Easterby-Smith, Thorpe and Jackson, 2008; Flowers, 2009) and 'what is knowledge and what are the sources and limits of knowledge' (ibid). Based on that, the main position of the research paradigm of the present study is based on the '**epistemological philosophy**'.

For this research project, mixed methods were required (eclectic methods) to suit the research problem and answer the research question(s) rather than that suit one philosophy stance; the research intends to use a subjective qualitative approach (case study-interview) and objective quantitative approach (questionnaire); it thus tends more towards the '**pragmatism approach**' (qualitative and quantitative approaches). This approach, as mentioned earlier, considers the application of eclectic or different methods (mixed methods) that suit the problem and answer the research question is more appropriate and highly recommended than those that suit one philosophy concerns.

The justification of adopting the pragmatism comes in part from Greenwood and Levin (2005; p23) view; the real world "*does not issue problems in neat disciplinary packages*" to which certain epistemologies can be neatly applied. Pragmatism adopts a holistic view grounded in the realities of practice, whereby the researcher moves between epistemologies (Higham, 2014), in a way that enables the selection of the most appropriate research tools to applied to the problem to allow solutions to be identified. Moreover, this adoption is recommended for the construction management researchers by many authors, such as Fellows (2010), who attests, this shift in the philosophical lens (pragmatism) adopted by construction management researchers can result in outcomes which are more reflective of the realities of the world that we study.

This method explores in detail the people's insights, perceptions and understanding of the process of materials management within the construction industry. The current research intends to investigate and explore the mechanisms and the measures used to evaluate the effectiveness of the construction materials management process; therefore, it is '**an exploratory** research study' with the primary aim of developing a framework for employing and operating these measures within the CMM process in the Jordanian building projects.

As understanding and uncovering Construction Materials Management (CMM) practices in real life situations is one of the research objectives, where the required detailed information is basically based on personal experience in a specific area, the **case study** approach is adopted in this study, because it offers a good opportunity to investigate in depth the area being studied, in addition to it is appropriate for investigating how theory or process applied in practice and to explain or explore conditions (Crowe, et al, 2011 citing Yin, 2009 p18).

Based on its advantages, which are stated in **Section 5.3.3**, the **triangulation-mixed method** (qualitative and quantitative) is used in this research for fulfilling the research aim and objectives and for answering the research question(s). The research techniques adopted for the data collection process comprise the **literature review**, the **case study-interviews**, and the **questionnaire survey**. The site observations and interview techniques are mainly adopted to collect data required for the case study approach, while the questionnaire is used to gain opinions and information for the evaluation of the proposed list of effectiveness-measures that resulted from the literature review process, and the workflow diagram of the practical CMM process that has been developed from the case study findings; justification of these choices is explained in the next sections below.

As discussed in the introduction chapter, the research concept was derived from the literature investigation, which identified the gap that should be bridged and the research topic and question. Based on that, the research was designed to develop a framework for evaluating the CMM performance. This framework is basically developed based on the literature review findings, and then it is tested within the Jordanian construction projects through the case study research. Therefore, based on its definition that is presented by

Punch (2000) and Trochim (2006) (see **Section 5.1.1.2**), this research project tends to be **deductive** research. However, from another perspective, one can observe that the main components of the framework were theoretically developed from the literature review findings (typical CMM process workflow-diagram + proposed effectiveness-measures), and then from the data collection process findings (case study approach), the practical components that on which basis the E.CMM.P framework was developed (practical CMM process workflow-diagram + practical effectiveness-measures) were developed, and finally the E.CMM.P framework was validated based on the data collected from the questionnaire and experts feedback, to contribute to the theory again. This could indicate that the research project began as a **deductive** research and then turned to **inductive** research. This means that the research involves both **deductive** and **inductive** reasoning approaches, and this situation is consistent with the logic put forward by Punch (2000) and Trochim (2006), and adopted by many construction management researchers such as, Ali (2011) and Daniel (2014).

5.5.2 Selection of Case Study Strategy/Approach:

Case studies are used when a researcher intends to support his\her argument by an in depth analysis of a person, a group of people, an organisation or a particular object. The case study approach is suitable for learning more about a little known or poorly understood situation (Leedy and Ormrod, 2001), and it is a preferred approach when the researcher has a little control over events, or when it is on a current phenomenon with some real-life contexts (Yin, 2003). Many other key benefits of the case study research have been advocated by several authors and researchers (Simon, Sohal, and Brown, 1996; Binti-Kasim, 2008; Fellows and Liu, 2008; Ali, 2011; among others).

According to Voss, Tsikriktsis and Frohlich (2002) case study research has become one of the most powerful research methods in construction and operation management. As mentioned earlier, using the case study techniques has many important advantages; however, the specific rationales for using the case study in the area of construction and engineering, and that induced the researcher to adopt it for this research are;

- Case studies are used widely in social sciences as well as in practice oriented fields in construction engineering management, science, and education (Yin,1994)

- Case studies help researchers understand the complex issues or objectives; thus, they can extend their experiences and promote their knowledge of what is already known in previous research studies (Mohamed and Anumba, 2006).
- In a case study, an investigator has the opportunity to observe and analyse phenomena previously inaccessible to scientific investigation (Yin, 2003)
- A researcher can better understand phenomena that influence organizational and project performance in construction (Love *et al.*, 2002)
- Case study's results have high validity for practitioners (the ultimate users of research); in particular through triangulation with multiple techniques of data collection, where validity can be increased further (Voss, Tsikriktsis and Frohlich, 2002).

In spite of these advantages, Voss, Tsikriktsis and Frohlich (2002) believe that there are several challenges in conducting case research; it is time consuming, it needs skilled interviewer, and care is needed for drawing generalisable conclusions from a limited set of cases and for ensuring rigorous research.

For this research project, the case study approach has been employed to achieve, partly, the third and fourth objectives; 'Identify concerns and uncover issues to understand Construction Materials Management practices in real life situations, and develop the practical workflow diagram for communicating the integrated functions and activities that shape/form the CMM process within the large-Scale concrete building projects in the Jordanian Construction Industry (J.C.I)'; 'Gather material-related measures, mechanisms and approaches currently in use within J.C.I, and establish the set of Practical Effectiveness Measures (**P.E.Ms**), that can be used for Evaluating the Effectiveness of the Construction Materials Management's Performance (E.CMM.P) in the Large-scale Concrete Building Projects in the J.C.I'.

5.5.2.1 The Case Study Research Design:

According to Mohamed and Anumba (2006), the main components of designing a case study include identifying the case study's question(s), defining the type of a case study, and specifying the units of analysis applied together with the case study protocols, as displayed in **Figure 5.7** and explained below.

1- Identify and Design the Case Study's Questions:

The starting point for the case study research is to formulate general research questions (Bryman, 2001). Yin, (1994) argues that case study research has been recognized as being particularly good for examining the How and Why questions. A design of the case study's question(s) is important to guide the data collection process (Huberman and Miles, 1994); it should represent the research main question and the objectives. Considering the above research objectives, the main case study's questions are;

- How is the CMM process performed in the practical life in the Jordanian Construction Industry (JCI)? And what are the integrated functions and activities that formed this process?
- How the effectiveness of CMM performance can be evaluated within the large-scale concrete building projects in JCI? And what are the mechanisms and measures used?

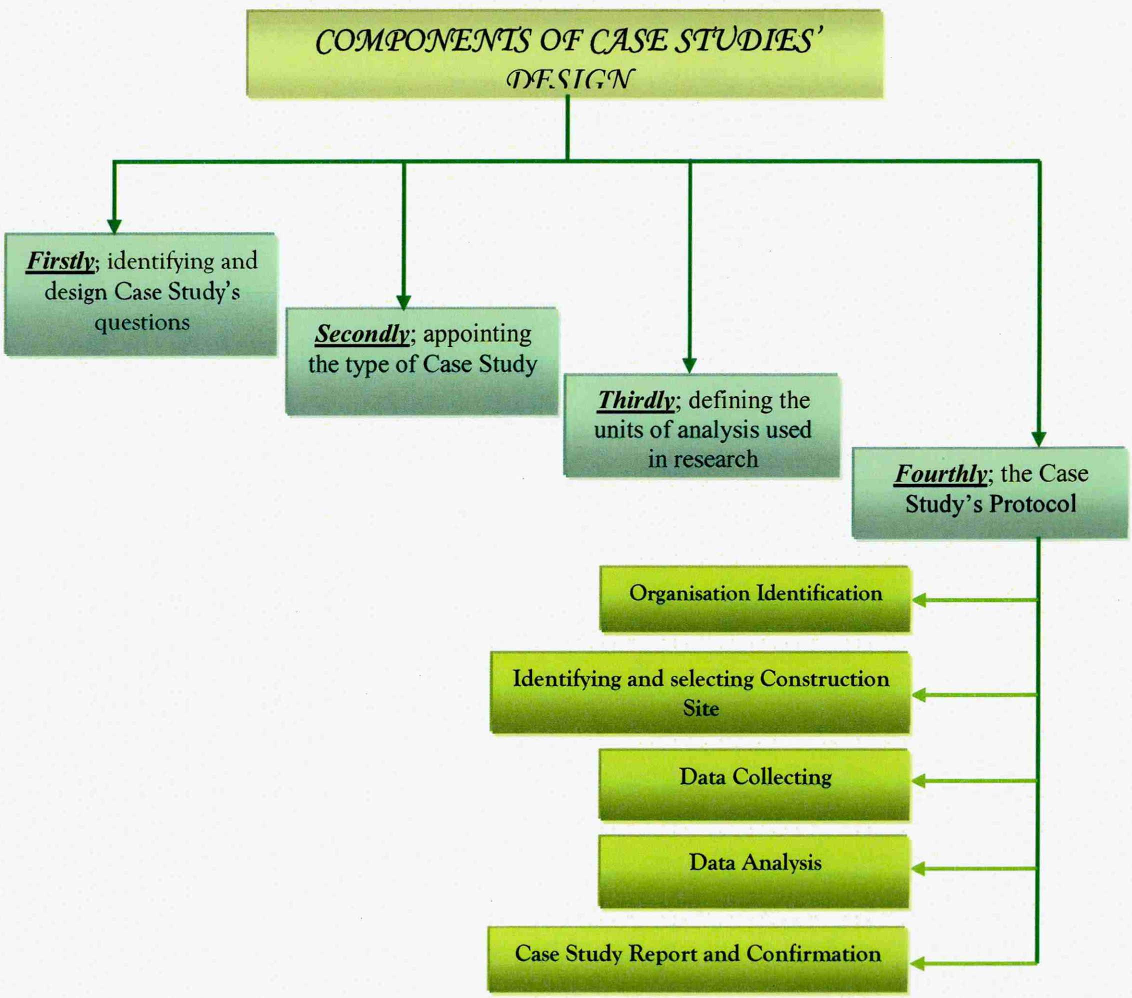


Figure 5.7: The Components and Steps of the case study design (Developed from Mohamed and Anumba, 2006)

2- Appointing the type of the Case Study (Single or Multiple):

According to Blumberg, Cooper and Schindler (2005), case study research can be categorised mainly as either single or multiple case studies. Voss, Tsikriktsis and Frohlich (2002) argue that a single case study is a greater opportunity for the depth of observation; however; it experiences limitation with respect to the generalisability of the constructions, models or theory that can be developed; biases may emerge such as misjudging the representativeness of a single event and exaggerating the available data. Although multiple case studies may reduce the depth of the study when resources are constrained, multi cases can both augment external validity, and help guard against the observer bias (Voss, Tsikriktsis and Frohlich, 2002). Multiple case studies are recommended and advised by a number of construction management-related researchers and authors, such as, Leonard-Barton (1990), Voss, Tsikriktsis and Frohlich (2002), Mohamed and Anumba (2006), Binti-Kasim (2008), Fellows and Liu (2008), and Alzohbi, Stephenson and Griffith (2011); in particular, the ability of multiple case studies to seek multiple viewpoints where there is likely to be subjective and bias. Furthermore, analytical conclusions independently arising from multiple-case study are more powerful than those coming from a single case alone.

The number of the case studies that are required to produce a good piece of work is still controversial. Fellows and Liu (2008) observe that the answer to the question of how many case studies should be undertaken to yield a robust piece of research, depends on the purpose of the research and the nature of the case studies undertaken. However, many researchers and authors in the construction management field are convinced that the ideal number of multiple-case studies is between four and ten cases (Eisenhardt, 1989; Perry, 1998; Voss, Tsikriktsis and Frohlich, 2002; Mohamed and Anumba, 2006; Binti-Kasim, 2008; Ali, 2011).

In this research project, the case study approach is intended to acquire more insight into the current practices of managing the building materials within the large-scale concrete building projects in the JCI, and to investigate the approaches that are used for evaluating the performance of the CMM process there. Thus, **multiple case studies** are more suitable to achieve these objectives. The building projects and organisations that are involved in the multiple case studies and the criteria of selecting these projects are described in detail within the discussion of the case studies protocol in **Section 5.5.2.2** below.

3- Defining the Units of Analysis:

The definition of the analysis units that may be used during the research is one of the major problems that face the process of designing a case study (Mohamed and Anumba (2006). McClintock, Brandon and Maynard (1979) assert that '*although the units of analysis are typically defined as individuals, groups, or organizations, they could almost be any activity, process, feature, or dimension of organizational behaviour*'. The selection of the 'analysis units' is directed towards achieving the case study research objectives (Mohamed and Anumba, 2006). Considering the objectives of using the case study approach in this study (as mentioned above), the 'units of analysis' adopted are as follows:

- *The CMM process Practices in the J.C.I:* This seeks to provide a general overview of the main features that characterise the CMM process within the Jordanian Construction Industry, and the responsibilities of the participants involved in the CMM process.
- *The functions and activities that form the CMM process within the J.C.I:* This aims to examine and identify the practical functions and their activities that form the CMM process within the Jordanian building projects.
- *The evaluation/measurement mechanisms practiced for monitoring and/or evaluating the performance of the CMM process:* This investigates the main mechanisms, approaches, or/and measures that are being practiced within the Jordanian building projects for evaluating the extent of the effectiveness of their CMM processes, systems, or strategies used.
- *Evaluating the Proposed Set of E.CMM.P Measures and developing the practical effectiveness-measures:* This can be a supplementary procedure to the previous unit and an introductory step to develop a set of the practical effectiveness-measures that are and can be used for evaluating the performance of the CMM process in the J.C.I.

5.5.2.2 Case Study Protocol:

Yin (2003) and Mohamed and Anumba (2006) suggest that one way to combat the inherent 'looseness' of the case research is to set up a 'case study protocol'. The protocol aims to guide the investigator in carrying out the case study, through outlining the procedures and general rules that will be used while collecting and analysing data (Mohamed and Anumba, 2006). A well-designed case study protocol is a very important tactic in multi-cases research, as it enhances the reliability and the validity of the case research data (Yin, 1994; Voss, Tsikriktsis and Frohlich, 2002). In this section, the procedures of the case study protocol that are adopted for the undertaken six case studies are discussed, and the justifications for the selection of organisations and projects that have been identified as case studies are explained.

1- Determining the Study Region:

This determines the location where the case studies were conducted. 'The Hashemite Kingdom of Jordan' has been chosen as one of the fastest Arab countries in developing its construction industry, and it could represent the Arab Construction Industry (A.C.I). This choice or decision was taken after strenuous efforts and attempts to identify and expand the research's region (e.g. email and phone contacts with many universities, relevant organisations, and research centres in many Arab countries). Additionally, it was based on many expanded discussions with the supervisors and the research's Keys-of-Contact (these will be defined later in this chapter). The main reasons behind this selection can be summarised in the following points;

- The lack of the possibility for collecting the required data, at the time of doing this research, in the countries of the so-called "Arab Spring" (my homeland Libya, Tunis, Egypt, Yemen, Bahrain, and Syria); because of the lack of security, the halting of the construction investments, the suspending of projects under implementation, the difficulty of reaching the construction-related individuals or groups (experts, professionals, managers) due to the collapse of the majority of the relevant government institutions and organisations.
- The lack of willingness to contribute to this research project by the majority of the institutions that were contacted in the Arab Gulf States, in addition to the difficulty of obtaining a visa to enter these States.
- The Arabic and English languages are not the mother tongue of some Arab Maghreb countries such as, Morocco, Algeria, and Mauritania, which mainly speaking French or local African languages. This, thus, makes the contact with the concerned individuals and the review of the relevant documents an impossible mission for the researcher.
- The Kingdom of Jordan is a mixture of the Arab; cultures: Middle East and North Africa cultures; weather: it is very hot in summer and very cold in winter; and topography: it has desert as it is in the most North Africa countries, and it has mountains, and plains as it is in Middle East area. This affects the building process,

style and materials used. This mixture between Middle East and North African culture makes one who visits different Arabic countries unable to feel the differences in the style and the type of the buildings. Therefore, the culture, weather and the buildings' style are very close to those in my homeland Libya.

- The Investment character; the rapid expansion of the construction sector in Jordan is an important developmental sign that is expected to attract investments worth 21 billion U.S. dollars over the next five years, 2012-2017, which will boost the domestic demand for project management services (*Albawaba*, 2011). The growth of this sector along with other sectors that are based on construction projects such as the real estate, infrastructure, and engineering has contributed to increasing the number and types of the large-scale projects, and thus realizes growth in the use of building materials that promotes the identification of the importance of the materials management services.
- As the researcher is from Middle Eastern and North African roots, where the researcher's mother originally came from a city located on the border of Jordan and Syria (Daraa) and since the researcher frequently visited that place, he is familiar with the Jordanian people and the system as it is his home-country.

2- Organisations and Projects Selection:

This involves choosing building projects that can provide adequate scope for exploring the practiced CMM process. The multiple case studies involve six on-going concrete building projects that are considered as large-scale projects in the Jordan Construction Industry. The selection of those companies and projects was the result of several meetings and discussions with members of the Jordanian Construction Contractors Association (JCCA) including the Chairman and the Secretary General of JCCA, and the research's Keys-of-contact members. As a result of these meetings and discussions, the case studies were carefully and deliberately selected according to the following main criteria;

- *Companies' Classification*: the focus of this research project was on the contracting building companies (the main contractors) where the process of construction materials management is mainly practiced; the building contractors are primarily responsible for managing the majority of (if not all) the functions and activities of the CMM process in the majority of the construction projects (Plemmons, 1995; Binti-Kasim 2008; Nasir, 2008). According to the Jordanian Construction Contractors Association Annual Report (2012), the construction companies in the Jordanian Construction

Industry (JCI) can be classified into **six** categories, in terms of their capital and financial solvency, the number and value of the projects implemented, the administrative body and the full-time technical staff and their experience in completing the projects on time within the budget (for further information, see the classification of the Jordanian construction contractors for the year 2012 in the JCCA web (JCCA, 2014)). According to the legislations and the standards of the JCCA, the first class building companies are the only building contractors who are accepted to execute large-scale projects (AL-Fassa, 2012). The adopted six organisations, which have implemented the six recommended projects, are first class building contracting companies (contractors), and they are specialists in carrying out the sophisticated and large-scale projects. Furthermore, the majority of the projects that were executed by these six contractors are considered as the best successful large-scale projects in the kingdom (AL-Tarawnh, 2012).

- *Projects' Classification:* 'in the JCI, there are no written standards or criteria for classifying construction projects in terms of their size' (Abu-Afifeh, 2012; Al-Fassa, 2012; Al-Tarawnh, 2012). According to the Assistant Secretary of Jordanian Engineers Association and the Chairman of Jordanian Construction Contractors Association, the six projects selected for the multiple-cases study research are considered as the Large-scale concrete building projects. These projects are considered among the largest investment and service projects in the kingdom of Jordan.
- *The Rate of Completion*: as previously mentioned in Chapter I, this research is concerned with the skeleton stage where the majority of the main building materials (concrete, steel, aggregate, etc.) are used. In order to ensure that the data collected embodies the entire stages of the skeleton work in the building projects, the selected projects were on different stages of implementation; two projects are at the beginning stages (Foundations), two projects are in middle stages (casting roofs) and two projects are at the final stage of execution (skeleton finishing works).
- *Geographical Distribution:* For the purpose of giving a more realistic picture that can simulate the reality of the process of managing the building materials that are practiced on the entire territory of Jordan, it was necessary to select projects from different zones in Jordan. Therefore, those six projects, which are involved in the case study research, were chosen from six different Jordanian governorates. These six Governorates are considered, according to the Jordanian Ministry of Public Works and

Housing annual report (2011), and to the Jordanian Construction Contractors Association (JCCA) annual report (2012), the most densely regions of the building projects in the Kingdom of Jordan; these are: Amman (2projects), the Dead Sea (1 project), Jarash and Ajloun (1 project), Madaba (1project), and Alzarqa (1 project), as shown in **Figure 5.8** below.

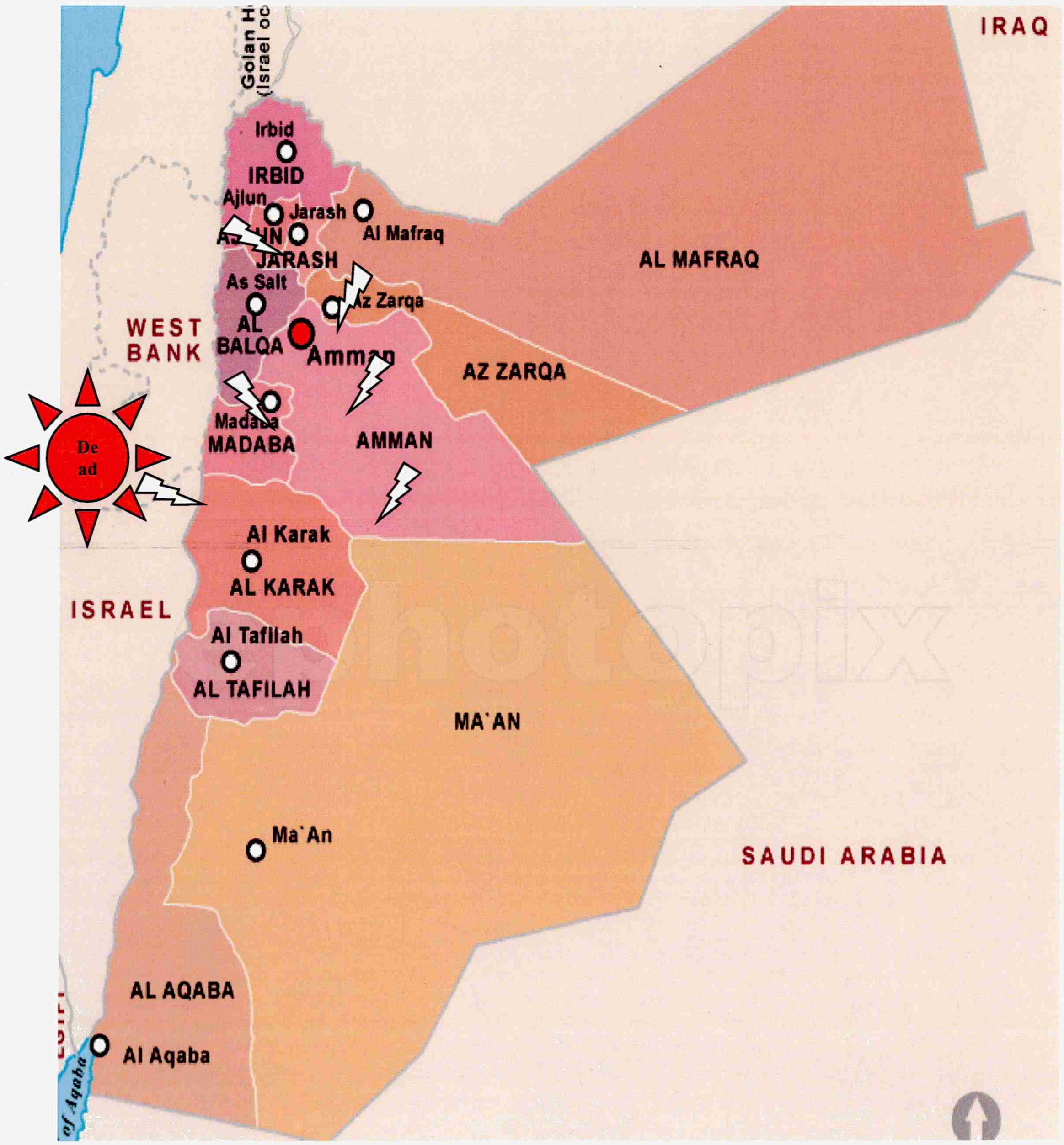


Figure 5.8: the Geographical Distribution of the Case Studies Selected in Jordan

- *Type of Projects:* in order to understand the actual implementation of the different CMM processes, and to obtain more reliable and valid results, different types of building projects were included in the multiple case study, including a Health Centre Building, a Hospital, a Presidential Resort and Five Star Hotels, a Hotel-Tower, a Huge store, and a Modern Rural Village.

This diversity in the type, stage, and location of the projects selected aims to provide an opportunity to explore the different approaches, to practice the CMM process and to depict a more realistic picture that can reflect the real-life of the CMM process that are practiced within the large-scale concrete building projects in the Jordanian Construction Industry (J.C.I). Moreover, this diversity is expected to gather as much as possible different materials-related measures, mechanisms, and approaches currently in use within the Jordanian Construction Industry (J.C.I). Background information on the six large-scale concrete building projects involved in the case studies are presented in **Table 6.2.**

5.5.2.3 Framework for Designing, Collecting and Analysing Data:

According to Mohamed and Anumba (2006, p234), "*a case study protocol was used to establish a framework for collecting and analysing data*". In order to apply a systematic case study approach, Yin (2003) developed a three stage protocol to help guide case study research; (1) Defining and designing stage; this includes theory development, and then displaying the case selection and data collection design; (2) Preparing, collecting and analysing stage: this includes conducting every case studies, and preparing an individual case report for each one; and (3) The analysis and conclusion stage which includes drawing the cross-case conclusions and providing a cross-case report.

With reference to Yin (2003) method of designing a multiple case study research, (as illustrated above), and adopting the above steps of the case study protocol in this research, the framework of the case study protocol for designing and analysing data while conducting the case studies has been established, as demonstrated in **Figure 5.9** below. This framework summarises the procedures that were adopted for designing and analysing multiple case study approach for this research.

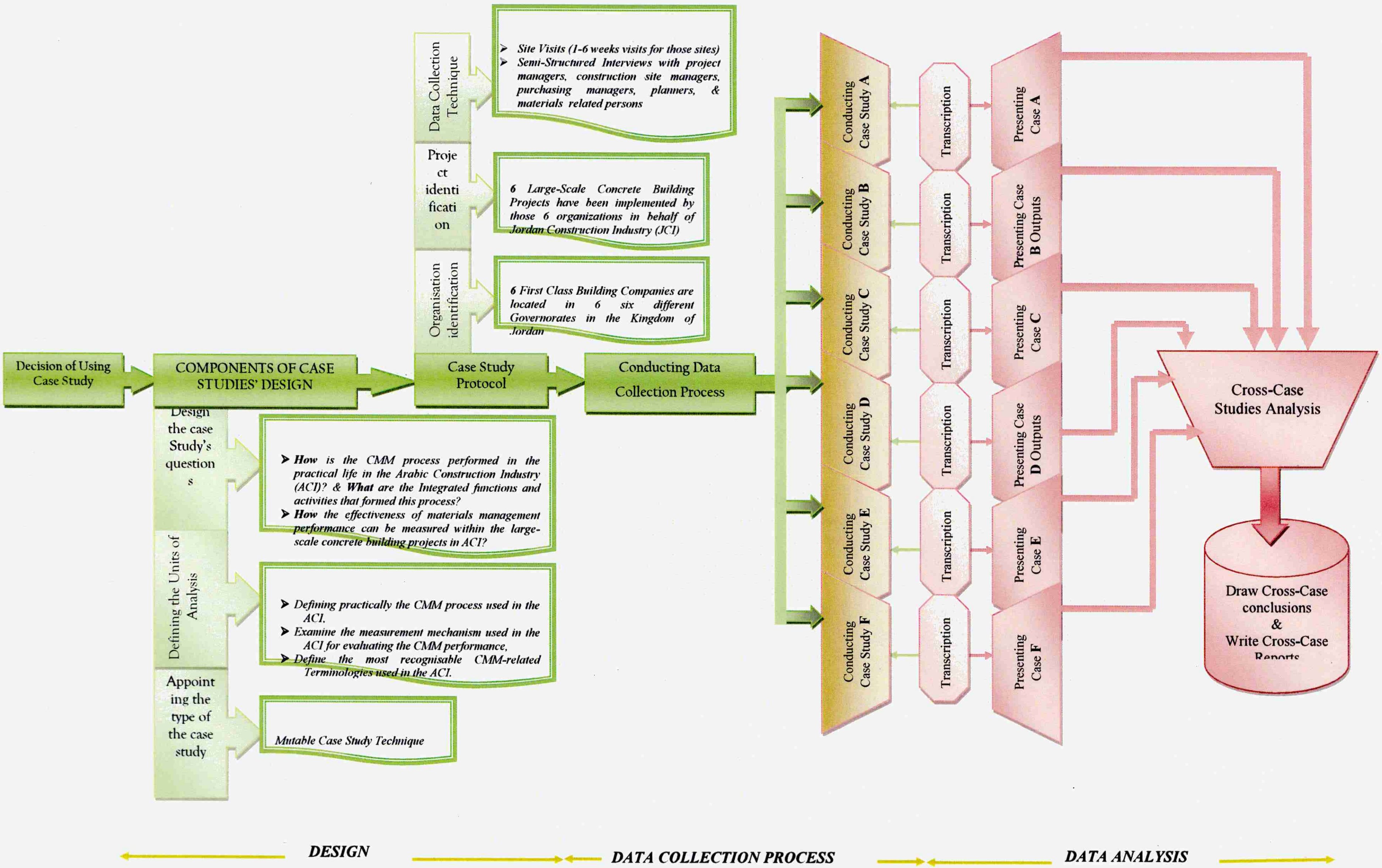


Figure 5.9: The Case Study Protocol Framework: Designing and conducting the case studies

5.5.3 Selection of Data Collection Techniques:

Voss, Tsikriktsis and Frohlich (2002) argue that the combination of different techniques, such as interviews, direct observation, content analysis of documents, and questionnaires, to be used to study the same phenomenon is an underlying principle applied to the collection of data in a case study approach. The authors (2008, p206) also stress that the "*reliability of data will also be increased if multiple sources of dada on the same phenomenon are used*". Two data collection techniques were carried out for collecting the required data from the six building projects involved in the case study research; 1) the 'Regular Site Visit' technique that is intended to understand the real-life of the construction management process practiced within the J.C.I; it includes field tours to the construction sites, the company's warehouses and site-stores, the company's home-offices, and purchasing and planning departments, and also reviewing various material-related documents; 2) the 'Semi-Structured Interviews' with high experienced material-related staff. The questions were organised under the broad headings including: a) A Process of Construction Materials Management (CMM); b) The functions and activities that form the CMM process; c) Effectiveness Measures of CMM Performance; d) Terminology. More details on justifying the selection and implanting these data collection techniques are available in the next sections of this chapter.

5.5.3.1 The Interview Selection:

The qualitative interview is considered as the most widely used qualitative method in case study research, and it has the potential to expand understanding and generate insights and concepts (Frankfort-Nachmias and Nachmias, 1996; Ali, 2011); besides, it allows researchers to capture some of the richness and complexity of their subject matter and explain it in a comprehensive way (Rubin and Rubin, 2005; Higham, 2014). Although the interview technique is considered the second data collection technique (after the site visit technique) used in the case study approach, it is the main technique that meets the case study's units including defining practically the CMM process that is practiced within the J.C.I and examining the measurement mechanism and approaches used there for evaluating the performance of this process. Because it is preferred by the interviewees and since its response rate is larger than that of the telephone interview (Blumberg, Cooper and Schindler, 2005), a personal interview is adopted in this research, even though it is rather costly in time and money (Ibid).

For this research project, the interview technique embraces the standard questions (open and close-ended questions) to obtain an understanding and overview of the realistic practice of the CMM process within the projects involved in the case studies, and to define the specific evaluation approaches used in these projects. However, some individually tailored questions are needed to acquire clarification or to probe a person reasoning. Therefore, the semi-structured interview seems to be more suitable to be used in this research. In addition to its advantages that are described by many authors, such as Ayton (1987) and Binti-Kasin (2008, p34), the main rationales and reasons behind the choice of using the semi-structured interview are:

- The conversation in the Arab culture should be two-way communication; otherwise it is considered as a kind of impolite investigation,
- The interviewees are highly experienced and have good knowledge of the subject matter of the research (CMM process), which, in turn, urges the researcher to learn more, and to ask for explanation for some controversial matters,
- The limited knowledge, about the issue of measuring the effectiveness of the CMM process in the Arab region, made more in-depth discussions are required in order to ensure that the responses reflect the participant's feelings and opinions about the issue,
- In order to enrich the in-depth discussions, some unstructured questions are necessary to confirm what is already known and to explore more specific details about the issue,
- Semi-structured interviews allow one to "*obtain full decision story from each of the senior managers, without unwanted interruption or direction, and to obtain reflections on their own perceptions*" (Gear, Shi and Ftes, 2013, p187), and
- Semi-structured interviews are "*widely used within the Construction Management (CM) researches*" (Dainty, 2008; cited in Higham, 2014), possible due to their capacity to gather rich data, which allows researchers to understand hoe things work in the 'real world' (Kvale, 2007).

The experts and professionals, who were involved in the interviews, were non-randomly selected by the points-of-contact person (s/he will be defined later in this chapter) for each case study. The main criteria applied for the selection of interviewees are;

- The experience, expertise and knowledge in at least one of the integrated materials management functions,

- The participants should be currently involved in one of the case studies and in one or more of the CMM activities including; managing and controlling materials, inventory quantities, evaluating suppliers, purchasing process, material's specification and conditions, the movement of materials off and on site, and the storage issues,
- Having experience and participation in managing the construction projects on behalf of the Jordanian or Arab Construction Industry with at least 10 years' experience,
- The ability to talk either the Arabic or the English language fluently, and
- The convenience and willingness to share their experience in managing materials within the J.C.I.

As a result of the effort of the points-of-contact at each case study, 14 interviewees (at least 2 interviewees at each case study) were assigned. Those include 3 Project Managers, 3 Construction Site Managers (CSM), 2 Warehouse Managers, a Project Administrator, a Procurement Manager, a Planner, a Civil Work Supervisor, an Executive Project Director, and a Senior Construction Manager. **Table 6.1** exhibits some details on the individuals involved in the semi-structured interviews. The procedures and the instruments that were used for performing the semi-structured interviews in this research are outlined in the **Section 5.6.1.2**.

Qualitative Data Analysis:

The key step in case study research is the systematic search for cross-case patterns. The cross-case analysis, which is mainly to pick a group or category and to search within the group for similarities or differences, is a simple and effective analytical approach; it can also increase the internal validity of the findings through the use of multiple data sources-Triangulation (Voss, Tsikriktsis and Frohlich, 2002). Qualitative data analysis presents and discusses the outputs, themes, and patterns that have emerged from both the site visits and the semi-structured interviews. This discussion involves a cross-case study analysis comparing the six case studies, with the help of NVivo9 software, including refining the obtained data, coding and then interpreting them using the units of analysis. More details on the procedure of data analysis are provided in **Chapter VI**.

5.5.3.2 The Questionnaire Selection:

The most common technique to the collection of such data whether within the construction management research (Dainty, 2008), social research (Malhotra and Grover, 1998; Blaxter, Hughes and Tight, 2006), and in the wider research community (Fellows and Liu, 2008) is the questionnaire survey. The questionnaire is considered as an efficient, reliable and convenient technique to gather the data required (Bell, 1993; Sherif, 2010), and it allows researchers to gather data from a large number of respondents within a relatively short timeframe (Simmons, 2008; Farrell, 2011).

In this research, the questionnaire technique is employed basically to evaluate the proposed effectiveness-measures of the CMM process that have been developed on the basis of the literature review, and to carry out the first stage of the validation process, the 'formative evaluation' through assessing the developed Practical CMM Process (PCMMP) Workflow Diagram that resulted from the case study research.

The use of the e-mail technique is not much familiar for some respondents in the Arab region; besides, in the Arab World including Jordan, the mail is neither accessible nor easy; moreover, it is time consuming. Thus, the use of the mail or e-mail questionnaire is not suitable in this study. Additionally, due to the topic of the study (the measurement of the CMM performance) is somewhat new in the J.C.I, and many of construction professionals have a limited knowledge about it; thus, many inquires need to be explained. In order to overcome the limitations and shortcoming of the e-mail and mail questionnaires, and in addition to utilizing the advantages of this technique that are mentioned below, a 'Group Administered Questionnaire technique' is selected to collect the quantitative data. Although it is not an easy task to have a group of respondents together at the same time and in the same place, the main rationales of using a group administrated questionnaire technique in this study can be summarised as follows;

- The proposed set of the measures that need to be evaluated is not familiar in the J.C.I, and hence in-detailed explanation is required,
- The need to clarify any ambiguous and incomprehensible issues to insure accurate answers, and
- To ensure a high response rate within the limited time whereby time is money over there.

Avoiding Bias:

According to Saunders, Lewis and Thornhill (2009), in order to obtain good questionnaire's design and to reduce the risk of responses' bias, the following criteria should be taken into the researcher's account; the questions` content is more important than the questionnaire length; short questionnaires draw more responses, and the questions should be clear, unambiguous and objective. This, in fact, supports what was suggested by Bryman (2001), who laid down seven points that need to be avoided to prevent any response bias; one has to avoid 1) ambiguous terms in questions, 2) long questions, 3) double-barrelled questions, 4) very general questions, 5) leading questions, 6) questions that are actually asking two questions and 7) technical terms. The researcher has to take all these points into consideration when designing the questionnaire for the research project.

Quantitative Data Analysis:

The data that were collected through the questionnaire survey were prepared and analysed using the Statistical Package for Social Science (SPSS) software version 19. A descriptive statistics analysis was administrated for the analysis of the questionnaire data. The quantitative raw data was analysed using frequency and cross-tabulation statistical functions. The statistical significant association between the usability, importance, and practicality of the effectiveness measures was determined. For the purpose of ensuring validity and reliability, the initial stage of analysis involves observing, sorting and grouping the data. The code book (**Appendix C**) was developed for coding the propositions, variables and values the questionnaires contain. The results of the SPSS are presented in tabular forms, as illustrated in **Chapter VII**.

5.5.3.3 The Questionnaire Sampling Size for this research:

As the questionnaire survey mainly aims to examine and evaluate the effectiveness-measures of the CMM performance in the large-scale projects, it is essential to set an intensive plan for conducting the questionnaire survey and to develop procedures and conditions for selecting the right respondents and projects. According to the annual report of the Jordan Engineers Association (JEA) (2011), 2961 civil engineers have registered within the JEA, 1049 of them are construction engineers, and 109 are construction management engineers cutting cross construction companies, government departments, academic institutions, and others. However, the assistant secretary of the Jordanian

Engineers Association (JEA), who is one of the Keys-of-Contact of this research, asserts that there is no classification in the JEA records that can show the exact current specialties, positions, field works, and workplace of its members, or whether these people were working inside Jordan or overseas. Additionally, the JEA record does not name the participants who are involved in the large-scale concrete building projects. Consequently, the Jordanian Construction Contractor Association (JCCA) was the only avenue for the researcher to access the right respondents in order to gather the accurate data required.

As gaining access to the source of data is a sequential process, ***the first step*** was to make a request for a meeting to be held with a member of the Jordanian Construction Contractors Association (JCCA), who was delegated by the President of the JCCA to provide any support needed for this research. The main aim of this meeting, which was conducted by the researcher, one of the research's Keys-of-Contacts, and the JCCA delegated member, is to obtain permission to access the JCCA records. The purpose of this step is to find out the first-class contractors that are currently implementing the large-scale concrete building projects in one of the six pre-selected Jordan provinces, which are considered as the most densely-populated regions of the building projects in the Kingdom of Jordan. According to the JCCA annual record (2012), among the total of 2619 different contractors that registered in the JCCA, 98 are classified as first class building contractors. The focus of this study is on the under-construction projects within the pre-selected six provinces; of the 98 first-class building companies, 57 building contractors have executed on-going concrete projects which are considered as big projects (estimated cost more than 25 million) within those six provinces.

According to Krejcie and Morgan (1970), to achieve statistical confidence from a population of 57, the required sample size should be a minimum of 49. In order to reduce the level of non-return, ***as the second step***, 57 invitation letters to participate in the survey were sent by JCCA to the pre-selected points–of-contacts of those building contractors. Among those 57, 26 building contractors were willing to be involved in this survey, representing 45.6% return rate. This is acceptable according to Krejcie and Morgan (1970) and Malhorta and Gover (1998); a return of 20-30% is acceptable. As a result of the discussions that made between the researcher, the Key-of-Contact and the delegated JCCA member, 30 on-going big concrete building projects, which have been carried out by those 26 contractors, were selected; their functional experts are involved in this survey.

The third step, which was considered as the biggest challenge in conducting the questionnaires, was the access to the right person (expert, manager, or professional) who is best informed about the data being researched. According to Voss, Tsikriktsis and Frohlich (2002, p206), in order to access the right informed person, "*an ideal prime contact should be someone senior enough to be able to open doors where necessary to know who best to access to gather the data required and to provide senior support for the research being conducted*". Indeed, the access to those experts and professionals was possible through the managers in their organisations, who were selected non-randomly by the key-of-contacts and the JCCA member based on their management level/position and willingness to serve as points-of-contact within their organisations for this research project. Selecting the sample was carried out randomly to cover the need for obtaining the required data from the opinions of functional experts, who are considered by their supervisors, bosses, or peers (points-of-contacts) to possess the materials management-related knowledge and expertise to provide desired information and qualified responses for their companies. This is consistent with the logic put forward by Emory and Cooper (1991) and emphasized by Plemmons (1995, p66) that "*The most appropriate application of a survey questionnaire is where conditions indicate that the respondents are uniquely qualified to provide the desired information*". Accordingly, 52 experts, managers, and professionals were selected; they were delegated by their organisations to participate in this survey. Those participants were responsible for and involved in at least one of the materials management functions or activities within those preselected under-construction 30 building projects. The questionnaire design and the process of conducting the group administrated questionnaire are discussed in **Section 5.6.1.3**.

5.6 RESEARCH DESIGN AND ADOPTED RESEARCH METHODS:

This section presents and explains the procedures that were designed to conduct the research and achieve its aim and objectives. This includes the stages of the data collection process, the steps of developing the practical E.CMM.P framework, the process of validating/evaluating the developed framework, and the pilot studies conducted.

5.6.1 The Research Data Collection Process:

The research process was designed to accomplish the aim of this research, and to do so, the research process is guided by the five main objectives as stated in **Chapter I**. For realizing the aim and objectives of this research, the overall research process was developed, as illustrated in **Figure 5.10**. The figure below presents diagrammatically the flowchart of the research process of this study, which mainly comprises; the literature review, the main investigations, the questionnaire survey, the framework development, and validation; it also translates the role of each method adopted in accomplishing the research objectives that has been previously outlined in **Table 1.1**. The bold capital title for each thick solid box represents each main task, and the detailed activities in each main task are presented inside its box (the dotted line means subsidiary activities). The document-boxes represent the outcomes of each stage. The arrows link tasks or activities which indicate their relative connections. A brief description of the research methods adopted for this research was presented in **Section 1.5**, and the following section provides further details on these methods.

5.6.1.1 Literature review:

According to Blumberg, Cooper and Schindler (2005), the fundamental part of any research project is the review of the current literature. Fellows and Liu (1999) and Neuman (2006) stress the necessity for reviewing the relevant literature. For this research, the literature review is designed to accomplish the first and second objectives through understanding the construction materials management (CMM) process, defining the typical workflow diagram of the materials management process, and to identify the evaluation mechanisms and measurement approach that have been offered to evaluate the performance of the materials management process in different industries and projects (Manufacturing Industry-M.I, Construction Industry-C.I and Industrial Projects), and then developing a theoretical set of proposed measures for Evaluating the Effectiveness of Construction Materials Management Process Performance (E.CMM.P).

As a result of the primary literature review, as mentioned earlier in **Chapter I**, the lack of related literature on building materials management became evident, in particular, the lack of references about the measurement approaches for evaluating the effectiveness of the CMM performance.

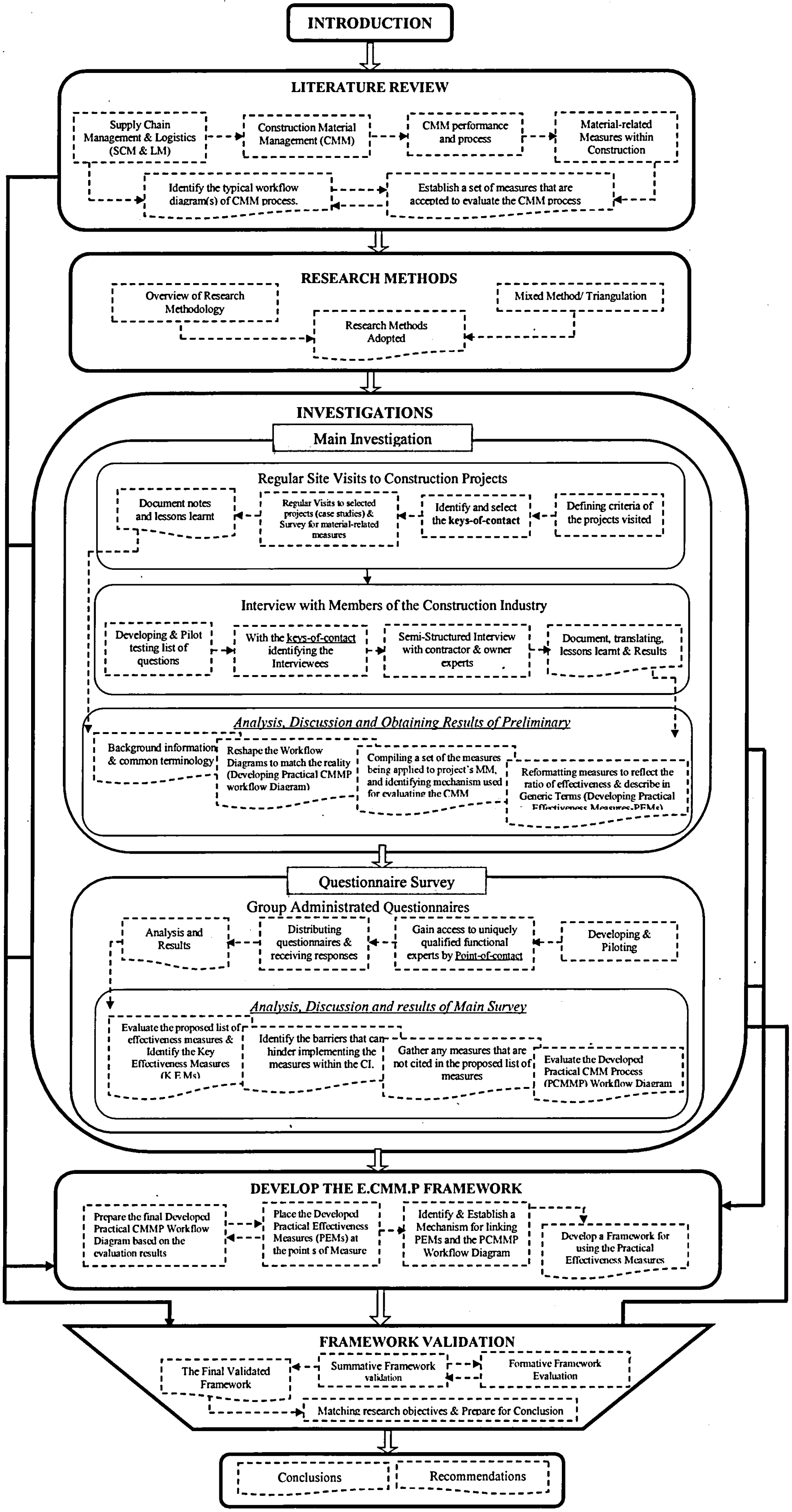


Figure 5.10: Flowchart of the Research Process

This limitation led the researcher to explore and consult relevant books, articles, research studies, and theses related to manufacturing industry and industrial projects. It is the researcher's conviction that to understand any idea properly, one should understand its roots first. Based on that, it was critical to develop a robust plan for organising the process of literature review, as graphically illustrated in **Appendix A**. This plan describes the flow chart plan of the literature review, which depicts the process of conducting literature review and identifies what is exactly to be investigated; it also explains the progressive sequence of performing the literature review from the relevant general issues: exposing the Supply Chain Management (SCM), Logistics Management (LM), and Material Management (MM) in both the Manufacturing Industries (MI) and the Construction Industries (CI) to the particular subject (evaluating the CMM process).

Based on the literature review plan, consequently, the literature review process begins with the review of literatures related to the Supply Chain Management (SCM), in manufacturing and construction industries, with emphasise on the relationship between the SCM and Logistic Management. To narrow it down, the literature review process moved to the logistics management (LM) issues, investigating in particular the relationship between the LM and CMM. Finally, the literature review process concentrated on the Construction Materials Management (CMM) process (as the focal point of the research); the evolution of the CMM process, defining the functions and activities that shape the CMM process, and investigating the existing literatures on mechanism and approaches to evaluating and measuring the effectiveness of the performance of the CMM process. The main findings of the literature review laid the foundation (the first step) for developing the framework of evaluating the effectiveness of the performance of CMM process (E.CMM.P Framework).

The literature review process is carried out through the guidance of the Sheffield Hallam University Library Catalogue. Related journals, books, and PhD thesis are reviewed. The Sheffield Hallam University Search Centre is used to access worthwhile and available facilities that contain various databases (Science Direct, Emerald Management) as well as electronic books and journals; besides, the internet search engines including the British Library ETHOS, Google Scholar, Conference Proceedings and the reports of the company.

In order to capture new issues and fill in gaps in the existing literature, the literature review was a continuous process; it was performed simultaneously with the other research processes including; the research methodology, the data collection process, the framework development process, and the validation and evaluation process.

5.6.1.2 The Main Investigation:

As the main purpose of this research project is to develop a framework for monitoring, analysing and evaluating the impact of continuous improvements in the CMM process in the JCI, it was essential, as a **first practical step**, to investigate the current practices of the CMM process and to develop a practical workflow diagram that can reflect the real-life of the CMM process that is practiced within the large-scale concrete building projects in the JCI. This step was then followed by the **second practical step**; examining and investigating the current measures, mechanisms, or approaches that are used (or can be used) for evaluating the performance of the CMM process, and then accordingly, identifying a set of the practical measures for evaluating the effectiveness of the CMM process (the Practical Effectiveness Measures (P.E.M(s)) in the Large-scale concrete building projects in the J.C.I. Therefore, the main investigation, which is planned to achieve, partly, the third and fourth objectives, is intended to;

- Identify the concerns and uncover issues to understand CMM practices in real life situations, and develop the Practical Workflow Diagram for communicating the integrated functions and activities that form the CMM process within the large-Scale concrete building projects in the J.C.I,
- Gather material-related measures, mechanisms and approaches currently in use within the J.C.I, and examine the usability of the proposed effectiveness measures within the Jordanian projects,
- Reformat and reformulate the measures and approaches to reflect the effectiveness ratio, and to establish the set of Practical Effectiveness Measures (P.E.Ms), that can be used for Evaluating the Effectiveness of the Construction Material Management Process Performance (E.CMM.P) in the Large-scale Concrete Building Projects in Jordan.

In order to achieve these objectives, the main investigation has been conducted through the case study approach using two data collection techniques: site visits and semi-structured interviews, for collecting the required data from the six building projects involved in the case study research as will be discussed in detail in the next sections.

The researcher agrees with Voss, Tsikriktsis and Frohlich (2002) position regarding access to the required data: it is vital to contact a senior to be able to obtain the data needed. Therefore, prior to start the data collection process (site visits and interviews), the **Keys-of-Contact** were selected non-randomly by the researcher based on their position and willingness to participate in the research. The majority of those keys-of-contact were contacted before starting the data collection process in Jordan, where the researcher individually contacted (via e-mail and personal call phones) those keys-of-contact, and discussed with them the aim of the research, the proposed data collection process, and their expected roles. Based on their willingness to be as keys-of-contacts, they then were provided with the primary data collection processing plan and schedule. The main roles of those keys-of-contact were; to guide the researcher through the entire journey of the data collection process in Jordan, to facilitate and arrange meetings with some construction-related decision makers, to provide an overview on the construction industry in Jordan and the system of managing the construction projects, to secure access to some relevant organisations (e.g. the JEA, and the JCCA), to participate in determining the projects to be covered in the case studies, to designate the points-of-contacts, and to contribute to the piloting process. Those Keys-of-contact included; 1) Academics: the Dean of Faculty of Engineering and Technology, University of Jordan; 2) Engineers' Association: the Assistant Secretary of the Jordanian Engineers Association and the General Director of the Engineering Training Centre; 3) Engineering Consultancy Firm: the Chief of the Development and Planning Department- SIGMA Consulting Engineers; 4) Construction Management Firm: the Client's Project Manager-SIGMA Consulting Engineers; 5) Private Construction Company: the Contractor's Project Manager; 6) Public Construction Company: the Owner's Senior Construction Manager (**See Appendix D**).

Based on a wide discussion between the researcher on the one hand and the research's Keys-of-Contact and the member of the JCCA on the other hand, the **Points-of-Contact** of each case study-project were designated. Those points-of-contact, who were selected on the basis of their management position and willingness to participate in the research, are often the contractor's project manager, the construction site manager, the owner's construction manager, or the consultant. The role of those individuals was to arrange the site visits, to identify the key individuals to attend the initial briefing and to function as the guides of the tours, to obtain the necessary approvals for conducting site visits and for reviewing the projects related-documents, and to designate the materials management experts and professionals to be interviewed.

As mentioned above, two data collection techniques were conducted within the main investigation for collecting the required data from the six case-study projects; site visits and semi-structured interviews.

1-Regular Site Visits:

The main objectives of this technique are to understand the process of managing building materials and to recognise the general features that characterise the CMM process within the Jordanian Construction Industry (J.C.I), with emphasise on the field activities, the approaches of requesting materials, the participants responsibilities, and the mechanisms currently in use for evaluating the performance of the CMM process, with no distinction made to whether these measures report effectiveness, productivity, or efficiency. Moreover, during the site tours, the researcher attempted to accrue background information and to obtain the common J.C.I-based terminology necessary to accurately describe these measures in terms of their effectiveness, and to develop the survey questionnaire. Prior to conducting the site visits, the research objectives and the purpose of the site visits were forwarded to the pre-designated points-of-contact in the six case studies; based on their feedback, the site visits' time-schedule and the plan for conducting these project visits were set up.

Depending on the circumstances, the nature of each project (case study), and the availability of the concerned staff, the site visits for the projects included different numbers of the field tours and the periods they took; the periods may last from a period of a week to seven weeks (see **Table 6.1, Section 6.2**). The site visit technique included; 1) conducting field tours to the building site, site stores, warehouses at the field level and visits to contractor home-office, purchasing department, and planning department in the main consultative office at the organisational level of each case study project, 2) reviewing various materials-related documents and reports, 3) following up the documentary cycle of requesting materials, and 4) monitoring the movement of materials within the site along with the process of storing materials in the warehouse. During the site tours, the notes, inquiries, information and the short meetings' data were recorded in the Site Visit Notebook, and a copy of the related documents and some site pictures were taken.

More details on conducting these site visits, the projects and organisations involved, and the periods and the techniques used to implement these site visits are provided in **Chapter VI**. Moreover, other details are provided in **Appendix J**, and some pictures that document the site visit processes are attached to **Appendix E**.

2- The Semi-Structured Interviews:

The second stage of the main investigation is the interview technique. Semi-structured interviews were conducted to meet the case study units; they include identifying practically the CMM process that is currently practiced within the J.C.I, and examining the measurement mechanism used in the J.C.I for evaluating the performance of this process. Therefore, this stage basically aims to obtain an overview of the practical CMM process applied, with specific emphasis placed on the materials management functions and activities. It also aims to investigate the evaluation mechanisms and related materials measures that are currently practiced for monitoring and/or evaluating the performance of the CMM process. Based on the findings, the set of the practical measures that are/or can be used for evaluating the effectiveness of the CMM performance was developed.

The interview questions were designed to meet the units of the case study research and the interview objectives. They are categorised into four main themes or sections; 1) Personal Questions, 2) Organisation's Background and General Overview, 3) Process of Construction Materials Management in the J.C.I, and 4) Effectiveness Measures of CMM Performance within the Jordan projects. For the pilot study purposes, a draft of these questions was sent to; the main director and the second supervisor of the research, three of the keys-of-contact in Jordan, and a PhD student in SHU (for more details, see Pilot Study III in **Section 5.6.4**). Based on their feedbacks, the questions were modified as demonstrated in **Appendix F**. The modifications were related to their size, the time allowed to answer questions, and the ability to obtain the required data that meet the identified objectives and their motivation.

Based on the interviewees selection criteria, as detailed above in **Section 5.5.3.1**, and with the help of the points-of-contact at each case study, the semi-structured interviews were conducted with 14 interviewees from the six case studies, including Project Managers, Construction Site Managers, Warehouse Managers, a Planner, a Civil Work Supervisor, a Executive Project Director, and a Senior Construction Manager (See **Table 6.1**). Covering letters, which include the aim and objective of the study and the guarantees for the confidentiality of the respondents together with the answers given, were forwarded to those interviewees, along with a copy of the interview questions, the list of proposed effectiveness measures, and the typical workflow diagram of the CMM process.

The interviews were conducted either individually or in groups of two interviewees (for those who share the same case study). These interviews lasted from three to six hours and were documented by using a digital voice recorder. The interviews were recorded in Arabic, loaded into the researcher's lap-top computer, and then transcribed into Microsoft Word format in both Arabic and English languages. The interviews were translated by the researcher, in the first place, and then they are corrected by an independent translator. For confidentiality and ethical purposes, the interviews were formatted and coded to remove any names and references to any specific individual or organisation.

5.6.1.3 The Questionnaire Survey:

In order to gain a wider response from the functional experts within the J.C.I, the main investigation is followed by a questionnaire survey. The questionnaire was designed based on the findings that were obtained from the two previous phases; the literature review and the case study research. The questionnaire survey aims to <u>partly achieve the fourth and fifth objectives of this research project</u>, including; I) evaluating the proposed effectiveness measures through assessing the respondents' perceptions of utilizing these measures, the role of the measures in communicating the effectiveness of the CMM performance, their practicality as implemented in the J.C.I, in addition to explore the barriers that hinder their implementation. This, in turn, leading to confirm the validity of the proposed set of effectiveness measures that have been established from the literature review process; II) carrying out the formative evaluation (the first stage of the validation process) through assessing the practical workflow diagram of the CMM process within the J.C.I, that has been developed from the findings of the case study research, and considered as one of the main components for developing the framework of evaluating the CMM performance.

In order to accomplish the above objectives, the survey was designed to comprise four sections: *Section 1*: it includes a set of instructions for filling the questionnaire and the exploratory questions in relation to the respondent's personal information; *Section 2*: it evaluates the proposed set of measures in terms of their usability, importance in communicating effectiveness, practicality to be implemented, and explores the barriers that hamper their implementation; *Section 3*: it identifies the additional measures that are not included in the proposed list of measures; *Section 4*: it assesses the practical CMM process workflow diagram that has been developed through the main investigation, in terms of its ability to embody and reflect what is currently practiced in the real-life of the CMM process within the large-scale concrete building projects in the J.C.I. Under these four sections, the questionnaire's questions were designed by the researcher and piloted by the main director and the second supervisor of the Research, three of the keys-of-contact in Jordan, and a PhD student in SHU (for more details, see Pilot Study III, **Section 5.6.4**). Based on their feedbacks, the questions were modified, as demonstrated in **Appendix G**. The modification was related to the shape of the questionnaire, the sequence of questions, the answer spaces, the size of the questionnaire and the time limitations.

As explained earlier, the Group Administrated Questionnaire was conducted to collect the required data from the concerned functional experts. The first step to access the experts and professionals was the designation of the points-of-contact in each pre-selected building company. Conducting the questionnaire survey started by sending invitation letters to the participants in the survey; the letters were sent by JCCA to the pre-selected points–of-contacts in those pre-selected building organisations. The invitation letters presented the research's overview, purpose, and benefits, and asked the points-of-contracts to delegate one or more of the material-related functional experts from their organisations to participate in the survey. The researcher emphasized the necessity to select those experts based on their knowledge in one or more of the integrated building material management functions. As a result of the points-of-contact efforts, 52 experts, managers, and professionals were delegated to participate in this survey.

Based on the personal contact between the points-of-contact and the researcher, the date and place of the meeting (for performing the survey) in each Governorate were specified. According to their governorates, the relevant points-of-contact were asked to send their functional experts on the identified date to the identified place. Six sessions of the Group Administrated questionnaire were conducted within the six pre-selected Jordanian governorates. During each survey session, the researcher gave a PowerPoint presentation explaining the purpose, objectives, data collection process of the research, and the instructions for filling out the questionnaires. This was followed by handing the questionnaires with the appendix documents to the participants by the researcher's assistants (the researcher's best friend and two volunteers; civil engineering students). For the purpose of clarifying ambiguous questions or measures, the researcher was available all the time while filling out the questionnaires. Finally, the researcher and his assistants collected the completed questionnaires from the participants. The data available in these questionnaires was prepared for analysis process involving; observing, sorting, grouping, and developing the code book, as explained and described in detail in **Chapter VII**.

The findings that were obtained from the data collection process, whether the literature review, the main investigation and the questionnaire survey constitute the basis for developing the framework of evaluating the effectiveness of the CMM process Performance (E.CMM.P framework) within the large-scale building projects in the Jordan, as outlined in the next stage of the research process.

5.6.2 Developing the E.CMM.P Framework:

Developing a framework for communicating the integrated CMM functions and operating their practical effectiveness-measures, for evaluating the performance of the construction materials management process (E.CMM.P), fulfils the fifth objective of the study. The development of the framework was a result of integrating the practical Effectiveness Measures (P.E.Ms) and placing them at the points of measurement within the practical workflow diagram of the CMM process, using an operational mechanism for communicating and operating the P.E.Ms within the practical CMM diagram.

The developed E.CMM.P framework consists of three key components; *The Main Body,* (the Basic Structure: a practical CMM workflow diagram), *The Main Elements* (a set of practical effectiveness measures), and *The Links* (Operational Mechanism), those components are detailed on **Section 8.1**. The framework development is achieved gradually through case study research findings supported by an extensive literature review of the materials management processes and measures as well as the benchmarking techniques. The process of developing the E.CMM.P framework was sequentially conducted through the research on six main stages, which have been numbered on the basis of the sequence of their implementation in the process of achieving of the research project;

1. *The First Stage*: Defining **theoretically** the typical workflow diagram(s) of the materials management process in the construction industry. The theoretical CMM process diagram was determined based on the extensive literature review which identified the functions and activities that shape the typical CMM process workflow diagram, as discussed in **Chapter III** and illustrated in **Figure 3.6,**
2. *The Second Stage*: establishing **theoretically** a proposed set of measures to evaluate the Effectiveness of the Construction Material Management Performance (E.CMM.P) in the building projects. For this stage, an extensive literature review was carried out to identify and critically assess the material-related measures used in the construction industry (or may be in other industries), and then to develop a set of effectiveness measures proposed to evaluate the effectiveness of the CMM performance, as explained in **Chapter IV** and shown in **Table 4.16,**
3. *The third stage*: developing the practical workflow diagram that can reflect the real-life of the CMM process that is practiced within the large-scale concrete building projects in the Jordanian Construction Industry (J.C.I). This stage is based on the findings that have been derived from the case studies-cross analysis, as discussed in **Chapter VI,**
4. *The fourth stage*: establishing the practical set of measures that can be practically used for evaluating the effectiveness of the CMM performance in the Large-scale Concrete Building Projects in the J.C.I. This was derived by investigating the effectiveness measures that are currently used in the case studies, and by discussing the possibility of the practical application of the proposed set of effectiveness measures to the Jordanian building projects (see **Chapter VI**),
5. *The Fifth Stage*: setting out an operational mechanism for communicating the practical Effectiveness Measures (P.E.Ms) and integrating them within the practical workflow

diagram of the CMM process at the points of measurement (see **Chapter VIII**), and developing the E.CMM.P framework,

6. *The Final stage*: conducting the validation process. This includes evaluating the body and the elements of the E.CMM.P framework (during the development stages) using the questionnaire technique (see **Chapter VII**), and evaluating the actual final developed framework based on the feedback obtained from the experts involved in the evaluation (see **Chapter IX**).

These six stages are grouped under four phases. The phases of developing the E.CMM.P framework are described in **Figure 8.1**, and discussed in detail in **Chapter VIII**.

5.6.3 Validity of the Research and the Framework:

5.6.3.1 Research Validity and Reliability:

Validity:

Generally, *research validity* is conceived as the accuracy or correctness of the research findings (Ritchie and Lewis, 2003). According to Punch (1998), Winter (2000), and Sweis et al. (2014), validity is concerned with two main issues: whether the instruments used for measurement are accurate and whether they are actually measuring what they want to measure. "*An instrument has content validity if researchers agree that the instrument is made up of a group of items covering the issues to be measured*" (Sweis et al., 2014, p179). The concept of validity is the same for both research traditions whether quantitative or qualitative (Ali, 2011). He further argued that in quantitative research, a valid instrument is one which actually measures what it claims to measure. Similarly, in qualitative research, a study is valid if it truly examined the topic which it claims to have examined. To ensure the validity of the questionnaire and interview, the researcher used the available literature, where the interview and questionnaire were designed based on concepts derived from literature review related to the research topic, and they were validated through pilot studies. In order to obtain a high level of valid information in this research, highly experienced professional and experts, who are knowledgeable and have been working in the J.C.I over long of time, participated in the interview sessions and in filling the questionnaires. Moreover, the validity of the questionnaire was, statistically, measured using and 'Chi-square goodness-of-fit' test (see **Chapter VII**; **Section 7.1**)

Reliability:

With regard to *research reliability*, it is known as to what extent the research findings can be replicated, if another study is undertaken using the same research methods (Ritchie and Lewis, 2003; Sweis et al., 2014). Similarly, "*an experiment is considered reliable if it yields consistent results of the same measure*" (Sweis et al., 2014, p179). Ali (2011) and Bryman (2008) argue that reliability refers to the consistency of a measure of a concept, and the ability of an instrument to produce consistent results whenever it is repeated. Furthermore, the reliability of the questionnaire was, statistically, measured using Cronbach's alpha measure (for more details, see **Chapter VII**; **Section 7.1**).

5.6.3.2 Assurance of Research Validity and Reliability:

To complete this research project successfully and to develop a validated framework, it is necessary to insure the validity and the reliability of the research information. To do so, many considerations were taken into the researcher's account to obtain valid and reliable information, among those are; *1) Triangulation*: multiple approaches have been undertaken to collect the data and to investigate the research issue from different angles and strengthen the validity of the findings; *2) Multiple Case Studies*: multiple and representative case studies have been selected to obtain the qualitative data, which helps to cover the most issues related to the study and increase the probability of generalisation; *3) Pilot Studies*: the use of the pilot studies to ensure the questionnaire are suitable to obtain valid and reliable data, and all the questions posed in the interviews were directly linked to the research's aim and objectives and covered all aspects of the topic; *4) Experiences/Professionals*: the selected respondents and interviewees are high experienced professionals; *5) Electronic Instruments and Software*: a digital voice recorder was used for the interviews, and computer software was used for analysing the quantitative data (SPSS) and qualitative data (Nvivo); *6) Transcription*: the qualitative data was transcribed with a high degree of accuracy; the interview data was transcribed by the researcher, and then rechecked by certified professional translator. Moreover, one of the transcriptions was rechecked with an interviewee to ensure the accuracy and the correctness transcription; *6) Validity and Reliability Test*: 'Cronbach's alpha' was used to examine consistency of a measure (reliability), and 'Chi-square goodness-of-fit' was used to test the validity during the questionnaire analysis.

The validity and reliability of the data collection and analysis techniques and resulted obtained are mentioned and illuminated during the discussions of the qualitative and quantitative data analysis in **Chapter VI** and **VII.**

5.6.3.3 Framework Validation:

The framework validation process, mainly, aims to assess the applicability and appropriateness of the developed 'E.CMM.P Framework'. The validation process includes two main types of validation techniques;

Formative Evaluation: it was carried out during the development stage (upon the output of each stage) before the final actual development takes place. This could be derived from the results of the questionnaire survey through evaluating the proposed list of the effectiveness measures, and the practical workflow diagram of the CMM process within the large-scale concrete building projects in the J.C.I, in addition to gathering any additional measures that are not cited in the proposed set of measures. This seeks to obtain wider expert's notions and opinions about whether the practical CMM diagram can reflect the real-life CMM process within the J.C.I, and the extent of practicality and usability of the proposed effectiveness-measures.

Summative Evaluation: the final stage of the research design is the evaluation of the actual final developed framework. This approach aims to test the appropriateness and applicability of the developed E.CMM.P framework for evaluating the effectiveness of the performance of the CMM process within the Jordanian building projects, and to assess the likely benefits of using the framework to enhance monitoring the continuous improvements that can be applied on the CMM process. This evaluation was conducted through sending the developed E.CMM.P framework to highly experienced professionals and functional experts. Those selected evaluators were asked to assess the framework through the following specified criteria: the framework's effectiveness, its applicability (possibility of its application) and usability, the main benefits, the barriers impeding the use of the framework, and the availability of all documents necessary for operationalizing this framework. The evaluators' comments and recommendations on the framework were obtained and analysed.

Chapter IX provides more details on the validation process, including its objectives, the implementation procedures, data collection and analysis, and the findings obtained.

5.6.4 The Research Pilot Studies:

In order to ensure the success of the research techniques design whether a questionnaire or an interview study, pre-testing or piloting is urgently needed, whether before or during the research project (Bryman, 2008; Knight and Ruddock, 2008). Woken (2009) (cited in Ali, 2011, p177) summarises the main benefits of using a pilot study in survey research, as follows;

- Pilot studies allow the researcher to verify the adequacy of instructions to interviewees or to respondent's completing a self-completion questionnaire; it evaluate how well the questions flow and whether it is necessary to move some of them around.
- Piloting an interview schedule can provide interviewers with some experience concerning its use; it can also give them a great sense of confidence.
- A pilot study allows such questions to be identified; during the interview survey, it might be possible to find some uncomfortable questions that can lead to losing the respondent's interest.
- Piloting the structure and the questions of the questionnaire or the interview allows the researcher to determine the ambiguous questions that can be skipped by the participants because of the confusing or threatening phrasing, the poorly worded instructions, or the confusing positioning in the questionnaire or interview schedule.
- A pilot study can generate ideas about the proposed statistical and analytical procedures; it might as well augment the opportunity for obtaining clearer findings in the main study.
- It usually provides the researcher with enough data for deciding whether to go ahead with the main study; the pilot study, thus, saves a lot of time and money.
- Pilot studies allow the researcher to detect unexpected problems and give researchers the opportunity to redesign parts of study to overcome them.

5.6.5.1 Pilot Studies Conducted in the research project:

The purpose and structure of the pilot studies differ from one research to another. They also rely on the type of the research and the structure of the methodology adopted (Fapohunda, 2009). In the present research, four pilot studies are conducted at different stages and for different purposes;

Pilot Study I:

This pilot study is the initial research pilot study that was carried out at the beginning of the research within the Libya Construction Industry (LCI). The study mainly aimed to familiarise the researcher with the research environment, to expand the researcher's knowledge about the Libyan and Arabic CMM process, to specify the pivotal points which need to be addressed in the research, and to enable the researcher to obtain the principal information, clarifications, and issues on the study's research problem(s). This pilot study involved: 1) conducting unstructured interviews with some decision makers in the Libyan Construction Industry, among them are the Ex-General Director of the Research Centre for Building Materials in Libya, the Secretary-General of the People's Committee for Housing and Facilities–the Central Zone, and the Senior Manager of the Technical Affairs and Planning Department in the Great Man-made River Authority–Central Zone; 2) visiting three large-scale construction projects (a Public Housing Project; a Semi-Public International Investment project, a State Project), and conducting certain informal conversations with some material-related professionals (see the pictures in **Appendix H**).

One of the most important outcomes obtained from this case study are that; although there are some general regulations, there is no a Libyan standard or a specific regulation for managing materials within the construction site; the lack of specific parameters or unified measures for evaluating the extent of the effectiveness of any change or strategy that might be applied on the materials management process to improve its performance; and there is no similar work or study has been carried out in the Libyan Construction Industry to measure the effectiveness of the performance of the CMM process. Pilot study I helped the researcher to develop the substantive research problem, and to further support the research contribution to society (more details on this pilot study are provided in **Chapter I; Section 1.1**).

Pilot Study II:

The second pilot study was considered as the main gate and the first step to get involved in the Jordanian Construction Industry environment. Prior to begin performing the data collection process in the Kingdom of Jordan, it was necessary to obtain an overview about the features of the Jordanian Construction Industry (J.C.I), in particular, the systems that were used for managing the building materials there. Pilot study II included individual interviews with some decision makers related to the Jordanian Construction Industry (J.C.I) including the chairman of the Jordanian Construction Contractors Association, the Assistant Secretary of the Jordanian Engineers Association, and The Senior Consultant of JCI, besides the Owner of the First and Oldest Construction Management (CM) Company in the Kingdom (see some pictures in **Appendix I**). Moreover, Pilot II included organising a meeting encompassed some of the decision makers above and the keys-of-contact. The meeting included 30 minutes PowerPoint presentation was presented by the researcher focused on the research objectives, the concept of measuring the effectiveness of the performance of the CMM process, and the proposed effectiveness-measures that resulted from the literature review process, in addition to a discussion lasted for more than two hours (see some pictures in **Appendix I**).

Among the most important topics raised through the pilot study were: the situation of the construction sector in Jordan and the Arab region; the construction management systems and the standards used, the contractors classifications and conditions, the National Construction Law, the classification of the construction projects, the standards that guide the construction management process including the materials management, the distribution of the building projects in the Jordanian Governorates, and many others. Besides, discussing the issues about conducting the research data collection process and the accessibility to the concerned organisations, projects, and data required. The findings of this pilot study confirmed what was concluded by pilot study I, but in Jordan; there is no study that addresses the topic of evaluation the CMM process, the lack of the government or public standards for classifying the construction projects in terms of their size in the JCI, and although there are some general regulations, there are no unified standards, guides or specific regulations for managing the building materials within the Jordanian construction sector.

Pilot study II assisted, somehow, in many aspects in performing the data collection process including designing the data collection process, determining the locations for undertaking the case study research, setting up the criteria whereby the contractors and projects were selected, obtaining the necessary permissions to access any relevant organisations or projects, and opening the door to access the right informed respondents and gather the required data. In addition, Pilot II helped in obtaining the first impression about the acceptance of the concept of measuring the performance of the CMM process.

Pilot Study III:

The third pilot study was conducted within the research data collection methods at two different times: at the interview design stage and the questionnaire design stage. The main objective of this pilot study is to ascertain the suitability and adequacy of the interview and questionnaire questions and the instructions that were planned for the research data collection. The drafts of the questionnaire and the interview, a list of the proposed effectiveness measures, and a workflow diagram of the materials management functions were sent to the pilot study participants. The participants in this pilot study are; academics: the main director and the second supervisor of the research; the functional experts: three of the keys-of-contact of the research in Jordan; and a construction management-related PhD student: one of the researcher's colleagues. Those pilot study III participants were asked to review the drafts of the questionnaire and the interview questions in terms of their size, the time allowed to answer the questions, their ability to obtain valid answers and the required data that meet the identified objectives and their motivation. Pilot study III assisted in refining the questionnaire and the interview design and in developing the final questionnaire and interview questions (e.g. improving the shape and layout of the questionnaire, the sequences of the interview questions, the answer spaces, and the wording of statements).

Pilot Study IV:

The fourth pilot study was undertaken within the stage of the development of the framework for evaluating the effectiveness of the CMM performance. This study was used for piloting the validation process of the E.CMM.P framework, in particular, the summative evaluation. The purpose of pilot IV was to check if the questions were adequate for validating the developed E.CMM.P framework, the ability of the question design to derive the data needed for evaluating the framework, and the capability of the questions to evaluate all the framework features and aspects; besides, obtain opinions and ideas about the method of conducting the evaluation process and the style of presenting and analysing the feedback obtained. A draft of the evaluation's questions that were designed for the summative evaluation and a copy of the developed E.CMM.P framework were sent to the research director and to a person who was suggested to be among those who are involved in the summative evaluation. The feedback obtained from this pilot study was used to refine the evaluation questions.

5.7 ETHICAL CONSIDERATIONS:

The research study received fully ethical approval prior to its commencement; 'Research Ethics Approval' for the PhD was applied for and approved by the Sheffield Hallam University. In order to avoid any ethical issues, many related considerations were taken into the account, and number of procedures was adopted while conducting the research. The majority of these considerations were taken during conducting the data collection process. For the purpose of conducting the main investigation (site visit and interview), approval was sought from appropriate authorities, such as the JCCA, JEA, and the construction contractors selected. Having obtained approval from the concerned organisations, formal requests were served to the project managers representing the contractor-organisations (points-of-contact) seeking consent to access the projects' sites, meeting the site staff, and to have interview discussions which would be recorded on a digital device. For questionnaire survey purpose, a consent clause was included in the cover-page of the questionnaire (the introductory section), and the participants consented to the clause before filling the questionnaire. The documents, related forms, and reports used in the writing of this thesis were obtained from the appropriate authorities directly or extracted from formal websites. Besides, any statements and clauses cited were properly referenced. All comments and notes, whether that were extracted from documents or those observed during the field tours, were properly acknowledged. The photographs that appear in this thesis were collected directly during the field survey and verbal consent was sought where necessary before taking the shots. In addition, the Keys-of-contact are happy and comfortable to mention them (writing their names and positions) in the thesis.

Finally, the confidentiality and anonymity of the respondents was cautiously taken into the consideration during the analysis and the discussion. For the interviewees, relevant initials were adopted to represent the actual names of the interviewees. The names and the distinctive characteristics of the survey respondents were hidden. The responses, which were obtained from the interviewees and the survey participants, were only used for the purpose of this research only. As far as I am aware, no participant was forced to participate, and all the respondents were entitled to withdraw from the study at any time. All subjects consented to participation and confidentiality and anonymity has not been compromised in any way, and all data were confidently stored and will be secretly destroyed once the research has been completed.

5.8 SUMMARY OF THE CHAPTER:

This chapter has described the research methodology and discussed the research methods adopted for this study. It displayed a nested approach to research design that highlighted the three main themes, the research philosophy, the research approaches, and the research techniques. An overview of the different research philosophies and paradigms has been provided. In order to achieve the research aim and objectives, the research data collection process was designed. This chapter also outlined the characteristics of the quantitative, qualitative and triangulation strategies. The adoption of the research methodology and the selection of the research approaches and techniques were explained and justified in this chapter. The research design and the methods adopted were presented under the four main titles: 1) The Research Data Collection Process; including the literature review; the main investigation (the case studies); and the questionnaire survey; 2) Developing the E.CMM.P Framework; 3) The Research and Developed Framework Validation; 4) The Research Pilot Studies. In this chapter, more emphasis has been placed on illustrating and explaining the selection on the multiple case study strategy including: the *components* of the case study design; the case study *protocol* (region, organisation and project identification, the data collection techniques, and the case study data analysis); and the *framework* for designing, collecting and analysing the data of the case studies. Besides, the research ethical considerations were outlined.

The next chapter focuses on presenting and discussing the data collected from the six case studies. It describes the raw data of each case study based on the 'units of analysis', including Project Description/Background, Organisation Profile, Data Collection Process Procedures, the Practiced Process of Construction Materials Management, the Mechanisms/Approaches Currently in use for Evaluating the CMM Performance; and the most common Terminologies used. It also explains the development of the practical workflow diagram of the CMM process and the development of the practical effectiveness-measures (PEMs) in the J.C.I.

CHAPTER VI:

QUALITATIVE DATA ANALYSIS AND DISCUSSION

6.0 INTRODUCTION TO THE CHAPTER:

As stated in '**Chapters I** and **V**', the implementation of the qualitative research (the main investigation) aims to accomplish the third and fourth research objectives. **Chapter VI** is mainly designed to present both the qualitative data analysis and discussion. However a quick overview on the Jordanian Construction Industry, the construction management practices, and construction projects and organisations in Jordan is outlined at the beginning of this chapter.

At the first place, the chapter focuses on displaying the qualitative data analysis process through presenting the key findings obtained and the lessons learnt from the research main investigation process using the Case Study approach (Site Visits and Semi-Structured Interviews). Here, the chapter provides a description for one of the six large-scale concrete building projects that were selected as case studies. Case Study C is displayed as an example to illustrate how the data collected and lesson learned from each case study are individually reported based on the six key report-categories. The rest of the case studies' reports (Case A, B, D, E, and F) are displayed in **Appendix J**. The step of documenting and reporting the case studies' data collected is considered as basis to discuss the data and findings that have been obtained from the research main investigation.

Secondly, this chapter provides an in-depth discussion of these qualitative research outputs towards achieving the above research objectives, which represent the third and fourth stages of the process of developing the practical E.CMM.P framework (as pointed out in **Chapter V**; **Section 5.6.2**). Consequently, the chapter starts with presenting the case study projects report, and then moves to discuss the investigation's findings, and to explain the development of the Practical Workflow Diagram of the CMM Process that is practiced within the Jordanian large-scale concrete building projects, in addition to describe and explain the process of establishing the set of the Practical Effectiveness Measures (PEMs), which can be practiced in those projects. Finally, it presents a summary of the chapter.

6.1 AN OVERVIEW OF JORDANIAN CONSTRUCTION INDUSTRY:

Despite the severe lack of literary studies on the management of materials in the construction industry in Jordan, this section provides a brief overview on the Jordanian

Construction Industry (JCI) as the research main case study, including giving a quick overview of Jordanian construction contractors and building projects, the practices of the construction management, and the scope of materials management in Jordan.

6.1.1 Jordan Location:

Jordan, a Middle Eastern kingdom, is called officially the Hashemite Kingdom of Jordan. It is sandwiched between Syria and Iraq in the north, the Kingdom of Saudi Arabia in the south and east (its longest border), and the Occupied Palestine (including the West Bank of the Jordan River) in the west. Jordan has an area of 34,445 square miles (89,213 square kilometres) with only 16 miles (26 kilometres) coastline along the Gulf of Aqaba in the south (Najmi, 2011; Encyclopedia of the Nations, 2015). According to the Department of Statistics: Jordan Statistical Yearbook (2013), the population of Jordan in 2013 was estimated to be 6,530,000, of which 82.6 percent are in urban (Urban Population).

Figure 6.1: Jordan's Map: The International Boundary (Maps of World, 2014)

Jordan is considered a modern nation, with a predominantly urbanized society. The CIA World FactBook classifies the Kingdom as an emerging market with a free market economy, and it has more free trade agreements than any other country in the region (Najmi, 2011).

6.1.2 Jordan Construction Industry (J.C.I):

The development of the construction industry in Jordan may go back to the period of Jordan's independence (Ashraf and Belluardo, 1998; Alsubeh, 2013). It started with the launching of the project of modernizing Jordan that was developed by 1st king Abdullah (Kalia, 1999; Prakash, 2002; Alsubeh, 2013). 1st king Abdullah believed that industrialization and urbanization are the key indicators of development, and the construction sector is the responsible to move the country towards a modern national identity (Ashraf and Belluardo, 1998; Kalia, 1999; Alsubeh, 2013). The Jordanian Construction Industry (JCI) continued to grow steadily through the oil boom in the 1970s, helped by the economy through the remittances flowing into the kingdom from Jordanian workforce that working in the Arab and Gulf countries (Najmi, 2011; Encyclopedia of the Nations, 2015).

Recently, the construction sector became one of the most active sectors and the essential drivers of the Jordanian national economy. It has grown to be the sector that responsible for millions of jobs (It provides jobs for more than 12 percent of Jordan's work force) and a significant proportion of the gross domestic product in the kingdom (Sweis et al., 2008, p665; Petra Agency News, 2010; Najmi, 2011). According to Attar and Sweis (2010) and the Department of Jordanian Statistics (2012), the construction sector accounted for 4.6 per cent of the GDP on average over 2002-2011. "*The sector has achieved an average growth rate of 13.3 per cent over the same period*" (Sweis et al., 2014, p176). The construction sector managed its position in 2013 relative to the previous year through increasing its percentage in the GDP to hit 5per cent (Department of Statistics: Jordan Statistical Yearbook, 2013), and it may increase to reach 8.3% of GDP in the next few years (Alkilani, Jupp and Sawhney, 2013).

The Jordanian construction sector has the support of the government through a true partnership with the private sector with the Jordanian Construction Contractors

Association-JCCA, which includes more than 2,619 (JCCA Annual Report, 2012) contractors; the Jordanian Engineers Association-JEA, which comprises about 6590 registered engineers (JEA Annual Report, 2011); and engineering offices, which has about 1,199 offices (Jordan Engineers Association (JEA), 2011). The associations that form the structure of the construction sector are tied to the Ministry of Public Works and Housing (MPWH) (Alkilani, Jupp and Sawhney, 2013).

6.1.3 Construction Management in the J.C.I:

The growth of construction industry, which was witnessed during the boom that occurred recently in Jordan, has encouraged investment in the construction sector and raising the importance of deploying construction management philosophies within the construction contractors and projects (Sweis et al., 2014). Moreover, because of the rising complexities of the construction business, management principles began to evolve more effectively (Najmi, 2011), which led to an increased interest within the Jordanian construction management community in exploring possibilities for applying knowledge gained from manufacturing and other industrial sectors to the field of construction management (Abdel-Salam and Gad, 2009; Heravitorbati et al., 2011; and Sweis et al., 2014). Recently, the implementation of the construction project management became essential in the majority of the complicated construction projects in the J.C.I.

In Jordan, the main construction contractors play a major role in managing their construction projects, including planning, field control, quality control, procurement, warehousing, and building materials management. However, given the prevailing perspective by the contractors that "*construction projects are hardly ever constructed as designed*" (Abu Hammad et al., 2008, p251), the existence of specialist and experienced entity in managing the construction projects became necessary. This led to increase the number of the experienced construction management companies (PMs) and consultant offices in the JCI. These construction management companies could represent a contractor or an owner, and they are responsible for the overall planning, coordination, and control of a project from commencement to completion in order to produce a functional project on time and within the allotted budget. This includes enhancing a construction project through: Budget management, Scheduling the project in logical steps and planning the time required to meet deadlines, Enhancing project design and construction quality, Managing procurement and construction materials, Inspecting and reviewing the project to monitor compliance with building, quality, safety codes, and other regulations, and Managing document control (Jordan and Associates Consulting, Inc, 2015).

6.1.4 Jordanian Construction Materials Management in Literature:

There is very little published works that comprehensively addressed the materials management specially the process of CMM and the factors that affecting the effectiveness and the quality of its performance in Jordan as well as the Middle East region (Sweis et al., 2008; Sweis, et al., 2014). This could be due to the lack of standardized functions and unified activities that can form the CMM process in Jordan. Yet, some studies that have been conducted in Jordan illustrate the importance and the necessity of managing the construction materials in the Jordanian construction projects. Among those, the study that conducted by Ministry of Housing and Reconstruction in 2013, and that found that the waste materials on Jordanian construction sites increased between 11.5% to 15.2%, during the period between 2010 to 2012 (cited in Bekr, 2014, p2). Likewise, Bekr (2014, P1) concluded from his study, which involved 240 Jordanian clients, contractors, and consultants that "*the percentage of wastage materials is accounted for by values between 15% and 21% on Jordanian construction sites*". The study exposed that the ten most important causes of materials wastage on the Jordanian construction sites were: 1) frequent design and client's changes; 2) rework due to workers mistakes; 3) poor contract documents; 4) wrong and lack of storage of materials; 5) poor strategy for waste minimization; 6) shortage and lack of experience of skilled workers; 7) poor site conditions; 8) damage during transportation; 9) theft and vandalism; and 10) mistakes in quantity surveying and over allowance. The majority of these cases could be due to the lack of the construction materials management, thus, an effective construction materials management system becomes mandatory and should be the first concerns for the Jordanian construction managers (Bekr, 2014).

Moreover, in the literature, there is no consensus on identification the problems and factors that affect the CMM system in the Middle East countries including Jordan (Sweis et al., 2008). However, there are few studies, such as Al-Haddad (2006) that revealed some problems that can be reduced when construction contractors practicing an effective construction materials management system: materials not available, materials not available with required quality and quantity, late delivery to the site, deliver wrong materials, destroyed materials when delivered, and slow response about submittals. In addition, a study conducted by Abu Hammad et al. (2008) concluded that due to that "*construction contracts in Jordan give the owner the right to modify, add and delete work items at anytime via a Variation Order (VO),.... thus, Variation Orders (VOs) are inevitable in all Jordanian projects*" (Abu Hammad et al., 2008, p250). This largely affects the efficiency and the effectiveness of the construction materials management system used.

Consequently, it can be concluded that; spite of the lack of the studies related to the CMM process and its evaluation in the literature, there is a consensus by the studies exist that there is a growing awareness in the Jordanian construction sector that construction materials management should be addressed as an integrated management process, and its performance should be continuously monitored to encounter; materials wastage, high interest rates, rising prices of materials, material shortages, competition, and many other challenges.

Regarding to the scope of materials management process within the J.C.I, as in the most countries, the system of construction materials management in Jordan comprises the major functions of identifying, acquiring, distributing, and disposing of materials on a construction site (Al-Haddad, 2006; Stukhart, 1995). The scope of CMM system can be released from the definition of materials management as "*a system for planning and controlling all of the efforts necessary to ensure that the correct quality and quantity of materials are properly specified in a timely manner, are obtained at a reasonable cost, and are available at the point of use when required*" (Al-Haddad, 2006, p15-16). As mentioned above, due to lack of standardized functions that form the CMM process in the Jordanian projects, each construction company has its particular materials management system. Yet, in the majority of the building contractors, the responsibility for the various CMM functions is usually divided between the departments of planning, purchasing, and construction, and it usually includes materials planning, material receiving and handling, procurement, expediting, warehousing and inventory management, and transportation (Al-Haddad, 2006).

6.1.5 Construction Projects and Contractors in Jordan:

The rising price of oil during the 2000s coupled with emergence of the World Trade Organization and restructuring of economies yielded unprecedented growth in construction activities, especially in the tourism, the curative tourism, and the residential sectors. In addition to, the recent events in the Middle East (The Arab spring = The Arab Mess, from the researcher's point of view), which made Jordan is one of the most stable countries in the Middle East, have attracted considerable amounts of investments from surrounding countries. Consequently, "*a huge number of large-scale projects are currently under construction or in the planning and contract-awarding phase*" (Sweis et al., 2008, p665). This growth in the construction sector could be clearly witnessed through the noticeable increasing of the Gross output of the registered construction contractors 2012; 1584 million JD (Bank Audi, 2014).

According to the Jordan Economic Report, which provided by Bank Audi (2014), the large-scale overseas investments, combined with increased State spending on investment and infrastructure projects, resulted in the Jordanian construction industry shifting its focus from the capital Amman, which had long been the centre of large-scale building projects, to other Jordanian Provinces. This led to the establishment of many large-scale construction projects in several Jordanian provinces, such as; the port city of Aqaba: a project of gas pipeline to bring Iraqi oil to the Aqaba port; the Dead Sea zone: huge projects of tourism therapeutic; and Jarash and Ajloun: Projects of development and investment for the archaeological and historical sites.

Abu Hammad et al. (2008) classified the types of the construction projects into three main categories; 1) Residential Construction Projects: villa and housing type projects; 2) Building Construction Projects (Non-residential): commercial and plant projects, hospitals, schools, malls, and hotels; 3) and Non-Building Construction Projects: infrastructure, highway construction, heavy, public and military projects". Although both the public and private sectors can execute these construction projects, more than 60 per cent of all construction projects in Jordan are implemented by private sector (Alsubeh, 2013).

Although a big number of the Jordanian construction contractors are "*independent, small in size, and often resorts to under-bidding rivals to win contracts*" (Sweis et al., 2008, p668), the growth of the large-scale construction projects in Jordan (as stated above) led to growth in the number, size and diversity of the construction contractors. Construction contractors in Jordan are registered and classified into six grade classes according to the Jordanian Construction Contractors Association (JCCA) and the Ministry of Public Works and Housing (MPWH). Grading is based on a contractor's registered capital, financial status and assets, administrative and technical staff, and qualifications and expertise provided (Abbasi, Abdel-Jaber and Abu-Khadejeh, 2005; Department of Jordanian Statistics, 2012; JCCA 2012; Alkilani, Jupp and Sawhney, 2013). The classification system ranges from 'Grade 1', which designates the largest in size and most experienced contractors that are qualified to undertake all the large-scale projects , to 'Grade 6', designating the smallest (JCCA 2012; Alkilani, Jupp and Sawhney, 2013).

6.2 CASE STUDY DATA COLLECTION METHODS:

As discussed in **Chapter V**, for achieving the essential purposes of the main investigation, a case study approach was adopted. The previous chapter, in particular in **Sections 5.5.2** and **5.5.3,** critically discussed the choice of a multiple case study strategy, the selection of its affiliated data collection techniques, and the scheme of the case study protocol for designing and analysing data while conducting the case studies in this research project, in addition to the selecting criteria of the six case studies involved. Regular site visits and semi-structured interview are the two data collection techniques that were employed for collecting the required data from the six building projects involved in the case study research.

Generally, the site visits to the six case study projects included field tours to the construction site, the company's warehouse, the company's home-office, following up the documentary cycle of requesting materials, and monitoring the movement of materials within the site. The guided tour usually follows the logical flow of information and materials on the project site, and this involved holding short meetings with many materials-related professionals. According to the data collection plan, site visits were performed by the researcher, his assistant (a friend of him) and one of the keys-of-contact. **Table 6.1**, below, provides some details on the data collection techniques used for each case study project. It can be noted that the site visits, which were conducted for the projects, included different number of field tours that lasted for different periods of time, whereby the period of observation lasted from a week to seven weeks. This difference occurred due to the circumstances, the nature of each project and the availability of the concerned staff. For example; because of the security of the project in 'Case Study C', the process of collecting data just included four full-day site visits within a week and one interview session; the unavailability of the majority of concerned staff due to their preoccupation within intensive executing works (to compensate for the period of suspension of the project), led to gathering all data needed for the 'Case D' during three full-time work day visits and for the interview session (for more details, see the section of "Data Collection Process Conducted" for each case study in **Section 6.5.1** for Case C, and **Appendix J** for the rest of the project-cases.

Table 6.1: Describing the Data Collection Techniques Used

Case Study Code	*Data Collection Techniques*	*Staff Interviewed*	*Work Exp*	*Dependency*	*Observe Period*
A	• Nine Site Visit Tours, • Two interview Sessions, • Reviewing Related Document	• Project Manager • Construction Site Manager (CSM) • Warehouse Manager	30 years 15 years 22 years	Contractor/F.L Contractor/F.L Contractor/ O.L	7 weeks
B	• Seven Site Visit Tours, • Two interview Session • Reviewing Related Document	• Project Administrator • CSM	25 years 19 years	Consultant/F.L Contractor/F.L	5 weeks
C	• Four Site Visit Tours, • One interview Session, • Reviewing Related Document,	• Project Manager • Planner • Civil Works Supervisor	28 years 13 years 12 years	Contractor/F.L Contractor/O.L Consultant/F.L	A Week
D	• Three Site Visit Tours, • One interview Session,	• Project Manager • CSM	33 years 27 years	Contractor/F.L Contractor/F.L	A week
E	• Five Site Visit Tours, • One interview Session, • Reviewing Related Document	• Executive Project Director/Manager • Warehouse Manager	29 years 12 years	Contractor/F.L Contractor/O.L	3 Weeks
F	• Nine Site Visit Tours, • Two interview Sessions, • Reviewing Related Document	• Senior Construction Manager • Procurement Manager	30 years 17 years	Contractor/F.L Contractor/O.L	6 Weeks

The second data collection technique for implementing the research main investigation is the interview technique. Semi-structured interviews were conducted with high experienced personnel for the six case study projects. According to the interviewees' selection criteria, the concerned staff members were assigned on the basis of their experience, expertise and knowledge in at least one of the integrated materials management functions, and their convenience and willingness to share their experience in managing materials within the J.C.I (see the interviewees' selection criteria detailed in **Section 5.5.3.1). Table 6.1** above demonstrates 14 individuals from the six case studies who were involved in the semi-structured interviews; including Project Managers, Construction Site Managers, Warehouse Managers, a Planner, a Civil Work Supervisor, an Executive Project Director, and a Senior Construction Manager. Those interviewees have civil engineering and construction management background (e.g. BSc in civil engineering, and MSc in construction management). They are all experienced construction professionals with a range of 12 to 33 years' experience in managing the construction projects on behalf of the Jordan Construction Industry (J.C.I). They are involved in the various issues of construction materials; managing and controlling building materials, inventory quantities, evaluating suppliers, purchasing process, material's specifications and conditions, the movement of materials off and on site, and storage's issues. This background and experience may give more confidence in good understanding for the CMM process directly practicing its functions and activities within the JCI. This could indicate the extent of the validity and reliability of the answers and information obtained, which could be reflected on the validity and reliability of the overall study.

The interviews were conducted either individually or in a session of two interviewees (for those who share the same case study). These interviews lasted from three to six hours and were documented by using a digital voice recorder.

6.3 CASE STUDY DATA ANALYSIS METHODS:

The qualitative data that were collected within the research main investigation included those that were collected through the site visits and the interviews conducted within the case study projects. The data that were obtained through the site visits (the notes, information and the site short meetings) were written in Arabic in the Site Visit notebook, and they were then formatted and summarised in the Site Visit Report that is prepared for each case study in English. For the data that were collected from the semi-structured interviews with experienced people in the

JCI; the interviews were recorded in Arabic, loaded into the researcher's lap-top computer, and then transcribed into Microsoft Word format in both Arabic and English. The interviews were translated by the researcher, in the first place and then corrected by an independent translator. For confidentiality and ethical purposes, the interviews were formatted and coded to remove any names and references to any specific individual or organisation.

As previously mentioned, the primary step in analysing the case study research is the systematic search for cross-case patterns. The cross-case studies analysis, basically, aims to create or choose groups or categories and to search within those groups for similarities or differences. According to Voss, Tsikriktsis and Frohlich (2002), the cross-cases analysis is an uncomplicated and efficient approach and the use of multiple data sources-triangulation within this approach can increase the internal validity of the findings. The cross-cases analysis was conducted using the qualitative data analysis (QDA) computer software package NVivo Version 9. The software is designed to help qualitative researchers organize and analyse non-numerical data; refine, code, classify, sort and arrange qualitative data. The work mechanism of NVivo is based on entering the key words into the software, and then combining all the sentences relating to the key words under nodes (the node could be a theme or a pattern). Through the software, the themes and patterns from both the site visits and the semi-structured interviews were identified (see the screen display of primary nods; **Appendix K**). After analysing the data thematically, the themes, which largely represent the 'case study analysis units' adopted, were further examined manually and discussed in-depth to identify the functions and activities that form the CMM Process and that were practiced within the Jordanian large-scale concrete building projects, and to explore the mechanisms and measures that can be practically applied in those projects.

6.4 A CASE STUDY REPORT:

Voss, Tsikriktsis and Frohlich (2002, p212) assert that "*the necessary first step is a detailed write-up of each site following the research protocol structure*". According to the case study protocol framework, which has been developed for this research to guide the design and analysis of the case studies (see **Figure 5.9**), the first step of the case study data analysis involves the documentation of the data that can be derived through conducting the case studies. The documentation included typing up the notes that were observed and the ideas and insights that arose during the field tours, transcribing the recorded interviews, and gathering the relevant documents from the sites or other sources (see the process of conducting each case study in the case study reports below for *Case C*, and in **Appendix J** for the rest cases).

Having documented the case study data collected, the following step is to construct a display of data. This step is intended to present the outputs of each case study through writing an individual case study report which is a format that displays information systematically so that the user can draw valid conclusions and allow the unique patterns of each case to emerge before generalising across cases (Eisenhardt, 1989; Voss, Tsikriktsis and Frohlich, 2002). The process of presenting the collected data for each case study is based on coding the data collected in the field into unified categories that can guide this process in each case study (Glaser and Strauss, 1967; Miles and Huberman, 1994). These categories could include the 'units of analysis'. *Case study A* is presented with somewhat more details than other cases to represent the detailed pattern for displaying the data collected (see **Appendix J**). However, the data collected and the lesson learned from the rest of the case studies in this research were summarised based on the six key categories below:

- *Project Background*: it provides an overview of the case study project including the project description, the build-up area, the current phase of implementation, the estimated cost, and the completion rate of the skeleton stage.
- *Organisation Profile*: the category is dedicated to describing the main contracting company (main contractor) that is responsible for implementing the skeleton works, regarding the company's classification, key characteristics, experience in executing the building projects, the main activities and the role of the sub-contractors.
- *Procedures of the Data Collecting Process*: this describes the techniques and procedures that were used to collect data from each case study. This involves describing the site visits including the number of tours conducted, the period of the observation process, the places that were visited, the activities that involved the site visits (short meetings with the field staff; reviewing material-related documents; recording and taking pictures; taking notes). This also provides brief description of the semi-structured interviews conducted, including the number of the interview sessions,

the period that the interview lasted, and the participants who were involved in the interviews.

- *Process of Construction Materials Management Practiced*: reporting the collected data regarding the process of the construction materials management which includes two main sections; General Overview and Functions and Activities of the CMM Process.
  - *General Overview*: this presents an overview about the CMM process that is practiced within each case study project, the CMM-related departments, the participants who contribute to the CMM process, and the scope of their involvement and responsibilities. It also displays the main procedures for requesting building materials within the construction site.
  - *Functions & Activities of construction Materials Management Process*: this presents the functions and activites that are currently practiced for managing the CMM process in each case study project. In order to facilitate presenting the outputs of this section, the practical functions and their activities, which form the CMM process in the case study project, were determined, discussed and compared with those that formed the typical workflow diagram of the CMM process, which has been developed by the literature review process. The aim is to examine the differences and similarities between the typical diagram and the practical CMM process; besides, appointing the present activities (Exist-Activities), the missing activities (Non-Exist Activities), activities that exist under another name, activities that are included under different functions, and the novel activities that have emerged in the case study project (New-Activities).

Based on the related findings of each case study project regarding the CMM process practiced, the process of CMM, which is practiced within each case study, was summarised and depicted graphically through a practical workflow diagram.

- *Effectiveness Measurement of the CMM performance*: the outputs regarding the measurement of CMM performance is presented into two main sections; the Mechanisms used for Monitoring and Evaluating the CMM Performance, and a set of Measures for the Effectiveness of the CMM Performance.
  - *The Mechanisms used for Monitoring and Evaluating the CMM Performance*: this section provides an overview of the mechanisms and approaches that are used in

the case study project for monitoring and evaluating the extent of the effectiveness of the current CMM system.

- *The Set of Measures for the Effectiveness of the CMM Performance*: this section defines the significant, visible and feasible measures that are applied and/or can be used for evaluating the effectiveness of the CMM process in a case study project. For facilitating the display of the related findings, the measures used in each case study were determined, discussed, and compared with the proposed set of measures that has been developed by the literature review process. This is intended to identify the measures that *exist* (or even used independently) and those that do *not exist*, the techniques which are *similar* to the proposed measures, and the *alternatives* that are practiced to monitor and follow-up the performance of the CMM process.

- *Terminology:* this section presents the most recognisable terminologies, forms, repors and documents related to the CMM process in the case study. In addition, it illustrates the distribution of responsibilities within the organisation and departments that participate in implementing the CMM process through the responsibility matrix for each case study project.

In this Chapter, Case Study C report is displayed as an example to illustrate how the data collected and lesson learned from each case study are reported based on the six key report-categories. This selection is based on the fact that Case C can represent a typical case study, where the majority of the functions of its CMM process are conducted, independently, by the main contractor, including Quality Assurance and Quality Control functions. Besides, Case C implementing largest number of proposed effectiveness measures. The rest of the case studies' reports including the detailed Case Study A (Case A, B, D, E, and F) are displayed in **Appendix J**.

6.5 CASE STUDY PROJECTS:

Case studies involving six building projects were undertaken to achieve partly the third and fourth objectives through answering the two case study questions; the first question falls into two parts: **1)** 'How is the CMM process performed in the practical life in the Jordanian Construction Industry (JCI)? And what are the integrated functions and activities that formed this process?'; **2)** 'How the effectiveness of CMM performance can be evaluated within the large-scale concrete building projects in JCI? And what are the mechanisms and measures used?'.

Six on-going large-scale concrete building projects were selected by six first class construction contractors to accomplish the main investigation section of the current research. The selection process of these six case study projects (cases) took a long time starting from identifying the most appropriate construction organisations to be involved in the case studies, determining the type and location of the building projects, and ending with assigning the points-of-contact in those projects to open the door to access the required data and relevant staff. The main criteria on basis of which the case studies were deliberately selected included the contractor organisation classification (first class contractors), the project size classification (large-scale projects), the rate of completion (different skeleton stages), geographical distribution (cases are located on six different Governorates); and the type of projects (six different types of concrete building projects). The choosing criteria and the justifications and rationales for selecting these case studies were presented and discussed in detail in **Chapter V; Section 5.5.2.2**.

Although all the case study projects were classified as large-scale concrete building projects, the estimated costs varied from £22,78 million to £65,85 million. Private construction contractors have executed the majority of the case study projects, and those main contractors have managed the majority of their CMM processes. Background information on the six large-scale concrete building projects that are involved in the case studies are summarised in **Table 6.2**.

The differences in the type, stage, and location of the case study projects provided an opportunity to explore variations, similarities and dissimilarities in the building materials management issues and the implementation of the CMM process, and to depict more realistic picture that can reflect the real-life of the CMM process that is practiced within the Jordanian large-scale concrete building projects. In addition, it provides insight into the different measures and approaches that are used to evaluate the performance of the CMM process within these projects.

The activities that were performed during the data collection techniques are detailed in each case study report, As it is mentioned above, Case Study C is only project that is displayed in this chapter in the following section, and the rest of the case studies' reports are displayed in **Appendix J.**

Table 6.2: List of Projects Involved in the Case Studies

Case Study Code	*Project Description*	*The Rate Completion of Skeleton Work*	*Estimated Cost*	*Organisation Type*	*Project Location*
A	Cancer Centre Building	10.5% Beginning Stages	Skeleton Works £22,789,370	Private-Engineering & construction Contractor	Amman
B	Presidential Resort & Five Star Hotels	65% Middle Stages	Skeleton Works £65,856,630	Private-Construction Management (CM) / Consultative	Dead Sea
C	Military Hospital	86% End Stages	Construction Works £25,486,887	Private- Building & Construction Contractor	Jarash & Ajloun
D	Huge IKEA Store Project	11.5% Beginning Stages	Completion Cost £51,159,811	Private-General Contracting Establishment/ Contractor	Madaba
E	Hotel-Tower Project	63% Middle Stages	Construction Works £59,531,416	International-Heavy Civil Engineering & Construction / Contractor	Amman
F	Modern Rural Village	91% End Stages	Construction Works £35,346,778	Public-Shareholding Organisation/ Contractor	Alzarqa & Jarash

6.5.1 CASE C: Military Hospital Project:

6.5.1.1 Project Description/Background:

The project is building a military hospital serving the militaries and the families of the population of the governorates of Jarash and Ajloun. It is a government project and it consists of the main building of the hospital, which includes two basements and nine floors with a capacity of 300-bed medical facility, which serves 300,000 local militaries, policemen and their families. In addition, the project includes building housing separate for hospital staff; doctors, officers, non-commissioned officers (NCO), and nurses, as well as a mosque and service buildings. It also includes car-parking, green spaces, internal roads and an airstrip. The project is built on 43500 m2 land area, and its estimated cost for the construction works is about 27,400,000 J.D = £25,486,887.77 (B.P=0.930J.D). It is at the end stage of the skeleton works (86% of skeleton works).

Figure 6.2: Collection of Some Pictures for the Case Study C

6.5.1.2 Organisation Profile:

The main contractor of the construction works is the focus of research in the Case Study C. The company is mainly responsible for managing and controlling the building materials used for implementing the concrete framework. The skeleton works' contractor is a first class construction company, which, according to JCCI, has a well-established history in carrying out large-scale projects, and its main activity is the implementation of the building and construction works. The main contractor is in charge of the entire skeleton works without any sub-contractors participation. The consultative and supervision team is an in-house client (The Directorate of Military Housing and Works), whose responsibilities are limited to following up the implementation process, monitoring and approving the quality of building materials.

6.5.1.3 Data Collection Process Conducted:

Because of the security nature of the project, the process of collecting data just included four full-day site visits within a week and an interview session. The field tours aimed to observe the process of managing, requesting, and the movement of building materials within the site, in addition to handling short discussions with some materials management-related people (a storekeeper, a material officer, a site engineers, and a foremen), comprehending and documenting the paperwork cycle related to the CMM process. A semi-structured interview session was held with the project manager and the planner from the contractor side and the supervisor of civil works from the supervision team. During the session, which lasted about four (4:17) hours, the researcher introduced a power-point presentation explaining the research aims, objectives and the proposed set of measures of the CMM performance. He then posed the interview questions, and the answers from the open-discussion with the participants were recorded, transcribed, and summarised in the case study report.

6.5.1.4 The Process of CMM Practiced:

1- General Overview and CMM-Related Departments and Responsibilities:

Like its counterparts, the organisation does not have a written policy or standard for managing the building materials; however, it has its own system and methodology for managing the procurement process and for ordering and moving materials, which are not too far from its peers. Although the majority of the procurement process is conducted in the purchasing department within the company-home office, the first actions that concern the building materials start from the general planning department throughout the planning phase. Based on the project's time schedule that is produced by the planning department, the Materials Planning team (Planning Department within the organisational level) along with the project management team (field level) set up the Material Submittal Log (M.S.L). M.S.L aims to assign the dates of submitting the materials documents to the consultant for approval; this is concerned with the project's milestone, target, time of deliveries, dates of manufacturing, transporting, customs, delivering to the site, handling, and other relevant information.

In parallel with this process, within the take-off phase, the required specifications, cost, and quantities of materials are studied and prepared, based on the shop drawings and primary Bill Of Quantity (BOQ). As a result, the Data Sheet for Materials, catalogues, and the submittal forms, which are produced, are sent along with the M.S.L to the client representative (consultant-in house) for approval. During this phase, the take-off team (including the Project Manager (PM), planner, Material Administrator and Quantities Surveyor) are updating the BOQ. The approved copies of the documents are submitted to the purchasing department to search for other offers with the same specifications but less cost, issuing RFQ, evaluating and identifying suppliers, bidding, signing contracts, and submitting the necessary materials related-documents. The warehousing department within the company's organisational level is competent in the process of receiving, controlling the quality, storing materials, controlling and updating inventory, and following up the site-stores. The Project Manager (PM), the Construction Site Manager (CSM), the Material Officer and the Site-Storekeeper within the field-level are responsible for requesting, delivery tracking, receiving and moving materials within the site, in addition to performing the field purchases of some materials.

The project team's structure, including those elements within the organisational level and field level, as described in **Figure 6.3** below, could provide more comprehension for the responsibility of securing and managing the building materials in Case C. **Figure 6.3** displays the organisational structure of the project management in Case Study C.

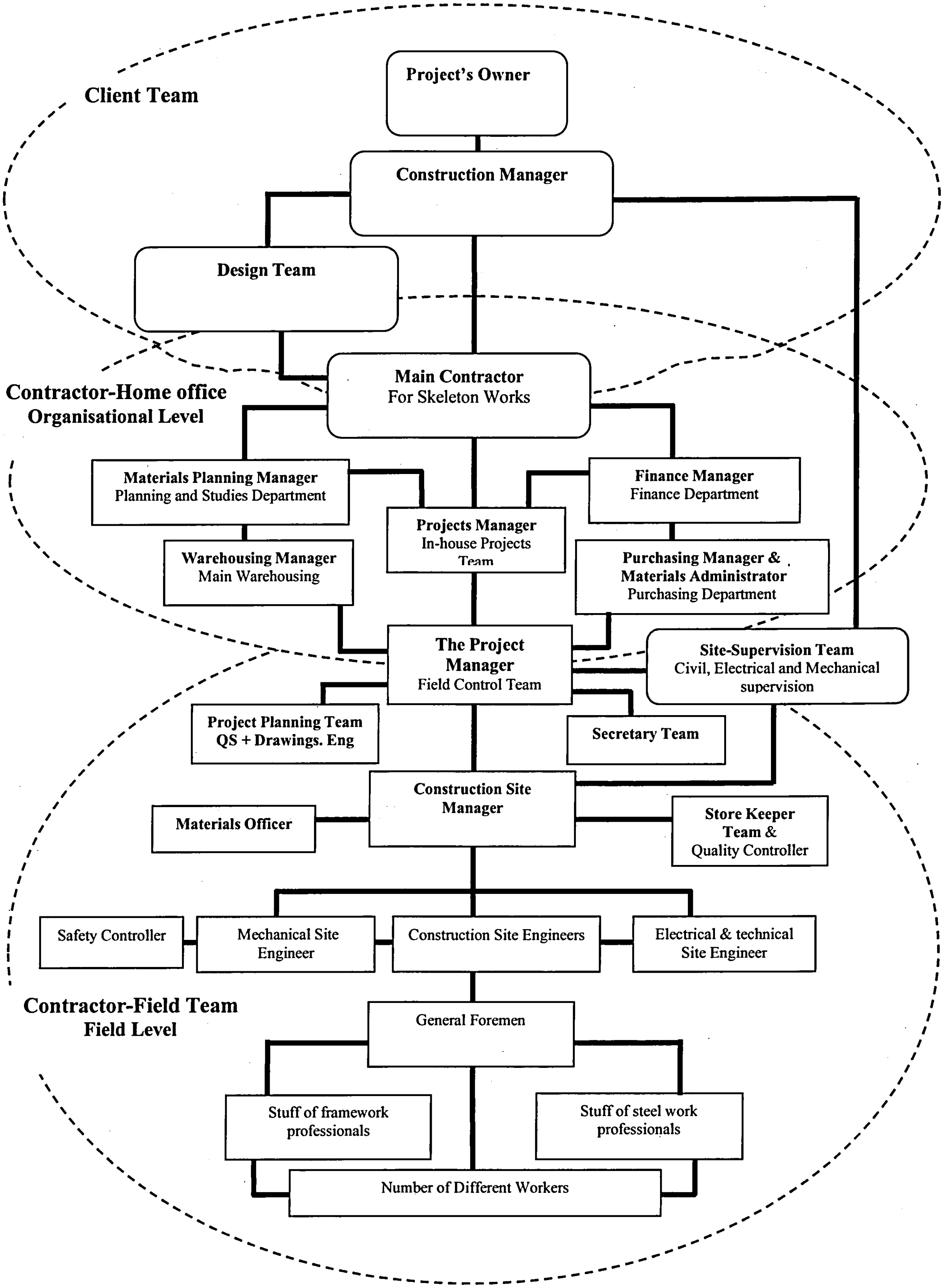


Figure 6.3: The Project Team Structure as Related to CMM Process in Case Study C

2- Process of Requesting Building Materials:

The procedures of ordering materials slightly differ according to their type, quantity, cost, and availability in the store. In general, the routine materials requests follow the following procedures;

a) Based on the shop drawings and the updated BOQ, the CSM and the materials officer determine the types and quantities of the materials that are required for a specific period or a stage of the project. This list of materials is sent to the site-storekeeper (site-workhouse in field level)for booking and preserving these items until needed on the field, with a copy to the PM,

b) In case the items or materials are available, they can be requested by the Internal Material Request (I.M.R) form, which is signed by the CSM, when they are needed,

c) In case the materials are unavailable, the storekeeper prepares the External Material Request (E.M.R) form and sends it along with the store availability's report to the PM within the field level,

d) The PM and his team, in particular the quantity surveyor, review the E.M.R and send it along with the availability report to the materials administrator within the purchasing department,

e) The purchasing department signs the E.M.R form and sends it to the main company's warehouse for preparing and delivering the required materials to the site-store in accordance with their quantities, the time needed and the space available on the site,

f) For fast track, sometimes these procedures are conducted by phone until the document cycle is completed,

g) In case the required materials are unavailable in the main warehouse, the purchasing department issues PO to the supplier, who is already assigned in earlier stages,

h) Before delivering the required materials, a form of Request for Material Approving, which includes the material types, quantity, source, agent, and drawing number, is sent to the consultant for approval,

i) The materials officer within the field level is responsible for following-up the transporting materials, shipment, tracking the deliveries to the site, preparing the Material Delivery Status Reports, and sometimes conducting some expediting activities,

j) The material officer and the storekeeper prepare the site for receiving the materials, including determining the handling and storage locations (on-store or out-store), identifying the required receiving-quality inspections and storage conditions based on the specifications required, and reviewing the contract agreements,

k) Once the materials have been received and updated in the inventory system, the receiving team prepares the related-receiving reports, Receiving Quality Control (R.Q.C) reports, Over, Short and Damaged (O.S&D) List/Reports, etc.

l) These materials, eventually, can be released to the need-point in the field as required and requested by the construction team and field team, and the surplus materials can be returned to the main warehouse.

m) As the material of concrete is supplied ready-mixed by the concrete supplier and the material of steel is supplied ready-shaped by the steel manufactory, the manner of requesting the concrete (a bulk material) and the steel (a fabricated material) is very similar to that of case A (see **Appendix J: Case A**).

The previous course of action is the general process used for requesting materials in the normal cases. However, the PM and CSM with the participation of the materials officer can directly perform many field purchases of some materials; that depends on the quantities and the cost of these materials. Furthermore, for the daily used materials, a building foreman can fill in the I.M.R form and sends it to the storekeeper directly; the storekeeper in turn issues the required materials, and sends a copy of the form, which was signed by the recipient, to the construction site manager. Additionally, the storekeeper can prepare a Store Shortfalls List and send it to the main warehouse; he can also prepare Non-Return Equipment List and send it to the CSM.

3- Functions and Activities that Form the CMM Process in the Case Study:

The following points summarise the main findings related to the functions and activities that form the CMM process within the case C. These findings, which are drawn from analysing the data collected through the site visits and the interview session, outline the functions and activities that are practiced within the CMM process in case C and their similarities and differences with the typical CMM workflow diagram;

a) The CMM process that is practiced in Case C consists of only seven functions. This is because the function of 'Vendor Inquiry & Evaluation' has been considered as an activity included under the 'Purchasing' function,

b) The expediting function is limited to following-up the process of transportation, handling, downloading, tracking, and shop inspection. It is rarely used in a skeleton phase, and it is usually called 'Transportation and Receiving Control',

c) The field control and warehouse functions are somewhat combined, and the all data of the site-store should be provided to the field control. Therefore, placing the field control before or up warehousing (site-warehouse) is reasonable for quality control issues as the field control team (the PM/CSM) has an authority to issue some materials directly to the site,

d) The final decision with regard to the management of the surplus material is usually the responsibility of the material administrator at the organisational level and the PM in the field level,

e) Since the majority of the skeleton works commence on the site, a copy of any feedback, which can be sent from and to any function, is sent to the PM within both the organisational and field levels,

f) Although there is a lack in using any emerging technologies (wireless technologies, bar-coding, radio frequency identification (RFID) or tagging technologies) in managing the materials within the case C, some particular computerised programs are used at the inventory, planning and field levels,

g) Some of the quality management activities are conducted with the participation of the consultant,

h) While the centre of the Quality Management function is the interface between the Transportation function (from one side) and the Field Control and Warehousing functions (from the other side), the quality assurance activities are distributed within the functions from the Take-off to the Transportation function, and the quality control activities are included within the functions from the transporting to issuing materials to the craft-workers,

i) Except for four activities (Determining Craft Preferences, Establishing Expediting Plans, Performing Route Survey, and Trial Allocations), the majority of the activities of the functions exist, even if some of them are under different names or are included under different functions,

j) Some activities exist but under other names (**Red**);

NO	Old Activity's Name	New Activity's Name
1	Establishing Responsibilities	*Establishing Organisational Chart,*
2	Developing Staffing and Training Plans	*Naming the Staff*
3	Developing Tag Numbering Scheme	*Developing Numbering Scheme*
4	Developing Quantity requirements of Consumables	*Primary Estimated Daily used Materials*
5	Establishing Project Catalog, Coding Systems	*Establishing a Project Catalogue*
6	Determining Quantities, Consolidate to Requisitions	*Developing Bill of Quantity (BOQ)*
7	Providing Performance Feedback	*Vendors Analysis/Filtration Report*
8	Financial Data	*Financial Solvency,*
9	Preparing Purchase Orders	*Pre-Purchase Orders*
10	Preparing Purchase Orders Administering Purchase Orders	*Issuing Purchas Orders (PO)*
11	Issuing Request for Quotations (RFQs)	*Issuing Call for Tenders*
12	Monitoring production and Transport and Status	*Monitoring Transport Status and Receiving,*
13	Inventory Materials	*Inventory Control*
14	Executing Field Procurement	*Executing Field Purchase*
15	Receiving and Inspecting Material Deliveries	*Job Site (receiving & Quality Control)*
16	Procedures Manual	*Procedures Guidebook*

k) Some activities are included under different functions (**Blue**);

NO	Activity's Name	Activity's Old Function	Activity's New Function
1	Developing Numbering Scheme	Planning	*Take-off & Design Interface*
2	Establishing Forms and Procedures	Purchasing	*Take-off & Design Interface*
3	Executing Transportation Agreements	Expediting & Transportation	*Purchasing*

l) New activities have emerged in this case study (**Green**);

NO	New Activity	Function Listed Below
1	Material Submittal Log	Take-off/Take-off output
2	Preparing Shop Drawings,	Material Take-off & Design Interface
3	Determining Material Priorities	Material Take-off & Design

NO	New Activity	Function Listed Below
		Interface
4	Developing Variation Orders Procedures	Material Take-off & Design Interface
5	Updating/Approving Forms and Procedures	Purchasing
6	Payment rate & conditions	Purchasing output
7	Developing a Delivery-Tracking's System,	Transportation & Receiving Control (Expediting)
8	Packing List	Output of Transportation & Receiving Control (Expediting) to PM
9	Participating in On –site QA & QC	Field Control & Warehousing
10	Material Surplus Report	Output of Field Control & Warehousing to the PM
11	Establish Compliance Sheet	Quality Management
12	Developing Site-Functional Plans and Procedures	Field Control
13	Sending a copy of Materials' quantities package, bid package (BOQ) to PM	Feedback from Material Take-off & Design Interface to Project Management
14	Sending a copy of all documents Issued from or Obtained by Quality Management to PM	Feedback from Quality Management to Project Management

It is worth noting that some of the professionals in the case thought that 'Developing *Variation Orders Procedures*' is part of '*Establishing Change Management Procedure*'.

Given the main findings above, the practical workflow diagram of the CMM process, which is applied in the case study C, can be graphically drawn as shown in **Figure 6.4**;

Black: The activities and Functions exist as named in the typical CMM functions,
Red: The activities and Functions exist but under other names
Blue: The activities and Functions exist, but are included under different functions
Green: New Activities and Functions have emerged within the cases

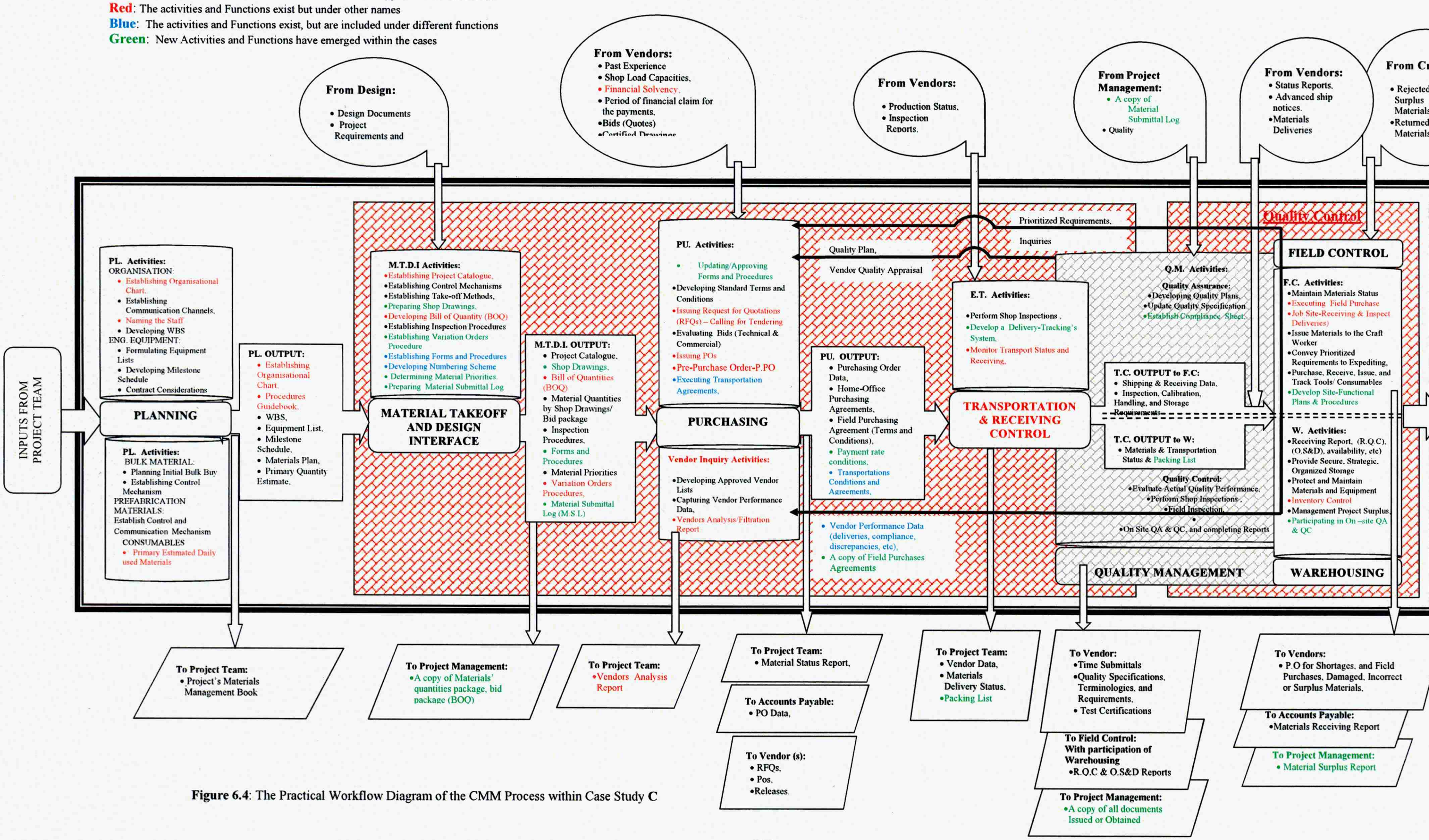


Figure 6.4: The Practical Workflow Diagram of the CMM Process within Case Study **C**

6.5.1.5 Evaluation Approaches and Measures of the CMM Performance:

1- Mechanisms/Approaches Currently in Use for Evaluating the CMM Performance:

A particular mechanism or a set of measures that could be used for appraising the performance of the CMM process does not exist in Case C, as is the case with its peers in this research. The CMM-related people, in this case, assess the performance of the entire CMM process with respect to the extent of its ability to secure materials on the field at the right time within the estimated cost and required quality and quantity. For this purpose, some qualitative and quantified approaches have been used to give indications on the extent of this ability, which is basically built on the use of irregular and separated (non-unified) techniques, as summarized below;

a) Monitoring and examining the effectiveness of the materials delivery process by making a comparison between the planned and the actual delivery time; comparing the planned material delivery schedule with the updated/actual one. This is considered as the key scale of the performance in this case.

b) Following up the process of requesting materials by observing the internal and external material requests for determining the Material Withdraw Request (MWR) lead time, which can give an indication to the ability of the field team to early identify and request the requirements; thereby minimize the time of waiting for materials.

c) Monitoring the ability of the warehouse or the site-store to processing the material requests and issue properly the required materials to construction operations on or prior the Field Need Date (FND) or (ESD). This could be performed by examining the dates of the requests and releases.

d) Controlling the proceedings of the quality assurance and control through recognising the rejections of nonconforming items prior and after shipment.

e) Evaluating the performance of the information management system and the documentary cycle used, and making certain whether the information is timely and correctly received. This is carried out by checking the reports, inputs, outputs, and the feedbacks from and to any function within the CMM process.

The contractor team, in particular the project management team within the field level, can carry out the majority of these functions.

2- A Set of Measures for the Effectiveness of the CMM Performance;

No clear system or a set of unified measures has been employed in case C for measuring the effectiveness of the performance of the CMM process. However, through the in-depth discussion with the interviewees and the individual observation for the CMM process on the site, in addition to make comparing with the proposed set of the effectiveness-measures, one can observe the presence of some measures, techniques and alternatives, which are non-systemically or indirectly used for evaluating the effectiveness of CMM, as summarised below;

a) Measures exist but they are practiced separately, even if they are for the purpose of monitoring and follow-up of the CMM performance and not for quantitative measurements;

NO	*The Measure's Code*	*Its Attribute*	*Notes*
1	AC1	Accuracy	Using R.Q.C, O.S&D Reports
2	AC2	Accuracy	Receipt Problem Sheet
3	Q2	Quality	Using Inspection Forms
4	QN1	Quantity	Using the RFQs
5	QN2	Quantity	Using the POs
6	T2	Timeliness	Using Documents related to the RFQs, the POs
7	T7	Timeliness	In-door delivery lead time
8	C3	Cost	
9	C5	Cost	For identifying the causes of delay
10	C8	Cost	The reason could be saving materials (considering as +/_). Using Warehouse System, Material Status Report
11	AV1	Availability	Using Materials Requests, Warehouse System
12	F3	Flexibility	Using Material Status Report and Inventory Record

b) Techniques, which are somewhat similar, in terms of their purpose, to the proposed measures, aim to evaluate the performance of the same functions that are measured by the proposed measures;

NO	The Technique Practiced	The Similar Measure/ Attribute	Notes
1	Periodic inventory inspection	AC3/Accuracy	
2	Measuring the processing time from issuing PO to receiving and updating materials in the warehouse system	T3 & T4/Timeliness	Warehouse/Inventory Record/System
3	Listing the deliveries that are not made on or before the required delivery date (delayed deliveries)	T6/Timeliness	Using the M.D.S Report

c) Alternatives that are practiced to monitor/follow-up the performance of the CMM process qualitatively (non-quantitatively),

NO	A Measure/Attribute	The Alternative
1	Q1/Quality	Following up the Construction Reports including equipment that was required for rework *(Field Work Reports)*
2	T5/Timelines	Evaluating the Materials Delivery position/Status
3	C4/Cost	Mentoring the number of express delivers through monitoring M.D.S Report and Monthly reports
4	AV2/Availability	Following up the materials availability by monitoring the Store Shortfalls List and the inventory data
5	F1/Flexibility	Updating the material delivery-related activities in the milestone schedule (Time Schedule) to move planned delivery dates forward, using the Delivery Time Schedule and Material Submittal Log

d) Some new measures that emerged in this case;

NO	The New Measure	Attribute	Notes
1	Measuring the ratio of the actual amount of waste materials to the materials that are expected to be waste (Planned waste)	Cost	Monitoring the Wastage Level

e) Some measures do not exist due to one or more than one of the following reasons;

- The difficulty involved in their calculation (e.g. lake of the required data); QN3, T1, C6, C7, F2,
- The irrelevance in skeleton works; QN3, QN7, but it could be in the finishing works
- Lack of their importance; QN5, QN4, QN3, C1, C2; where employees are paid monthly salaries,
- he lack of culture and strategy underlying their practicing in the Jordan; QN8, C1, C2
- Unused technique; QN6; EDI technology is unused in this project,
- F2 is similar to the measure 'Installing Equipment Rework (Q1)', and there is no need for F2

6.5.1.6 Terminology:

The contractor company, in Case study C, uses to some extent the same type of forms, reports, and the CMM-related documents that are used within its peers. The next terminologies are the most recognisable ones that were observed during the data collection process;

- Material Submittal Log: (M.S.L)-Document
- Supply & Apply Sub-Contractor: Sub-contractor is responsible for providing (Supplying) material and fixing it on the field
- Jordanian Institution for Standards and Metrology: (JISM)-Government Institution
- Compliance Sheet: Report and List
- Request for Concrete Pour: (R.C.P)-Form
- Data Sheet for Materials: (D.S.M)-Catalogue/Document
- Store Shortfalls List: (S.S.L)-List
- Materials Delivery Status Report: (M.D.S.R);Report
- Internal/External Material Request forms: (I.M.R/E.M.R)-Forms
- The activity Early Start Date: (ESD)-Specific Time
- The Field Need Date: (FND)-Specific Time
- Materials Receipt: (MR)-Receipt
- Request for Material Approving: (R.M.A)-Form

- Bar Bending Schedule = Reinforcement Steel Bars: (B.B.S)-Schedule,
- Surplus is not/over planned = waste in skeleton materials (bulk materials)

Responsibility Matrix for Materials Management:

The integration of the functions of the CMM process requires the involvement of many project participants from both the organisational and field levels to complete this process. Therefore, managing building materials in Case C involved a number of individuals and groups, including the PM team, CSM team, planner team, purchasing team, storekeeper, and so on. In Case Study C, however, the individuals, who are more closely associated with the CMM process, are the Material Administrator and the Material Officer;

1- **Materials Administrator** is located in the purchasing department within the organisational level; his/her team are mainly responsible for carrying out the purchasing process (issuing RFQ, evaluating bids, committing contracts, issuing POs) and participating in some activities related to the planning and take-off phases.

2-**Materials Officer** is one of the construction site management team at the field level. S/he is responsible for securing the required materials on the site including tracking materials delivery, following up the CMM-related documentary cycle, monitoring the vendor performance, and preparing the M.D.S reports. In addition, s/he participates in identifying priorities of the required materials with the CSM, and in receiving materials and performing on site QC and QA with the storekeeper.

The responsibility matrix below (**Table 6.3**) exhibits the distribution of responsibilities for managing the CMM functions in Case C.

Table 6.3: Responsibility Matrix for Managing Materials in the Case Study C

	CLIENT LEVEL		CONTRACTOR LEVEL							
	PROJECT OWNER		CONTRACTOR-HOME OFFICE				CONTRACTOR-FIELD TEAM			
FUNCTION	In- house Consultative office	Site Consultative office	Planning Team	Purchasing Team	Projects Management Team	Warehousing Team	Project Management Team	Construction Site Management Team	Materials Team (Material Officer)	Site-Store Team
Planning	**A**		**I,E**		**E**		**C**			
Materials Take-off & Design Interface		**A**			**I**		**I,E**	**C,E**		
Vendor Inquiry & Evaluation				**I,E**	**A**		**C,E**		**C**	
Main Purchasing				**I,E**	**A**	**C**	**C,E**		**C**	
Field Purchasing				**A**			**E**	**I,E**	**E,C**	
Expediting & Transportation						**C**	**A**	**I,E**	**C,E**	**C**
Field Control					**A**		**I,E**	**E**	**C**	**C**
Warehousing						**I,E**	**A**	**C**	**C**	**E**
Quality Management (QA+QC)		**A, E**			**I**	**E**		**E,C**	**C**	**E**
		Keys of Actions: **I**=Initiate; **A**=Approve; **E**=Execute/Prepare; **C**=Coordinate;								

6.6 ANALYSIS OF THE CASE STUDIES' OUTPUTS:

This section discusses the outputs, themes, and patterns that have emerged from the main investigation of the research. The discussion involved the cross-case studies analysis for the data collected from the six case study projects including both site visits and interviews. The sequence of the discussion progress is guided by the four 'units of analysis': 1) the CMM process practiced; 2) the functions and activities that form the CMM process within the J.C.I; 3) the measurement mechanisms or/and evaluation approaches practiced for monitoring the performance of the CMM process; and 4) the set of practical effectiveness measures that can be used in the J.C.I. In addition, the characteristics that distinguish the CMM process in the Jordanian building projects is discussed based on the qualitative data collected and the facts and ideas obtained from the second pilot study (Pilot Study II).

6.6.1 The Process of CMM Practiced within the J.C.I:

6.6.1.1 The Characteristics of the CMM Process within the J.C.I:

This section seeks to provide a general overview of the main features that characterise the CMM process within the Jordanian Construction Industry (JCI), and the responsibilities of the participants involved in the CMM process.

Reviewing the related documents and the discussions with the decision makers and the interviewees revealed that although there could be general procedures and fundamentals for managing the construction materials, which are performed in the majority of construction companies within the J.C.I, there is a consensus among the interviewees in all the case studies that "*in Jordan and may be in the entire Arab region, there are no certain standards, uniform mechanism or binding written policy in contracts regarding the details of the process of managing building materials in the construction projects*", a Senior Consultant of J.C.I (a Decision Maker) and a Project Manager stated. Because of that, each company, or may project, has its own policy, system, and procedures for managing its building materials in proportion to the nature of a project and the circumstances surrounding, even if there are some similarities in the main functions and procedures. This is consistent with the conception crystallized by a number of authors and researches such as, Muya (1999), Beatham et al. (2004), Cox et al. (2006), Sullivan, Barthorpe and Robbins (2010) and Pellicer et al. (2013), who believe that each construction project is unique and typified by its temporary nature particularly with respect to the fragmentation and the geographical dispersion of the production sites. Despite the nature of the fragmentation of projects, technically, the management of materials is subject to certain essential specifications and procedures that are defined under the project's contract, especially those related to approving the quality of materials and suppliers including, approving samples, tests requirements, supplying materials, and examination on site, a Project Administrator clarified.

The management of the building materials, in the Arab Construction Industry (A.C.I), can be affected by many factors (Grifa, 2006). A Project Manager, a Project Administrator, and a Planner believe that three are main factors that can affect the CMM process within the Jordanian concrete building projects; they might also contribute to forming the shape of the CMM process; 1) the cost or value of the contract, 2) the type and size of the company, and 3) the strength and the clarity of the contract and specifications included. In fact, this is consistent with the logic put forward by Ali (2011, p163) "*... among a variety of factors that can affect the materials management process in Libya are the size of the organisation and the value and type of the contract*". This may indicate the extent of convergence in the materials management process within the Arab construction projects and the factors affecting its formation.

- ***With regard to the value/cost of the contract:*** a Planner believes that this factor can affect the CMM process directly, "the *main thing that governs the CMM process in Jordan is the cost (the contract value)*". This could appear through the tender's stage in Jordan, in particular for the period of the economic recession in the Arab region and around the world, whereby "*the competition between the Jordanian building companies is based largely on the cost, which often negatively affects the process of quality materials selection*", elucidated the Planner. He added that reducing the tender's cost can lead a contractor to look for the materials that meet the minimum specifications, and/or to limit some unnecessary procedures or activities within the CMM process, which leads to some changes in its shape. Consequently, this also can affect the performance of the CMM process, as "*good contract's value means good performance*", said, a Project Manager. This could be in line with what was concluded by Sweis el al. (2014) that the value the contract is one of the factors that can affect the production-quality of the projects in the Jordanian housing sector.

- ***Respecting the size and strength of a company:*** the form of the CMM process can be affected by the strength and the size of the contractor that executes a project. A Project Administrator and a Supervisor stated that the big building contractor companies that have a high score in the JCCA classification (Class 1 or 2) have their own system for managing the building materials, and the form of the CMM process within these companies is somewhat clear and understandable. Within the same perspective, "*the low-rated companies (e.g. Class 4 or 5) have no system or standards for managing materials, the features of their CMM process are not clear, and the CMM there depends on individual/personal plans*", a Project Administrator declared. This perspective was accepted by a number of authors and researchers such as, Ibn-Homaid (2002) and Shakantu (2004), who believe that the materials management process in small building projects does not have particular criteria or standard procedures, and that it is dependent on the person`s behaviour and talents. This was one of the rationales that led the researcher to make the project size and the company's classification among the criteria of selecting the organisations and projects involved in the case study research (large-scale projects and first class companies). Nonetheless, a Civil Works-Supervisor perceives that the CMM process, even in those first class companies, overlaps in its activities with the roles of its participants, especially on warehousing issues, the material request system, quality management, and others. This supports what it has been observed during the field tours; there is no clear separation between the participants' responsibilities on the activities of the CMM process.
- ***Finally, the Strength and clarity of the contract:*** the extent of the contract's clarity in describing, in details, its clauses, conditions, specifications, and the participants' responsibilities and roles can affect dramatically the process of the CMM. An example related to the clarity of the contract was provided by an interviewee; "*in some materials, such as GRP or ductile pipes, the manner of their storage and handling can harmfully affect their quality. Consequently, if the details of their storage and handling are not cited in the contract, the impact of any mistake in selecting the process of their supply to the site can lead to unexpected extra cost and time, which can affect the success of the whole project*", a Project Administrator explained.

During the field visits conducted, it was noted that numerous participants have contributed in the CMM process; however, the scope of their involvement and responsibilities widely overlapped and it was not clearly defined nor stipulated in the contractual document. A Material Coordinator confirmed that "*there is no clear definition for the participants' responsibilities, which creates problems and confusion within the limits of the authority and duties assigned to each participant*". However, these responsibilities could be initially derived from the project team structure. Apart of case studies B and F, whose main consultant governs the majority of the implementation process including CMM process, the process of CMM, in general, starts from 'Planning Department' within the contractor home-office (organisational level), whose personnel are responsible for planning the entire implementation process for building projects including the CMM process. This is carried out with the participation of the 'Projects Management' department within the organisational level. Those departments in the contractor's home-office (organisational level) with the participation of the 'Project Management' team (project manager, construction site manager, and/or material coordinator) within the field level are responsible to carry out all the activities of the take-off function. In all the case studies (A,B,C,D,E, and F), the 'Purchasing' department within the head-office (organisational level) is responsible for managing the procurement's process for all the projects, a Project Manager, Materials Administrator and Construction Site Manager explicated. The 'Materials Administrator' within the 'Purchasing' department along with the PM within the field team are the ones responsible for selecting and evaluating the majority of the suppliers and for sending the 'Vendors Analysis Reports' to the Projects Management department and the consultant for approving issue. A project Manager (PM) said "*Both the materials administrator within the organisational level and the project manager within the field level are also responsible for the entire process of purchasing from buying small item to securing bulk materials on the site*". However, the project manager and the construction site manager along with the materials coordinator in the field level usually conduct the field-purchasing for some consumable or daily used materials. A warehouse manager stated that "*the functions of Field Control and Warehousing, especially on the site, significantly overlap, and it is difficult to segregate their activities*"; this can explain the overlap in the responsibilities between the field control staff and the warehousing personnel, in particular, on the issues of ordering, receiving, controlling and issuing materials within the site. The responsibility of performing the quality management function could be exchanged between the other functions' participants, a Project Manager believed. Excepting the case studies A, B and F whose quality assurance activities were conducted by the consultant and construction management company, the Quality Management team (in the quality management and follow up department within the organisational level) with the participation of the personnel of the Take-off and Procurement functions perform the majority of the quality assurance activities, while the Quality Management team with the participation of the personnel of the Field Control and Warehousing functions perform the majority of the quality control activities.

The responsibility and position of all the key material-related participants for each organisation or project are best illustrated on the organization charts that reflect the organisation structure or that are developed for the specific project (Stukhart, 1995). Despite the absence of a clear definition for the participants' responsibilities in the contractual documents within the JCI, the organisational structure of the project management and the responsibility matrix for the CMM process for each case study were drawn based on the field tours notes recorded, the interviews data collected and the related documents reviewed. The project team structure related to the CMM process illustrates the most prominent relevant sections, departments, and personnel that are responsible for managing the construction materials within the organisational structure of the project management in each case study (see **Figures J.1, J.2, J.4, J.6,** and **J.8** in **Appendix J**). The responsibility matrix for managing materials illustrates the distribution of the responsibilities within the organisation and departments that participate in the CMM process in each case study (see **Tables J.1, J.2, J.3, J.4,** and **J.5**). These charts and matrixes aim to promote better understanding of the different organizational groups participating in the CMM process, and to provide clearer understanding of the authority of key personnel and illustrating the flow of information through the line of authority.

From both the organisational structure and responsibilities matrix, one can observe the absence of a material manager's character. This was interpreted by a Construction Site Manager, who stated that "*in the majority of building projects in Jordan, there is no specific materials engineer or materials manager who guides the CMM process and conducts the entire related functions, therefore, a project manager and construction site manager along with the materials coordinator/officer, who is assigned by the project manager, usually implement the CMM process during the construction stage*". This leads to general misunderstanding of the roles and responsibilities of the personnel who supposed to drive the CMM process (e.g. a material manager) and a lack of experience and knowledge within the construction workforce in the J.C.I. This underlines the logic that adopted by Stukhart and Marsh (1986), Stukhart (1995, p37), and Oswal (2007), which believes that "*materials responsibilities are diffused among various organisations, so a proactive role by the materials managers is essential for coordination*".

In short, the weakness in managing the materials within the concrete building projects in the JCI can be attributed to "*the weak policies applied in JCI concerning managing contracts including the building materials management*", outlined the JCCA Chairman. The proof of this is that the majority of the successful foreign companies, which have executed the building works in Jordan, are based on a solid standards and stable system, and these companies follow specific standards that are set forth in a contract or in the conventional operation systems developed by their construction industries, the Senior Consultant of JCI noted.

The fact that can be interpreted is that the absence of a particular uniform standard, written policy or clear criteria that can be followed to manage the materials in building projects within the JCI has led to the lack of a clear definition for the material-related participants' responsibilities. This, in turn, has resulted in a lack of expertise and specialists in managing the construction materials within the Jordanian building projects. All of these have pushed each company or project to develop its own policy and procedures to manage its materials. This can interpret the puzzlement that appeared on the majority of the interviewees' faces, when they were asked about the character of the CMM process within the J.C.I.

6.6.1.2 The Functions that form the CMM Process in the JCI:

In order to develop a practical workflow diagram that reflects the real-life of the CMM process that are practiced within the large-scale concrete building projects in the Jordanian Construction Industry (J.C.I), it was essential to examine the practical functions and their activities that form the CMM process within those projects. Therefore, the main purpose of this section is to discuss the CMM related functions and activities that have been practiced within the case studies and that are discovered through the qualitative data outputs. Within this section, those functions and activities, which were drawn from analysing the data collected by the site visits and the interview sessions, are compared with the typical workflow diagram of CMM process, which was developed from the literature review process. This analysis process aims to examine the differences and similarities between the typical CMM diagram and the current practiced CMM processes in the case studies; including appointing any of the activities that exist or exist under another name (different terminology), and that is non-existent along with the alternatives. Based on the site tours, extensive discussions with the relevant field participants, deep explanation by the interviewees, and comparison with the findings of reviewing the literature, one can explore and identify the main practical functions and activities that form the CMM process within the Jordanian projects. In order to do so, and to facilitate presenting the results of the cross-cases analysis, regarding the practical functions and activities that form the CMM process in the case studies, the workflow diagrams that were developed to depict the CMM processes practiced within these cases, are summarised in one matrix as shown in **Figure 6.5**. The schedule below contains the six-workflow diagrams of the CMM processes that were practiced within the case studies (see **Figures J.3, J.5, J.7,** and **J.9**). This can help realising and identifying the differences, similarities and the commonalities between these cases.

In response to the general question regarding 'how far one thinks that the typical CMM Workflow Diagram (functions, sub-functions & activities) matches the CMM workflow diagram that is used in the project or company?', the interviewees in all the case studies agreed on the existence of similarity between the typical CMM process and what is applied in the Jordan construction projects, though some differences exist in the functions' sequences and activities' names, in addition to the existence of some overlapping between the functions' responsibilities. A Project Manager confirmed that *"there are some activities that are somewhat similar to what we are implementing here in the J.C.I. In fact, there may be some differences in the functions' sequences and the activities included in the functions, but in general, I think that there is similarity too"*, whereas a Procurement Manager and a Senior Construction Manager see that apart from the overlapping between the functions and distribution of the activities under different functions, the majority of the activities, which are in the typical workflow diagram of the CMM process, are practiced within the CMM process in the J.C.I.

Black: The activities and Functions exist as named in the typical CMM functions, **Red**: The activities and Functions exist but under other names

Blue: The activities and Functions exist, but are included under different functions **Green**: New Activities and Functions have emerged within the cases

CMM FUNCTIONS	PLANNING		MATERIAL TAKEOFF & DESIGN INTERFACE		VENDOR INQUIRY AND EVALUATION		PURCHASING		E TRA
ACTIVITIES	ORGANISATION: P1=Establish Responsibilities, P2= Establish Communication Channels, P3= Develop Staffing and Training Plans, P4= Develop Functional Plans and Procedures,P5= Develop WBS and Work/Bid Packages ENGINEERED EQUIPMENT: P6=Formulate Equipment Lists, P7= Develop Milestone Schedule, P8= Contract Considerations BULK MATERIAL: P9=Quantity and Update Requirements, P10= Plan Initial Bulk Buy, P11= Establish Control Mechanism PREFABRICATION MATERIALS: P12=Develop Tag Numbering Scheme, P13= Establish Control and Communication Mechanism, CONSUMABLES: P14=Develop Quantity Requirements		TD1=Establish Project Catalog, Coding Systems TD2=Establish Control Mechanisms TD3=Establish Take-off Methods TD4=Determine Quantities, Consolidate to Requisitions TD5=Determine Craft Preferences TD6=Establish Inspection Procedures TD7=Establish Change Management Procedures		VE1=Develop Approved Vendor Lists VE2= Capture Vendor Performance Data VE3= Provide Performance Feedback		PU1=Establish Forms and Procedures PU2=Develop Standard Terms and Conditions PU3=Issue Request for Quotations (RFQs) PU4=Evaluate Bids (Technical & Commercial) PU5=Prepare Purchase Orders PU6=Administer Purchase Orders PU7= Perform Close Out activities		ET1= ET2= ET3= Mech ET4= Agree ET5= ET6= Trans
CASE STYDY									
CASE A	P1(Tasks distribution), P2, P3(Staff Naming), P4, P5, P6, P7, P8 , P10, P13, P14(Primary Estimated Daily Used Materials)		TD1(Establish Project Cataloge), TD2, TD3, TD4(Develop Bill of Quantities-BOQ), TD6, PU1, P9, P12, TD* =Determine Material Priorities, TD**=Establish Variation Orders(VOs) Procedures, QM3 (update Requirements)		PURCHASING VE1, VE2, VE*=Vendor Filtration Report PU2, PU3 PU4, PU5, PU6 ET4, ET2, ET6 (Delievery Tracking & Control) QM4				
CASE B	P1(Organisational Structure), P4, P5, P6, P7, P10, P14, P*=Develop Delivery Plan		TD1, TD2, TD3, TD4(BOQ), TD6, P2, P9, PU1, Update QM3, TD* =Determine Material Priorities, TD**=Establish Variation Orders(VOs) Procedures, TD***= Preparing Shop Drawings		PURCHASING VE1, VE2, VE*=Vendor Analysis Report PU2, PU3 PU4, PU5(Pre-Purchase Order-P.PO), PU6 (Issue PO), PU*=Update/Approve Forms and Procedures ET4,				TI ET2, I ET*= Track
CASE C	P1(Organisational Chart), P2, P3(Staff Naming), P5, P6, P7, P8, P10, P11, P13, P14(Primary Estimated Daily Used Materials)		TD1, TD2, TD3, TD4(Develop Bill of Quantities-BOQ), TD6, PU1, P12(Numbering Scheme), TD* =Determine Material Priorities, TD**=Establish Variation Orders(VOs) Procedures, TD***= Preparing Shop Drawings, TD****= Develop Material Submittal Logs		PURCHASING VE1, VE2, VE*=Vendor Analysis Report PU2, PU3 (Calling for Tendering), PU4, PU5(Pre-Purchase Order-P.PO), PU5+PU6 (Issue PO), PU*=Update/Approve Forms and Procedures ET4				TR REC ET2, I Status ET*= Tracki
CASE D	P1, P2, P3(Staff Naming), P4, P5, P6, P7, P8, P10(Plan Intial Pluck Supply), P11, P13, P14(Primary Estimated Daily Used Materials) QM1,Update QM2 P** Establish Fabrication Plan		TD1, TD2, TD3, TD4(Develop Bill of Quantities-BOQ), TD6, PU1, P12(Numbering Scheme), Update QM3 TD* =Determine Material Priorities, TD**=Establish Variation Orders(VOs) Procedures, TD***= Preparing Shop Drawings		LOGISTICS PU*= Update/Approve Forms and Procedures L1= Securing the Materials and Equipments needed, L3=Coordinating between the internal suppliers and the sit, and Follow up the sup L4=Giving permission/authorisation to the main warehouse for issuing materials t L5=Execute Sole Source Purchases (Skeleton works), ET4 (develop and execute material delivery plan), ET6, QM7				
CASE E	ESTIMATING & MATERIAL TAKEOFF TD1, TD2, TD3, TD4(Develop the detailed BOQ for the all materials), P2, P4, P5, P7(Develop Time-Framework of when materials are needed), P10(Prepare Buy Packages for Major Materials), P11, P13, PU1, PU2 TD***=Develop the engineering Drawings (Shop Drawings) and the Site Layout TD*****= Prepare Pre-Requisition for the commodities/ Issue Material Stock Requisition (M.S.R), TD*=Determine Material Priorities,				MATERIAL PROCUREMENT VE1,VE2,PU3(Request & Approve Submittals from suppliers), PU4(Evaluate Bids, Award Contract to a Supplier/Manufacture), PU5+PU6(Issue Pos), ET4, ET6 MP=Prepare Temporary Purchase Order, MP=Procure Material				
CASE F	ESTIMATING & MATERIAL TAKEOFF P2, P7(Develop/update Time-Framework of when materials are needed, P4, P10(Prepare Buy Packages for Major Materials), P14(Primary Estimated Daily Used Materials), TD2, TD4(Develop the detailed BOQ for the all materials), PU1 TD* =Determine Material Priorities, TD*****=Prepare Primary Material Requisition Schedule for the commodities, TD***=Review and update the Executive Drawings & and the Site Layout, EMT=Re-estimate the Quantities for the Materials Needed for each Building Stage,				MATERIAL PROCUREMENT & TRANSPORTATIO PU3(Request Quotations from the Pre-selected Suppliers), PU4(Evaluate Bids, Ne Contract to a Supplier/Manufacture, PU5+PU6 (Issue POs), PU7 ET4 (Establish and execute Transportation Agreements), ET6 MPT=Prepare & Issue Temporary Purchase Order, MPT=Forward O,S&D Sheet to the Supplier/Manufacture to resolve problems				

Figure 6.5: A Summary for the Workflow Diagrams of the CMM Process

1- A *Function of Planning:*

Although sometimes the functions of the CMM process are not in steady and clear sequence, "*the function of planning is usually the first step in managing the building materials and should begin from tendering stage*", an interviewed Executive Project Director stated. In line with this view, a Planner declared (during a site tour) "*the process of managing the construction materials should take place concurrently with the project planning stage and engineering designs*". This is consistent with what was stated by Stukhart and Bell (1985, p74) that "*the material management process actually begins with a material management plan incorporated into the project plan*", and it further supports the fact, which was introduced by McConville (1993), Stukhart (1995), and Binti Kasim (2008), that 'there is a need for an appropriate planning within a process of CMM, which must be done with engineering, construction and other project plans'.

Apart from Case E and F, the function of Planning clearly exist in the other cases, Case A, B, C and D. It can be noted from the **Figure 6.5** that the majority of the activities that form the Planning function within these cases (Case A, B, C, and D) are similar and match those included in the typical workflow diagram of CMM process, which has been developed by the literature review process. However, there are few activities under other names, or they are included under other functions (e.g. Takeoff function). For example; activities of 'Establish Responsibilities', 'Develop Staffing and Training' and 'Develop Quantity Requirements' are called/named in these cases 'Establish Organisational Structure', 'Staff Naming' and 'Primary Estimated Daily Used Materials' respectively; activities such as, 'Developing Tag Numbering Scheme' and 'Quantity and Update Requirements', were conducted within the 'Takeoff & Design Interface' Function in those cases (A, B, C, D).

Additionally, new two activities in the Planning function that were not cited in the typical CMM process diagram were found in the Planning function (Case B, D): 'Developing Delivery Plan' and 'Establishing Fabrication Plan'. Moreover, it can be observed that the Planning team in Case D has conducted some activities regarding the Quality Management function, such as 'Develop Quality Plan' and 'Develop Quality Specification'.

In Case E and F, an independent Construction Management company and a Consultative Subsidiary, respectively, have conducted the majority of the Planning's activities and some of the Take-off and Design Interface function's activities; including design process, preparing the executive drawings, initially identifying and estimating the materials and equipment needed for the project, developing bid packages, and others. Consequently, the implementation of these activities was outside the scope of the contractor's works. As a result, there is no noticeable emergence of the function of Planning independently within the CMM processes that have been practiced by the main contractors in Cases E and F. Some Planning's activities have been combined with the function of Take-off and were conducted by the main contractors (Cases E, F) within a function called 're-Estimating and Material Take-off', which was considered as the first function of the CMM process in those two cases. For more details, see **Figures J.3, J.5, J.7,** and **J.9** in **Appendix J**.

2- A *Function of Material Take-off and Design Interface:*

An interviewed Project Manager sees that 'Planning' function in the CMM process within the majority (if not all) of the Jordanian building projects is usually followed by a Function of Take-off and Design Interface. This underlines the view claiming that "*Based on the documents and instructions that resulted in the Planning function, updating the requirements, developing the Bill of Quantities, and obtaining an initial technical approval for items or materials officially by an owner or his representative are usually done within the stage of 'Take-off'*", pointed out one Planner. This is consistent with the definition that was provided by Bell and Stukhart (1986) and Al-Darweesh (1999) that materials take-off is a function of identifying what materials are needed and how much, it can be executed initially from plot plans or flow sheets, and then they are updated later during the construction process.

As discussed above, due to the existence of an independent 'Construction Management' company and a 'Consultative Subsidiary' in Cases E and F, the activities of 'Take-off' functions and some 'Planning' activities were combined in one function of 're-Estimating and Materials Take-off' in those two cases while the function of Take-off and Design Interface and its activities emerged independently from the Planning function in the rest of cases; Cases A, B, C, and D.

However, the comparison between the activities of Take-off function that were practiced within the case projects (Cases A, B, C, D, E, F) and those form the typical workflow diagram of CMM process, clearly demonstrates the presence of new activities, activities exported from other functions, and activities existing under other designations (see **Figure 6.5**). For instance, one can recognise that within all the cases, the activity of 'Determine Quantities' has been replaced with more specific terminology 'Developing Detailed Bill of Quantities', which is a well-known and very important activity performed for this function. It is also evident that the existence of some activities, which are listed under other functions in the typical workflow diagram of the CMM process, are exported to the Take-off function. For example, the activity of 'Establishing Forms and Procedures', which is listed under the Purchasing function, has been carried out by the Take-off team in all the Cases (Case A, B, C, D, E, and F); the activity of 'Determining Terminologies and Requirements', which is listed under Quality Management function, has been carried out by the Take-off team in Cases A, B, and D.

Among the most noticeable new activities emerged in this function are 'Determining Material Priorities' (All Cases), 'Establishing Variation Orders Procedures' (Cases A, B, C, D), 'Preparing and Updating Shop Drawings and Site Layout' (All Cases), and 'Preparing Pre-Requisition/Primary Requisition Schedule for the Commodities' (Cases E and F).

3- A *Function of Vendors Inquiry and Evaluation:*

Although the majority of the activities that form this function exist and are considered essential procedures, this function does not emerge independently in all the cases (Cases A, B, C, D, E, and F). The activities of the function merged within the function of 'Purchasing' in Cases A, B, and C. They were included under the function of 'Material Procurement' in Case E. This was one of the controversial issues discussed within the interviews. A Procurement Manager strongly believes that "*all these activities that shape the function of Vendor Inquiry & Evaluation are included under the Purchasing Function*". A Project Manager added, "*The purchasing department within the organisation level is responsible for preparing a list of the selected vendors*". In fact, the merger and integration of the 'Vendor Inquiry and Evaluation' function's activities within either 'Purchasing' function or 'Material Procurement' function was noted during the site visits and from some participant's statements; where the purchasing team is authorised to perform all the activities of the 'Vendor Inquiry' function and the 'Purchasing' function, clarified a Material Administrator and one Purchasing Manager. This contrasts with the typical workflow Diagram of the CMM process, which has been developed from the literature review on the basis of what has been concluded from the perspectives of the authors and researchers such as, Bell and Stukhart (1986), CII (1987), Plemmons and Bell (1994), Plemmons (1995), Plemmons and Bell (1995), Kini (1999), UL-Asad (2005), Al-Quriesha et al. (2006), Al-Alawi et al. (2007), Beil (2010), among others. On the other hand, this integration might be considered as a normal case for those who believe that the function of 'Vendor Inquiry' is a set of activities that are included under the Purchasing function, which is, in turn, involved under a 'Material Procurement' process, such as, McConville (1993), Stukhart (1995), Al-Juaid (2005), Perdomo-Rivera (2004), Nasir (2008), and Vyas (2011).

As result of the fact that the main contractor and the suppliers of the required building materials (in skeleton work) for the Case D belong to the same holding organisation (somewhat similar to the sole source purchase/non-competitive purchase), the function of 'Vendor Inquiry & Evaluation' is not predominantly involved in the formation of the CMM process, outlined the Project Manager of Case D. Similarly, in Case F, "*the function of the Vendor Inquiry and Evaluation is not essential, because the suppliers of the major materials of skeleton works have been already selected amongst those who the contractor trusts or has worked within the previous projects for long time. Yet, in case a new supplier/vendor was needed, the function's activities are sometimes distributed within the Procurement function and Warehousing function*", elucidated a Project Manager.

With respect to the function's activities, excepting the activity of 'Providing Performance Feedback', which is considered as a 'feedback' activity that is conducted by the personnel of Field Control and Warehousing functions, the other activities are existent and are implemented by the personnel of the Purchasing function. A new activity of 'Providing Vendor Filtration/Analysis Report' has been added to the set of 'Vendor Inquiry' activities (Cases A, B, and C). In order to accomplish those activities within the JCI, "*the vendor/supplier should provide documents such as, past experience, shop load capacity, finance solvency, and period of financial claim for the payments*", a Construction Site Manager explicated. This is exactly what was stated by the Construction Industry Institution (CII 1988, p8) and stressed by Kannan and Tan (2002), Al Haddad (2006), Ho, Nguyen and Shu (2007) "*Vendors must be selected on the basis of their capabilities, small and disadvantaged business considerations, geographic location, prior experience, and* *owner preference. Measurement of capabilities includes such considerations as past performance, financial condition, bargaining agreements, shop capacity, engineering support, quality assurance/quality control programs, competitiveness, responsiveness, and schedule adherence*".

The discussion above explains the absence of the function of 'Vendor Inquiry and Evaluation' as an independent function, as shown in **Figure 6.5**, though its activities can be realised within the Cases A, B, C, and E.

4- A *Function of Purchasing:*

This function has many controversial matters with regard to its name, activities involved, and the limits of its authorities and responsibilities. Nevertheless, there is a consensus among all the interviews within the case studies on that the function of Purchasing is the main function in the CMM process and in the department of Purchasing/ Procurement/Logistics that lead the most of CMM process. A Senior Construction Manager (Case F) confirmed that "*in the J.C.I or maybe in all the Arab building projects, the purchasing or procurement department leads the majority of CMM process and its personnel with the participation of the construction team have the authorisation to implement the majority of the CMM process including evaluating and selecting suppliers, performing purchasing procedures, monitoring production and setting up procedures to implement a delivery plan*". A Project Administrator added "*this function, which is also called Procurement in the J.C.I, is one of the most important functions, and the department, which is responsible for implementing its activities, is the most important department related to the CMM process*". This supports what has been concluded in the literature review that 'purchasing' is a fundamental function of any construction-related organisation, and that the boundary of its responsibilities and activities is very wide and different from one organisation to another (McConvill, 1993; Stukhart, 1995; Oswal, 2007; among others).

It is evident that from **Figure 6.5** that the function of 'Purchasing' included the activities of the 'Vendor Inquiry and Evaluation' function in the Cases A, B, C, and E, it also included some activities of the function of 'Expediting and Transportation' in all the Cases, but under different terminologies such as, 'Purchasing', 'Logistics' or 'Material

Procurement'; 'Performing Shop Inspection' in Case A, and 'Execute Transportation Agreements' in all the cases. The 'Purchasing Department' within the head-office (organisational level) in Cases A, B, and C is responsible for managing the majority of the Purchasing activities (as cited in the typical workflow diagram) for the entire project, along with the construction team who are responsible for selecting and evaluating the majority of the suppliers, obtaining the required approvals, and performing the process of purchasing from buying a small item to securing bulk materials on the site.

Due to the organisational structure and the dependency of the main contractor in cases D, E and F (in Case D, the main contractor and the suppliers belonging to the same holding organisation; in Case F, the main contractor is one of the client's subsidiaries), the activities of the Purchasing function, Vendor Inquiry function and a part of the activities of the Expediting and Transportation function are combined under one function called Logistics (Case D) or Material Procurement (Cases E, F). It is evident that the terminology of Purchasing, Procurement, and Logistics are frequently used interchangeable in the Jordanian Construction Industry (J.C.I). This supports what has been mentioned in the literature review that 'although the differences in their meaning, purchasing, buying, and procurement are frequently used interchangeable in the construction industry' (Stukhart, 1995; *Glossary of Defence Acquisition Acronyms & Terms*, 2011; Wright, 2013; Wilkinson, 2014).

Owing to this combination/integration, the procurement/purchasing department and project management team carry out many of the activities that are related to other Functions; Vendor inquiry and Evaluation (Cases A, B, C, and E), Expediting and Transportation (Cases A, D, E, and F), and Quality Management (Case A, D). Furthermore, by comparing the practiced function's activities with the function's activities cited in the typical workflow diagram of CMM process, new activities have emerged in this function; for instance, 'Updating/Approving Forms and Procedures' (Cases B, C, D). Moreover, new activities have emerged within the functions of 'Logistics', 'Materials Procurement' (see **Figure 6.5** above), such as 'Preparing and Issuing Temporary Purchase Order' (Cases E, F). Some activities are known by different names; the terminologies of 'Prepare/Issue Pre-Purchase Order', and 'Evaluate Bids, Negotiate, and Award a Contract' are used to indicate the activities of 'Preparing Purchasing Order' and 'Evaluating Bids' respectively.

5- A *Function of Expediting & Transportation:*

At the first glance, the term of 'Expediting' was not agreeable to all participants. A Project Manager (Case A) confirmed that "*in general, this function is not familiar with the J.C.I, and it could be used only in the cases of delivery delay*". This also was realized within the field tours (Case C), where a Warehouse Manager also believes that "*There is no term of 'Expediting' within the process of materials management that is practiced by the Arab companies, this may be replaced by the function of 'Transportation & Recieving Control*". However, when the researcher explained the objectives and activities of the function, the majority of interviewees confirmed the existence of some of these activities, but they are conducted within other functions or under different names.

Away from Cases B and C, in Cases A, D, E, and F, implementing the activities of this function depends on their specified needs, and they are included under the responsibility of the function of 'Purchasing', 'Logistics' or 'Material Procurement', elaborated a Project Manager (Case A), an Executive Project Director (Case E), and a Senior Construction Manager (Case F). This is contrary to what was derived from the literature review and confirmed by many researchers, such as Bell and Stukhart (1986), CII (1987), CII (1988), Plemmons and Bell (1994), Plemmons (1995), Plemmons and Bell (1995), Al-Draweesh (1999), Kini (1999), Al-Juaid (2005), UL-Asad (2005), Al-Quriesha, et al. (2006), and Al-Alawi et al. (2007), who consider 'Expediting' as an independent and essential function for managing the building materials. On the other hand, the perspective of combining the functions of 'Vendor Inquiry and Evaluation', 'Purchasing' and 'Expediting and Transportation' under one function, regardless of its name, is accepted upon some scholars such as, McConville (1993), who believes that "*the activities related to quality, inspection, expediting, and transportation for any construction project are specialized elements of the overall purchasing management program*". The 'Expediting' activities, which were practiced within those cases (A, D, E, F), are limited to 'monitoring production', 'follow-up the processes of transportation (handling, downloading, and tracking)', and 'shop inspection', which are usually carried out by the project management team and the purchasing personnel, added the Project Manager (Case A), the Executive Project Director (Case E), and the Senior Construction Manager (Case F).

Although the participants in Cases B and C confirm that the function of 'Expediting' is rarely practiced during a skeleton phase and it is just used when there is a delay in a materials delivery, they see that some of the function's activities are practiced under independent functions called 'Transportation Control' and 'Transportation and Receiving Control' respectively. A Construction Site Manager (Case A) provided an example; "*within the process of requesting reinforced steel (steel was fabricated and formed by a manufactory), the project manager or materials officer phone (or sometimes conduct a visit to) the steel manufactory to ensure that the order/requisition is progressing well, the materials are being delivered to the construction projects in accordance with the stipulated delivery time within the transportation agreement or the purchase order, and the materials are being handled according to the specifications, in addition to tracking the materials deliveries*". In fact, these procedures form a kind of expediting that is called '*Routine Status Reporting*' according to Stukhart (1995).

Generally, the main activities of 'Expediting' function, which were practiced within all the cases (A, B, C, D, E, F), were limited to 'Performing Shop Inspection', 'Monitoring Production and Transportation Status (Delivery Tracking and Receiving Control)', and 'Developing and Executing Transportation Agreements (Developing and Executing Materials Delivery Plan)'. In addition to 'Developing Delivery Tracking System' that is considered as a new activity emerging in Cases B and C. (For more details, see **Figure 6.5** above and see **Figures J.3, J.5, J.7,** and **J.9** in **Appendix J**).

6- A *Function of Field Control:*

According to the field tours' notes and the interviewees' statements from all the cases (A, B, C, D, E, F), the border between the 'Field Control' and 'Warehousing' functions, is somewhat inconspicuous, and their activities, to some extent, overlapped. A Project Manager (Case B) asserted "I*n fact, the function of Warehousing significantly overlapped with Field Control function, and it is difficult to segregate their activities*". This also was observed during the sites' visits, where many of activities and actions that are conducted by the warehouse personnel should be performed by the authorization, or at least with the knowledge, of the Field Control Team (e.g. Construction Site Manager). An example was given by a Civil Work Supervisor "*Some Site-Warehouse activities are somewhat overlapped with the field control function, and the Field Control team contributes to* *managing some Warehousing activities, and all the data of the site-store must be provided to and approved by the Field Control Team. For example, when a craft-worker requests materials, items or equipment, the requisition form should be signed by a foreman or a site engineer, and these materials or items should be released and issued from the site-warehouse (store) with the authorisation of the project manager or the construction site manager within the field level*". This strongly confirms the vision based on which position of the Field Control function has been modified in the typical workflow diagram of the CMM process within the literature review process (see **Figure 3.6**) whereby the participants see that placing the 'Field Control' function above the 'Warehousing' function is reasonable for quality control issues since it empowers the Field Control team to monitor the movement and consumption of materials. On the other hand, the perspective of combining the 'Field Control' and 'Warehousing' has not been raised within the literature review.

The comparison with the typical CMM workflow diagram indicates that the majority of the function's activities exist and are practiced in the CMM process in the Jordanian building projects, even if there are a few changes in some activities' labels. Moreover, it was observed that the Field Control team performs some activities of a 'Vendor Inquiry' function; such as 'Providing Vendor Performance Feedback' (Cases A, B, C, D). Its team, also, participates in some Quality Management activities, such as 'On-Site Quality Assurance and Quality Control and Receiving Quality Control Report'(Case B, D) besides conducting some 'Quality Control' activities (Cases C, E). A number of new activities has been realised in this function (see **Figure 6.5**); for instance, 'Developing Site-Functional Plans' (Cases B, C), 'Issuing and Administrating Material Requisition Forms' (Cases E, F), 'Issuing and Administrating a Material Release Request' (Cases E, F), and 'Issue Notification of Delivery to Warehouse' (Cases E, F).

7- A *Function of Warehousing:*

As discussed in the Field Control section above, the participants concerned with this function, in all cases, again stressed that "*the Field Control and Site-Warehousing functions are somewhat combined, and that the Field Control team has an authority to managing some activities/actions in the site-store. The site-staff or workers should request their requirements from the field control staff, not directly from the warehousing* *personnel*', expounded the Construction Site Manager (Case D). This furthers the necessity for placing the 'Field Control' function above the 'Warehousing' to represent the direct relationship between the function and the craft-worker, as practiced within all the cases. In accordance with what has been noted during the site's visits and what can be concluded from the interviewees' responses, it can be emphasized that the majority of the key activities that form the 'Warehousing' function in all the cases (A, B, C, D, E, F) are largely similar to those, which were revealed by reviewing the literature and listed in the typical CMM process workflow diagram; regardless of whether the materials were delivered and stored directly on the site (sub-stores) or they were delivered to workshop for fabrication or to the main warehouse. Due to the overlapping between the field and warehousing functions, some of the field activities are conducted with the participants of the warehousing personnel, such as 'Receive and Verify Materials Received against the Supplier's Package List, or N.D.W'. Moreover, the warehouse personnel perform some activities of a 'Vendor Inquiry' function; such as 'Providing Vendor Performance Feedback' (Cases A, B, C, D, and E).

In spite of the fact that the function is managed by the Storekeeper (at the Field Level-site store) and the Warehouse Manager (at the Organisation Level-main warehouse), most of the interviewees (Cases A, B, C, D) agree that the final decision, with regard to the management of the surplus materials (whether returning them back to the main warehouse or to the vendor, or use them in other projects) is usually the responsibility of the 'Materials Administrator' in the organisational level and the 'Project Manager' in the field level with coordination with the warehouse personnel. Although this contradicts the points of view of Perdomo-Rivera (2004) and WRAP (2007), who believe that the surplus decision is usually the responsibility of the Contractor-organisational level personnel with the Client level, it supports the vision that the Warehousing activities should be under the authority of the Field Control personnel. In addition to, the activity of 'Receiving Notification of Delivery' has been realised as new activity.

Despite the lack of using any emerging technologies (wireless technologies, bar-coding, or radio frequency identification (RFID)) in managing the materials within the cases, some basic computerised programs are used at the inventory level, planning level and field level for most of the cases. In addition, the technology of the intranet is adopted in case D for communicating and sending the CMM-related documents between the main warehouse and the logistics department at the company's organisational level and their internal suppliers and manufactories.

8- A *Function of Quality Management:*

Generally speaking, there is good understanding of the meaning and importance of Quality Management (QM) in the context of CMM and good knowledge and awareness of the tasks and procedures of its two branches (Quality Assurance (QA) and Quality Control (QC)) by the JCI participants. "*Quality Assurance is a proactive quality practice to avoid defects, while Quality Control is a reactive practice to identify defects*", outlined a Planner (Case C). It was evident from the statements made by a Project Manager, a Planner, and a Construction Manager that the traditional notion of the quality management within all case studies was built on dividing the QM into two sub-functions; 1) the Quality Assurance (QA) that refers to the course of action used to ensure that vendors and suppliers have conformed/committed to procedures that were established before the fabrication and manufacturing processes including the establishment and implementation of quality plans to ensure conformance to requirements; 2) the Quality Control (QC) that refers to the actual quality related actions to verify the conformity to requirements, including the actual inspection, field testing, and documentation for materials and the installation methods used. This notion is consistent with the definitions provided by many authors and researchers such as McConville (1993), (Stukhart, 1995), Al-Delma General Contracting LLC (2010), *Legacy Site Services* (2011), and TeamGrowth (2013).

Concerning the location (reposition) of the Quality Management function; although there is a consensus on that the centre of the QM function overlapped with the Transportation function (from one side) and the Field Control and Warehousing functions (from another side), the function's activities are transferable (moveable) among the other functions of the CMM process. A Planner in Case C explained, "*While the centre of the QM function is an interface between the Transportation function (from one side) and the Field Control and Warehousing functions (from another side), the QA's activities are distributed and they overlapped between the functions starting from the Take-off function to Transportation function, and the QC's activities are conducted within the functions starting from Transportation to issuing materials to the craft-workers; they are both conducted with the* *participation of the consultant*". He added that the centre of the QM function means the point where the QA and QC are intersected (overlapped).

In line with the above, in Cases C and E, the majority of the QA's activities are conducted within the functions of 'Take-off', 'Purchasing' and 'Expediting' (or of 'Estimating Take-off' and 'Procurement' in Case E), whilst most the QC's activities are performed within the 'Field Control' and 'Warehousing' functions. Similarly to some extent, in Case D, the majority of the QA's activities are conducted within the functions of 'Planning' and 'Take-off', whilst the QC sub-function is the interface between the 'Logistics' function (from one side) and the 'Field Control' and 'Warehousing' functions (from another side). In other words, the Quality Management (QM) team with the participation of the personnel of the Take-off and Purchasing/Procurement functions perform the QA activities, and the QM team with the participation of the personnel of the Field Control and Warehousing functions perform the QC activities, described a Senior Projects Manager, a Project Manager and an Executive Project Director. The situation in Cases A, B and F is slightly different, where the Construction Management (CM) company and the consultant essentially conduct most QA activities (with some participation of the contractor), and the contractor is basically responsible for conducting QC activities, which could be located in the interface between the Material Purchasing/Procurement and Transportation functions (from one side) and the Field Control and Warehousing functions (from another side). Although this is contrary to what was discovered by Matthews and Burati (1989), it is in line with the perspective of Stukhart (1995, p185), who believes that "*Quality assurance has traditionally been away from the contractor to demonstrate to the owner that proper procedures would be followed*".

With regard to the activities that form the function of QM, the comparison between the activities of the QM function that are practiced within all cases (see **Figure 6.5**) and those form the typical workflow diagram of CMM process (see **Figure 3.6.6**) shows that the majority of the activities exist, even if they are practiced within different functions. A new activity related to the Quality Management function has been found; 'Establishing the Compliance Sheet - QA' (Cases A, C).

In short, from the discussion above, one can infer that the activities of QM function are conducted within the functions of the CMM process as follows: the QA activities in the most cases, if they are not carried out by a consultant, they are implemented by the personnel of 'Take-off', 'Purchasing'/'Procurement', and Transportation' functions; and the QC activities are implemented by the participation of 'Procurement and Transportation' staff, 'Field Control' team and 'Warehousing' personnel. Nevertheless, QA and QC are intersected; they overlap to form the QM function, which should be an interface between the function of 'Procurement and Transportation' from one side and 'Warehousing' and 'Field Control' functions from the other side, and its team (if exist) participates in performing the activities of both QA and QC. This is inconsistent with what has been concluded by reviewing the literature and with the typical workflow diagram of CMM process, where the Quality Management function has been placed above the function of 'Expediting and Transportation' according to its sequences in the functions found in the literature.

6.6.1.3 Developing Practical Workflow Diagram of CMM process Practiced within the J.C.I:

One of the main objectives of this research (the Fifth Objective) is to develop a framework for Evaluating the Effectiveness of the Construction Material Management Process's Performance (the E.CMM.P Framework) in the Large-scale Concrete Building Projects in the Jordanian Construction Industry (J.C.I). As stated earlier, the third stage of developing the E.CMM.P framework is the development of a practical workflow diagram that can reflect the real-life of the CMM process that is practiced within the large-scale concrete building projects in the J.C.I (see **Section 5.6.2** and **Figure 8.1**).

Based on the cross-cases analysis and the wide discussion of the data outputs collected from the six case study projects (visiting construction sites and interviews) regarding the CMM process that is practiced within the Jordanian building projects, it can be concluded that there is a lack of certain standards or a written policy that can draw a unified construction materials management process within the JCI. This has led each building company or maybe each project to develop and implement its own CMM process. However, there have been similarities, commonalities, and fundamentals between the CMM processes that are practiced within the majority of the Jordanian building companies and that are familiar in the J.C.I, which could allow linkage between these processes and generating a unified practical CMM process. Therefore, in order to develop a unified practical work flow diagram that can reflect the real-life of managing the construction materials within the Jordanian building projects, it was necessary, at the first place, to investigate the current functions and activities that have been practiced within the CMM process of each case study.

As a result of the comparison between the findings resulting from analysing the case studies' outputs and reviewing the literature (The typical CMM process diagram), the main practical functions and activities that form the CMM process within each case-project were identified; based on which, the practical CMM workflow diagram for each case was developed (as presented in Cases B, C, D, E, and in **Figures J.3, J.5, J.7,** and **J.9** respectively). To facilitate realising and identifying the differences, similarities and the commonalities between the practical functions and the activities that shape the CMM processes in these cases, the developed workflow diagrams of the CMM process that was applied in each case study, were summarised in one place as shown in **Figure 6.5**.
A wide discussion addressed the relationship between the CMM processes that were applied within the six case studies and the extent of their conformity/compatibility with the typical workflow diagram of the CMM process that was developed based on the literature review process, in terms of the sequences of the functions, the existence and distribution of activities, and terminologies used. It can be detected, from the discussion section, that apart from the overlapping among the functions and the distribution of the activities under different functions, the majority of the activities, which were practiced within the CMM process in the J.C.I, are similar to those cited within the typical workflow diagram of the CMM process, besides some new activities that have emerged in these cases.

Through performing the following actions and procedures, the Practical Workflow Diagram of the CMM Process practiced in the J.C.I has been developed, as shown in **Figure 6.6**, and discussed below; these actions include:

- Considering the typical workflow diagram as the main reference and the basis for building the practical diagram,
- Compiling the recurring activities of the common denominators (commonalities) under its functions,
- Deleting the irregular activities,
- Re-naming some of the activities in line with the terminology commonly used,
- Repositioning the exported activities, which were positioned on different functions, under the functions that take place underneath, and
- Adding the new activities that were detected.

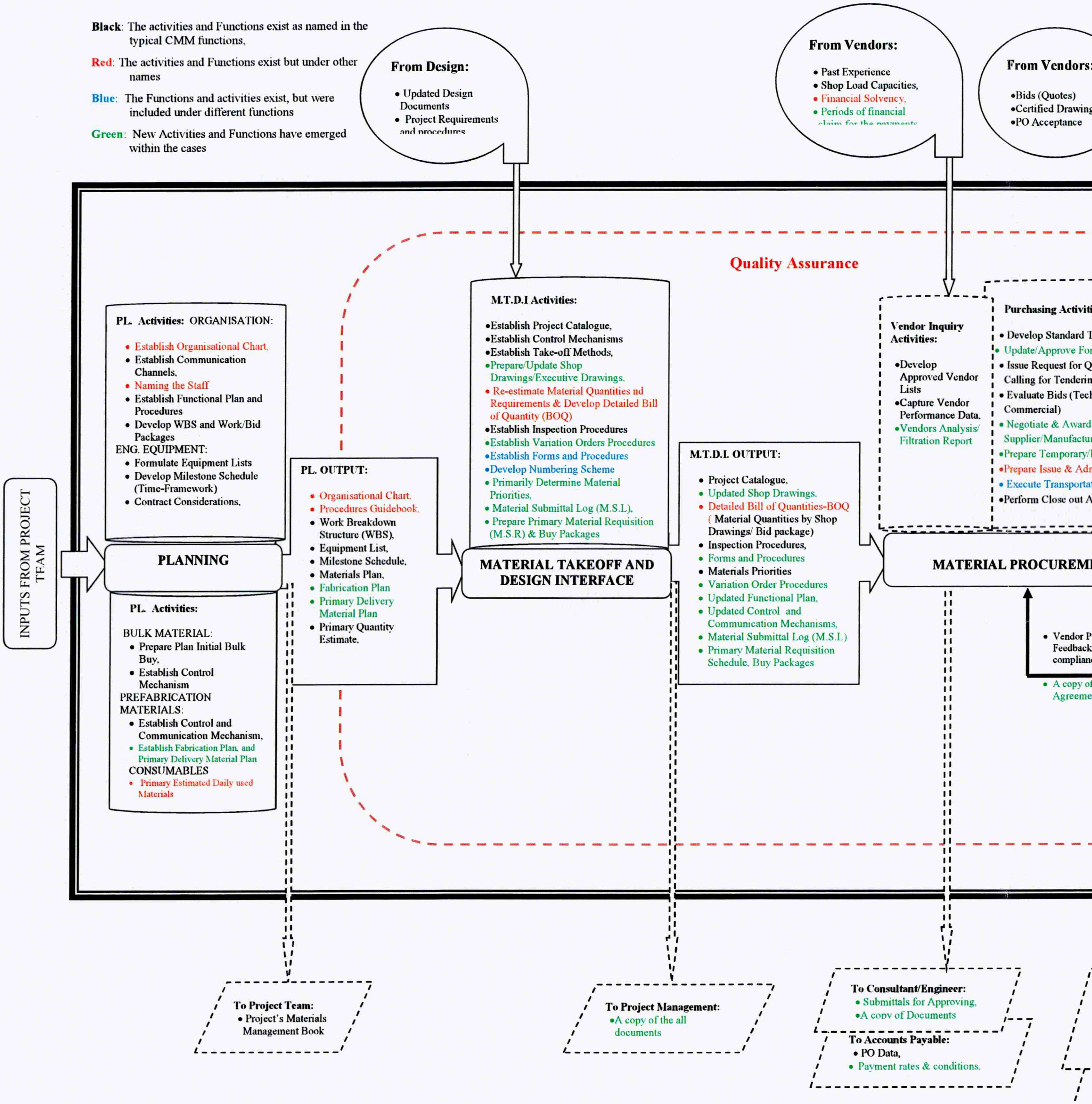


Figure 6.6: The Practical Workflow Diagram of the CMM Process Practiced in the J.C.I

Figure 6.6 provides a realistic workflow diagram that can reflect the real-life of the CMM process that was practiced within the large-scale concrete building projects in the Jordanian Construction Industry (J.C.I). It illustrates the functions and activities that form the CMM process within the J.C.I, regarding their entity, position, sequences, and their relation among each other and with the external participants (Customers, vendors, and clients).

The figure can clearly report that the Practical CMM Process (P.CMM.P) workflow diagram consists of **six** main functions. **'Planning'** function is the first function in the P.CMM.P diagram, and its activities are conducted based on the inputs of a project team or a consultant, while its output is forwarded to the following function. The second function followed 'Planning' is the function of **'Take-off and Design Interface'**. Based on the outputs of the 'Take-off and Design Interface' in addition to the data submitted from vendors, the function of **'Material Procurement and Transportation'** is implemented and includes a combination of the activities of the functions 'Vendor Inquiry', 'Purchasing', and 'Expediting'. The outputs of this function along with the data and information from vendors and craft-workers are submitted to the last two overlapped functions **'Warehousing'** and **'Field Control'**, which, in turn, issue the required material, equipment, tools, and orders to the workers. Although the centre of the function of **'Quality Management'** is positioned as interface between the 'Material Procurement and Transportation' function (from one side) and the 'Field Control and Warehousing' functions (from another side), its activities are distributed within the rest of the functions (Quality Assurance activities are irregularly distributed within the functions of 'Take-off', and 'Material Procurement and Transportation'; Quality Control activities are irregularly managed within the functions of 'Material Procurement and Transportation', 'Field Control' and 'Warehousing'). It is worth mentioning that some considerations regarding the QA could be taken within the planning function.

A wide explanation for the functions, which form the Practical Workflow Diagram of the CMM Process, is provided in the Chapter of Development the E.CMM.P Framework; **Chapter VIII-Section 8.2**.

With regard to designing the activities that form the functions of the practical CMM workflow diagram developed, **Figure 6.6** explains that; the activities that are similar to those included within the functions in the typical workflow diagram of the CMM process and they were found repeated in most cases, have been designated to form the developed practical diagram; whether with the same name that is used in the typical diagram (those with **black** font), or with some modification to conform with the common terminologies used (those with **red** font). All the new activities, which emerged, were added to their functions where they were found (those with **green** font). The activities that were exported from other functions (those in the **blue** font) were designated under their new functions to form the Practical Workflow Diagram of the CMM Process that practiced within the J.C.I.

6.6.2 The Measures of the Effectiveness of CMM Performance within the J.C.I:

6.6.2.1 An Overview of Mechanisms of Monitoring and Evaluating of the CMM Process Practiced within the J.C.I:

This section aims to introduce a general overview of the main mechanisms and approaches that have being practiced within the six case studies, which represents a large segment of the building projects in the JCI, for evaluating the extent of the effectiveness of their CMM process, system, or strategies used.

The extensive discussion of the results of the main investigation that was conducted within the six case studies, undoubtedly illustrates the need for adopting a specific set of measures, particular mechanisms, or unified approaches for evaluating, quantitatively and continuously, the effectiveness of the performance of the CMM process within all case studies. The lack of a specific mechanism to evaluate the effectiveness of the CMM performance in the Jordanian building projects proves what was derived from the statements of the authors, scholars, and researchers such as, Mentzer and Konrad, 1991; Al-Darweesh, 1999; Bhatnagar and Sohal, 2004; Gunasekaran, Patel and Mccaughey, 2004; Nudurupati, Arshad and Turner, 2007 (see **Table 4.1**). This also reinforces the importance of the research in developing a basis for monitoring and evaluating the continuous improvements on the CMM process. Alternatively, non-uniform and irregular qualitative mechanisms and some few quantitative techniques have been practiced separately for monitoring and follow-up the performance of the CMM process within the J.C.I. Although, the majority of these approaches rely on using qualitative applications, the bases of using these mechanisms and techniques differed from one case to another depending on the concerns, purposes, applicability, and requirements of each.

Some cases (Cases A and B) have, largely, applied a qualitative-based approach for continuously monitoring the effectiveness of the CMM performance on the basis of the follow-up and scrutiny of all the materials-related documents and periodical projects' reports. This mechanism included follow-up and examining Daily/Monthly reports, Materials Delivery Status reports, Receiving Quality Control (R.Q.C) reports, Over, Short and Damaged (O.S&D) List/Reports, Request for Quotations (RFQs), Purchasing Orders (POs), Releases, and the entire Material-related Documentary Cycle; thus, through reviewing and examining the data included within these documents and reports, and comparing the planned schedules with the actual works and procedures, any defects, irregularities, delays, unplanned procedures can be determined, and on such basis the extent of the effectiveness of the CMM performance can be evaluated.

Within other cases like Case C and F, the mechanism used for evaluating the Performance of the CMM system was based on assessing the ability of the system to secure materials at the right time, within the estimated cost, required quantity, and acceptable quality. Therefore, the mechanism and techniques have been practiced through examining these four parameters (Cost, Time, Quantity, and Quality) qualitatively and quantitatively, in terms of their compatibility with the planned scheme. Among those techniques that are more reflective of this approach were; **a**) Monitoring expenditure on the purchases of materials, in terms of meeting the planned and estimated cost: this is through matching the material prices listed on the packaging list with those in the Bill Of Quantities (BOQ); **b**) Examining delivery dependability (the capability of providing on-time the type and volume of materials that are required by the construction operation), whether the materials were ordered, delivered, and received on time: this could be achieved through examining the requesting dates of the materials (Material Request from the Warehouse (M.R.W) and Material Release Request (M.R.R) forms) and the actual dates of receiving the material (R.Q.C reports) and the dates needed; **c**) Ascertaining the materials quality, in terms of their conformity to the approved specifications and requirements: this is conducted through monitoring the Over, Short, and Damaged (O,S&D) reports and the rejections of nonconforming items; and **d**) Examining the flexibility of a CMM system, in terms of its ability to react to the changes in design or field operation requirements without affecting the estimated cost and planned time schedule: this could be examined by investigating the Variation Orders (VOs), field work reports and the Daily and Monthly Reports. Those approaches are somewhat similar to the metrics that were proposed by Venkataraman (2004) to assess the project supply chain performance (See **Table 4.9**), and those were listed by Wegelius-Lehtonen (1995) and reported by Hatmoko (2008) for assessing the logistics management process (See **Table 4.8**). Within the context of evaluating the performance of the CMM process, the first three techniques to some extent are similar to those found through the survey that was conducted by Plemmons (1995), and were classified into Cost, Time and Quality attributes.

Assessing the performance of the CMM process in Cases E and D basically relies on evaluating the efficiency of the material-related information system, whether manually or electronically (Material's Reporting System). This approach is based on assessing the Material Reporting System in terms of its ability to and efficiency in transferring the relevant data, requisitions, reports, inquiries, and feedback between the participants of CMM process timely and correctly from and to the right place, in addition to measuring the extent of the response's speed. Although there are some quantitative techniques, more qualitative mechanism has been used to meet the aim of the approach. This qualitative mechanism has been designed to monitor information exchange (sharing of information between participants) and information quality (accuracy, adequacy, timeliness, and credibility of information exchange). For the operation of this mechanism/approach, the most noticeable techniques used were; **a**) Following up the information exchange between the participants: this is processed through frequently monitoring and examining the order's fulfilment lead time and processing time including requesting, delivering and receiving the materials required; **b**) Monitoring the accuracy of the information and data exchanged within the system (manually or computerised): this is performed through examining some related documents, such as forms of Request for more Information (R.F.I) and Re-Request materials for detecting any discrepancies, erroneous or inaccurate data, **c**) Periodically evaluating the responsiveness of the participants to the information exchanged through the system: this is conducted by examining the streamlines/flow accuracy and the speed of the documentary cycle, procedures and feedback. Referring to the literature review, this approach is adopted by number of researchers and authors who believe that measuring the performance of the information system is the key measure of the CMM process performance (CII, 1988; Stukhart, 1995): whether the information is timely (Stukhart, 1995), correct and accurate (Senn, 1990; Plemmonce, 1995), and valuable (Stukhart, 1995).

In short, these mechanisms and techniques, which have been practiced within the six cases that represent the Jordanian building projects, can be classified into three main approaches; **1**) Monitoring the Material-related Documents and Reports, **2**) Examining the Ability of the CMM System to meet its objectives, and **3**) Observing the Efficiency of Material-related Information System (Reporting System). According to some studies, such as those carried out by Plemmons and Bell (1994) and Stukhart (1995), those approaches could be categorised as internal and qualitative measures. Indeed, it can be observed that the majority of the approaches and techniques, which had been used for evaluating the CMM performance, were based on monitoring and following up the report system and the information involved. This indicates the importance of the reports and the information system in developing any consolidated system or framework for managing the mechanism of evaluating the performance of the CMM process in the J.C.I. Indeed, the **Chapter VIII** will show how the reporting system and the CMM-related documents contribute, significantly, to developing the E.CMM.P framework.

6.6.2.2 Practical Effectiveness Measures of the Performance of CMM process Practiced within the J.C.I:

As mentioned earlier, the fourth stage of developing the E.CMM.P framework intended is to establish a set of the Practical Effectiveness Measures (P.E.M) that are/can be used for Evaluating the Effectiveness of the Construction Material Management Process's Performance (E.CMM.P) in the Large-scale Concrete Building Projects in J.C.I (see **Section 5.6.2** and **Figure 8.1**). For that purpose, the main investigation has been implemented to I) examine and determine the measures, mechanisms, or/and approaches that are currently applied to evaluate the CMM performance, II) to gather CMM-related measures currently in use within the Jordanian building projects, III) to reformat those measures to reflect the effectiveness ratio, and then, finally, IV) to establish the set of Practical Effectiveness Measures (**P.E.Ms**).

As a result of the field tours including brief discussions with the relevant participants on the sites and reviewing the CMM-related documents, there is no clear unified set of measures for assessing the effectiveness of the CMM performance that has been observed while conducting the case study research. However, based on the in-depth discussions with the interviewees, and on examining the proposed set of measures, which have been developed on the basis of the literature review process, through comparing it with the actual procedures and techniques practiced within the six case-projects, it was discovered: 1) there were some measures that match the proposed measures but they were used irregularly and separately; 2) the presence of some quantifiable techniques that are somewhat similar, in terms of their purpose, to the proposed measures; and 3) the appearance of some alternative procedures that have been practiced qualitatively (non-measurable) to follow-up the performance of the CMM process within these projects. In order to facilitate the display of the measures, mechanisms, and approaches, which were drawn from the cross-cases analysis and which reflect the measurements that have been practiced within the six case studies, those measures and approaches categorised into three categories; Exist (✓), Quantitative Techniques (**ϕ**), and Qualitative Techniques (**Ω**), as summarised in the matrix displayed in **Table 6.4**, and defined below;

- ***The Exist*** **Measures** are those measures that have been practiced irregularly and separately in the cases, and they match or are largely similar to those cited in the proposed set of measures;
- ***The Quantitative Techniques*** are those techniques that use quantitative methods to evaluate the performance of the CMM process. These techniques could be similar to or different from the proposed measures, in terms of the method of calculation, the approach applied, and the purpose of their use;
- ***The Qualitative Techniques*** are those non-quantitative techniques and approaches that have been used in one or more case study to follow up the CMM process alternative to the proposed measure, and they were never practiced quantitatively in any of the six case studies.

Table 6.4 summarizes the measures, techniques, and approaches (Exist, Quantitative and Qualitative) that have been used within the case studies to evaluate the performance of the CMM process, in addition to the related documents, forms and reports that are used to execute these measures.

Table 6.4: Matrix: A Summary of Practical Measures, Approaches and Techniques of Evaluating the CMM Performance Practiced within the Case Studies

ATTRIBUTES	CODE	MEASURE NAME	CASE A SITUATION	CASE A RELATED DOCUMENTS	CASE B SITUATION	CASE B RELATED DOCUMENT	CASE C SITUATION	CASE C RELATED DOCUMENT	CASE D SITUATION	CASE D RELATED DOCUMENT	CASE E SITUATION	CASE E RELATED DOCUMENT	CASE F SITUATION	CASE F RELATED DOCUMENT
ACCURACY	AC1	Material Receipt Problems	Ω Providing reports including the number line items that received with discrepancy	•R.Q.C reports, •O.S&D reports, •Material Status on the Site	✓	•R.Q.C reports, •O.S&D reports	✓	•R.Q.C reports, •O.S&D reports			Φ Counting & Listing the line items that received with discrepancy	Problem Sheet	✓	•R.Q.C, O.S&D Reports
	AC2	Material Receipt Problems - Internal			✓	•Receipt's Problem Sheet	✓	•Receipt's Problem Sheet	✓	•R.Q.C reports, •O.S&D reports				
	AC3	Warehouse Inventory Accuracy	Φ Periodic review of the inventory	•Inventory Record Database •Warehouse Observation	✓		Φ Periodic inventory inspection		Φ Periodic inventory inspection		Φ Periodic inventory inspection		✓	
QUALITY	Q1	Installing Equipments Rework	Ω Providing Construction Status Report	•Construction Status Report			Ω Following up the Construction Reports including equipments that were required for rework	•Field works report	Ω Following up the Construction Reports including equipments that were required for rework		Φ Following up the Construction Reports and listing the number of equipments that were required for rework for the issues of VOs s	•Construction Reports, •Daily & Monthly Reports.	Ω Monitoring the Site Work (structure) Reports include the number of installing equipments that were required rework, and the VOs	•Site Works Repo[rts] •VOs
	Q2	Jobsite Rejections of Tagged Equipment	Φ Counting the Notifications of Return/non-conforming Items	•Material Returned/Rejection Form •Material Inspection Request (M.I.R)	✓	•M.I.R forms, •Notifications of Non-conforming Items,	✓	•Inspection Form	Φ Counting the number of notifications of return/non-conforming items	•Material Returned/Rejection Form	✓	•Notification of Non-conforming Items		
QUANTITY	QN1	Home Office Requisition Ratio	Φ Listing the number of the RFQs performed	•RFQ forms within Monthly/Quarterly Report	Φ Listing the number of the RFQs performed	•RFQ forms	✓	•RFQ forms			Φ Measuring the number of performed M.R.Rs	•M.R.Rs	Ω Following up the progressing of M.R.R	•M.R.Rs
	QN2	Home Office Purchase Order Ratio	Φ Listing the number of the POs performed	•PO forms within Monthly/Quarterly Report	Φ Listing the number of the POs performed	•PO forms	✓	•PO forms			Φ Measuring the number of performed POs	•PO forms	✓	•POs
	QN3	Average Line Items Per Release												
	QN4	Commitment – Home Office												
	QN5	Commitment – Field			Φ Counting the value of materials that are purchased by the field and compare it with the total value of purchased materials during a specific time period	•Field Works Report, •Field Pos.							Φ Listing the number and the type of materials that purchased by the field team,	•Daily & Monthly Reports
	QN6	Electronic Data Interchange (EDI) Purchases												
	QN7	Sole Source Purchases												
	QN8	Minority Suppliers												
TIMELINES	T1	Procurement Lead Time												
	T2	Bid/Evaluate/Commit Lead-time					✓	•Using Documents related to the RFQs, the POs					✓ "Evaluate Bids, Negotiate, and Award Contract to a Supplier"	•RFQs, •POs
	T3	Purchase Orders (PO) to Material Receipt Duration												
	T4	Material Receiving Processing Time			Φ Measuring the processing time from issuing PO to receiving and updating materials in the warehouse system	•PO forms, •Receiving Quality Control (R.Q.C) reports	Φ Measuring the processing time from issuing PO to receiving and updating materials in the warehouse system	•PO forms, •Receiving Quality Control (R.Q.C) reports, •Warehouse/Inventory Record/Database	Φ Measuring the processing time from issuing E.M.R to receiving and updating materials in the warehouse system,	•E.M.R forms •Receiving Materials Report •Inventory record	Φ Measuring the processing time from issuing PO to receiving and updating materials in the warehouse system	•PO forms, •Inventory Record	Φ •Measuring the processing time of PO to receiving material in the warehouse,	
	T5	Commodity Vendor Timeliness	Ω Monitoring the Material Delivery Status (MDS)Report	•Material Delivery Status (MDS) Report	Ω Following-up the Material Delivery Status (MDS)Report	•Material Delivery Status (MDS) Report	Ω Evaluate the Material Delivery position	•M.D.S Report	Ω Following-up the Material Delivery Status (MDS)Report	•The M.D.S Report	Ω Observing the material delivery progress	Using Electrical System	Ω Following-up the Material Delivery Status (M.D.S) Report	•M.D.S Reports
	T6	Commodity Timeliness	✓		Ω Following-up the Material Delivery Status (MDS)Report	•Material Delivery Status (MDS) Report	Φ Listing the deliveries that are not made on or before the required delivery date (delayed deliveries)	•M.D.S Report	Φ Listing the deliveries that are not made on or before the required delivery date (delayed deliveries)	•The M.D.S Report	✓	•The M.D.S Report	Φ Listing the deliveries that are not made on or before the required delivery date (delayed deliveries)	•M.D.S Reports
	T7	Materials Withdrawal Request (MWR) Lead-time					✓	•In-door delivery lead time Plan •The I.M.R	Ω Following up the process of Internal Material Request	•The I.M.R				
COST	C1	Average Man-hour /Work hour Per Material Take-off (MTO)												
	C2	Average Man-hour /Work hour Per PO												
	C3	Freight Cost Percent	✓		✓	•Materials Financial reports •Statements of Cash flows Reports	✓				✓	•The M.D.S Report, •Document related to Material Financial Reports and Statements of Cash flows Reports	✓	•Schedule of the general expense[s]
	C4	Express Deliveries Percent	✓ Measuring the Percentage of Urgent Deliveries	•M.D.S Report, •Monthly Report (Urgent Deliveries), •PO	Ω Mentoring the number of express delivers,	•M.D.S Report	Ω Mentoring the number of express delivers by M.D.S Report	•M.D.S Report •Monthly reports	Φ Counting the Expenses Deliveries		Φ measuring the number of the urgent/express deliveries that were done within a specific period of time	•M.D.S Report, •PO(s)	Φ Listing the number of the urgent/express deliveries that were done within a specific period of time	•POs •M.D.S Report
	C5	Construction Time Lost	✓	•The daily & monthly reports, •Financial statements	✓	•Daily labour sheets, •Time Schedule – Milestone Schedule	✓	•For identifying the causes of delay	✓	•A Copy of the Monthly supervisor/ Consultant Report	✓	•Construction Works Status report	✓	•The daily & mo[nthly] reports, •Daily labour sh[eets]
	C6	Payment Discounts			Ω Monitoring and comparing the actual with planned materials' cost									
	C7	Warehouse Safety Incident Rate									Ω Monitoring and record any warehouse safety incidents	•	Ω Monitoring the incidents in the warehouse	•R.Q.C reports, •O.S&D reports
	C8	Total Surplus	✓	•Notifications of Return/Non-conforming Items •Inventory Record/ Warehouse System, •Site Material Status Report, Availability Report	✓	•Material Returned/Rejection Form •Inventory Record/ Warehouse System, •Material Status Report •Availability Report	✓	•Warehouse System, •Material Status Report	✓	•Site Material Status Report, •Availability Report	✓	•Electronic Warehouse System (SMS), •Material Status Report	✓	•Material Returned/Reject[ion] Form •Inventory Reco[rd/] Warehouse Syst[em] •Site Material Sta[tus] Report, •Availability Rep[ort]

✓ = EXIST, Φ = QUNTITATIVE TECHNIQUE, Ω =QUALITATIVE TECHNIQUE

Table 6.4: Matrix: A Summary of Practical Measures. Approaches and Techniques of Evaluating the CMM performance Practiced in the Case Studies

ATTRIBUTES	CODE	MEASURE NAME	CASE A SITUATION	CASE A RELATED DOCUMENTS	CASE B SITUATION	CASE B RELATED DOCUMENT	CASE C SITUATION	CASE C RELATED DOCUMENT	CASE D SITUATION	CASE D RELATED DOCUMENT	CASE E SITUATION	CASE E RELATED DOCUMENT	CASE F SITUATION	CASE F RELATED DOCUMEN
AVAILABILITY	AV1	Material Availability	✓	•Materials requests (MRS & MRW form), •Releases Record, •Inventory Reports/ Record	✓	•Materials requests (MRS & MRW form), • Releases, • Site Receipt, •Availability Reports	✓	•Materials Requests, •Material Issuances •Warehouse System			Φ Measuring the percentage of issued materials to required materials	•Releases, •Site Receipt, •Availability Reports	✓	•Materials reques (MRS & MRW form), • Inventory Reco • Site Receipt, Availability Re
	AV2	Stock out Analysis	Ω Following up the material availability & Reporting the materials that were unable to be issued.	•Section of Out of Stock Materials in Materials Status Report/ •Inventory Record..	Φ Listing and recording quantities and types of the materials that were unavailable in the Warehouse when they were requested by the craft-workers on the site.	• Material Availability Reports	Ω Following up the material availability by monitoring the Store Shortfalls List and the inventory data	•Store Shortfalls List, •Material Availability Reports			✓		Φ Counting and recording quantities and types of the materials that were unavailable in the Warehouse when they were requested by Field Control	•Material Availal Reports
FLEXIBILITY	F1	Delivery Flexibility	Ω Following up the Delivery Time Schedule; the overlapping between delivery lead times and other project function lead time and slack time	•The Delivery Time Plan:, •Millstone Schedule, •Material Submittal Log	Ω Updating the material delivery-related activities in the milestone schedule to move planned delivery dates forward		Ω Updating the material delivery-related activities in the milestone schedule (Time Schedule) to move planned delivery dates forward	•The Delivery Time Schedule:, Material Submittal Log	Ω Updating the material delivery-related activities in the milestone schedule (Time Schedule) to move planned delivery dates forward	•The milestone schedule, •Delivery Plan	Ω Following up the milestone schedule (Time Schedule) to determine the overlapping between delivery lead-time and other activities' lead-time and slack time	•The milestone schedule	Ω Monitoring the delivery lead-time with other project functions' lead-times and slack time	
	F2	Changes Flexibility			Ω Monitoring the ability of construction team to modify the delivered materials to react any changes without affecting the cost of field construction phase	•Construction Works Report, •Materials Status Report					Ω Monitoring & Examining the flexibility in supplying different types of items and equipments in order to meet changing field operation needs.	•VO(s) •RE-PO(s)		
	F3	Volume Flexibility	Ω Reporting the volume of required demand and the volume demand that have been already met	•Materials Status Report; •The Bill of quantities	✓	• Material Status Report, •Material Requests,	✓	•Material Status Report, •Inventory Record.			✓	•Material Status, •Availability Report •Warehouse System	Ω Examining & Providing a report shows the required demand volume, planned demand, and the volume of the demand that have been already met	•M.S.R Reports, •Material Availal Report
NEW MEASURE	T		Φ •Measuring Materials Withdrawal Request (MWR) Processing Tim	•Delivery Status Report, •Internal Materials Requests (RMS), • External Materials Requests & RMW	Φ •Counting the MWR processing time (From issuing IMR to sign the material receipt), Φ •Measuring the Procurement processing time from submitting RFQ until issue the PO	•IMR, •Material Receipts •RFQ forms, •PO forms				• The E.M.R forms,	Φ •Measuring the Procurement processing time from issuing the M.R.R to issue the PO Φ •Measuring the order fulfilment processing time from issuing the I.M.R to issue material to the craft	•Using Documents Related to M.R.R and PO(s) •Internal. Material. Request (I.M.R) • Site-Store	Φ •Measuring and Examining the processing time of the In-door delivery	•Using M.R.W ar •the Material Rec
	Q												Φ Counting the number of all the materials inspections that rejected to the total number of inspections	•Material Returned Rejecti (M.I.R) forms
	C				Φ The percentage of value of the materials that considered as waste (Unusable Materials +Surplus) to compare with the total material costs		Φ Measuring the ratio of the actual amount of waste materials to the amount of the materials that expected to be waste (Planned waste)				Φ Measuring the ratio of the actual amount of waste materials to the amount of the materials that expected to be waste (Planned waste)		Φ Measuring the ratio of the actual amount of waste materials to the amount of the materials that expected to be waste (Planned waste).	•M.R.W Form, •Material Receipt

✓ = EXIST, Φ = QUNTITATIVE TECHNIQUE, Ω =QUALITATIVE TECHNIQUE

6.6.2.2.1 An Accuracy Attribute:

Generally, all the three measures that are included under the accuracy attribute have been found as an existent measure, a quantitative technique, or a qualitative technique in the majority of cases. This could indicate the importance of those accuracy-measures in following up the performance of the CMM process in the Jordanian organisations. The importance of this attribute appeared regardless of the accuracy of the computerized systems that are used to manage the building materials in those projects whether using basic project management-related computer systems or programs or using a special computerised system (Stock Management System) as in Case E.

1- Material Receipt Problems External and Internal (AC1 & AC2):

These two measures (AC1 and AC2) have been combined and used as one measure, whether these problems were external or internal, in Case F. The technique of combining AC1 and AC2 has also been implemented quantitatively, in Case E, by listing and counting the line items that are received with discrepancy, and it has applied qualitatively, in Case A, through monitoring and providing reports that inform the presence of discrepancies in some items. However, those measures have been applied separately, as proposed in the theoretical set of proposed measures, in Cases B and C. Because of that the majority of the suppliers of the skeleton-related materials in Case D are the contractor-in house, there was no need for implementing AC1 in this case study.

Due to the activities of receiving and verifying the delivered materials are basically implemented by the vendor and the warehouse, the two measures are located at the interface between the 'Vendor' and the 'Warehousing' function. The most recognisable documents that have been used to conduct those measures are reports of Receiving Quality Control (R.Q.C), Over, Short and Damaged (O.S&D), and Problem Sheet Forms.

2- Warehouse Inventory Accuracy (AC3):

Although this measure has been used in all the cases for the purpose of investigating the accuracy of the information recorded within the inventory system or database used in the Warehousing function, the techniques used to apply the measure differed from one case to other. Cases B and F conducted this measure through four steps; firstly, taking a sample of a specific kind of materials or items; secondly counting the actual physical assets in the warehouse and the controlled laydown areas; thirdly, comparing the actual physical counts with those recorded in the inventory database; finally, calculating the percentage of the number of items found accurate. This technique is largely similar to that listed in the proposed measure (AC3) (see **Table 4.16**). A project Manager (Case B) suggested counting the actual physical assets for the whole items and materials in the warehouse and controlled laydown areas rather that taking a sample. Periodical inventory inspections have been conducted quantitatively on the rest of cases (Cases A, C, D, E) by counting and listing the whole materials and items that do not conform to the inventory database without any calculations to measure or evaluate the effectiveness of the CMM performance. As this measure (AC3) aims to evaluate the accuracy of the information associated with the inventory's activity in the warehouse function, it is located within the 'Warehouse' function, and the main documents used to fulfil it are inventory record or warehouse system or database.

6.6.2.2.2 A Quality Attribute:

It was observed while conducting the main investigation that there is a consensus among the interviewees and the participants on that the quality of the CMM process can reveal itself in the physical characteristics associated with the materials in terms of damage resulting from the problems affecting usability. Therefore, evaluating the quality of the CMM process within the J.C.I focuses on quantifying the impact of the items and materials that do not conform to the requirements rather than measuring the resources required to correct the problems, argued a 'Project Administrator' and 'Construction Site Manager'. This could account for the concentration on the measure of 'Jobsite Rejection of Tagged Equipment (Q2)' by all cases (Cases A, B, C, D, E, F) rather than on another measure listed under the Quality Attribute 'Installing Equipment Rework'.

1- Installing Equipment Rework (Q1):

Except for Case E, which used the technique of listing the installing equipment that required rework, there are no quantified techniques that have been practiced within other case studies to address or use this measure as an indicator of the extent of the effectiveness of the CMM performance. Nevertheless, the used qualitative techniques are limited to following up the technical reports, such as the Construction Status reports, Field Works reports, Site-Daily reports and Variation Orders (VOs), and to identify the equipment that required reworking by the personnel of the 'Field Control' function and quality related team. This measure is not frequently applied due to the fact that it is usually used for evaluating and reporting the performance of the quality material-related processes for a designer and a supplier (fabrication) rather than for the contractor (Plemmons, 1995). In line with this view, a Project Administrator (Case B) outlined "*within the Jordanian contractor companies, the emphasis is placed on evaluating their internal CMM process, apart from evaluating the designers or the suppliers, which is usually considered as the task of the consultant or the project management agent*". Despite this, a number of the respondents confirmed the possibility of calculating this measure by using reports such as, 'Construction Status' report and 'Field Progressing Works', which usually provide data and information that include the total number of installing requirements or items required for the rework.

2- Job Site Rejections of Tagged Equipment (Q2):

Unlike the previous measure, this measure has been practiced quantitatively throughout all the case studies. The measure has been used in Cases B, C, and E to evaluate the ability of the CMM process to provide tagged equipment in accordance with the requirements, even though it was used separately and not specifically for measuring the effectiveness of the CMM performance. The technique that has been used in these cases is similar to the proposed measure, whereby the percentage of all rejections tagged equipment is calculated to reflect the quality of the CMM process. Cases A, D, and F have applied different quantified techniques of those listed within the proposed measures; whereas Cases A and D sufficed to hold counting the notifications of return and non-confirming items and reporting them within the material related reports, Case F has undergone something slightly similar to the proposed one (Q2) with some expansion to include all returned materials. Within Case F, the measure depends on counting the number of all the material-inspections that were rejected by the warehouse, Field Control or Supervision team for all the materials and items used, to the total number of inspections (M.I.R, Notification of Non-conforming Item, etc.), (see **Section 6.6.2.3-Q*).** One Senior Construction Manager (Case F) stated "*Whether measuring the ratio of the number of the rejected items or materials to the total number of items and materials, or the ratio of the number of inspections that were rejected to the total number of inspections, both can determine the effectiveness of CMM performance from the perspective of quality*".

The interviewees stressed the importance of the activity of 'Receiving Material and Inspection' within the 'Field Control' function, which is considered by Plemmons (1995) and Bowerson et al. (1992) as a critical activity of the this function, and measuring it, can provide a clear indication of the quality of the CMM process. This is also consonant with the perspective that was adopted by the 'Industrial Projects' in measuring the performance of their materials management, which considers the measure (Q2) as one of the Key effectiveness measures. The majority of the participants (Cases A, B, C, D, E) agrees with Plemmons (1995), Al-Darweesh (1999), and Al-Khalil et al. (2004) in that a rejection occurs when the construction operation notifies the 'Field Control' on the return of an item. The participants in Case F see that rejection can occur when the defective components are identified by the warehouse personnel through the inspection process; thus, this supports the positioning of the measure at the interface between the construction operations (Craft-workers) and the Field Control function, as proposed in the literature review. The most documents used to process this measure are the 'Notification of Return/Non-conforming Items', 'Material Inspection Requests (M.I.R)', and the 'Inspection Forms'.

6.6.2.2.3 A Quantity Attribute:

In general, the measures of this attribute were not familiar to the participants who are related to the CMM process; therefore, most of these measures in most cases were totally ignored, and some of them have not been practiced as they have been proposed by the literature review. Different reasons behind the lack of using these measures, range from their irrelevance to the 'Skeleton' stage, such as 'Average Line Items Per Release (QN3), the absence of some actions in the Arab Culture, such as 'Minority Suppliers (QN8)' and the lack of using some technologies within the J.C.I overall, such as, 'Electronic Data Interchange Purchases (QN6)'. This further supports the results of the surveys that were conducted by Plemmons (1995) in the USA and by Ul-Asad (2005) in Saudi Arabia, who found no measures related to the quantity attribute were listed within the set of the key effectiveness measures of the materials management performance within the Industrial Projects. Moreover, this may explain the lack of implementing the quantity-related measures in some Arab experimental researches, such as those applied on the industrial projects by Draweesh (1999), Al-Khalil et al. (2004), and Al-Juaid (2005).

1- Home office Requisition Ratio (QN1):

The use of the measure to report the percentage of requisitions for the quotations (RFQ) performed by the home office to the total number of RFQs during a period of time (as proposed) has been adopted by Case C only. A Planner confirmed that "*the contractor calculates this ratio to evaluate the extent of the speed of processing the flow activities to purchase specified materials*". Nevertheless, in Cases A, B, and E, the number of the performed RFQ has been monitored, listed, and included within the monthly and quarterly reports for the purpose of following up, but not as a unit of effectiveness measurement. The measure is totally neglected in Cases D and F. Where, in Case D, the partnership between the main contractor and the suppliers of the building materials led to the disappearance of some activities including activities of issuing RFQs; consequently, there is no need to use this measure. While in Case F, the concerned people follow up the processing Material Release Request. Although the lack of using this measure was clearly illustrated in most cases, the data and information that are needed to calculate it are made available; since most of these cases record and list the number of the performed RFQs. This gives an indication to the potentiality of applying this measure in those cases.

As this measure addresses the home office requisition ratio, the only document required to processing the measure is the Request for Quotations (RFQs), whose number could be listed within the Daily or Quarterly reports and the Material Status reports. Due to the RFQ is an actionable format that is processed between the purchasing department and a vendor, the measure location is at the interface of the 'Purchasing' function with the 'Vendor'.

2- Home Office Purchase Order (PO) Ratio (QN2):

The extent of using this measure is somewhat similar to that of the previous measure (QN1). Although Cases A, B and E have adopted the quantified technique of counting and listing the number of the 'Purchase Orders (POs)' that is performed by the home office for the organisational purposes, the only Cases C and F that have practiced the measure to report the percentage of Purchase Orders (POs) were performed by the home office compared to the total number of POs transactions during a period of time. The measure in Cases C and F aims to "*evaluate the extent of completing the purchase order activity effectively by the home office, and to determine any delay or defects in processing this activity*", explained a Planner. As a result of the organisational structure of the company executing the project in Case D, (the partnership between the main contractor and suppliers of the building materials), there is a lack for the need to practice the activity of issuing POs; consequently, this measure does not apply to Case D.

Similar to the previous measure, the fact of that this measure reports the home office PO ratio, the only document required to implement the measure is the 'Purchase Orders', which can be listed within the Daily or Quarterly reports and the Material Status reports. Moreover, practising the activities of the issuance and purchase order management between procurement or purchasing department and the vendor requires that this measure be located at the interface of the 'Purchasing' (Procurement) function with the 'Vendor'.

3- Average Line Items Per Release (QN3):

Reporting the ratio of the average line item per release and the planned number of line items per release to indicate the effectiveness of the CMM performance is completely an unfamiliar technique that is not practiced, whether quantitatively or qualitatively, in all the case studies (A, B, C, D, E, F). The interviewees in most cases, like Cases A, C, E, and F, attributed the lack of this measure to the lack of the its important in evaluating the effectiveness of the CMM performance within the skeleton stage. This gives greater support to what was deduced from the survey that was conducted in the Kingdom of Saudi Arabia by Ul-Asad (2005), which was intended to rank the measures used to evaluate the materials management within the Saudi Industry Projects, where, it was found that this measure is one of the less important measures used. However, other perspectives, in cases like Case A, B, and C, believe that this measure is not used due to the difficulty of its calculation for the materials used within the skeleton stage. A Project Manager (Case A) confirms that "*The productivity for a given amount of effort to generate a release is something vague, and calculating it could be very difficult and not practical in the Jordanian building projects*". "*I think that the documents, which usually resulted from the Planning function and the Take-off function, do not include the planned number of line items per release*", he added. Based on these statements, one can note the lack of potentiality to practicing this measure within the J.C.I.

4- Commitment – Home Office (QN4):

The status of this measure is similar to the previous one (QN3). No such interviewees in all cases have recognised this measure. A sarcastic statement was made by a Senior Construction Manager (Case F) "*Because of the lack of credibility in most companies, the* *department that is authorised to conduct this evaluation, which is usually assigned at the organizational level (Home Office), is not going to evaluate its efficiency*". But, there are no evidences that can confirm or deny the validity of this view. The reason behind the lack of using this measure might be the lack of the importance for evaluating the performance of the CMM process, as conceived by the participants in most cases. While reviewing the CMM related documents (through the technique of site visits), the researcher did not find any specific documents that can be used to apply this measure, which could lead to a lack in the potentiality to practice this measure within the J.C.I.

5- Commitment – Field (QN5):

The measure of the 'Commitment – Field' is a companion measure to 'Commitment – Home Office', the status of its existence and application in the case studies is somewhat similar to the situation of the previous measure (QN4). In all the case study projects, this measure has not been practiced as proposed in the set of measures that resulted from the literature review process (see **Table 4.16**). Nevertheless, the rationales for the lack of the use of this measure might be to some extent different from those reported for the previous measure, and they differ from one case to another. In Case D, the lack of using this measure was attributed to the lack of the measure's importance, whereas the reason behind this lack in Case E was due to the fact that the 'Field Control' team, during the Skeleton work, is not authorized to purchase any building materials, or it is only authorized to purchase some specific materials with a small value and amount as in Cases A, and C, explained an Executive Project Director (Case E) and Construction Site Managers (Cases A, D). This could give an indication for the irrelevance of the measure in the skeleton stage (the focus of the current study). Cases B and F have adopted different quantitative techniques ranging from listing and reporting the quantity and the type of materials that are purchased by the field team as in Case F, to reporting the percentage of the value of materials that are purchased by the field to the total value of purchased materials during a specific time period, as in Case B. Both techniques were practiced for organisational purposes rather than for evaluating the performance of the CMM process. The main documents related to this measure are 'Field Works' reports, 'Field POs' and Daily and Monthly' reports. The availability of the required data for calculating QN5 raised the possibility of using QN5.

6- Electronic Data Interchange (EDI) Purchase (QN6):

The interviewees in most cases agree with (CII, 1993) and Datex (1999) in that the construction industry, in Jordan as in other regions, has a need to electronically transfer the purchase's documents between the participants (purchase orders, requests for quotations, invoices, shipping notifications, material lists, and payment transfers), and they realise the importance of EDI in reducing the paperwork and data transmission costs. However, there is a lack in using any EDI technology within all the case studies. The use of email is the only technology that has been adopted by the case studies for transmitting unofficially some documents between owners, designers, contractors, and materials suppliers in addition to using the intranet to transmit standard documents between the contractor's departments in Case E.

The lack of using the EDI technology has been attributed to the "*Poor infrastructure of the country in terms of Internet and telecommunications networks, and the penetration of a culture of mistrust in dealing with electronic documents in various business fields of life in the Arab society*", stated a Senior Construction Manager. Another perspective was given by a Project Administrator to clarify the reason behind the lack of using the EDI within the J.C.I; he believes that "*Non-adoption of electronic documents (or those that are usually sent electronically) as official documents in front of the competent courts in the event of any disputes, led to encourage the use of paper-based transactions between the contractors and materials suppliers, and to trust much more the paperwork in the activities of purchasing*".

Apart from the reasons behind the lack of adopting EDI as a purchase technique within the J.C.I, this absence led to the lack in the need and importance of this measure for evaluating the performance of the CMM process within all cases. The potentiality of applying this measure might require a change in some concepts and cultures surrounding the Arab and Jordanian C.I, which could be difficult to implement in the foreseeable future.

7- Sole Source Purchase (QN7):

The definition of the Sole Source Purchase that has been adopted in this study is the 'non-competitive procurement process whose evaluation is limited to the compliance of acquired materials, equipment or services to the requirements set forth in POs and specifications' (Auburn University, 2010; Cornell University, 2012). Considering this conception, this technique was not found in the case studies, at least within the stage concerned in this study (skeleton stage). However, as result of its organisational structure (the partnership between the main contractor and the suppliers of the building materials), the contractor in Case D applies something similar to this technique; the majority of the materials and equipment (if not all) of the skeleton works are provided by suppliers who are under the umbrella of the partnership. The lack of using this purchase manner in the skeleton stage led to underestimating the importance of the measure of 'Sole Source purchase' by the majority of the interviewees. A Procurement Manager argued "*I do not see any meaning for reporting the ratio of materials purchased via sole source to provide an indication of the extent of the effectiveness of the CMM performance; though the types of materials used within the skeleton stage are limited, they are used in huge numbers and the competition is essential for completing the project within the budget*". Therefore, one can note the lack of using this measure (QN7) for evaluating the effectiveness of the CMM performance in all the case studies.

8- Minority Suppliers (QN8):

The strategy of promoting the maintenance and growth of the minority-owned enterprises under the planned Minority Supplier Purchasing Program does not exist in the culture of the Jordanian Construction Industry, stated a Senior Consultant of J.C.I (a Decision Maker). Although some daily used materials are purchased by the field team (Field Purchase) from local shops and minority suppliers, these purchases are made occasionally for the benefit of the contractor to shorten the time and the cost of the procurement process. But, this has not been adopted as a strategy to encourage Minority Suppliers in order to develop a broad customer base to ensure an orderly growth and business environment, explained a Project Manager, a Procurement Manager, and a Decision Maker. Failure to adopt the strategy of the 'Minority Suppliers' purchases by the J.C.I led to a lack in the need for measuring of 'Minority Suppliers (QN8)' within the Jordanian building projects. This could be the reason that led to the absence of this measure in evaluating the performance of the CMM process within the case studies.

6.6.2.2.4 A Timelines Attribute:

Contrary to the previous attribute, the majority of measures of the timelines characteristic is adopted to monitor the performance of the CMM process in most of the case studies, despite some differences in the ways of their application whether quantitatively or qualitatively. This reflects the importance of the timelines attribute of the Jordanian building contractors in determining and following up the performance of the CMM process. This importance is compatible with the perspective put forward by Swanson (1994) and Plemmons (1995, p41), Al-Khalil et al., (2004), and Venkataraman (2004) that considers the measures that report the duration aspect of the materials management process are essential to evaluate the extent of the effectiveness of the CMM performance.

The outputs of data collection analysis illustrates that the CMM-related participants prefer measuring the processing time rather than the lead-time of the CMM activities for examining and assessing the performance of the CMM process; a Procurement Manager confirmed "*Although I cannot deny the importance of measuring the 'lead-time' that is given to prepare an activity, the reality in the Jordanian projects, the focus is usually on measuring the time spent to achieving an activity or a job (processing time)*". This somewhat contradicts the proposed set of measures that has been developed from the literature, which equally focuses on the measures of lead-time and processing time.

1- Procurement Lead-time (T1):

A term of 'Procurement' is still ambiguous in the J.C.I and it is used interchangeably with other terms like purchase; consequently, the activities that are situated in the context of the procurement function are still uncertain and unclear. Considering the point of view of Stukhart (1995, p82), Wright (2013) and Wilkinson (2014) who believe that "*...purchasing, buying and procurement are frequently used interchangeably,... and the differences in meaning needs to be clarified*", one can say that this situation is expected within the environment of the CMM process, whether in the J.C.I or other construction industries around the world. Accordingly, the border of the procurement function is not unified; the average procurement lead-time has been defined in this study as 'the average duration bounded by the transmission of the request for quotation (RFQ) until the receipt (assigned) acceptance of the purchase order from the vendor (the duration encompasses RFQ, bid evaluation, negotiation and award, and the issuance of the PO)'; whereas, in some cases (Cases A and F) "*the procurement duration starts from issuing RFQ until receiving materials in the warehouse*", said one Construction Site Manager. He also added that "*there are no steady sequences in conducting this function, in addition to the presence of idle periods that could be difficult to be calculated within this period for evaluating the performance of implementing this function*".

The difference in the meaning of procurement and the scope of its activities does not make developing a unified measure to evaluate the performance of this function an easy task, which can interpret the reason behind the lack of using this measure in all cases. However, in Cases B and E, a technique for measuring the procurement processing time (rather than Procurement Lead-time) has been used to monitor the performance of the CMM process; this is considered as a new measure (for more details, see **Section 6.6.2.3-T***).

2- Bid/Evaluate/Commit Lead-Time (T2):

Despite the lack of focus on monitoring and using the lead-time given to implement an activity as an indicator for the effectiveness of the CMM performance, this measure has been applied, as proposed at the list of measures, in Cases C and F. The measure reports the average duration reported (in days) to bid, evaluate, and commit (BEC) to the purchase of materials to the planned BEC duration (in days). Within Cases C and F, the BEC lead-time is bounded from receiving the Vendor's response to the RFQ until the issuance of the decision of selecting the supplier. However, this is slightly different from what has been adopted in the proposed set of measures developed in the literature; the measure within the proposed set is bounded by 'the receipt of vendor's response to the RFQ until the issuance of the PO. The lack of the uniform sequence in the activities of the materials procurement function could be the reason behind the fact that "*issuing RFQ and selecting the supplier or the vendor are not always followed by issuing the PO directly, issuing the PO can depend on the need of materials on the site*", outlined a Procurement Manager.

Considering the activities that are performed within the duration from the receipt of the vendor's response to the RFQ until the issuance of the decision for selecting the supplier, it is logical to be the RFQs and the POs that are the most noticeable documents used for practicing this measure. Because the RFQs and POs are mutually processed between a purchasing department and a vendor, this measure is located at the interface of the

'Vendor' with the 'Purchasing' function, and it is also at the interface of the 'Purchasing' Function with the 'Vendor'.

3- PO to Material Receipt Duration (T3) & Material Receiving Processing Time (T4):

There is no clear separation between the duration from the issuance of the PO until the receipt data of the materials and the material receiving processing time in all the cases selected. The duration concerned, which is monitored to follow the performance of materials management in these cases, starts from issuing the PO and ends when the received materials are updated to a' received status' in the materials management system used in the warehouse, explained a Project Administrator, a Project Manager, and an Executive Project Director. For this reason, the lack of using measure 'T3' and 'T4' separately can be evident in all cases, while it can be observed the merger (somewhat consolidation) between the two measures with one measure in Cases 'B', 'C', and 'E'. Although Cases D and F have been used the same approach of integration T3 and T4, the duration integrated and the activities underneath slightly differ from the other cases; while Case D measures the processing time from issuing the E.M.R to receiving and updating materials in the warehouse system, Case F measures the processing time from issuing the PO to receiving materials in the warehouse. Since this merged measure is different from the measures that are proposed to evaluate the performance of the CMM process, it can be considered as a new measure. This new measure is discussed in detail in **Section 6.6.2.3-T****.

4- Commodity Vendors Timelines (T5):

The technique of measuring the number of vendor's deliveries that were delivered 'on promised-delivery date' to the 'total number of deliveries' was not familiar to all case studies. Although determining the number of the 'on Promised-time deliveries' is a possible procedure, the participants argued that this measure is not important for evaluating the performance of the CMM process within the contractor organisation. A Warehouse Manager confirmed "*this measure examines the performance of the supplier, in terms of his ability to deliver materials on the planned-time, more than assessing the effectiveness of the contractor's performance in managing its materials. Nevertheless, I think this measure could be essential to set up the vendor performance feedback*". It was observed that most interviewees focus on monitoring and evaluating the performance of their CMM process rather than on the supplier's performance. Therefore, they believe that "*the emphasis should be placed on examining and evaluating the ratio of deliveries that is made on or before the required date, which can provide an indication for the ability of a contractor to manage his POs and delivery operations to obtain the materials in the time needed*", said a Senior Construction Manager. This can explain why the answers for practicing this measure were, in general, unspecified and they concentrated on qualitatively monitoring 'Material Delivery Status' reports.

Despite the lack of using this measure, reviewing the related documents confirms the possibility for practicing '**T5**', as the number of the supplier's deliveries made on time (on the promised-delivery date) is available within the contractor's records and the relevant documents (Materials Delivery Status, and R.Q.C reports).

5- Commodity Timelines (T6):

Given the statements cited in the previous measure (T5), one can clearly understand that the material-related participants within the Jordanian projects tend to report the ratio of deliveries that are supplied on or before the required date as an indicator of the extent of the effectiveness of the CMM performance. For that reason, two quantitative techniques were applied in most case studies (Cases A, C, D, E, F). Whereas, Cases A and E have used nearly the same technique that was proposed in the set of measures (the percentage of deliveries made on the required delivery date to the total number of deliveries), the second quantitative technique that has been practiced by Cases C, D and F relied on listing and counting the deliveries that are not made on the required delivery date (delayed deliveries). Different documents can report the deliveries that were made on the required time and those that were delayed such as, the 'Materials Delivery Status' report and 'R.Q.C' reports. Since the operational procedures and the documents of materials delivery are usually between the warehouse and the vendors, the measure '**T6**' is located at the interface of the 'Vendors' and the 'Warehousing' function.

7- Material Withdraw Request (MWR) Lead-time (T7):

The majority of interviewees considered giving a lead-time to allow the warehouse's individuals to withdraw specific materials from the inventory and to prepare them for pickup or delivery as an important procedure. This should be practiced by the construction operations. However, reporting the ratio of the actual lead-time to the planned lead-time for evaluating the CMM performance has only been used in Case C. This inconsistency between the recognition of the importance of the lead-time and the lack of measuring it could give an indication to the extent of the disinterest in evaluating the CMM performance within the Jordanian building projects. Moreover, this is contrary to what has been revealed by some studies, such as, Plemmons (1995), Al-Draweesh (1999), and Al-Khalil et al. (2004), who found out that '**T7**' is a key measure for evaluating the CMM process within the Industrial projects in the United State. The small difference in the terminology between Case C and what was proposed by the literature review can be evident; within Case C, "the lead-time is the difference between the date of issuing an Internal Material Request (I.M.R) to the warehouse personnel and the required material receiving date. Many documents have been used to process 'T7', such as, forms of Internal Material Request (I.M.R) and Delivery Plan. Because of that, the elements concerned in conducting the set of activities, which form the action of requesting a withdrawal materials, are the construction operation staff and the warehousing personnel, the location of this measure (T7) is at interface of 'Construction' with the 'Warehouse' function.

Instead of that, Cases A, B, E and F address Materials Withdraw Request (MWR) processing time; a Warehouse Manager (Case E) stated that "*in order to evaluate the effectiveness of the warehousing function's performance, the order/request fulfilment processing time from issuing the I.M.R or E.M.R to issuing the required materials to craft are measured*". This proves the fact that evaluating CMM performance within the 'timeliness' in the Jordanian building projects is processing time-based. This technique is not listed within the proposed set of measures; thus, this technique can be considered as a new measure, (see **Section 6.6.2.3-T*****).

6.6.2.2.5 A Cost Attribute:

Many of researches that studied the CMM process in the 'Manufacturing Industry' and 'Industrial Projects' found out that the focus within the cost attribute is on the efficient use of labour and the introduction of labour-saving technology (Plemmons and Bell, 1995; Fairs, 2002; Venkataraman, 2004). In contrast to that, the evaluation of the CMM process by the cost attribute in the Jordanian building projects concentrates on avoiding the unreasonable and unnecessary expenses and meeting the construction planned cost, outlined a Decision Maker (a Senior Consultant of JC). The Jordanian environment, the

Arabic culture, and the manner of financial management used in the Jordanian building projects affect the presence of some measures under the cost attribute; for example, the payment system for the employees and labours that is applied in Jordan using either monthly salaries or lump sum. Thus, measures like 'Average Man-hour/Work-hour per Material Take-off' and 'Average Man-hour/Work-hour per PO' did not exist in all the case studies.

1- Average Man-hour/Work-hour per Material Take-off (C1) and Average Man-hour/Work-hour per PO (C2):

As mentioned above, the technique of reporting the average number of man-hours required to 'generate a Material Take-off for a single drawing sheet (C1)' or to 'establish a Purchase Order (C2)' for evaluating the performance of the related-functions has not been applied to any of the case studies used in this research (Cases A, B, C, D, E, F). This was attributed to the nature of the payment system within the J.C.I as stated by a Procurement Manager "*the payment system for employees and labour in the Jordan building projects which might exist in the entire Arab Construction Industries is either monthly salary-based or lump sum-based; thus, there is no mention to the man-hours in the contractual documents*". The majority of the participants confirmed this fact. They suppose that due to the lack of contractual and operational documents that can include and illustrate the planned man-hours or work-hours and the lack of a systematic record that can record the actual man-hours used to execute a job, these measures are irrelevant and they have no feasibility in evaluating the CMM performance within the J.C.I, explained a Project Manager and a Planner.

2- Freight Cost Per cent (C3):

It is evident from the measurement's approaches and techniques that are summarised in **Table 6.4**, that the freight cost per cent (C3) has been measured quantitatively in the majority of the case studies. Except Case D, whereby the majority of its suppliers of the skeleton-related materials are under the umbrella of the contractor company (contractor-in house), the rest of cases (Cases A, B, C, E, and F) have adopted the measure 'C3'. A Project Manager believes that "*examining and measuring the ratio of freight costs to the material expenditures is essential, and it is conducted in period-based time, but this action is practiced for the purpose of following up the cash flow without focusing on evaluating* *the concerned CMM functions*". Although this measure is not specifically used for evaluating the effectiveness of the CMM performance in the J.C.I, most cases (Cases A, B, C, E, F) have practiced this measure as theoretically proposed in the set of measures (the total freight cost is divided by the materials expenditures for the time period). In order to calculate the percentage of freight costs, it is essential to address the documents related to the Material Financial Reports and Material Expenses schedules. As the freight's activities are included within the function of 'Material Procurement and Transportation', the C3 should be located within this function.

3- Express Deliveries per cent (C4):

There is a consensus regarding the importance of this measure for providing an indicator on the ability of the used CMM system to plan and utilize standard means of transportation and delivery. A Construction Site Manager emphasises "*measuring the percentage of the urgent deliveries, which were conducted to meet a quick response for transporting the required materials during a period of time, is fundamental to monitor the premium price that should be paid to secure these deliveries, which can affect the overall project budget*". This underlines the fact that was provided by a Decision Maker: cost evaluation in the Jordanian CMM process usually concentrates on the assessment of the ability of the CMM system to avoid the unreasonable, unnecessary, and unplanned material expenditures rather than concentrating on the efficient use of labour and the introduction of labour-saving technology.

Table 6.4 illustrates the different qualitative and quantitative approaches that have been used to monitor the express deliveries. Cases A practiced this measure by examining and measuring the percentage of the urgent deliveries that were made during a period time, which is similar to the proposed set of measures. Cases D, E and F have counted and recorded the number of the urgent deliveries that were supplied within a specific period of time while Cases B and C sufficed with only monitoring the number of express deliveries that are listed in the Material Delivery Status reports and Monthly reports.

Reporting the percentage of express deliveries made (the number of the express deliveries to the total number of deliveries for a specified time period) may somewhat be an easy task, since the number of the express deliveries and the total number of deliveries made to the project during a period of time can be listed within the different material related documents, such as the Materials Delivery Status report, Material Status report, and

Monthly Report, pointed out a Project Manager and a Project Administrator. The availability of the documents needed makes practicing 'C4' possible. The fact of that any delivery activity is a matter between the vendor and the warehousing function led to the agreement by the participants to position 'C4' at the interface between the 'Vendor' and 'Warehouse' function.

4- Construction Time Lost (C5):

Reporting the percentage of the construction time lost due to the impact of materials was the technique applied to all cases (Cases A, B, C, D, E, and F). This reflects the importance of this measure in managing the building materials in J.C.I. It also supports the results of the survey that was conducted on the material management in the American Industrial projects by Plemmons 1995, which revealed that the "*Construction Time Lost was found to be the best to communicate the effectiveness of the material management process for cost reimbursable contracts*".

However, measure (C5) was not practiced, basically, for the purpose of monitoring and evaluating the performance of the CMM process in some case studies (Cases A, C, D, and E). "*The main aim of monitoring the construction time lost due to the impact of materials and calculating its per cent to the construction time is to identify the causes of delay for the purpose of matters of the complaints and claims for the disputes that can emerge between a contractor, a supplier and an owner*", clarified a Project Manager (Case A). The staffs in Cases B and F see that the use of this measure can offer an indication to the ability of the Field Control staff to manage the building materials on the site and to request these materials as required by the construction operations, described a Project Administrator and a Senior Construction Site Manager. Despite the differences in the purpose of practicing 'T5', there is a consensus among the interviewees on the importance of this measure in evaluating the performance of the CMM process. They emphasise that the construction supervisor (whether a consultant or a construction management company) is the one responsible for estimating construction time that is lost due to the impact of materials. Various documents can be used to practice 'T5', such as, Construction Status reports, Daily Labour Sheets, the Equipment Utilization reports, Time Record: Inactivity Timesheet for Machineries, Periodical Consultant reports, Time Schedule (Milestone), and Daily and Monthly reports. Since 'construction time lost' is a contentious issue between the construction operation and field control, positioning 'C5' between the Construction Operations and Field Control function, was acceptable by the interviewees.

5- Payment Discounts (C6):

Unlike the European and American markets, the culture of regular and systematic discounts is not present in the majority of the Jordanian building materials markets, and these payment discounts, if any, could be found in disorganised and unregulated form according to the supply and demand situation in the local market. Consequently, there are no specific or regular discounts periods that can be exploited to reduce normal payments, explained a Planner, a Procurement Manager, and a Decision Maker. According to Grifa (2006) and Alzohbi (2008), this lack could result from the lack of meaningful competition in the Arab markets of building materials, economic instability, and the lack of a national plan for the development of construction processes. The lack of the payment discounts in the culture of the J.C.I led to the lack of using this measure by the entire case studies, except Case B, which used qualitatively the technique of examining the difference between the actual and planned materials cost. Thus, it is not possible to practice this measure within the Jordanian building projects.

6- Warehouse Safety Incident Rate (C7):

Although some cases can monitor and record events regarding warehouse safety incidents (Cases E and F), the technique of reporting the ratio of warehouse safety incidents to the total number of incidents for the project was not used in all the case studies (Cases A, B, C, D, E, F). The reason, from the participants' point of view, may be that "*Determining the warehouse safety rate is irrelevant in evaluating the extent of the effectiveness of the CMM performance, because many of these incidents can happen accidentally or because of reasons beyond the control of warehouse or the CMM system*", said a Warehouse Manager. Additionally, the calculation of the percentage of warehouse lost time incidents compared to the total number of incidents for the project is very difficult and it needs an accurate system to report the impact of these incidents; many issues and required documents should be taken into account, explained a Planner and Civil Works Supervisor.

7- Total Surplus (C8):

"*It is one of the best indicators for the extent of the effectiveness of the CMM system used*", outlined a Project Manager. All interviewees agree with this view, and this can be discerned from the results of the interviews' analysis that are summarized in **Table 6.4**. The technique of determining the ratio of the value of unused materials has been implemented as criterion revealing the extent of the effectiveness of the current CMM performance in all cases (Cases A, B, C, D, E, F). Practicing this measure, within these cases, is similar to the method that was described within the set of proposed measures; calculating 'C8' through dividing the value of unused material by the total value of purchased materials. This underscores what has been adopted by most of the Industrial Projects, which have defined this measure as one of the key effectiveness measures used to evaluate the performance of the CMM (Al-Darweesh, 1999; Al-Khalil et al., 2004). One the other hand, this could support what was revealed by Nudurupati, Arshad and Turner (2007) regarding the possibility of adopting some methods and measures that are used within the Manufacturing Industry and the Industrial Projects to be used in the construction context (building projects).

The inclusion of all material waste into the surplus category was a controversial issue between the interviewees. A Project Administrator believes that the "*Total Material surplus should include all material waste, and thus this measure should report the percentage of all material waste to be compared with the total material cost*", while a Senior Construction Manager argues that "*Material waste differs from material surplus, and that waste management is a separate measure that can also be used to evaluate the performance the CMM system used*". This can indicate a new cost-related measure, which deals with the Total Surplus as a combination of surplus and unusable (non-usable) materials (as suggested by Case B), detailed in **Section 6.6.2.3-C***. A new technique that relies on measuring the ratio of the actual amount/value of waste materials to the materials that are expected to be waste (Planned Waste) was suggested by Cases C, E, and F (see **Section 6.6.2.3-C****). Among the most recognisable documents that were used to practice 'C8' are Notifications of Return/Non-conforming Items, Materials rejection Form, Inventory Record/ Warehouse System, Site Material Status Report, and Availability Report. All interviewees believe that 'C8' should be located where the surplus appears, within the 'Warehouse' and 'Field Control' functions.

6.6.2.2.6 An Availability Attribute:

Determining the ability of the materials management process to meet requests for materials at the required time and place is one of the most important approaches that are used to continuously assess the effectiveness of the CMM performance in the J. C.I, outlined, a Decision Maker. This is consistent with the opinion of Firth et al. (1988) and the findings that resulted from the American materials management-related survey (1995), where the measures related to availability attribute were among those that classified as the best measures that communicate the effectiveness of the material management process.

The interesting of the Jordanian projects and organisations to adopt the availability attribute can be reflected by the fact of using the measures involving underneath by all case studies. This also confirms what was observed during the site visits, where the interest of most cases in evaluating the warehouse related activities was evident, especially, under the availability attribute. Overall, different qualitative and quantitative techniques have been used to evaluate the availability attribute as shown in **Table 6.4**.

1- Material availability (AV1):

In general, there is consensus on the importance of this measure in determining the ability of the CMM process practiced to issue properly the required material to the construction operations prior to the field needed date (FND). However, the ways of its calculation slightly differed among the cases. According to the participants in most cases (Cases A, B, C, and F), AV1 is a measure concerning the performance of a warehouse; thus, it was calculated within these cases by dividing the number of material line items issued by the total number of material line items requested. One Project Manager (Case A) confirmed, "*Measuring the percentage of issued materials to requested materials is essential to identify the extent of the effectiveness of a warehouse performance to deliver or issue the materials as required or scheduled, and consequently on the basis of which one can evaluate fully materials management process*". This technique is the same one used within the proposed set of measures. While, Case E has a problem with the terminology used with this measure, it is believed that the term 'Material Required' is different from 'Material Requested', in terms of the activities' sequences that secure the required materials or requested materials, and those who are responsible for conducting these activities. A Warehouse Manager stated, "*if the materials were requested by the construction operations, this measure thus evaluates the warehousing function, but if we used the* *'required material', this means that the delay in issuing the required materials could be attributed to these materials that were not requested by the construction operations, thus, this measure can evaluate the general CMM process without any identification whether for warehouse or construction operations*". This could be due to the fact that the contractor in Case E is an overseas contractor, and the terminology used could differ from those used in the J.C.I. **Table 6.4** shows that there are no qualitative or quantitative techniques regarding the material availability (AV1) have been practiced in Case D. Whether AV1 reports the percentage of the total number of materials line items to the total number of material line items requested or required, the main documents that are required to practice AV1 are nearly the same in both cases: Materials Requests forms (M.R.S & M.R.W forms), Inventory Reports, Releases Record, Availability Reports, Material Issuances/Receipts, and Material Flow Schedule. The measure is still located as suggested by the proposed set of measures (at the interface of the Warehouse Function with Construction Operation).

2- Stock-out Analysis (AV2):

Despite the recognition of the importance of this measure by the most participants, Case E is the only one that has practiced AV2 to assess the ability of the adopted CMM system to provide the required materials as needed by the craft worker, regardless of the cause of occurrence of this stock-out situation. Unlike what was identified in the literature review, Case E does not classify the stock-out situations to groups or subgroups on the basis of their root causes analysis, outlined one Warehouse Manager. AV2 is used as an aggregate measure, and it has been calculated by dividing the total number of line items that a warehouse is unable to issue to the construction operations by the total number of line items requested. Other cases, Cases B and F, employed a quantitative technique to report 'Stock-out Analysis', which is based on counting, listing and recording quantities and types of the materials that were unavailable in the Warehouse when they were requested by the craft-workers on the site. During the site visits and reviewing the documents, it was observed that Cases A and C, though they did not use any quantitative technique to report 'AV2', they follow up the materials availability by monitoring the Store Shortfalls List and the Inventory Database, and then report the materials that were unable to be issued. Material Availability Report, Material Status Report (Section of Materials Stock out), Inventory Record, and Store Shortfalls List are among the most required documents to practising AV2. Since all the documents required are related to Warehousing function, AV2 can be located within this function. The availability of the documents required in the Jordanian projects and the ease of calculating AV2 give indication on the potentiality of practicing this measure in the J.C.I.

6.6.2.2.7 A Flexibility Attribute:

Based on what has been concluded from the literature review, a flexibility attribute has never been used or even evaluated in Construction Industry. Within this research, this attribute are adopted for the first time from the supply chain management within Manufacturing Industry to be involved in the evaluation of the performance of the CMM process.

From manufacturing point of view, flexibility measurement examines the ability of a supply chain management system to accommodate scheduling and volume fluctuations of the customers, manufactures, and suppliers, and its ability to respond to a changing environment (Beamon, 1999; Duclos, Vokurka and Lummus, 2003). Flexibility measurement is essential for evaluating the effectiveness of the manufacturing supply chain management performance (Slack, 1983; Wu and Liu, 2008). Theoretically, based on the literature review, three measures have been adopted from the manufacturing industry. They were modified to fit the building context, and then they were added to the proposed set of measures. Within the main investigation stage (case study research), the research project attempts to investigate and find out the usability of these measures in the Jordanian projects, and thus the potentiality of practical application of the flexibility attribute to evaluate the performance of the CMM process within the J.C.I.

Based on the findings of analysing the data collected from the case studies, one can observe that the measure 'Volume Flexibility (F3)' is the only one that has been quantitatively practiced within some case studies, while different qualitative techniques reported the 'Delivery Flexibility (F1)'. Due to different causes, 'Changes Flexibility (F2)' was not practiced quantitatively in all the case study projects.

1- Delivery Flexibility (F1):

"*It is impossible to measure the extent of the flexibility of a delivery*", declared a Project Manager (Case A); this statement gave the first impression of some participants. However, based on an in-depth explanation and discussion, it was revealed that the action of changing the planned date of some deliveries usually occurs during the process of delivering materials, and the check of the ability to move a planned delivery date forward is a familiar technique to the most selected projects. Nevertheless, this ability is not measured or quantified for reporting the performance of the CMM process, explained a Project Administrator (Case B), an Executive Project Director (Case E), and a Decision Maker. An example is cited by a Construction Site Manager (Case A) to illustrate when and how the process of moving the planned delivery date can occur; "*When the consultant (Engineer) discovered later a mistake in the width of a wall, after he gave us a permission for casting concrete. This led to examining the possibility to move the concrete delivery date forward by coordinating the process with the supplier, examining the delivery milestone schedule, and identifying the potential options to overlap the activities' lead-time, slack time, and the delivery time*".

The results of cross-case analysis (**Table 6.4**) illustrate that the techniques used in all cases are qualitative-based, ranging from following up the delivery milestone schedule (Cases A, E), determining the potentiality to overlap between deliveries of lead-time and slack-time within and across the different activities (Cases A, E, F), and continuously updating the material delivery-related activities in the milestone schedule (Time-table) to move the planned delivery date forward (Cases B, C, D).

Given the way, which has been proposed to calculate the 'Delivery Flexibility' based on the delivery's Last Time Period (L.T.P), Earliest Time Period (E.T.P), and Current Time Period (C.T.P) (see **Appendix Q-F1**), the practice of the measure 'F1' in the J.C.I is possible due to the needed data are available within the executive and planning documents and reports. Though interviewees believe that practicing F1 is not an easy task, they confirm the potentiality of its use in the Jordanian building projects. The possibility of using 'F1' in the building projects confirms the validity of adopting the 'Flexibility' attribute from Manufacturing Industry to be used within the Construction Industry. This provides another indication that emphasizes the possibility of adopting some measures that are used within the Manufacturing Industry to be applied in the Construction Industry. Among the most important documents expected to be required are those related to the delivery time schedule and milestone schedule. The expected location of this measure, which is at the interface between the 'Vendor' and 'Warehouse' function and the' Warehouse' with the 'Construction', was accepted by the interviewees.

2- Change Flexibility (F2):

The technique of quantifying the ability of the CMM process to react to any changes whether design changes, quality's changes or decision's changes, without affecting the cost of field construction, was not used in all case studies (Cases A, B, C, D, E, F). The rationale for the lack of practicing the measure 'F2' is due to different reasons; a Project Manager (Case A) believed that "*the identification of the direct and indirect cost of rework, which were performed in the field due to materials-related changes, in order to calculate F2, is a very difficult job*'', whereas one Senior Construction Manager (Case F) argued that "*F2 is an irrelevant measure, and it could reflect the ability of the supplier or vendor to react to these changes, without affecting the planned cost or operation process, rather than the contractor CMM process*". Another view was presented by a Planner (Case C), who sees that this measure is similar to that of 'installing Equipment Rework 'Q1', and that there is no need for 'F2'. A Construction Site Manager (Case A) provided an example for the change flexibility; "*After requesting the prefabricated reinforcement steel, a mistake in the length of steel bars required was discovered. Therefore, it was necessary to find a method that saves the amount of the formed steel. What happened was that part of the steel was re-formed in the site and used somewhere else in the roof, another part was kept in the store to be used in the next floor, but this action is not measured in the Jordanian CMM process, because it is difficult to be quantified in terms of effectiveness*".

Based on the above statements, one can note the lack of potential for using this measure in most cases within the J.C.I, as a result of the difficulty involved in calculating 'F2' within the context of Construction Industry. However, Cases B and C have used some qualitative technique either to monitor the ability of the construction team to modify the delivered materials to meet any changes without affecting the cost of the field construction phase (Case B), or to examines the ability of the supply system to deliver different types of items and equipment in order to meet the changing field operation needs (Case C).

3- Volume Flexibility (F3):

A project Manager (Case A) explained the meaning of 'Volume Flexibility' through an example; "*In some cases, the supplier could be unable to provide the contractor with the materials, which the contractor needs for a particular demand volume and at a specific time with specific specifications. In order to meet the change in the demand volume and to* *secure the required demand volume, the CMM staff usually chooses more than one supplier for an item or material to be replaced with the one who is unable to secure the entire demand value. This could reflect the ability of the CMM system to adjust capacity to meet changes in quantities required for the construction operations*".

Although 'F3' has been imported from manufacturing industry, the approach of reporting the ratio of the demand volume that can be met by the CMM system has been applied by three cases (Cases B, C, and E) for monitoring the performance of the CMM system. This could reflect the importance of this measure, which was confirmed by a Project Administrator (Case B), who said; "*one of the good indicators of the CMM performance is the extent of its ability to meet changes in customer quantities and to secure the required demand volume*". This is consistent with the logic put forward by Duclos, Vokurka and Lummus (2003) and Sanchez and Perez (2005), which stressed the importance of volume flexibility in highly cyclical industries.

The use of 'F3' in building projects, again, indicates the possibility of converting techniques, approaches, technologies, and measures from the Manufacturing Industry to the Construction Industry. This further supports the perspective provided by Luhtala et al. (1994) and Vrijhoef and Koskela (2000), which supposes that 'the principles and methods of SCM that are applied in the manufacturing industry can be translated and used in construction industry'. The technique of practicing this measure differs among these three case studies. Whereas Case C calculates this measure by dividing the average of the demand volume that can be met by the CMM system by the planned demand volume (as proposed by the literature review), Cases B and E apply 'F3' through dividing the average of the demand volume that can be met by the CMM system by the required demand volume.

In addition to the quantitative techniques, which have been applied in Cases B, C, and E, a qualitative technique has been used in Cases A and F. This qualitative technique was built on the bases of examining the demand volume and providing a report illustrating the required demand volume, planned demand and the volume of the demand that has already been met. The required data for this measure (The required demand volume , planned demand volume and the demand volume that has been already met) could be available in materials demand related documents such as, Materials Status Report, Bill of Quantities, Availability Report, Material Requests, and Warehouse and Inventory system Recode. As securing the demand volume is a mutual function between the vendors and the warehouse, the interviewees agreed with locating the measure at the interface between them.

6.6.2.3 Establishing a Set of Practical Effectiveness Measures (P.E.M) that are and/or can be implemented in J.C.I:

After completing the in-depth discussion for the measures, mechanisms, and approaches that were practiced within the case studies selected, as presented above, this section was designed to complete the fourth stage of developing the E.CMM.P framework. This stage aims to 'establish a set of Practical Effectiveness Measures (**P.E.Ms**), which are already used and/ or can be used for evaluating the Effectiveness of the Construction Material Management's Performance (**E.CMM.P**) in the Large-scale Concrete Building Projects in the J.C.I'. Based on the above discussion of the outputs that resulted from the research's main investigation (Cross-case studies analysis), one can conclude that, in spite of the lack of a certain standard set of measures or unified approaches for quantifying continuously the effectiveness of the performance of the CMM process in the J.C.I, numerous quantitative measures and qualitative techniques are practiced irregularly and separately within the Jordanian building projects to monitor and follow-up the performance of the CMM system.

These existing measures and techniques have been practiced in different ways, but the majority of them generally relied on examining and monitoring the information system and the data transferred through following up the reporting system and the data included. As discussed in the previous section, the comparison between the used measures and mechanisms and the proposed measures, which are listed in the set of proposed measures developed on the basis of the literature review, led to classify these measures and approaches into five main groups; **1)** Measures that match, or are largely similar to the proposed measures, even if they were practiced irregularly and separately within one or more of the case studies selected **(Exist-Measures)**; **2)** Measures that are cited in the proposed measures, but have not been practiced quantitatively or qualitatively within any of the case studies selected (**Not Exists-Measures**); **3)** Alternative mechanisms or procedures that have been practiced (unquantifiable/ unmeasurably) as substitute for one of the proposed measures to follow up the performance of one or more of the CMM functions (**Qualitatively Techniques/ Approaches**); **4)** Techniques practiced quantitatively (measurable) to evaluate the performance of a function or an action within the CMM process; they could be somewhat similar, in terms of their purpose, to one of the proposed measures (**Quantitative Techniques**); and **5)** Quantitative approaches or measures that have not been cited within (and they are not similar to) the theoretical set of the proposed measures and practiced in one or more of the cases (**New Measures**).

Based on this categorisation, the measures, techniques, and approaches that have been practiced by the selected case studies, in addition to the related documents, forms, and reports that are used to processing these measures, are summarised in the next table (**Table 6.5** and **Table 6.5.1**). On the basis of the above classification, the mechanism of establishing the set of the Practical Effectiveness Measures (P.E.Ms) is based on the findings that result from processing those five measures groups as described and discussed below;

1. ***Processing Exist-Measures:*** Gathering the measures that were practiced in the case studies and listed under the 'Exist' group (even if within one case study), and then adopting them in the set of P.E.Ms
2. **Processing Not Exist-Measures:** Examining and investigating the measures that were not used in all case studies, in terms of their usability (possibility of using) in evaluating the CMM performance in the J.C.I. In case there is a potential to use those measures, they will be adopted and listed within the P.E.Ms; otherwise, they will be disregarded.
3. ***Processing Qualitative- Approaches:*** Omitting and deleting the measures that have only practiced qualitatively in the all cases (they were listed only under Qualitative group) and there is no chance to be formulated for quantified use (to reflect the effectiveness of the CMM performance quantitatively).
4. ***Processing Quantitative-Techniques:*** Reformatting and reformulating the measures that were just listed under Quantitative group to reflect the effectiveness ratio and to represent either the original proposed measure or a new measure.
5. ***Processing New Measures:*** Reformulating new measures to reflect the effectiveness ratio, and then adding them to the set of P.E.Ms.

Note: the usability of a measure means the possibility of calculating this measure quantitatively, based on the information and documents that are available, and on the extent of the easy in providing the data required to quantify and calculate the measure.

Table 6.5: Classification of the Practical Measures, Approaches and Techniques of Evaluating the CMM Performance Practiced within the Case Studies

CODE	SITUATION / MEASURE NAME	EXIST ✓	Not Exist	QUANTATIVE ϕ	QUALITATIVE Ω	DOCUMENTS USED	Notes
AC1	Material Receipt Problems	✓ 3	× 1	Φ 1	Ω 1	• R.Q.C reports, • O.S&D reports, • Problem Sheet Form	Those two can be Combined A1 + A2
AC2	Material Receipt Problems - Internal	✓ 4				• Receipt's Problem Sheet Form, • R.Q.C reports,	
AC3	Warehouse Inventory Accuracy	✓ 2		Φ 4		• Inventory Record/Database • Warehouse Observation	This measure could be calculated for the entire items in the Warehouse
Q1	Installing Equipments Rework		× 1	Φ 1	Ω 4	• Site works Report, • Daily & Monthly Reports. • Field Progressing Works Report • Construction Status report • Variation Orders (VOs)	
Q2	Jobsite Rejections of Tagged Equipment	✓ 3		Φ 3		• Inspection Form, • Material Returned/Rejection Form • Notifications of Return/Non-conforming Items, • (Materials Inspection Request (M.I.R) forms	
QN1	Home Office Requisition Ratio	✓ 1	× 1	Φ 3	Ω 1	• RFQ forms within Comprehensive Monthly/Quarterly Report,	
QN2	Home Office Purchase Order Ratio	✓ 2	× 1	Φ 3		• PO forms within Comprehensive Monthly/Quarterly Report	
QN3	Average Line Items Per Release		× 6				
QN4	Commitment – Home Office		× 6				
QN5	Commitment – Field		× 4	Φ 2		• Field Works Report • Field Pos, • Daily & Monthly Reports	
QN6	Electronic Data Interchange (EDI) Purchases		× 6				
QN7	Sole Source Purchases		× 6				
QN8	Minority Suppliers		× 6				
T1	Procurement Lead-Time		× 6				
T2	Bid/Evaluate/Commit Lead-time	✓ 2	× 4			• Using Documents related to the RFQs, the POs	The BEC lead-time (in the cases) is bounded from receiving the Vendor's response to the RFQ until the issuance of the decision of selecting the supplier
T** T3	Purchase Orders (PO) to Material Receipt Duration		× 1	Φ 5		• PO forms, • Receiving Quality Control (R.Q.C) reports, • Warehouse/Inventory Record/Database	The measured duration starting from issuing the PO and ending when the material is received and updated in the warehouse System (T3+T4)
T** T4	Material Receiving Processing Time		× 1				
T5	Commodity Vendor Timeliness				Ω 6	• Material Delivery Status (M.D.S) Report • R.Q.C Reports,	It is not familiar in J/ACI
T6	Commodity Timeliness	✓ 2		Φ 3	Ω 1	• Material Delivery Status (M.D.S) Report • R.Q.C Reports	
T7	Materials Withdrawal Request (MWR) Lead-time	✓ 1	× 4		Ω 1	• Material Receipt • Delivery Status Report, • Internal Materials Requests (RMS/I.M.R), • External Materials Requests (RMW/EMR) • Milestone Schedule and Delivery Plan	
C1	Average Man-hour /Work hour Per Material Take-off (MTO)		× 6				
C2	Average Man-hour /Work hour Per PO		× 6				
C3	Freight Cost Percent	✓ 5	× 1			• The M.D.S Report, • Document related to Material Financial Reports and Statements of Cash flows Reports, • Schedule of the general expenses. • Schedule of the general expenses	
C4	Express Deliveries Percent	✓ 1		Φ 3	Ω 2	• M.D.S Report, • Materials Status Report, • Monthly Report (Urgent Deliveries)	
C5	Construction Time Lost	✓ 6				• The daily & monthly reports (Contractor and Supervisor), • Daily labour sheets, • Time Record: Inactivity Timesheet for Machineries • Time Schedule, Milestone • Equipment Utilization reports	Could be done by the consultant to identify the reasons of delay
C6	Payment Discounts		× 5		Ω 1		
C7	Warehouse Safety Incident Rate		× 4		Ω 2	• R.Q.C reports, • O.S&D reports	
C8	Total Surplus	✓ 6				• Material Returned/Rejection Form • Notifications of Return/Non-conforming Items, • Inventory Record/ Warehouse System, • Material Status Report • Site Material Status Report, • Availability Report	Sometimes, surplus could be resulted because of good using for material on the site, so could be +
AV1	Material Availability	✓ 4	× 1	Φ 1		• Materials requests (MRS & MRW form), • Inventory Reports/ Record, • Releases, • Site Receipt/ Material Issuances • Availability Reports • Material Flow Schedule	
AV2	Stock out Analysis	✓ 1	× 1	Φ 2	Ω 2	• Section of Out of Stock Materials in Materials Status Report/ • Materials Availability Reports, • Inventory Record, • Store Shortfalls List, • Material Flow Schedule	
F1	Delivery Flexibility				Ω 6	• The Material Delivery Plan, • The Delivery Time Schedule:, • Millstone Schedule,	
F2	Changes Flexibility		× 4		Ω 2	• Construction Works Report, • Materials Status Report, • VOs • RE-PO(s)	
F3	Volume Flexibility	✓ 3	× 1		Ω 2	• Material Status Report, • Materials Availability report, • Warehouse/Inventory Record/Database • The Bill of quantities (BOQs), • Material Requests,	

Table 6.5.1: The New Practical Measures, Approaches, and Techniques Practiced in the Case Studies

Attribute	Code	New Measures	Documents Used
T	T*	Φ • Case B and E: • Measuring the Procurement processing time from submitting RFQ until issue the Temporary-PO • Measuring the Procurement processing time from issuing the M.R.R to issue the Temporary-PO	• The documents that are related to the RFQs, POs, and Temporary POs
	T***	Φ Case A, B, E, F • Counting the MWR processing time (From issuing IMR to sign the material receipt), • Measuring Materials Withdrawal Request (MWR) Processing Tim • Measuring the order fulfilment processing time from issuing the I.M.R /or E.M.R to issue material to the craft • Measuring and Examining the processing time of the In-door delivery	• IMR, • Material Receipts, • The Signed Package Lists, • Delivery Plan, and Inventory System • Using M.R.W and • the Material Receipt • Material Request Schedule, • Daily/Monthly Reports • Material Release Request • Signed Package Lists
Q	Q*	ϕ Case F Counting the number of the all materials inspections that rejected to the total number of inspections	• Inspection Form, • Material Inspection Request (M.I.R) forms • Notifications of Return/Non-conforming Items,
C	C*	ϕ Case B; • Measure reports the percentage value of the materials that considered as waste (Surplus + Unusable) to compare with the total material costs	• Material Status Report, • Material Returned/Rejection Forms,
	C**	ϕ • Case C, E, F; Measuring the ratio of the actual value of waste materials to the value of the materials that expected to be waste (Planned waste)	• Notifications of Non-confirming Items, and • Availability Reports, Design documents related to material utilization management.

1- Processing the Exist-Measure:

The Exist-Measures are those measures that have been practiced irregularly and separately in one or more than one case study, and they are either identical or largely similar to those cited in the proposed set of measures. Based on **Table 6.5**, sixteen (16) measures are grouped under 'Exist' category. Those measures are; 1- Material Receipt problems (AC1), 2- Material Receipt problems-Internal (AC2), 3- Warehouse Inventory Accuracy (AC3), 4- Jobsite Rejections of Tagged Equipment (Q2), 5- Home Office Requisition Ratio (QN1), 6- Home Office Purchase Orders Ratio (QN2), 7- Bid/Evaluate/Commit Lead-time (T2), 8- Commodity Timelines (T6), 9- Materials Withdrawal Request (MWR) Lead-time (T7), 10- Freight Cost Percent (C3), 11- Express Deliveries Percent (C4), 12- Construction Time Lost (C5), 13- Total Surplus (C8), 14- Material Availability (AV1), 15- Stock-out Analysis (AV2), and 16- Volume Flexibility F3). Those measures have been used to evaluate the performance of one or more function or activity related to the process of the CMM, regardless of whether they were used irregularly, separately or not specifically for measuring the effectiveness of the CMM performance.

As a result of the availability and usability of the data needed for calculating these measures in the case studies, these measures will be adopted as proposed in the set of measures developed in the literature review including the methods of calculation, the measure's location, and the measure's purpose and description. Additionally, adopting the documents and reports observed during the site visits and suggested by the interviewees to be used for practicing these measures, as can be seen in **Table 6.5**.

2- Processing Not Exist-Measures:

The Not Exists-Measures are those measures that have been listed within the proposed set of measures (see **Table 4.16**), but they were not practiced quantitatively or qualitatively within any of the case studies. **Table 6.5** shows the number of the measures that were not applied to all the case studies. However, prior to making a decision whether to omit or exclude any of these measures of the set of the P.E.Ms, they will be examined in terms of their usability within the J.C.I based on the possibility of calculating these measures and the availability of the data, information and documents required for implementing the quantified measurement process. The lack of using these measures was attributed to different reasons, as discussed in depth in **Section 6.6.2.2**. In this section, the reasons behind the lack of using each measure are briefly highlighted and the possibility of adopting these measures to the J.C.I is discussed.

QN3: Average Line Items Per Release:

Two main views explain the reasons behind not using this measure: the first view was the lack of the measure's importance in evaluating the effectiveness of the CMM performance within the skeleton stage and the second was the difficulty involved in its calculation. Regarding the potentiality of practicing this measure within the J.C.I, due to the required data for calculating this measure (such as the planned number of line items per release) is not included in the project design documents, it is not possible to practice this measure within the J.C.I.

QN4: Commitment – Home Office:

The causes for the lack of using this measure are similar to QN3; the lack of its importance and the absence of any related specific document that can help in practicing this measure during the skeleton stage. Consequently, QN4 is not usable within the Jordanian building projects.

QN7: Sole Source:

The irrelevance of the measure in the skeleton stage of building projects is the main reason for not practicing this measure. The materials used during the skeleton stage, even if they are limited in their types, are used in huge amounts; thus, the competition is essential for determining the project's budget, which leads to the lack of using the 'Sole Source purchases' within this stage. Consequently, not using the technique of 'Sole Source Purchase' during the skeleton works (stage), and the absence of documents that identify the purchases made by the Sole Sources have led to the inability and irrelevance of quantifying this measure.

QN6: EDI Purchase and QN8: Minority Suppliers:

Although the main reasons for not using these two measures are slightly different, they can be attributed to one root, which is the 'Arab Culture'. The penetration of the culture of mistrust in dealing with electronic documents in various business fields of life in the Arab society, in addition to the inability to trade and handle the electronic documents in the public sector because of being considered as unofficial documents led to the lack of using the technology of EDI purchase in the majority of the Arab countries including Jordan.

Likewise, the absence of a strategy for promoting the maintenance and growth of the minority-owned enterprises in the culture of the Jordanian, and may Arab, contractors led to non-adopting the 'Minority Supplier Purchasing Program'. In short, the lack of adopting these technologies and strategies by the J.C.I culture has led to the absence of measures like 'EDI Purchase (QN7)' and 'Minority Suppliers (QN8)' in assessing the effectiveness of the CMM performance within the Jordanian building projects. Therefore, there is no visible means to apply these measures unless some changes are made in the concepts that surround the culture of Arab and Jordanian Construction Industry.

T1: Procurement Lead Team:

The ambiguity of the border of the procurement function and the difference in activities, situated in the context of the procurement function between J.C.I and those adopted for the set of proposed measures, led to the lack of adopting this measure. Therefore, the lack of clarity in the scope of the procurement's activities made developing a unified measure to evaluate the performance of procurement's function is not easy task; thus, the opportunity of practicing this measure in the J.C.I is not available.

C1: Average Man-hour/Work hour per Material Take-off and C2: Average Man-hour/Work hour Per PO:

Based on the nature of the J.C.I, the payment manner used in the Jordanian building project is based on a monthly salary or a lump sum price. Consequently, there is not a clause or an article in the contractual documents that refers to the man-hour or Work-hour. The inability to identify or recognize the planned man-hours or work-hours in any contractual or operational documents, and the lack of systematic man-hour record made C1 and C2 difficult to be measured (immeasurable) and they have no viability and feasibility with respect to evaluating CMM performance within the J.C.I.

3- Processing Qualitative Approaches/Techniques:

As described earlier, the 'Qualitative Technique' is a non-quantitative technique or approach that has been used in one or more than one case study, alternative to a proposed measure, provided that it has never been practiced quantitatively in any of the six case studies. Similarly as processing the Non-Exist measures, each Qualitative Technique will be investigated, in terms of the possibility to reformulate it to reflect the effectiveness ratio, its usability within the J.C.I, and the availability and ability of the used documents to provide the required data for practicing the proposed measure or developing a new measure. Based on the results, a decision of excluding or adopting those techniques in the set of the P.E.Ms will be taken.

Table 6.4 and **Table 6.5** show five of the proposed measures that have alternatively been practiced only qualitatively without using any quantified techniques by any of the six case studies; 1- Commodity Vendor Timelines (T5), 2- Payment Discounts (C6), 3- Warehouse Safety Incident Rate (C7), 4- Delivery Flexibility (F1), and 5- Changes Flexibility (F2).

T5: Commodity Vendor Timelines:

The fact ingrained in the minds of the participants is that this measure is designed to assess vendor's performance rather than to evaluate the performance of a contractor. This view created a consensus regarding the lack of the importance of this measure in the Jordanian building projects/contractors, which mainly focuses on the assessment of the performance of the CMM process implemented within the scope of the contractor job. However, reviewing the documents that are used to implement, qualitatively, the technique of 'Monitoring Material Delivery Status Reports' confirms that the required information and data for practicing this measure (the number of the vendor's deliveries that were made on time in regard to the promised delivery date and actual delivery date) are available in the contractor's records and documents (Materials Delivery Status, and R.Q.C reports). The availability of the required data to calculate 'T5', in addition to its importance in setting up the vendor performance reports confirm the potentiality of using 'T5' in the Jordanian projects, Consequently this measure will be adopted in the set of P.E.Ms.

C6: Payment Discounts:

The absence of the culture of regular and systematic discounts (payment discounts) in most of the Arab countries, including Jordan, was the main cause for not using this measure in the most case studies. Qualitatively monitoring of the actual and planned material cost was the only technique that has been used in one case study, which does not reflect, in any way, the effectiveness of the used CMM performance. As a result of the absence of specific discount periods that can be exploited to reduce the project's cost, one cannot see any chance to practice C6 within the Jordanian building projects; thus, C6 will be omitted, and it is not going to be involved in the P.E.Ms.

C7: Warehouse Safety Incident Rate:

The qualitative technique used within the context of this measure, which is based on monitoring the incidents in the warehouse, is not related to measure C7. Similar to some other measures, the lack of the importance of C7 in evaluating the CMM process, the difficulty of calculating the ratio of warehouse lost time incidents, and the unavailability of the accurate documents required were the key rationales behind excluding the existence of any possibility for using this measure within the Jordanian Building Projects.

F1: Delivery Flexibility:

This measure is adopted from the manufacturing industry; it is the first attempt to investigate its usability within the construction industry. This could explain why this measure has not been quantitatively practiced by all cases; its implementation was limited to qualitative techniques such as following- up the delivery milestone schedule and continuously updating the material delivery-related activities in the milestone schedule to push the planned delivery date forward. Although there is a lack of using this measure in the Jordanian building projects, there is a consensus by the interviewees regarding the possibility of its use in the J.C.I. The usability (the possibility of using) of this measure stems from the availability of the data and information needed for its calculation, such as (The delivery's Last Time Period (L.T.P), Earliest Time Period (E.T.P), and Current Time Period (C.T.P), within the executive, design and planning documents and reports. Consequently, the measure 'Delivery Flexibility (F1)' will be adopted to be involved in the P.E.Ms. This confirms the validity and possibility of adopting techniques, technologies, or strategies from the Manufacturing Industry to be used within the Construction Industry.

F2: Change-Flexibility:

Examining the changes-flexibility was reported qualitatively through examining the ability of a supply system to deliver different types of materials in order to meet the changes in the field operation needs. The lack of the importance of the measure (F2) in assessing the CMM process, and the difficulty involved in determining the direct and indirect cost of materials required for rework led to the inability of practicing this measure within the Jordanian projects. Therefore, one can conclude that the use of 'F2' is not possible in the J.C.I; accordingly, this measure will not contribute to setting the P.E.Ms.

4- Processing Quantitative Techniques:

As defined earlier, Quantitative techniques are calculation-based approaches, which have been practiced by one or more than one case study to evaluate the performance of the CMM process. Based on their method of calculation and the purpose of their use, these approaches applied could be similar to or different from the proposed measures. Processing Quantitative Techniques relies on reformulating and reformatting each technique that was only categorised under the title Quantitative Techniques (and it was not categorised as an

Exist-measure in any of the six cases) to put it on the formula of a proposed measure, or to develop a new measure.

Q1: Installing Equipment Rework:

Under this title, it was just one Case which conducted a quantitative technique based on recording and listing the installing equipment that were required for rework. Apart from the reasons behind not practicing this measure quantitatively by the rest of cases (which provided and discussed in precious section; **Section 6.6.2.2)**, practicing this measure is possible as confirmed by a number of respondents. Whereby the total number of installing requirements identified as requiring rework and field modification (the main data required for practicing Q1) is available in reports like 'Construction Status' report and' Field Progressing Works'. Accordingly, this measure can be adopted to contribute in establishing the set of the P.E.Ms.

QN5: Commitment–Field:

From the perspective of most interviewees, QN5 is irrelevant in the skeleton stage of projects building; The Field Control team, during the Skeleton work, is authorized to purchase only some specific materials with a small value and amount. This leads to a lack of reliance, mainly, on the field purchase of the Jordanian construction projects. This fact was the leading cause for not practicing the measure 'Commitment-Field' within most cases. However, a similar quantified technique was used by one case (Case B) that is based on calculating the value of materials that are purchased by the field and compared with the total value of the purchased materials during a specific time- period. Although the use of this technique was for organisational purposes rather than for monitoring the performance of the CMM process, the data and information that are used and that resulted from applying this technique can be adopted and reformatted to be used for calculating QN5 through reporting the percentage of the value of materials that are purchased by the field to the total value of purchased materials during a specific time period. As a result, QN5 can be involved in the P.E.Ms with a few modifications.

T3+T4=T: New Time-Measure: Material Receive and Update in the System duration:**

As pointed out previously within the context of the T3 and T4 measures, the integration of durations from 'the issuance of PO until the receipt data of the materials' and 'the material receiving processing time' in most projects resulted in the inability for practicing T3 and T4 separately. Accordingly, one can observe the use of a new technique that is, on some way, based on merging two measures T3+T4 in one measure in some projects. This integrated measure, which has been used in Cases B, C, and E, is the measurement of the processing time from issuing PO to receiving and updating materials in the warehouse inventory. This includes activities such as processing and administrating POs, preparing and delivering materials, receiving the deliveries, inspecting the paperwork and the materials, verifying the Over, Short, and Damaged (OS&D) status, adjusting the quantities by PO supplement, documenting the damaged and missed Materials, and updating the material status within the warehouse system (inventory). Although the integrated duration and the involved activities slightly differ from the other cases, Cases D and F have been used the same approach of integration T3 and T4. This technique can establish a new measure within the 'Time' attribute which can be called 'T**'. T** uses a ratio format to communicate the average actual duration and the planned duration. Due to the fact that the average duration is calculated based on each PO line item, the average in this measure could be the sum of issuing to receive and update durations divided by the total number of receipts.

Based on the definition of the T** duration and the activities included, the whole data needed for implementing this measure are included in documents, such as PO forms, Receiving Quality Control (R.Q.C) reports, and Warehouse Database/Inventory Record. Those could be considered the most noticeable documents used to process T**. Moreover, the new definition of 'T**' could give an indication to the location of this measure, which can be in two places; the first measure location 'T**a' is at the interface of the 'Procurement' function with the 'Vendor'; the second location 'T**b' is at the interface of the Vendor within the Warehouse function.

5- Processing New Measures:

New-Measure is a quantitative technique that is not listed with the set of the proposed measures, which have been developed by the literature review, and discovered during examining the proposed measures; it aims to monitor or follow up the performance of one or more than one functions of the CMM performance. The 'New Measures will be adopted within the set of P.E.Ms as they were used within the Jordanian building projects after reformatting them to reflect the effectiveness ratio.

Q*: New Quality Measure: Construction Operation Returns:

The return of the materials by the construction operation can occur due to many reasons; for instance, wrong requisition, wrong order, wrong vendor shipment, wrong issuance, materials damaged or defective, among others. Case F has suggested this measure under 'Quality Attribute' to include all the returned or rejected materials (Materials, Tagged Equipment and Items). A Procurement Manager (Case F) believes that "*measure 'the Construction Operation Returns' is vital to evaluate the ability of the overall CMM system to provide the right required materials and items, and it can facilitate determining the root causes of returning the requested materials*". It can be evident that this measure is very similar to that of 'Jobsite Rejections of Tagged Equipment (Q2)', with some expansion to include all returned materials. Similar to Q2, this can be calculated through the ratio of the number of all material inspections that were rejected by the Warehouse, Field Control or Supervision team for all the materials and items used to the total number of inspections (M.I.R, Notification of Non-conforming Item, Materials Returned/Rejected Forms, etc.). Consequently, the documents that were used to practice Q2 can be used in this measure and the location of Q* is the same place of Q2 as well (at the interface between the construction operations (Craft-workers) and the Field Control function).

T*: New Time-Measure: Procurement Processing Time:

Through discussing the measure 'Procurement Lead-Time (T1), a new technique was discovered; it is adopted by Cases B and E for monitoring the performance of the materials management staff to accomplishing procuring a material or an item (T*). 'T*' reports the percentage of average actual procurement processing time in days to the planned procurement processing time in days. The average procurement processing time is the average duration bounded by the transmission of the request for quotation (RFQ) until issuing the temporary purchase order for the vendor/supplier. The duration encompasses RFQ, bid evaluation, negotiation, award, and issuance of the Temporary PO. Thus, the documents that are related to the RFQs, POs, and Temporary POs are necessary to conduct this measure. As the operational documents of the 'Procurement' function are mutual between the vendor and the procurement department, it is normal that the location of T* is at the interface between the 'Vendor' and the 'Procurement' function. This supports the fact, which was confirmed by a Procurement Manager, 'No one can deny the importance of measuring the 'lead-time' that is given to preparing an activity, but the reality in the Jordanian projects is that the focus is usually on measuring the time spent to achieve an activity or a job (processing time)'.

T*: New Time-Measure: Material Withdraw Request (MWR) Processing Time:**

While addressing the time attribute's measures, in particular T7, it was noted that the trend of most cases to measure the activities' processing time rather than their lead-time. Based on this fact, Cases A, B, E and F have reported the 'Materials Withdraw Request (MWR) processing time' in order to evaluate the effectiveness of the warehousing function's performance in terms of its ability to meet the requirements of the construction operations. Despite the difference in processing the MWR from one case to another, 'T***' is reported as the percentage of the Material Withdraw Requests (MWRs) that were processed on or before the required date, during a period of time. The average duration for the fulfilment of a request is bounded by issuing either an Internal Material Request (I.M.R) or an External Material Request (E.M.R) until issuing the required materials to the craft.

This measure is located within the 'Field Control' function, which requests the materials, and the Warehousing function, which is responsible for issuing these materials. However, the interviewees argued that in case the materials requested from external warehouse (main warehouse) or directly the supplier by 'E.M.R', 'T***' can be located at the interface of the 'Field Control' function (the one is responsible for issuing the E.M.R) and the one who is responsible for issuing the required material (the main Warehouse, the Procurement function, or Vendor).

Generally, among the documents that can be used to practice this measure are the Material Receipts, Materials Requests (E.M.R/R.M.W, M.R.R, and RMS/I.M.R), Material Request Schedule, Daily/Monthly Reports, Receiving Reports, The Signed Package Lists, Material Release Request/External Materials Requests, Delivery Plan, and Inventory System.

C*: New Cost-Measure: Material Waste Ratio:

While conducting the investigation into the measure 'Total Surplus (C8)' within the case studies, it was found that some cases (Case B) define the material waste as a term that includes both the surplus and the non-usable (unusable) materials. Therefore, the material-related participants believe that measuring the wastage ratio is a necessary cost-indicator for evaluating the effectiveness of the performance of the CMM system applied. This measure reports the percentage of the value of the materials that is considered as waste (surplus and non-usable materials) compared with the total materials costs, asserted by Construction Site Manager (Case B). Measure 'C*', though it is not listed within the proposed set of measures that were developed in the literature review, is similar to the measure 'Total Surplus (C8)', the only difference is that the all material waste is included into the surplus category. Therefore, the same documents used for practicing C8 can be used for C*, in addition to that 'C*' can also be located within the 'Warehouse' and 'Field Control' functions, or between those responsible for minimizing the wastage; between 'the Construction Operations and Field Control function'.

C: New Cost-Measure: Waste Management:**

Contrary to the perspective that has been provided by Case B on previous measure (C*), Cases C, E, and F suggested a new technique that relies on examining the ratio of the waste materials value. For the projects in which the expected value of the material waste is determined at the beginning of the project design stage (Planned Material Waste Value) and written within the project's documents, the determination of the waste management effectiveness is possible to be practiced; it provides a good indicator for the effectiveness of the CMM performance, argued a Planner, an Executive Project director, and a Senior Construction Manager. The measure 'Waste Management (C**)' can be calculated by dividing the actual material waste value by the planned waste material value (Expected to be waste).

The entire material waste-related documents are needed for monitoring this measure including, the Material Status Report, Material Returned/Rejection Forms, Notifications of Non-confirming Items, and Availability Reports, in addition to designing documents related to material utilization and waste management. The location of C** could be between those responsible for managing the material waste; 'Between the 'Construction Operations' and 'Field Control function'.

Combining and consolidating the discussions of the outputs that has resulted from the main investigation is employed to derive the Practical Effectiveness Measures (s) that are/or can be used for evaluating the effectiveness of the performance of the CMM process within the Large-scale Concrete Building Projects in the J.C.I. The process of combining and consoldating the above discussions is accomplished through the following actions and procedures;

- Adopting the 'Existing-Measures' as proposed by the set of measures that has been developed in the literature. Sixteen (16) Existing-Measures have been adopted to be involved in establishing the set of the P.E.Ms; Material Receipt problems (AC1), Material Receipt problems-Internal (AC2), Warehouse Inventory Accuracy (AC3), Jobsite Rejections of Tagged Equipment (Q2), Home Office Requisition Ratio

(QN1), Home Office Purchase Orders Ratio (QN2), Bid/Evaluate/Commit Lead-time (T2), Commodity Timelines (T6), Materials Withdrawal Request (MWR) Lead-time (T7), Freight Cost Per cent (C3), Express Deliveries Percent (C4), Construction Time Lost (C5), Total Surplus (C8), Material Availability (AV1), Stock-out Analysis (AV2), and Volume Flexibility (F3)

- Reformatting and reformulated 'Qualitative' approaches and 'Quantitative' techniques that are found usable in the J.C.I based on their possibility of calculation and the availability of data and documents needed. Two (2) measures of the five (5) measures that were only listed within qualitative approaches have been adopted to be within the set of the P.E.Ms; Commodity Vendor Timelines (T5) and Delivery Flexibility (F1). The four (4) quantitative techniques have been examined and reformulated to put them on the formula of one of the proposed measures; Installing Equipment Rework (Q1), Commitment-Field (QN5), and combination of T3 and T4 to form the new measure 'Purchase Order (PO) to Materials Receipt and Updated in System Duration' (T**).
- Deleting the 'Not-Exist Measures', and omitting the 'Qualitative' techniques that were found impossible to reflect the effectiveness of the CMM performance quantitatively, and they have no any chance or potential to be used within the J.C.I, whether because of the difficulty of their calculation, the lack of the required documents availability, or their incompatibility with (or the absence of their conception within) the Arab Jordanian culture. Eight (8) proposed measures are not used (Not-Exist) within the J.C.I; Average Line Items Per release (QN3), Commitment-Home Office (QN4), EDI Purchases (QN6), Sole Source Purchases (QN7), Minority Suppliers (QN8), Procurement Lead-Time (T1), Average Man-hour/Work hour Per Material Take-off (C1), and Average Man-hour/Work hour Per PO (C2). Three measures of the five qualitative approaches have been omitted because of the lack of the potentiality to reflect the effectiveness format to be used; Payment Discounts (C6), Warehouse Safety Incident Rate (C7), and Change Flexibility (F2).
- Adding the new measures, which were revealed from the case studies cross-analysis, with some modifications, if needed, to reflect the effectiveness format. In addition to the measures that resulted from combining T3+T4 (T**), other five new measures have been reformulated to reflect the effectiveness ratio and then added to

be involved within the set of the P.E.Ms; Construction Operation Returns (Q*), Procurement Processing-Time (T*), Materials Withdraw Request (MWR) Processing-Time (T***), Material Waste Ratio (C*), and Material Waste Management (C**).

As a result of the above Consolidation's procedures, the set of **26 Practical Effectiveness Measures (PEMs)**, which can be used for evaluating the Effectiveness of the Construction Material Management's Performance (E.CMM.P) in the Jordanian Large-scale Concrete Building Projects, was developed as shown in **Table 6.6**.

Table 6.6 includes a set of 26 P.E.Ms and a brief description of each P.E.M, including measurement attribute, measure's code, measure's name, point of measurement (Measure's Location), and the definition of this measure (Measure Formula). In addition, the table includes the documents and reports that were observed during the site visits and suggested by the interviewees to be used for practicing these measures as they include the needed data and information.

In fact, there is no particular order has been used for numbering the documents (Document Code: DU1, DU2 ....DU39), as exposed in Table 6.6. They were numbered as they have been found during conducting the process of 'Site Visit' technique: reviewing the documents of the case studies.

Detailed descriptions and Classifications for the P.E.Ms are summarised in **Table 8.1** in **Chapter VIII**.

Those adopted P.E.Ms will contribute in developing a practical framework for continuously monitoring, analysing, and evaluating the impact of the CMM process improvements in the Jordanian building projects, as discussed in **Chapter VIII**.

Table 6.6: The Set of Practical Effectiveness Measures (P.E.Ms) that Can be Used for Evalua

CATEGORIES ATTRIBUTES	CODE	MEASURE NAME	AREA/POINT OF MEASUREMENT	
ACCURACY	AC1	**Material Receipt Problems**	The interface between vendor and warehouse function	➢ **AC** **mat** inac ➢ This disc
	AC2	**Material Receipt Problems - Internal**	At the interface of the Vendor with the Warehouse Function.	➢ **AC** data ➢ AC disc
	AC3	**Warehouse Inventory Accuracy**	Within the Warehouse functions	➢ This **sam** in th ➢ AC the form
QUALITY	Q1	**Installing Equipments Rework**	At the interface of Construction with the field control Function.	➢ **Q1** equi tota cum ➢ **Q1** requ insta ratio
	Q2	**Jobsite Rejections of Tagged Equipment**	At the interface of Construction operation with the field control Function.	➢ **Q2** ➢ **Q2** equi mul
	Q*	**Construction Operation Returns**	At the interface between the construction operations (Craft-workers) and the Field Control function	➢ Simi num Cont num Mat
QUANTITY	QN1	**Home Office Requisition Ratio**	At the interface of the Procurement Function with the Vendor.	➢ **QN** perf requ
	QN2	**Home Office Purchase Order Ratio**	At the interface of the Procurement Function with the Vendor.	➢ **QN** the duri
	QN5	**Commitment – Field**	At the interface of the Procurement Function with the Vendor.	➢ **QN** equi com
TIMELINESS	T2	**Bid/Evaluate/Commit Lead Time**	The first measure **T2a** is at the interface of the Vendor with the Procurement Function. The second measure **T2b** is taken at the interface of the Procurement Function with the Vendor.	➢ **T2** com ➢ **T2** **and**
	T5	**Commodity Vendor Timeliness**	At the interface of the Vendors with the Warehouse Function.	➢ **T5** on t **deli**

CATEGORIES ATTRIBUTES	CODE	MEASURE NAME	AREA/POINT OF MEASUREMENT	
				➢ **Cal** deli peri
	T6	**Commodity Timeliness**	At the interface of the Vendors with the Warehouse Function.	➢ **T6 i** deli ➢ **Cal** mad num
	T7	**Materials Withdraw Request (MWR) Lead-time**	At the interface of Construction with the Warehouse Function.	➢ **T7 r** mat ➢ **T7 i** deli ➢ The and
	T*	**Procurement Processing Time**	The interface between vendor and Procurement function,	➢ **'T*'** days
	T**	**Purchase Orders (PO) to Material Receipt and Updated in the System Duration**	The first measure location **T**a** is at the interface of the Procurement Function with the Vendors.. The second location **T**b** is at the interface of the Vendor with the Warehouse Function.	➢ **T**** proje ➢ **T**** recei **plan**
	T***	**Materials Withdraw Request (MWR) Processing time – Internal**	Within the Field Control and the Warehouse Functions	➢ **T***** (MW of tin
	C3	**Freight Cost Percent**	Within the Procurement (Expediting and Transportation) function.	➢ **C3 r** mate
	C4	**Express Deliveries Percent**	At the interface Between the Vendor and the Warehouse Function.	➢ **C4 r** ware num
	C5	**Construction Time Lost**	Between Construction Operations and the Field Control Function.	➢ **C5 i** mate ➢ **To c** mate
	C8	**Total Surplus**	Within the Warehouse and Field Control Functions.	➢ **C8 r** the t
COST	C*	**Material Waste Ratio**	Between Construction and Field Control Function	➢ **C* r** wast

CATEGORIES ATTRIBUTES	CODE	MEASURE NAME	AREA/POINT OF MEASUREMENT	
	C**	**Material Waste Management**	Between Construction and Field Control Function	➢ The actu be v
AVAILABILITY	AV1	**Material Availability**	At the interface of the Warehouse Function with Construction Operations.	➢ **AV** **iten** ➢ **AV** mat **req**
	AV2	**Stockout Analysis**	Within the Warehouse function.	➢ **AV** **una** line
FLEXIBILITY	F1	**Delivery Flexibility**	The first measure location **F1a** is at the interface of the Vendor with the Warehouse. The second location **F1b** is at the interface of Warehouse Function with Construction Operations	➢ **Del** tim ➢ Del slac
	F3	**Volume Flexibility**	The first measure location F3a is at the interface of the Procurement Function with Vendor. The second location F3b is at the interface of Warehouse Function with Construction Operations	➢ The den ➢ Thi den syst volu

6.7 SUMMARY OF THE CHAPTER:

Chapter VI is mainly intended to report the analysis of the data collected and the discussion of the outcomes of the case study research. The chapter began with displaying the main findings revealed and the lessons learnt from the research main investigation that used the case study technique. The process of displaying the qualitative data collected is built on reporting the outputs of each case study individually through unified categories. The six unified categories, which were designed to summarise the data collected and the lessons learnt for each case study involved in this research, are largely based on the 'units of analysis'. They include; 1) Project Background, 2) Organisation Profile, 3) Procedures of the Data Collecting Process, 4) Process of Construction Materials Management Practiced, 5) Effectiveness Measures of the CMM performance, 6) Terminology. The individual report for each case included depiction for the CMM process that was practiced in the case study project and definition for the mechanism and measures that were used and/or that can be used for evaluating the effectiveness of this process in the case study project. However, this chapter provides individual report for only one of the case studies that are involved in the research (Case Study C), and the individual reports for the rest of the six case studies are presented in **Appendix J**.

Based on the above step, the chapter then reported an in-depth discussion of the findings obtained and lessons learnt from the cross-cases analysis for six large-scale concrete building projects that were selected as case studies. The chapter provides an explanation for employing the findings resulting from the main investigation to accomplish the third and fourth stages of the process of developing the practical E.CMM.P framework.

As a result of the discussion of cross-case analysis, the practical workflow diagram that reflects the realistic CMM process practiced within the Jordanian large-scale concrete building projects was developed (see **Figure 6.6**), and the stages for developing the functions and activities that form the CMM process, including their position, sequences, and the relations between each other and with the external participants, were thoroughly explained.

In chapter VI, the stages for establishing a set of practical effectiveness measures were also explicated. This process begun with introducing an overview of the mechanisms and approaches practiced for monitoring and evaluating the performance of the CMM process within the J.C.I. This was followed by evaluating the proposed set of effectiveness measures and establishing the set of 'Practical Effectiveness Measures (P.E.Ms)' that can be practiced in the Jordanian building projects. As a result of consolidating the stages and procedures of the establishment process, a set of 26 Practical Effectiveness Measures (PEMs) was established (see **Table 6.6**). Those measures include sixteen proposed measures, five measures resulting from reformulating and reformatting the qualitative and quantitative approaches used, and five new measures used within the Jordanian projects.

The next stage, before developing the final framework for Evaluating the Effectiveness of the CMM Process Performance (E.CMM.P Framework) within the large-scale concrete building projects in the J.C.I, is the one involves conducting the first stage of the validation process (Formative Evaluation). This includes evaluating the proposed set of measures and the Practical CMM Process (P.CMM.P) workflow diagram using the questionnaire technique, as will be discussed in **Chapter VII**.

A Framework for Evaluating Material Management Performance in Jordanian Concrete Building Projects

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CHAPTER VII:

QUANTITATIVE DATA ANALYSIS AND DISCUSSION

7.0 INTRODUCTION TO THE CHAPTER:

According to the plan of the data collection process that is illustrated within the flowchart of the research (See **Figure 5.10**), this chapter reports the last phase of the data collection process using a questionnaire survey. The questionnaire was developed on the bases of the findings obtained from the literature review and the main investigation process. Basically, the survey is intended to perform the first stage of the validation process 'formative evaluation', which is designed to assess the basic structure and the main elements of the Developed E.CMM.P Framework (the practical workflow diagram of the CMM process, and the proposed set of effectiveness-measures). A group administrated questionnaire survey was conducted to generate a wider response from the functional experts in the Jordanian Construction Industry (J.C.I). The questionnaire data analysis is displayed under four main headings that form the main sections of the questionnaire questions (see **Appendix G**); these are: **1)** Respondents Background Information; **2)** Evaluation of the proposed set of the measures of the Effectiveness of the CMM Performance (usability, importance, and practicality), and identification of the barriers to implement the effectiveness-measures; **3)** Exploration of additional measures used; **4)** and Evaluation the Practical Workflow Diagram of the Construction Materials Management Process. Finally the chapter is summed up in the chapter summary.

7.1 ANALYSIS METHODS AND TECHNIQUES:

In order to provide robust and structured analysis, it was recommended to use a statistical software package. According to Bryman (2001), Ali (2011) and many others, the Statistical Package for the Social Sciences (SPSS) for quantitative analysis is the most popular statistical software package used by social science scholars and engineering researchers. Therefore, SPSS 19 was used to analyse the questionnaire data in this research. A total of **52** questionnaires were handed to construction professional experts; however, **47** of the completed questionnaires were used in the analysis. Five questionnaires were removed as considered invalid data. These questionnaires were considered invalid due to various reasons; for example, incomplete questionnaires where the respondents failed to complete the majority of the main questions, the lack of logic in the majority of answers (selecting/ticking the first space or box for all the optional answers) and the loss of some answering sheets either because they were not returned by the respondents or missed by the researcher.

The issue of data reliability and validity was carefully taken into consideration in the researcher account during the process of data analysis. For the purpose of ensuring the validity and reliability, the initial stage analysis involves observing, sorting and grouping the data. The code book (**Appendix C**) was developed for coding the prepositions, variables and values specified in the questionnaires. Entering the data into a Statistical Package for the Social Sciences (SPSS, version 19) is followed by a number of stages of data analysis which were consistent with the logic of treating survey data:

1) Data Screening: Data screening and transformation techniques were carried out to make sure that the data were correctly entered and the variables and scales that are to be used in the analysis are appropriate.

2) Descriptive Analysis: A descriptive statistics analysis was administrated for the analysis of the questionnaire data. Descriptive statistics are used to explore the data collected (Coakes, 2010). A univariate analysis (the descriptive aspect of statistics) was undertaken to enable researchers to reduce and summarise large masses of data using measures that are easily understood by observers (Burns, 2000; Ali, 2011). In this study, the median and the mean were the main measures used to quantify the centre of distribution. Generally, the descriptive analysis deals mainly with ranking of the variables based on their mean value. Due to its simplicity and ability to represent the data properly, especially for identifying the ranking of items (Field, 2009), the mean score was used for ranking the propositions (effectiveness-measures) in the majority of the evaluation area (such as, the importance, practicality, and usability of the proposed effectiveness-measures) in addition to using the mean score as a measure of the central tendency in this study. However, the mean is very sensitive to extreme values, which can make it less representative of the data set and less useful as a measure of central tendency (Salkind, 2000; Hatmoko, 2008). Consequently, in addition to the mean, the median was also chosen as the measure of the central distribution to draw inferential differences from measured values. According to Hamburg (1970), Burns (2000), Bryman (2001), Field (2009), and Ali (2011, p192), the median is relatively free from distortion by skewness in an ordinal distribution; it provides a more accurate value for the analysis than the mean, and thus becomes a particularly desirable parameter for descriptive purposes. Previous work by Abdul-Kadir (1996), Cheung and Yeung (1998), Wang et al. (1999), Akintoye (2000), Akintoye and Fitzgerald (2000), Ofori and Lean (2001) and Li (2003), Takim (2005), Hatmoko (2008), Takim and Adnan (2008), Ali (2011), and Higham (2014) have used a similar approach (mean and median) with survey data.

For the purpose of evaluating the proposed set of measures (Section 2) and evaluating the practical workflow diagram of the CMM process (Section 4), a five-point Likert Scale was used. Through the use of the Likert Scale, the functional experts were asked to select the appropriate option relating to the assessment of the relative importance and practicality of the proposed effectiveness measures (1=Not Important, 2=Slightly Important, 3=Moderately Important, 4= Very Important, and 5=Extremely Important), while they were required to tick the box that best represented their assessment of the statements on the practical CMM process workflow diagram on a scale of: 1 (strongly disagree), 2 (disagree), 3 (neutral), 4 (agree) to 5 (strongly agree).

3) Variables Association Analysis: a relationship between the variables was determined through testing the statistical significance (Daniel, 2014). This analysis focused on discovering the relationship between the practicality and the importance of the measures, and exploring the association between the estimated cost of the projects and their size. A bivariate analysis was conducted and the significant association between variables was identified through two statistical tests; Pearson's Chi-square and Cramer's V statistics. Pearson's Chi-square test determines whether there is a statistical significant association between two variables or whether they are independent; if the significance value is small enough (conventionally, significance should be less than 0.05) then a statistical association is said to exist between the variables under consideration (Wuensch, 2011; Daniel, 2014). Cramer's V statistic is used to compare the relative strength of the association between two variables, the Cramer's V statistic takes values from a minimum of 0 to a maximum of +1; the closer the statistic is to +1, the stronger the association between the variables (Demack 1, no date; Field, 2009; Daniel, 2014).

4) Reliability and Validity Tests: among a number of procedures that ensure the validity and reliability of the used data (see **Section 5.6.3**), some reliability and validity tests were undertaken. For examining the ***reliability*** (consistency of a measure), Cronbakh's alpha coefficient is "*the most important reliability index*" (Anastasiadou, 2011, p2), and it is the most commonly and widely used scales for finding the internal consistency reliability; for checking that the scales being used are reliable (Field, 2005; Takim, 2005; Pallant, 2007; Ali, 2011); whereby, for a set of items to be considered self-consistent and reliable, the Cornbach's alpha should not be less than 0.7 (>0.7). However, it is common to find a quite low Cronbach value with scales of fewer than ten items. In this case, the reliability of the scale can be accepted if it was found 'inter item correlation' of all items in the scale ≥ 0.2 (Bryman and Cramer, 2005; Ali, 2011). With regard to the ***validity*** test; for testing the validity of items, the 'Chi-square goodness-of-fit' test (non-parametric) was used to find out whether an observed value is significantly different from an expected value. The 'Chi-square goodness-of-fit' (*p* value) is usually considered significant at values equal or less than 0.05 (⩽0.05) (Bryman and Cramer, 2005; Field, 2005; Pallant, 2010). This means that there are statistically significant differences between the observed and expected values, which, in turn, means that the probability which is happening due to chance is very small (⩽0.05). This can confirm that the propositions (items) are valid, and it also gives an indication to the possibility of publishing the results and generalizing from the current research sample to the entire population (Ali, 2011; uk.ask.com, 2011).

7.2 ANALYSIS OF THE QUESTIONNAIRE'S OUTPUTS:

Thirty Large-scale building projects were selected to be involved in the questionnaire. These projects were spread on six different governorates (they are the same six pre-selected Jordanian governorates that were involved in the main investigation), and they are executed by **26** first class building contractor organisations (according to JCCA classification 2011) that represented a broad cross-section of the organisations within the Jordanian Construction Industry (J.C.I). Due to the reasons stated in the previous section, out of **52** questionnaires, which were handed to the functional experts who were appointed by the points-of-contact within their organisations, **47** questionnaires were involved in this analysis process.

The sample size design, the selection criteria for respondents, projects and organisations, and the procedures of conducting the survey have been detailed in **Sections 5.5.3.3** and **5.6.1.3**.

7.2.1 Section 1 Analysis: Respondents Background Information:

The respondent's profile sheet, which is included in section 1, aims to obtain data comprising personal information of the respondents including their current position/title, years of experience, the type of their organisation and the projects they are currently working on, along with the perspective that was chosen to answer the questionnaire.

Table 7.1 illustrates details of the respondents who completed all the sections of the questionnaire. From the personal information provided, the Project Manager and Construction Site Manager groups were the largest of the respondents, whereby they represented 31.9% and 23.4% of the respondents respectively. The remaining percentage of respondents was distributed as following; 8.5% Material Managers/Administrators, 8.5% Purchasing/Procurement Managers, 6.4% Warehouse Manager/Storekeepers, 6.4% others including two Quantity Surveyors and a Concrete Foreman, 4.3% Logistic Manager/Coordinator, 4.3% Material Officers/Coordinators and, 4.3% Planners, and 2.1% Quality Manager. These results are in line with what has been noted through the site visits and concluded from the interviews, that a project manager and a construction site manager are the most relevant to and responsible for managing the building materials in the majority of the Jordanian construction projects.

Table 7.1: Frequency Analysis of Respondents' Position Title

The Current Position	*Frequency*	*Percent %*	*Cumulative Percent%*
Material Manager/Administrator	4	8.5	8.5
Material Officer/Coordinator	2	4.3	12.8
Warehouse Manager/Storekeeper	3	6.4	19.1
Purchasing/Procurement Manager	4	8.5	27.7
Project Manager	15	31.9	59.6
Logistic Manager/Coordinator	2	4.3	63.8
Construction Site Manager	11	23.4	87.2
Planner	2	4.3	91.5
Quality Manager/Coordinator	1	2.1	93.6
Other	3	6.4	100.0
Total	47	100.0	
Std. Deviation		**2.45609**	

The diversity of the respondents position-titles accompanied by the diversity in the perspective that has been chosen to answer the questionnaire's questions. One can observe from **Table 7.2** that between a third and a half (42.6%) of the respondents have answered the questionnaire from the Field Control's perspective where the CMM process is usually concentrated, followed by 19.1% Planning and Administrative, 14.9% Material Takeoff and Material Control, 8.5% Purchasing-Organisational Level, 6.4% Vendor Inquiry and Evaluation, and equally 4.3% of the respondents answered the questionnaire from the perspectives of Warehousing-Organisational Level and Warehousing-Construction Level.

Table 7.2: Frequency Respondents for the Perspective that has been Chosen to answer the Questionnaire's Questions

Area of Expertise	*Frequency*	*Percent%*	*Cumulative Percent%*
Planning & Administration	9	19.1	19.1
Material Takeoff & Material Control	7	14.9	34.0
Vendor Inquiry & Evaluation	3	6.4	40.4
Purchasing (Organisational Level - Home Office)	4	8.5	48.9
Warehousing (Organisational Level - Home Office)	2	4.3	53.2
Warehouse (Field Level – Site Store)	2	4.3	57.4
Field Control	20	42.6	100.0
Total	47	100%	
Std. Deviation		**3.97273**	

This diversity of the respondents' positions and their area of expertise, which covers a broad range of CMM-related experiences, could provide more realistic assessment to the CMM process in the Jordanian Construction Industry (J.C.I) and in-depth evaluation to the effectiveness measures that are proposed to assess its performance. This, consequently, can increase the validity and reliability of the responses and the entire research project.

Table 7.3 illustrates the experience of the respondents in terms of both; years of construction experience within the J.C.I and years of management experience in the areas related to building materials management. In terms of the construction experience within the J.C.I, the results demonstrate that the majority of respondents have more than ten years' experience working within the Jordanian construction industry; 36.2% between 11-

15 years, 36.2% between 16-20 years, 8.5% between 21-25 years and 10.6% more than 25 years, while only 4.3% of the respondents have experience between 5-10 years and 4.3% have less than 5 years' experience of working within the J.C.I. With regard to the respondents' years of experience in one or more CMM function, **Table 7.3**, also, demonstrates that about two-third of respondents claimed that have worked in areas related to materials management for more than ten years distributed as follows; 36.2% between 11-15 years, 23.4% between 16-20 years, and 6.4% 21-25 years. While about a quarter of the respondents claimed to have worked in managing the building materials for a period between 5-10 years, and just 8.5% claimed to have been involved in this area for less than 5 years.

Table 7.3: Respondents' Years of Experience

Years of Experience Range	***Years of Construction Experience within JCI % N=47***	***Years of management experience related to material management% N=47***
<5	4.3%	8.5%
5 -10	4.3%	25.5%
11 – 15	36.2%	36.2%
16 - 20	36.2%	23.4%
21 - 25	8.5%	6.4%
>25	10.6%	00.0%
Total	100%	100%
Std. Deviation	**1.17403**	**1.05097**

The results above indicate that very high experienced respondents have participated in this questionnaire survey, and this could mean that those, who have a good experience in working within the Jordanian building projects and particularly in areas related to building materials management, may have better dealings with managing the building materials and better understanding and wider perception of evaluating the effectiveness of the CMM performance. With such long experience of work, it can be said that the information gathered was reasonably reliable, since the involvement of experienced professionals in the survey can increase the validity and reliability of the results, and thus the validity and reliability of the entire research.

The respondents came from **30** concrete building projects distributed at slightly different proportions in three main types of construction projects that represented a broad cross-section of the projects within the Jordanian Construction Industry (J.C.I); 26.7%

Residential/Housing Building Project, 46.7% Institutional Building Project, and 26.7% Commercial Building Project, as shown in **Figure 7.1**. However, **Figure 7.2** displays that the majority of those respondents came from building companies generally associated with main building contractors (74.5%), and just 11%, 11% and 4% of the respondents came from organisations associated with clients, engineering consultants, and sub-contractors respectively.

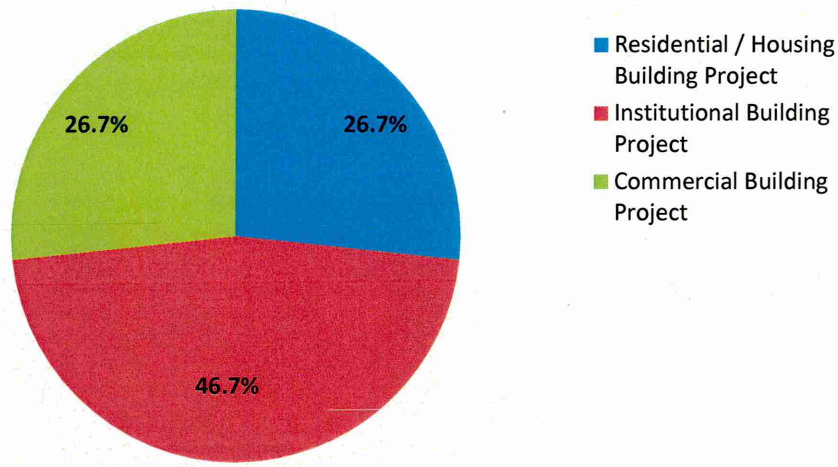

Figure 7.1: The Percentages of the Type of Projects

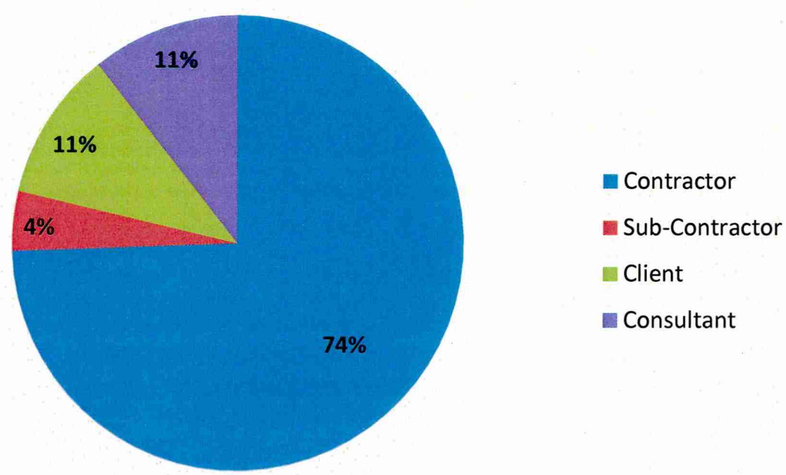

Figure 7.2: The Percentages of the Type of Organisations

Table 7.4 illustrates that, although the estimated costs of the projects were different from one to another and that they ranged from £15 to £55 millions, the vast majority of the respondents (95.7%) described the projects as being Large-scale projects, regardless of their estimated cost or the building area. This result confirms what was stated by the chairman of Jordanian Construction Contractors Association (JCCA), that there are no specific criteria for classifying the construction projects in terms of their size in the J.C.I (Al-Tarawnh, 2012). However, statistical significant association tests (see **Table 7.4**) suggest that the 'Estimated Cost of Project' has a strong significant association with the 'Project's Size' ($p<0.05$, Phi=Cramers V= 1.000). The reliability analysis test clarifies that the Cornback's alpha for the scale was only 0.637 (see **Table 7.4a**), which is less than the usually recommended 0.7 (0.637<0.7). In this case, however, this could be an acceptable result, because the number of items in our list (5) is fewer than ten items (Pallant, 2007; Bryman; Cramer, 2005; Ali, 2011), and the scale was considered reliable since the inter-item correlation is 0.467, which is greater than the recommended minimum 0.2 (0.467>0.2) (Pallant, 2007; Field, 2005; Ali, 2011).

Table 7.4: Estimated Cost of the Case Projects and the Size of these Projects

Estimated Cost of Current Project	Size of Projects		Total	Chi-Square (*p*) & Cramer's V
	Medium-Scale Project	Large-Scale Project		
£15 - 25 m	4.3%	0	4.3%	- P= 00.00<0.05
£26 - 35 m	0	21.3%	21.3%	
£36 - 45 m	0	42.5%	42.5%	- Phi = 1.000
£46 - 55 m	0	25.5%	25.5%	- Cramer's V = 1.000
> £55 m	0	6.4%	6.4%	
Total	4.3%	95.7%	100%	

Table 7.4a: Reliability Analysis for the Estimated Cost of the Projects and the Size of these Projects

The Current Position	Inter-Item Correlation		Cronbach's Alpha
	Estimated Cost of Current Project	Size of current Projects	
Estimated Cost of Current Project	1.000	0.467	0.637
Size of current Projects	0.467	1.000	

Although there is a difference in the estimated cost of the projects, the majority of the projects, with 83%, have been implemented under the Unite Price (Re-measured Based) type of the projects' contract, as shown in **Table 7.5**. This could interpret the similarity in some answers related to evaluating the performance of the CMM process among the different types of projects and the barriers that can hinder the use of the proposed set of effectiveness measures.

Table 7.5: Types of the Projects Contracts

The Current Position	*Frequency*	*Percent%*	*Cumulative Percent%*
Fixed Price (Lump Sum)	8	17	17
Unite Price (Re-measured Based)	39	83	83
Total	47	100	100
Std. Deviation		**0.3798**	

7.2.2 Section 2 Analysis: Evaluation of Effectiveness Measures:

Section 2 was, generally, designed to evaluate the 33 proposed effectiveness measures in terms of their utilization (whether they were used in the past or are currently in use), their importance in communicating effectiveness, and their practicality with respect to applying those measures. In addition to, this section is intended to explore the barriers that might hinder the measures application. To meet the section's main purposes, six questions were included in this section. They deal with four areas of evaluation; 1) measures' utilization (past, current in use, and potential), 2) importance in communicating the effectiveness, 3) practicality to implement, and 4) significant barriers related to measures implementation. Auxiliary data on each of the proposed measures, including measures' attributes, measures' location, and measures' meaning and description, was submitted with this section to provide the respondents with insight and comprehension about the measures in order to avoid misunderstanding and to obtain more accurate evaluation. The following discussion of the section's results highlights some of the rankings and relationships that may be drawn from this research.

7.2.2.1 Evaluation of Measures' Utilization:

In order to evaluate the measures' utilization, the functional experts (respondents) were asked to answer the following questions for each measure;

1- Question 2.1 (Q2.1): in the Past, did you use this or a similar measure?

2- Question 2.2 (Q2.2): currently, are you using this or a similar measure?

(If yes, Skip question 3)

3- Question 2.3 (Q2.3): given the opportunity and the ability to collect the data, would you consider using this measure to monitor operations or identify problems with the materials management function (s) under your control?

The possible answers for those questions were "yes" or "no". The respondents were alerted to ignore and skip the third question, if the answer to the second question was "yes".

Table 7.6 summarises the positive responses to the three questions regarding the measures' utilization. The measure's rank within this area of evaluation (the 'Measure's Utilization') is based on the 'Positive Response Percentage'. Examination of **Table 7.6** reveals that the majority of the effectiveness measures that were used in the past are somewhat similar to those that are currently used within the Jordanian Construction Industry (J.C.I), though there are irregular variations between their ranks. Therefore, the responses in the section were classified into two groups; *Group 1*: those measures that are commonly used within the J.C.I, *Group 2*: those measures that are not commonly used, but given the opportunity and the ability to collect the data (data availability), the respondents would consider implementing them. Logically, Group 1 and Group 2 should have an inverse relationship to each other, in other words, a measure that has been ranked high in Group 1 (Currently being Used column) should be, correspondingly, ranked low in Group 2 (the Potential Usage column). In fact, it can be clearly seen that the measures that have a high rank (percent of positive response) in Group1 have a low rank in Group2 gradually; for example, excepting T6, the highest five measures in Group1 ('Currently being Used' column) with a descending order, AC3, Q2, C8, C4, T6, have been ranked as the lowest in Group2 (the 'Potential Usage' column) in an ascending order.

Namely that, whenever the rank of a measure is increasing in the first group, it is correspondingly decreasing in the second group. In order to identify the reality of this relationship, an analysis by using 'Venn' diagram technique was performed. Groupings from the positive responses were taken at three levels of response rates; equal to or greater than **70%**, **50%**, and **30%** of both Group 1 and Group 2, as illustrated in **Figure 7.3**.

Table 7.6: The Positive Responses' Frequency and Percentage of the Utilization of Proposed Effectiveness Measures

Rank	Measures Used in the Past			Measures Currently Being Used			Measures With Potential Usage		
	Label	Response Frequency	Response Percent	Label	Response Frequency	Response Percent	Label	Response Frequency	Response Percent
1	C8	35	74.5	AC3	47	100%	T7	32	68.08
2	AC2	32	68.1	Q2	43	91.5	F1	31	65.9
3	AC3	30	63.8	C8	43	91.5	T2	21	44.6
4	Q2	29	61.7	C4	41	87.2	T5	21	44.6
5	T6	29	61.7	T6	41	87.2	F3	21	44.6
6	C5	27	57.4	AC2	41	87.2	T1	20	42.55
7	C3	25	53.2	C3	40	85.1	QN1	18	38.29
8	C4	24	51.1	C5	39	83	QN3	17	36.77
9	AV1	23	48.9	AV1	39	83	QN4	17	36.77
10	AC1	22	46	QN2	38	80.9	T3	16	34.04
11	AV2	21	44.7	QN5	37	78.8	C7	16	34.04
12	F3	19	40.4	AC1	34	72.3	QN5	13	27.6
13	QN2	17	36.2	AV2	31	66	Q1	12	25.5
14	QN5	16	34	T5	26	55.3	AV2	12	25.5
15	QN1	15	31.9	T2	26	55.3	AC1	11	23.4
16	T5	15	31.9	F3	26	55.3	QN6	11	23.4
17	QN7	14	29.8	QN1	23	48.9	QN7	11	23.4
18	C1	14	29.8	Q1	19	40.4	T4	9	19.14
19	Q1	12	25.5	QN7	13	27.7	C1	9	19.14
20	QN4	12	25.5	T7	13	27.7	C2	9	19.14
21	T2	12	25.5	QN6	13	27.7	T6	8	17.02
22	C2	12	25.5	T3	9	19.1	C5	8	17.02
23	F1	10	21.3	F1	8	17	C6	8	17.02
24	QN3	8	17	C7	7	14.9	QN2	7	14.84
25	T7	7	14.9	T1	4	8.5	QN8	7	14.89
26	QN6	6	12.8	F2	4	8.5	F2	7	14.89
27	T1	4	8.5	QN3	2	4.3	C4	6	12.76
28	F2	4	8.5	QN4	2	4.3	C3	4	8.51
29	C6	3	6.4	C6	2	4.3	C8	4	8.51
30	T3	2	4.3	QN8	-	-	AV1	8	7
31	QN8	-	-	T4	-	-	AC2	2	4.2
32	T4	-	-	C1	-	-	Q2	2	4.2
33	C7	-	-	C2	-	-	AC3	-	-

Venn diagram in **Figure 7.3** indicates that up to the level of the percentage of 30 from the positive response of proposed measures, just four measures have been identified as not conforming to the inverse relationship. The four measures are Home Office Requisition Ratio (QN1), Bid/Evaluate/Commit Lead-time (T2), Commodity Vendor Timeliness (T5), and Volume Flexibility (F3). Because these four measures were found to have a 30% or greater current utilization while being viewed from potential usage by respondents who do not currently use them, they are considered disproportionate. In general, this result interprets the extent of the accuracy of professional experts in selecting their responses, and consequently the reliability of the data collected in this research.

Among the most important indications that have been derived from examining **Table 7.6,** is the relationship between the results of the survey and what has been discovered by the main investigation (Case Study Research) regarding measures' utilization. Through considering Group 1, it can be evident that the majority of the measures (all measures except QN5 & T5) that have a 50% or greater current utilization are those ones that are found "exist" in one or more of the case studies selected in the J.C.I. Moreover, excepting QN1 and T7, all the measures that have less than 50% of positive responses for current usage are those found to be "not-existent" in the case studies (see **Tables 6.4 and 6.5** in **Chapter VI**). This could offer a further support for the validity and the reliability of the main investigation's outcomes, and consequently confirm the validity and reliability of the framework that has been developed based on those outcomes.

The comparison of the above results with what was concluded from a survey, which were conducted within the 'Industrial Projects' in the USA (Plemmons, 1995), revealed that there is, disparity between those results. While in Plemmons's study, measures such as, C7, QN8, T1, C2, and T3 were found among the ten best key measures to communicate the effectiveness of CMM performance (see **Table 4.10**), those measures are among those that are ranked as the ten lowest measures in terms of their current use in this study. In fact, this might be due to various reasons: the difference between the Arab and American cultures (promoting 'Minority Suppliers QN8'), the difference in the manner used for the payment system ('C1') and the manner of assessment ('T1'), the difference in the requirements and procedures of conducting the materials management process within the Industrial and Building projects ('T3') and the difficulty involved in calculating a measure within the Building projects ('C7'), for more detail see the section of establishing the P.E.Ms.

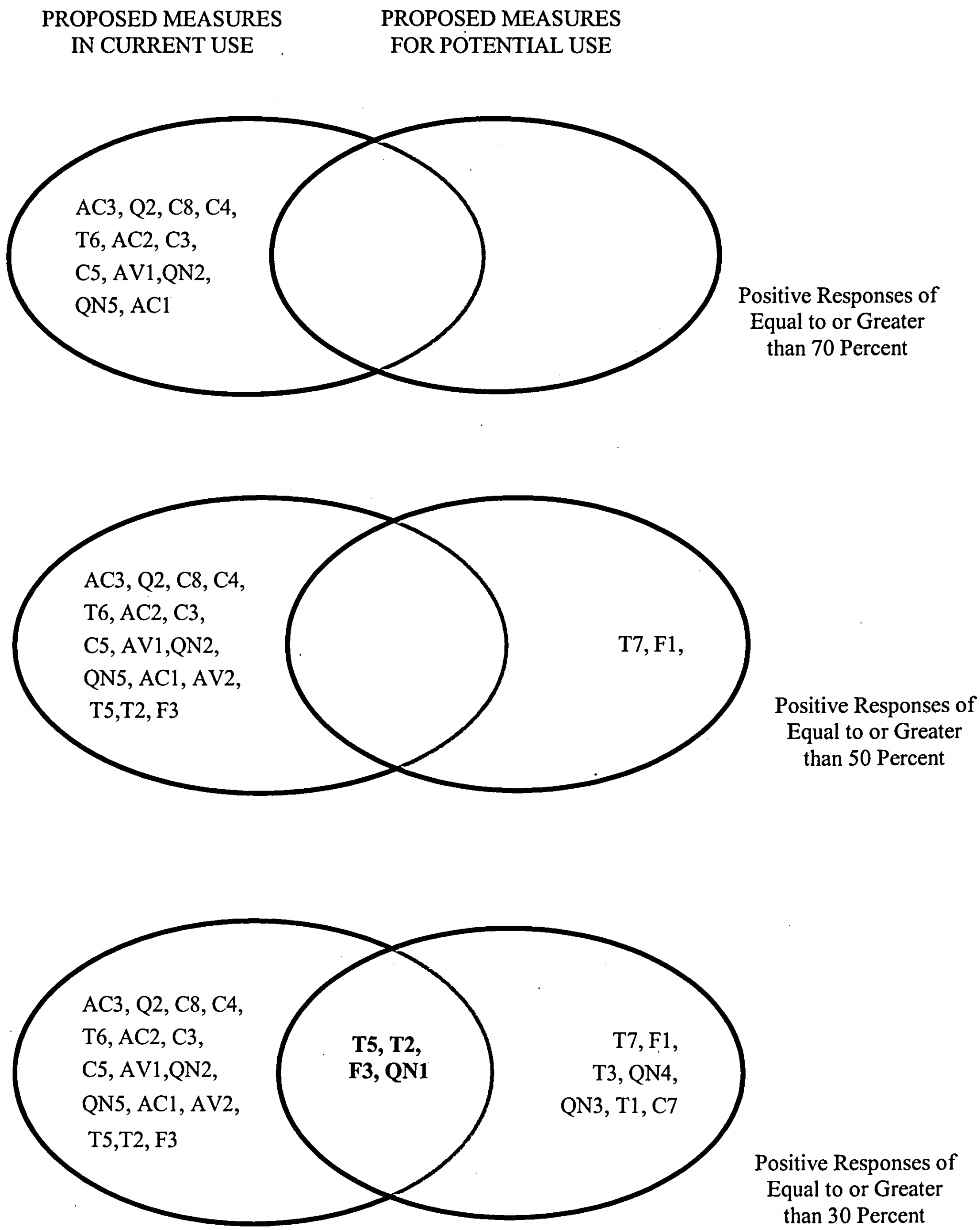

Figure 7.3: Venn diagram of Positive Responses of Equal to or Greater than 70, 50, and 30 Percent of Proposed Measures Group1 (in Current Use) and Group2 (Potential Use)

7.2.2.2 Evaluation of Measures' Importance:

Answering the fourth question in section 2 aims to obtain insight on the importance of each proposed measure in communicating the effectiveness. To do so, the professional experts were asked to evaluate the effectiveness measures in terms of their importance through answering this question using five-point Likert Scale;

Question 2.4 (Q2.4): "how important is this measure in communicating the effectiveness of the materials management process?"

The responses to the questions are presented in **Table 7.7**. Examination of the Table provides an evaluation of the importance of each effectiveness measure in communicating the effectiveness of the performance of the CMM process. The results of the 'Chi-square goodness-of-fit' test indicate that there are statistically significant difference between the actual observed and the expected value of the majority of the measures. Except 'T6', 'C5', 'C8', 'C4', 'QN7', 'C6', and 'QN8', the *p* values for the rest of the effectiveness-measures are less than 0.05. This means that the probability occurs due to chance is very small ($\leqslant$ 0.05). This can confirm that the vast majority of propositions (items= effectiveness measures) are valid. With regard to the reliability test, the Cronbach's alpha for the scale was 0.712, which is greater than the recommended value (>0.7); this confirms the reliability of the scale; the entire set of items in the scale are considered self-consistent and reliable.

Table 7.7 illustrates the response score for each measure (%); for example, all of the respondents with 100% claim that the 'Minority Suppliers' are not important or slightly important (63.8% not important and 36.2% slightly important) in communicating the effectiveness, with a median score of 1, while 100% of the respondents considered 'Commodity Timeliness (T6)' important or very important with 61.7% very important and 38.3% important, and with a median score of 5. Similarly, 100% of the respondents were rated 'Construction Time Lost' and 'Total Surplus' as important and very important (51.1% important and 48.9% very important; and 53.2% important, 46.8% very important respectively), but they obtained median scores of 4. As shown in **Table 7.7**, the remaining effectiveness measures had different scores of median ranging from 4 to 2.

Table 7.7: Descriptive Analysis (Scores and Median) and Validity and Reliability Analysis of Scales for the Importance of the Proposed Effectiveness Measures

LABEL	MEASURE NAME	RESPOSE SCORE %					MEDIAN	CHI-SQUARE (p)	CRONBACH'S ALPHA
		Not Important	Slightly Important	Moderately Important	Important	Very Important			
T6	Commodity Timeliness	0	0	0	38.3	61.7	5	0.109	Cronbach's Alpha = 0.712
C5	Construction Time Lost	0	0	0	51.1	48.9	4	0.884	
C8	Total Surplus	0	0	0	53.2	468	4	0.662	
AV1	Material Availability	0	0	6.4	46.8	46.8	4	0.00	
AC3	Warehouse Inventory Accuracy	0	0	4.3	55.3	40.4	4	0.00	
AC2	Material Receipt Problems-Internal	0	0	6.4	57.4	36.2	4	0.00	
Q2	Jobsite Rejections of Tagged Equipment	0	0	6.4	59.6	34	4	0.00	
T5	Commodity Vendor Timeliness	0	0	6.4	66	27.7	4	0.00	
AV2	Stock out Analysis	0	0	8.5	63.8	27.7	4	0.00	
C4	Express Deliveries Percent	0	0	19.1	46.8	34	4	0.067	
F3	Volume Flexibility	0	0	12.8	61.7	25.5	4	0.00	
T2	Bid/Evaluate/Commit Lead-time	0	0	17	57.4	25.5	4	0.02	
AC1	Material Receipt Problems	0	0	25.5	51.1	23.4	4	0.035	
F1	Delivery Flexibility	0	8.5	12.8	63.8	14.9	4	0.00	
T7	Materials Withdraw Request (MWR) Lead-	0	0	23.4	68.1	8.5	4	0.00	

LABEL	MEASURE NAME	RESPOSE SCORE %					MEDIAN	CHI-SQUARE (p)	CRONBACH'S ALPHA
		Not Important	Slightly Important	Moderately Important	Important	Very Important			
	time								
C3	Freight Cost Percent	0	6.4	34	42.6	17	4	0.02	
QN2	Home Office Purchase Order Ratio	2.1	2.1	31.9	53.2	10.6	4	0.00	
QN5	Commitment – Field	4.3	8.5	36.2	44.7	6.4	3	0.00	
QN1	Home Office Requisition Ratio	2.1	10.6	48.9	36.2	2.1	3	0.00	
T1	Procurement Lead Time	0	19.1	46.8	29.8	4.3	3	0.00	
Q1	Installing Equipments Rework	4.3	12.8	48.9	31.9	2.1	3	0.00	
T3	Purchase Orders (PO) to Material Receipt Duration	2.1	31.9	42.6	19.1	4.3	3	0.00	
C7	Warehouse Safety Incident	19.1	31.9	40.4	8.5	0	2	0.011	
QN4	Commitment – Home Office	25.5	29.8	42.6	2.1	0	2	0.01	
QN3	Average Line Items Per Release	23.4	38.3	34	4.3	0	2	0.05	
F2	Changes Flexibility	36.2	10.6	51.1	2.1	0	2	0.00	
QN6	Electronic Data Interchange (EDI) Purchases	31.9	34	31.9	2.1	0	2	0.04	
QN7	Sole Source Purchases	31.9	34	34	0	0	2	0.979	
C6	Payment Discounts	44.7	34	21.3	0	0	2	0.144	
C1	Average Man-hour/Work-hour per Material Take-off (MTO)	46.8	38.3	12.8	2.1	0	2	0.00	

LABEL	MEASURE NAME	RESPOSE SCORE %					MEDIAN	CHI-SQUARE (*p*)	CRONBACH'S ALPHA
		Not Important	Slightly Important	Moderately Important	Important	Very Important			
T4	Material Receiving Processing Time	53.2	27.7	19.1	0	0	2	0.012	
C2	Average Man-hour/Work-hour per Purchase Order (PO)	48.9	42.6	4.3	4.3	0	2	0.00	
QN8	Minority Suppliers	63.8	36.2	0	0	0	1	0.058	

In this area of evaluation (the importance of the proposed measures in communicating effectiveness), the process of ranking the effectiveness-measures is based on 'the Value of the Mean Score).

Table 7.8 gives more details about ranking the proposed effectiveness measures based on their mean scores. It can be noted that Commodity Timeliness (T6) had the highest mean score with a mean score of 4.6170; it is then followed by Construction Time Lost (C5), Total Surplus (C8), Material Availability (AV1), Warehouse Inventory Accuracy (AC3), Material Receipt Problems-Internal (AC2), Jobsite Rejections of Tagged Equipment (Q2), Commodity Vendor Timeliness (T5), Stock out Analysis (AV2), Express Deliveries Percent (C4), Volume Flexibility (F3), Bid/Evaluate/Commit Lead-time (T2), Material Receipt Problems (AC1), Delivery Flexibility (F1), Materials Withdraw Request (MWR) Lead-time (T7), Freight Cost Percent (C3), Home Office Purchase Order Ratio (QN2), Commitment – Field (QN5), Home Office Requisition Ratio (QN1), Procurement Lead Time (T1), Installing Equipments Rework (Q1), Purchase Orders (PO) to Material Receipt Duration (T3), Warehouse Safety Incident (C7), Commitment – Home Office (QN4), Average Line Items Per Release (QN3), Changes Flexibility (F2), Electronic Data Interchange (EDI) Purchases (QN6), Sole Source Purchases (QN7), Payment Discounts (C6), Average Man-hour/Work-hour per Material Take-off (MTO) (C1), Material Receiving Processing Time (T4), Average Man-hour/Work-hour per Purchase Order (PO) (C2), and finally the lowest mean score is for Minority Suppliers (QN8) with a mean score of 1.3617. The ranking of the 33 proposed effectiveness-measures' importance in communicating effectiveness can be presented graphically in **Figure 7.4**.

Excepting very few effectiveness-measures (AC3 and C5), there is no clear convergence in importance-ranking between the above ranking **(Table 7.8)** and the one that was revealed by Ul-Asad (2005) on the measures within the industrial projects (see **Table 4.12**). This might be due to the difference in the strategy and the procedures of managing the materials between the Industrial' and 'Building' projects.

Table 7.8: The Importance-Rank of the Proposed Effectiveness Measures by Means Scores

RANK	LABEL	MEASURE NAME	MEAN	STD. DEVIATION
1	T6	Commodity Timeliness	4.6170	0.4913
2	C5	Construction Time Lost	4.4894	0.5052
3	C8	Total Surplus	4.4681	0.5043
4	AV1	Material Availability	4.4043	0.6136
5	AC3	Warehouse Inventory Accuracy	4.3617	0.5682
6	AC2	Material Receipt Problems-Internal	4.2979	0.5866
7	Q2	Jobsite Rejections of Tagged Equipment	4.2766	0.5786
8	T5	Commodity Vendor Timeliness	4.2128	0.5491
9	AV2	Stock out Analysis	4.1915	0.5762
10	C4	Express Deliveries Percent	4.1489	0.7216
11	F3	Volume Flexibility	4.1277	0.6120
12	T2	Bid/Evaluate/Commit Lead-time	4.0851	0.6537
13	AC1	Material Receipt Problems	3.9787	0.7067
14	F1	Delivery Flexibility	3.8511	0.7796
15	T7	Materials Withdraw Request Lead-time	3.8511	0.5508
16	C3	Freight Cost Percent	3.7021	0.8318
17	QN2	Home Office Purchase Order Ratio	3.6809	0.7831
18	QN5	Commitment – Field	3.4043	0.9007
19	QN1	Home Office Requisition Ratio	3.2553	0.7652
20	T1	Procurement Lead Time	3.1915	0.7977
21	Q1	Installing Equipments Rework	3.1489	0.8335
22	T3	Purchase Orders (PO) to Material Receipt Duration	2.9149	0.8804
23	C7	Warehouse Safety Incident	2.3830	0.8981
24	QN4	Commitment – Home Office	2.2128	0.8581
25	QN3	Average Line Items Per Release	2.1915	0.8505
26	F2	Changes in Flexibility	2.1915	0.9699
27	QN6	Electronic Data Interchange (EDI) Purchases	2.0426	0.8586
28	QN7	Sole Source Purchases	2.0213	0.8206
29	C6	Payment Discounts	1.7660	0.7861
30	C1	Average Man-hour/Work-hour per Material Take-off (MTO)	1.7021	0.7778
31	T4	Material Receiving Processing Time	1.6596	0.7878
32	C2	Average Man-hour/Work-hour per Purchase Order (PO)	1.6383	0.7640
33	QN8	Minority Suppliers	1.3617	0.4856

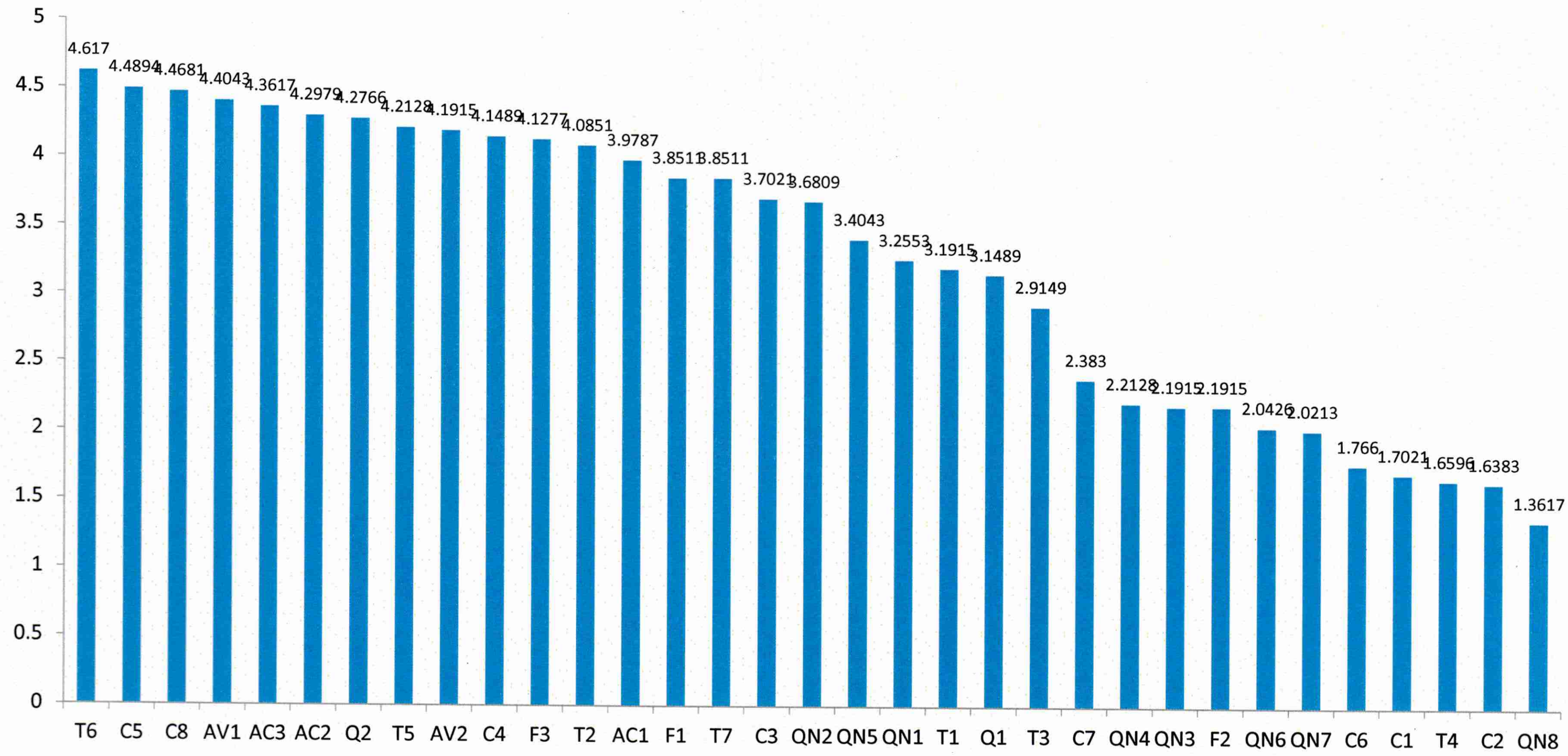

Figure 7.4: Graphically, Ranking of the Importance of the Proposed Effectiveness Measures by Means Scores

The comparison between the contents of **Tables 7.6**, with the contents of **Table 7.7** and **7.8** reveals the relationship between the importance of the proposed effectiveness measures and the extent of their utilization within the J.C.I. It can be noted that eight of the ten highest ranked measures considered important in communicating effectiveness are currently in use (they have been highly ranked in current utilization), even if their use was not for the purpose of evaluating the effectiveness of the CMM performance. This may be attributed to one of two probabilities, either the participants have evaluated the importance of the measures from the perspective of the extent of their use, or that the use of such measures in the Jordanian construction projects has been limited to those of high importance from the respondents' point of view. Furthermore, through consideration of **Tables 7.7** and **7.8** and comparing their contents with what resulted from the previous main investigation (**Table 6.6** in the previous chapter), one can note that all of the ten highest ranked measures considered important in communicating effectiveness are included within the set of Practical Effectiveness Measures (P.E.Ms) that can be used, practically, for evaluating E.CMM.P in the J.C.I (which on their basis, the Developed E.CMM.P Framework will be built).

With respect to the framework's formative evaluation, which is one of the questionnaire objectives and a part of the validation process, the above discussion confirms the validity and the reliability of the outcomes that will be employed in evolving the Developed E.CMM.P Framework; it thus confirms the validity of the framework itself.

7.2.2.3 Evaluation of Measures' Practicality:

Within the context of assessing the proposed list of effectiveness measures that have been developed from the literature review, these effectiveness measures are examined from a different aspect, as a supplementary stage. As noted from many studies and researches regarding the assessment of processes; such as, Plemmons and Bell (1995), Al-Darweesh (1999), Al-Khalil (2004), and many others, the 'Practicality' aspect is the criterion that usually accompanies the importance criterion. Therefore, the fifth question in section 2 asks the professional experts to evaluate each of the proposed effectiveness measures in terms of its practicality to be implemented within the J.C.I, using five-point Likert Scale;

"**Question 2.5 (Q2.5)**: How practical would this measure be to implement?"

Table 7.9 describes the details of the respondents' responses to the question. Studying the table presents the perspective of the professional experts to the possibility of application and the ease of the implementation of the effectiveness measures within the large-scale concrete building projects in the J.C.I. The results of the chi-square test confirm that all propositions (items=Effectiveness measures) are valid excluding 'F1' and 'Q1'; the probability is happen due to chance; it is less than 0.05 (p value for them <0.05) for the vast majority of the effectiveness measures. The Cronbach's alpha for the entire set of items (33 items) in the scale was 0.674, which is less than the one usually recommended: 0.7. However, to make the scale reliable, two items with the highest values of 'Cronbach's Alpha if Item Deleted' (QN1 and QN5) were removed to increase the Cronbach's alpha value. Accordingly, the Cronbach's alpha for the scale, with 31 items, became 0.713 (>0.70), and this concludes that the vast majority of items in the scale are the reliability.

The survey shows that over 50% of the respondents considered the following nine measures practical and even very practical, and gave them a median score of 4; 'Commodity Timeliness' (T6) rated as practical and very practical by 91.4% of respondents, similarly, 80.8% 'Warehouse Inventory Accuracy' (AC3), 76.6% 'Material Receipt Problems-Internal' (AC2), 72.3% 'Material Availability' (AV1), 70.2% 'Express Deliveries Percent' (C4) , 68.1% 'Total Surplus' (C8), 55.4% 'Freight Cost Percent' (C3), 55.3% 'Jobsite Rejections of Tagged Equipment' (Q2), and 51% 'Commodity Vendor Timeliness' (T5). In contrast, 100% of the respondents considered 'Minority Suppliers (QN8)', 'Average Man-hour/Work-hour per Material Take-off (MTO) (C1)', and 'Average Line Items Per Release (QN3)' not applicable or slightly applicable to be implemented practically in the J.C.I, with a median score of 1. This could be attributed to the lack of these strategies and payment methods in the culture of J.C.I, as has been discovered through case studies. The rest of the effectiveness measures listed had median scores between 3 to 1, as demonstrated in **Table 7.9**.

Similar to the importance evaluation area, ranking the proposed measures, in terms of their practicality to be applied in the Jordanian building projects, is based on 'the Value of the Mean Score'. Regarding the ranking for the most practical effectiveness measures to be implemented in the Jordanian projects, **Table 7.10** sets out the mean score and the rank for each of the measures listed.

Table 7.9: Descriptive Analysis (Scores and Median) and Validity and Reliability Analysis of Scales for the Practicality of the Proposed Effectiveness Measures

LABEL	MEASURE NAME	RESPOSE SCORE %					MEDIAN	CHI-SQUARE (*p*)	CRONBACH'S ALPHA
		Not Practical	Slightly Practical	Moderately Practical	Practical	Very Practical			
T6	Commodity Timeliness	0	0	8.5	72.3	19.1	4	0.00	Cronbach's Alpha for 33 measures = 0.674 Cronbach's Alpha for 31 measures = 0.713
AC3	Warehouse Inventory Accuracy	0	0	19.1	72.3	8.5	4	0.00	
AV1	Material Availability	0	0	27.7	57.4	14.9	4	0.01	
AC2	Material Receipt Problems-Internal	0	0	23.4	76.6	0	4	0.00	
C8	Total Surplus	0	06.4	25.5	53.2	14.9	4	0.00	
C4	Express Deliveries Percent	0	4.3	25.5	68.1	2.1	4	0.00	
Q2	Jobsite Rejections of Tagged Equipment	0	4.3	40.4	44.7	10.6	4	0.00	
C3	Freight Cost Percent	0	6.4	38.3	51.1	4.3	4	0.00	
T5	Commodity Vendor Timeliness	0	4.3	44.7	48.9	2.1	4	0.00	
QN2	Home Office Purchase Order Ratio	2.1	6.4	55.3	36.2	0	3	0.00	
AC1	Material Receipt Problems	0	2.1	66	31.9	0	3	0.00	
AV2	Stock out Analysis	0	8.5	76.6	14.9	0	3	0.00	
QN1	Home Office Requisition Ratio	2.1	19.1	51.1	27.7	0	3	0.00	
T2	Bid/Evaluate/Commit Lead-time	8.5	12.8	53.2	25.5	0	3	0.00	

LABEL	MEASURE NAME	RESPOSE SCORE %					MEDIAN	CHI-SQUARE (*p*)	CRONBACH'S ALPHA
		Not Practical	Slightly Practical	Moderately Practical	Practical	Very Practical			
F3	Volume Flexibility	8.5	17	44.7	29.8	0	3	0.03	
C5	Construction Time Lost	4.3	25.5	46.8	19.1	4.3	3	0.00	
T7	Materials Withdraw Request (MWR) Lead-time	4.3	23.4	46.8	25.5	0	3	0.01	
F1	Delivery Flexibility	12.8	23.4	40.4	23.4	0	3	0.061	
QN5	Commitment – Field	8.5	27.7	48.9	14.9	0	3	0.00	
Q1	Installing Equipments Rework	25.5	42.6	31.9	0	0	2	0.353	
QN4	Commitment – Home Office	51.5	38.3	10.6	0	0	1	0.02	
QN7	Sole Source Purchases	55.3	31.9	12.8	0	0	1	0.02	
T3	Purchase Orders (PO) to Material Receipt Duration	55.3	40.4	4.3	0	0	1	0.00	
C7	Warehouse Safety Incident	55.3	40.4	4.3	0	0	1	0.00	
T4	Material Receiving Processing Time	59.6	31.9	8.5	0	0	1	0.00	
QN6	Electronic Data Interchange (EDI) Purchases	57.8	40	2.2	0	0	1	0.00	
C6	Payment Discounts	63.8	29.8	6.4	0	0	1	0.00	
F2	Changes Flexibility	83	10.6	6.4	0	0	1	0.00	
T1	Procurement Lead Time	68.1	29.8	2.1	0	0	1	0.00	
C2	Average Man-hour/Work-hour per Purchase Order (PO)	72.3	25.5	2.1	0	0	1	0.00	
QN3	Average Line Items Per Release	66	34	0	0	0	1	0.029	

LABEL	MEASURE NAME	RESPOSE SCORE %					MEDIAN	CHI-SQUARE (p)	CRONBACH'S ALPHA
		Not Practical	Slightly Practical	Moderately Practical	Practical	Very Practical			
C1	Average Man-hour/Work-hour per Material Take-off (MTO)	72.3	27.7	0	0	0	1	0.02	
QN8	Minority Suppliers	76.6	23.4	0	0	0	1	0.00	

Table 7.10 shows that Commodity Timeliness (T6) ranked the most practical effectiveness-measure, whereby it had the highest mean score (4.1064). Based on their mean scores, the remaining proposed measures have been ranked (in a descending order) from the most practical to the least practical as follows; Warehouse Inventory Accuracy (AC3), Material Availability (AV1), Material Receipt Problems-Internal (AC2), Total Surplus (C8), Express Deliveries Percent (C4), Jobsite Rejections of Tagged Equipment (Q2), Freight Cost Percent (C3), Commodity Vendor Timeliness (T5), Home Office Purchase Order Ratio (QN2), Material Receipt Problems (AC1), Stock out Analysis (AV2), Home Office Requisition Ratio (QN1), Bid/Evaluate/Commit Lead-time (T2), Volume Flexibility (F3), Construction Time Lost (C5), Materials Withdraw Request (MWR) Lead-time (T7), Delivery Flexibility (F1), Commitment – Field (QN5), Installing Equipments Rework (Q1), Commitment – Home Office (QN4), Sole Source Purchases (QN7), Purchase Orders (PO) to Material Receipt Duration (T3), Warehouse Safety Incident (C7), Material Receiving Processing Time (T4), Electronic Data Interchange (EDI) Purchases (QN6), Payment Discounts (C6), Average Line Items Per Release (QN3), Procurement Lead Time (T1), Average Man-hour/Work-hour per Purchase Order (PO) (C2), Average Man-hour/Work-hour per Material Take-off (MTO) (C1), and finally both Minority Suppliers (QN8) and Changes Flexibility (F2) had the lowest mean score (1.2340). **Figure 7.5** graphically draws the ranking of the practicality of the 33 proposed effectiveness measures to implement.

The comparison of the above practicality-ranking with the one, which has been conducted by Al-Alawi, Al-Ghazwi and Al-Saeed (2007) in the industrial projects (see **Table 4.13**), demonstrates that there is no rapprochement between them; excepting 'warehouse Inventory Accuracy (AC3)', the ten highest practical measures found in this study are not included within those found in the above study in the industrial projects. This, as pointed out previously, could be due to the difference between the 'Building' projects and the 'Industrial' projects in terms of strategies used and the functions and procedures applied for managing their materials management processes, besides, the difference in the place where the studies were conducted; the Kingdom of Saudi Arabia for the above study, and the Hashemite Kingdom of Jordan for this study.

Table 7.10: The Practicality-Rank of the Proposed Effectiveness Measures by Mean Score

RANK	LABEL	MEASURE NAME	MEAN	STD. DEVIATION
1	T6	Commodity Timeliness	4.1064	0.5206
2	AC3	Warehouse Inventory Accuracy	3.8936	0.5206
3	AV1	Material Availability	3.8723	0.6466
4	AC2	Material Receipt Problems-Internal	3.7660	0.4279
5	C8	Total Surplus	3.7660	0.7861
6	C4	Express Deliveries Percent	3.6809	0.5936
7	Q2	Jobsite Rejections of Tagged Equipment	3.6170	0.7387
8	C3	Freight Cost Percent	3.5319	0.6868
9	T5	Commodity Vendor Timeliness	3.4894	0.6210
10	QN2	Home Office Purchase Order Ratio	3.2979	0.5071
11	AC1	Material Receipt Problems	3.2553	0.6746
12	AV2	Stock out Analysis	3.0638	0.4847
13	QN1	Home Office Requisition Ratio	3.0426	0.7505
14	T2	Bid/Evaluate/Commit Lead-time	2.9574	0.8586
15	F3	Volume Flexibility	2.9574	0.9078
16	C5	Construction Time Lost	2.9362	0.8945
17	T7	Materials Withdraw Request (MWR) Lead-time	2.9362	0.8183
18	F1	Delivery Flexibility	2.7447	0.9661
19	QN5	Commitment – Field	2.7021	0.8318
20	Q1	Installing Equipments Rework	2.0638	0.7634
21	QN4	Commitment – Home Office	1.5957	0.6807
22	QN7	Sole Source Purchases	1.5745	0.7145
23	T3	Purchase Orders (PO) to Material Receipt Duration	1.5319	0.7178
24	C7	Warehouse Safety Incident	1.4894	0.5850
25	T4	Material Receiving Processing Time	1.4894	0.6551
26	QN6	Electronic Data Interchange (EDI) Purchases	1.4444	0.5458
27	C6	Payment Discounts	1.4255	0.6166
28	QN3	Average Line Items Per Release	1.3404	0.4789
29	T1	Procurement Lead Time	1.3404	0.5223
30	C2	Average Man-hour/Work-hour per Purchase Order (PO)	1.2979	0.5071
31	C1	Average Man-hour/Work-hour per Material Take-off (MTO)	1.2766	0.4521
32	QN8	Minority Suppliers	1.2340	0.4279
33	F2	Changes Flexibility	1.2340	0.5600

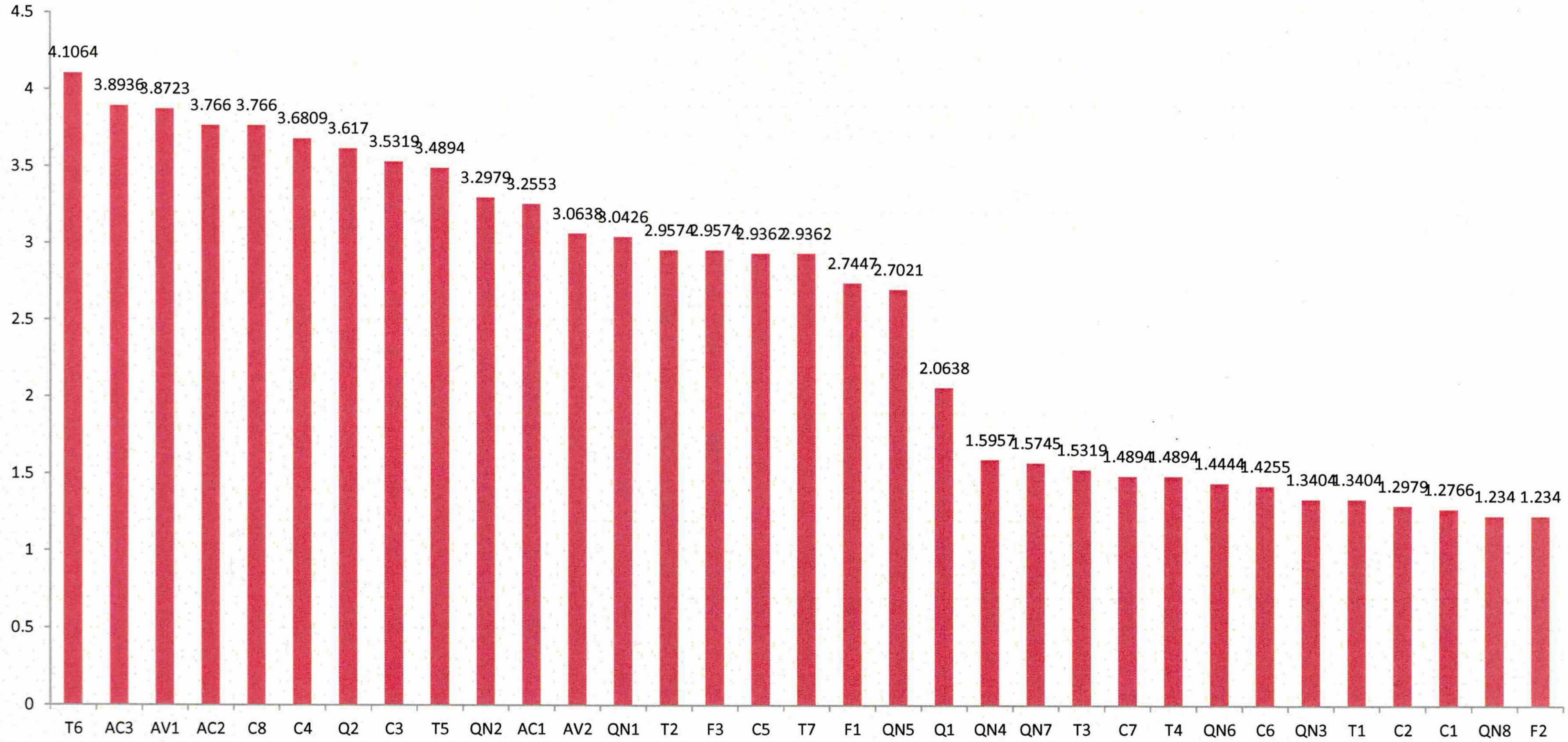

Figure 7.5: Graphically, Practicality Ranking of the Proposed Effectiveness Measures by Means Scores

Regarding the relationship between the practicality of the proposed effectiveness measures and the in-use measures and those considered for potential usage, the comparison of those evaluation's areas (through comparing **Table 7.6** with **Table 7.10**) observed that nine of the ten measures ranked highest as being practical to implement have also been highly ranked in current utilization. This is in line with what has been reached in the research that was undertaken by Plemmons and Bell (1995) within the industrial projects, that 'there is a logical relationship between practicality to implement and utilization of the effectiveness measures'. The only one measure that has been considered practical to implement but was not ranked with the ten highest measures currently being used, is 'Commodity Vendor Timeliness' (T5), however, it has a ranking of potential usage of being fourth. This indicates that 'Commodity Vendor Timeliness' (T5) is considered to be relatively practical to implement; it is also desirable for potential usage, though it is not found in common usage. This indication could interpret the rationale behind selecting the measure (T5) to be included within the 'Practical Effectiveness Measures', which have been developed out of the main investigation, though it has not been used within all the case studies, (see **Table 6.6** in the previous chapter). Moreover, a comparison between the above findings regarding the measures' practicality (**Table 7.10**) with the outcomes that have resulted from the main investigation (see **Table 6.5 and Table 6.5.1** in previous chapter), revealed that all the sixteen measures that were found in current use (Exist) within one or more of the selected case studies are those that are found to be among the seventeen most practical measures to implement. Those seventeen effectiveness measures are involved in the development of the 'Practical Effectiveness Measures' that can be used for evaluating the E.CMM.P in the large-scale concrete building projects in the J.C.I.

In short, the above findings and comparisons could provide a strong support to the validity and reliability of the elements of the E.CMM.P Framework, which in turn, supports the validation of the framework itself.

Discovering the relationship between the practicality and the importance of the proposed effectiveness measures needs to, at the first stage, to identify statistically the significant association between those variables, using tests such as, the Person Chi-square test of association and Cramer's V, as detailed in **Table 7.11**.

Table 7.11: A Comparison between the Importance and Practicality of the Effectiveness-Measures and the Values of the Association's Tests

NO	LABEL	MEASURE NAME	IMPORTANCE		PRACTICALITY		SIG	CRAMER'S V
			Rank	Mean	Rank	Mean		
1	AC1	Material Receipt Problems	13	3.9787	10	3.2553	0.254	0.288
2	AC2	Material Receipt Problems-Internal	6	4.2979	4	3.766	0.005	0.472
3	AC3	Warehouse Inventory Accuracy	5	4.3617	2	3.8936	0.156	0.266
4	Q1	Installing Equipments Rework	21	3.1489	20	2.0638	0.036	0.418
5	Q2	Jobsite Rejections of Tagged Equipment	7	4.2766	7	3.617	0.242	0.291
6	QN1	Home Office Requisition Ratio	19	3.2553	13	3.0426	0.000	0.593
7	QN2	Home Office Purchase Order Ratio	17	3.6809	11	3.2979	0.000	0.734
8	QN3	Average Line Items Per Release	25	2.1915	28	1.3404	0.165	0.329
9	QN4	Commitment – Home Office	24	2.2128	21	1.5957	0.001	0.491
10	QN5	Commitment – Field	18	3.4043	19	2.7021	0.004	0.456
11	QN6	Electronic Data Interchange (EDI) Purchases	27	2.0426	26	1.4444	0.016	0.407
12	QN7	Sole Source Purchases	28	2.0213	22	1.5745	0.001	0.458
13	QN8	Minority Suppliers	33	1.3617	32	1.234	0.000	0.734
14	T1	Procurement Lead Time	20	3.1915	29	1.3404	0.000	0.570
15	T2	Bid/Evaluate/Commit Lead-time	12	4.0851	14	2.9574	0.011	0.419
16	T3	Purchase Orders (PO) to Material Receipt Duration	22	2.9149	23	1.5319	0.000	0.758
17	T4	Material Receiving Processing Time	31	1.6596	25	1.4894	0.000	0.739
18	T5	Commodity Vendor Timeliness	8	4.2128	9	3.4894	0.133	0.323
19	T6	Commodity Timeliness	1	4.6170	1	4.1064	0.195	0.264
20	T7	Materials Withdraw Request (MWR) Lead-time	15	3.8511	17	2.9362	0.127	0.325

NO	LABEL	MEASURE NAME	IMPORTANCE		PRACTICALITY		SIG	CRAMER'S V
			Rank	Mean	Rank	Mean		
21	**C1**	Average Man-hour/Work-hour per Material Take-off	**30**	1.7021	**31**	1.2766	0.000	0.602
22	**C2**	Average Man-hour/Work-hour per Purchase Order	**32**	1.6383	**30**	1.2979	0.000	0.687
23	**C3**	Freight Cost Percent	**16**	3.7021	**8**	3.5319	0.000	0.648
24	**C4**	Express Deliveries Percent	**10**	4.1489	**6**	3.6809	0.003	0.461
25	**C5**	Construction Time Lost	**2**	4.4894	**16**	2.9362	0.257	0.336
26	**C6**	Payment Discounts	**29**	1.766	**27**	1.4255	0.000	0.573
27	**C7**	Warehouse Safety Incident	**23**	2.383	**24**	1.4894	0.039	0.375
28	**C8**	Total Surplus	**3**	4.4681	**5**	3.766	0.011	0.488
29	**AV1**	Material Availability	**4**	4.4043	**3**	3.8723	0.000	0.474
30	**AV2**	Stock out Analysis	**9**	4.1915	**12**	3.0638	0.632	0.165
31	**F1**	Delivery Flexibility	**14**	3.8511	**18**	2.7447	0.035	0.358
32	**F2**	Changes Flexibility	**26**	2.1915	**33**	1.234	0.001	0.507
33	**F3**	Volume Flexibility	**11**	4.1277	**15**	2.9574	0.004	0.452

Examination of **Table 7.11** above illustrates that statistical significant association between the importance and practicality of the effectiveness measures has not been found for all the effectiveness-measures, and the degrees of their association strength were different from one measure to another; for example, whereas there is no statistical significant association between the importance of the 'Material Receipt Problems (AC1)' measure and its practicality (Sig=0.254, $p>0.05$) and the strength of the association between them (Cramer's V=0.288) is very weak, the importance of 'Minority Suppliers (QN8) measure is found to have a statistical significant association with its practicality to implement (Sig=0.000, $p<0.05$), and Cramer's V suggesting a high strength association between them (Cramer's V= 0.734).

However, a relationship could be found through the comparison between the ranking of the importance and practicality of those proposed measures. Given **Table 7.12**, one can see that the importance ranking is somewhat close or slightly similar to the practicality ranking for the most of the measures, and this can also be seen graphically in **Figure 7.6**. As noted from both the table and the figure, eight of the ten highest ranked measures considered important have been ranked among the ten highest as being practical to implement (Exception C5 and AV2), even though they are in a slightly different sequence (Blue Shading). Those measures, which are ranked as the highest ten important and practical measures simultaneously, can be considered as the **Key Effectiveness Measures (K.E.Ms).** As clarified in **Table 7.12**, the Key Effectiveness Measures (K.E.Ms) are; Commodity Timeliness (T6), Construction Time Lost (C5), Total Surplus (C8), Material Availability (AV1), Warehouse Inventory Accuracy (AC3), Material Receipt Problems-Internal (AC2), Jobsite Rejections of Tagged Equipment (Q2), Commodity Vendor Timeliness (T5), Stock out Analysis (AV2), Express Deliveries Percent (C4). Those K.E.Ms can represent the main effectiveness-measures that can be used to evaluate the performance of the entire CMM process and reasonably reflect the extent of its effectiveness. They might be used instead of the 26 Practical Effectiveness-Measures (P.E.Ms) for facilitating operationalizing the mechanism of evaluating the CMM performance.

According to Ali, Al-Sulaihi and Al-Gahtani (2013) Swan and Kyng (2004), the suitable number of Key Performance Indicators (KPIs) should be 8–12, therefore the ten K.E.Ms that were selected based on the values of the mean of their importance and practicality seem to be very appropriate.

Table 7.12: A Comparison of the Importance Ranking with the Practicality Ranking of the Proposed Effectiveness Measures by the Means Scores

LABEL	MEASURE NAME	IMPORTANCE RANK	IMPORTANCE MEAN	PRACTICALITY RANK	PRACTICALITY MEAN
T6	Commodity Timeliness	1	4.6170	1	4.1064
C5	Construction Time Lost	2	4.4894	16	2.9362
C8	Total Surplus	3	4.4681	5	3.766
AV1	Material Availability	4	4.4043	3	3.8723
AC3	Warehouse Inventory Accuracy	5	4.3617	2	3.8936
AC2	Material Receipt Problems-Internal	6	4.2979	4	3.766
Q2	Jobsite Rejections of Tagged Equipment	7	4.2766	7	3.617
T5	Commodity Vendor Timeliness	8	4.2128	9	3.4894
AV2	Stock out Analysis	9	4.1915	12	3.0638
C4	Express Deliveries Percent	10	4.1489	6	3.6809
F3	Volume Flexibility	11	4.1277	15	2.9574
T2	Bid/Evaluate/Commit Lead-time	12	4.0851	14	2.9574
AC1	Material Receipt Problems	13	3.9787	10	3.2553
F1	Delivery Flexibility	14	3.8511	18	2.7447
T7	Materials Withdraw Request (MWR) Lead-time	15	3.8511	17	2.9362
C3	Freight Cost Percent	16	3.7021	8	3.5319
QN2	Home Office Purchase Order Ratio	17	3.6809	11	3.2979
QN5	Commitment – Field	18	3.4043	19	2.7021
QN1	Home Office Requisition Ratio	19	3.2553	13	3.0426
T1	Procurement Lead Time	20	3.1915	29	1.3404
Q1	Installing Equipments Rework	21	3.1489	20	2.0638
T3	Purchase Orders (PO) to Material Receipt Duration	22	2.9149	23	1.5319
C7	Warehouse Safety Incident	23	2.383	24	1.4894
QN4	Commitment – Home Office	24	2.2128	21	1.5957
QN3	Average Line Items Per Release	25	2.1915	28	1.3404
F2	Changes Flexibility	26	2.1915	33	1.234
QN6	Electronic Data Interchange (EDI) Purchases	27	2.0426	26	1.4444
QN7	Sole Source Purchases	28	2.0213	22	1.5745
C6	Payment Discounts	29	1.766	27	1.4255
C1	Average Man-hour/Work-hour per Material Take-off	30	1.7021	31	1.2766
T4	Material Receiving Processing Time	31	1.6596	25	1.4894
C2	Average Man-hour/Work-hour per Purchase Order (PO)	32	1.6383	30	1.2979
QN8	Minority Suppliers	33	1.3617	32	1.234

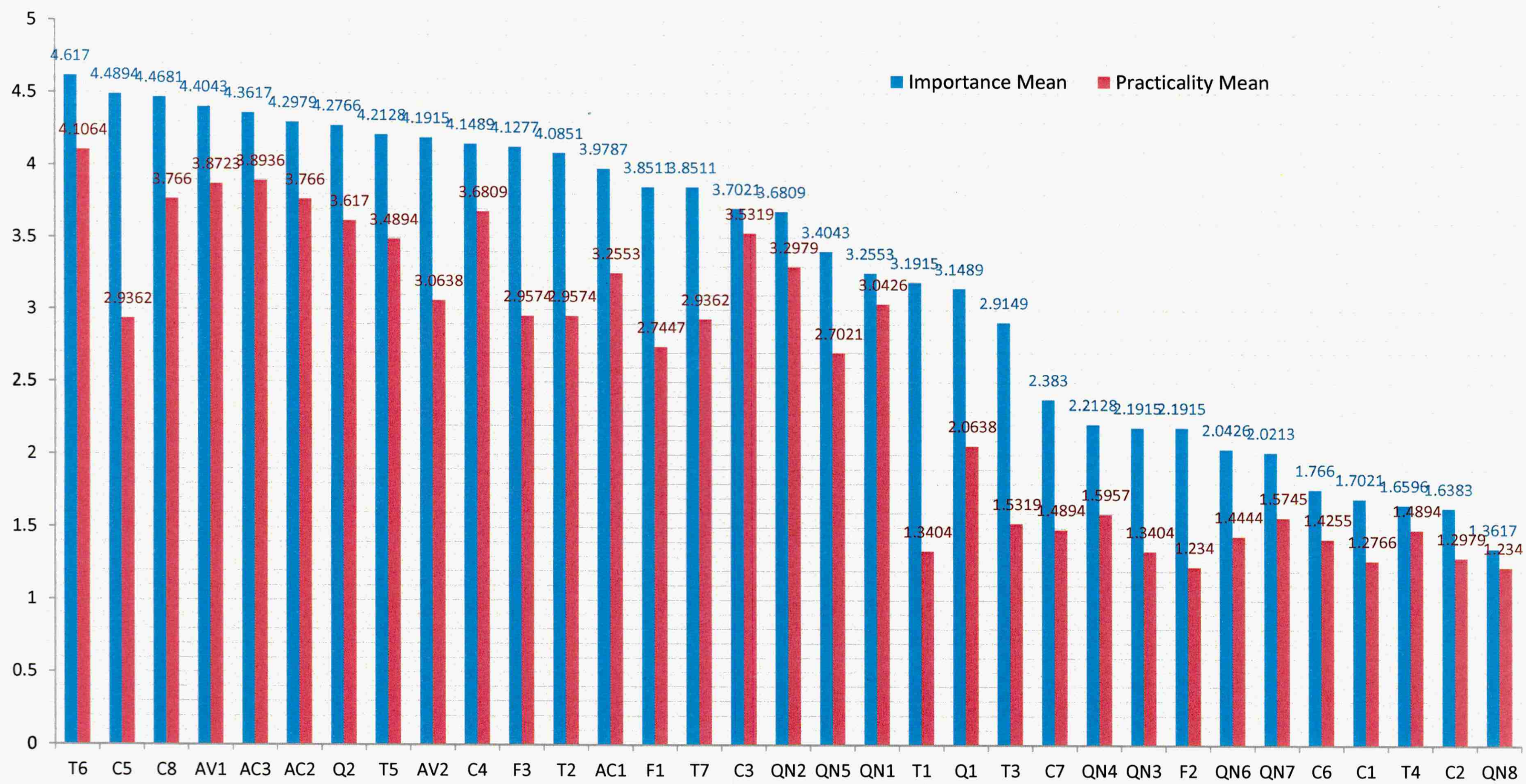

Figure 7.6: Graphically, a Comparison of the Importance Ranking and the Practicality Ranking of the Proposed Effectiveness Measures by 'Mean Scores'

Additionally, it can be observed (Green Shading) that eight out of ten medium-importance measures, which are ranked between 11 and 20, have been ranked within this range in terms of their practicality to implement (Exception C3 and T1). Similarly, the all lowest thirteen measures in terms of their importance, which are ranked between 20 and 33, have been found to be the lowest thirteen in terms of their practicality, regardless of the sequence (Light Red Shading).

The discussion above may indicate that although there is a clear relationship and association between the importance and practicality of measures, the extent of the importance of a measure in communicating effectiveness does not always express the extent of the possibility of its application within Jordanian building projects.

7.2.2.4 Barriers of Measures' Implementation:

Question six in section 2 was designed to discover the significant barriers that could hinder practicing each measure in the Large-scale concrete building projects within the Jordanian Construction Industry (J.C.I). Therefore, professional experts were solicited to answer the next question below;

"**Question 2.6 (Q2.6)**: identify any significant barrier (s) you feel would be associated with implementing this measure".

The answers to this question were individual and in a narrative form that produced a collection of verbatim comments expressing the respondents' opinions. Those verbatim comments that were made by functional experts for each measure provide insights and information about the barriers associated with implementing each measure. Based on these statements, the most significant barriers to practice the proposed effectiveness measures within the Jordanian building projects were summarised in **Table 7.13**. The table demonstrates the responses' percentage for each barrier and for each measure. Investigation of **Table 7.13** shows that the responses' percentages of the barriers were different from one measure to another, which could explain the effect of each barrier on implementing the proposed measures. For instance, 51.1% of the respondents considered '*The absence of the culture of Minority Suppliers Purchasing Program in the J.C.I*' (B17) is the most significant barrier that hinders implementing 'Minority Suppliers' measure

(QN8), while 44% of the respondents observed that '*the lack of employing a technology of Electronic Data Interchange (EDI) within the J.C.I*' (B25) prevents applying the measure of 'Electronic Data Interchange (EDI) Purchases QN6'. Moreover, it can be seen from the table below that '*the absence or the difficulty of implementing strategies such as Sole Source Purchases, Average Man-hour per Material Take off, Average Man-hour Purchase Order, and Payment Discounts in the J.C.I*'(B5), was the most significant barrier for practicing the measures of QN7, C1, C2, and C6 respectively, with 40.4% for each. In fact, these results confirm what was discovered from analysing qualitative data, and they interpret the reasons that hinder contributing these measures (QN6, QN7, QN8, C1, C2, and C6) in establishing the set of 26 Practical Effectiveness Measures (PEMs) that were developed from the outcomes of the main investigation. This indirectly confirms the validity of the data used in the development of the 'E.CMM.P Framework', which in turn confirms the validity of the framework itself.

Considering the 'Total Percentages of Responses for each Barrier' as a scale of the significance of the barrier in preventing the implementation of effectiveness measures, can provide an understanding of the effect of these barriers on the application of the proposed measures, in addition to offering ratings for these barriers in terms of their significance. Accordingly, from the perspective of ranking these barriers, **Table 7.13** can confirm that the following barriers; '*The lack of a central project material management database of multiple project procurement cycle milestone chains*' (B1), '*No system is available to gather the required data or the Lack of the ability to collect data through the entire cycle*' (B2), '*The measure is irrelevant and/or not worthy in skeleton works/level*' (B3), in addition '*The lack of clear, consistent, and appropriate reporting system/process*' (B4), were found to be the major barriers (based on the total percentage) that can hinder practicing the majority of the effectiveness measures in the J.C.I, with total percentage responses for each barrier 361.5%, 208.7%, 191.6%, and 189.4% respectively. While, '*the cost of implementing the measure might be more than any realized savings*' (B36), it was the less significant barrier for hindering the implementation of the proposed measures (4.3%).

Table 7.13: Barriers that can hinder the Implementation of the Proposed Effectiveness Measures within the J.C.I

NO	BARRIERS DESCRIPTION	The Response Percentage for Each Proposed Effectiveness-Measures																																	Total Percentage of each Barriers
		AC1 %	AC2 %	AC3 %	Q1 %	Q2 %	QN1 %	QN2 %	QN3 %	QN4 %	QN5 %	QN6 %	QN7 %	QN8 %	T1 %	T2 %	T3 %	T4 %	T5 %	T6 %	T7 %	C1 %	C2 %	C3 %	C4 %	C5 %	C6 %	C7 %	C8 %	AV1 %	AV2 %	F1 %	F2 %	F3 %	
B1	The lack of a central project materials management database of multiple project procurement cycle milestone chains	31.9	8.5	38.3		23.4	17	31.9	4.3	19.1	19.1								12.8	17	12.8	10.6	14.9					17		31.9	17			34	361.5
B2	No system is available to gather the required data/ Lack of ability to collect data through the entire cycle	12.8			14.9		27.7	17	10.6	17	17					4.3	12.8	8.5			4.3	4.3						23.4		12.8			21.3		208.7
B3	The measure is irrelevance/ The lack of the measure's need in skeleton works/ It is not worth at the skeleton level						8.5	4.3	12.8	17		21.3	25.5	17				23.4				4.3	4.3	31.9			21.3								191.6
B4	The lack of clear, consistent and appropriate reporting system/process	14.9	36.2		12.8	17												31.9			12.8			10.6		4.3		10.6	10.6		27.7				189.4
B5	The absence of this strategy in the J.C.I/ Hard to implement this strategy in the government											4.3	40.4									40.4	40.4				40.4								165.9
B6	The Limited information, data and required documents that are necessary to calculate this measure	21.3	17		12.8	14.9		4.3	14.9	8.5					4.3		12.8									8.5		23.4				4.3	10.6	4.3	161.9
B7	The lack of the measure's importance in evaluating the ECMMP/ This is not an important issue to be measured									8.5	4.3	17	21.3	31.9				31.9				12.8	12.8				21.3								161.8
B8	The absence of any clauses in the contractual/executive document that provide for the lead time/ it is nebulous								21.3						14.9	31.9	8.5				46.8												17		140.4
B9	the continuous change in the required delivery dates/ The most schedules are not static																		21.3	40.4					36.2		8.5					31.9			138.3
B10	The difficulty of measure calculation (Difficult to be calculated)/ Difficult to be implemented/understood				25.5		4.3		14.9		4.3				29.8						4.3	4.3							4.3			10.6	17	4.3	123.6
B11	Changes in the construction schedule (accelerations) are not communicated well								12.8										21.3	8.5					31.9	21.3				4.3		21.3			121.4
B12	Difficult to obtain clear and accurate required data and information, due to work around plans to avoid delays	14.9	14.9																							27.7		8.5	4.3	8.5		6.4		21.3	106.5
B13	Part of the CMM system/process/procedures are out of the contractor's responsibility/control					24.4									4.3	8.5	21.3		27.7	14.9													4.3		105.4
B14	Poor feedback and inadequate record keeping					7.3	6.4	10.6												4.3	10.6			14.9							27.7			19.1	100.9
B15	Lack of uniform accounting process across projects and company/ Accounting function may not participate									17		4.3	4.3											29.8	8.5								10.6	12.8	87.3
B16	No Response	4.3	4.3	12.8		12.8													6.4	14.9	4.3		4.3		14.9									4.3	83.3
B17	The absence of this culture in the J.C.I, which led to the lack of using this measure											4.3		51.1								12.8	12.8				4.3								72.5

NO	BARRIERS DESCRIPTION	The Response Percentage for Each Proposed Effectiveness-Measures																																	Total Percentage of each Barriers
		AC1 %	AC2 %	AC3 %	Q1 %	Q2 %	QN1 %	QN2 %	QN3 %	QN4 %	QN5 %	QN6 %	QN7 %	QN8 %	T1 %	T2 %	T3 %	T4 %	T5 %	T6 %	T7 %	C1 %	C2 %	C3 %	C4 %	C5 %	C6 %	C7 %	C8 %	AV1 %	AV2 %	F1 %	F2 %	F3 %	
B18	The lack of reliability of input by the field/ Lack of trust in data,		19.1		17						6.4															21.3					8.5				72.3
B19	Lack of common materials management system across projects						14.9	23.4							10.6	17														6.4					72.3
B20	Limited capabilities of the used computerized CMM system			23.4			8.5	8.5			4.3																			23.4					68.1
B21	There are no clear boundaries (overlapping) between the tasks and functions of the activities						8.5								19.1	14.9	21.3																		63.8
B22	Tracking method is not available/ Inadequate central surplus tracking system			8.5			4.3																					12.8	27.7		6.4				59.7
B23	There is no a clear and a certain line or procedures for the documentary's cycle of the CMM process														17	10.6														12.8	12.8				53.2
B24	Often there is disagreement over causes				12.8																					12.8			12.8				8.5		46.9
B25	The lack of employing this technology within the J.C.I/ The technology is not applicable											44.7																							44.7
B26	Other									8.5			4.3								4.3	6.4	6.4	4.3					4.3						38.5
B27	The multi-project environment complicates the issue of surplus																8.5							4.3					25.5						38.3
B28	Lack of automated milestone tracking system on large projects															4.3										4.3						25.5			34.1
B29	Many variables impact on this measure (client involvement, specifications, and type of project)									4.3							10.6	4.3											10.6				4.3		34.1
B30	Commitments are often difficult to be recorded and controlled in field.										31.9																								31.9
B31	The measure reflects and evaluates the ability of the suppliers/Clients rather the CMM process of contractors				4.3														10.6														6.4		25.6
B32	There are no clear boundaries for the responsibilities and authorities (overlapping) of those who participate in the CMM process										17					4.3	4.3																		25.6
B33	No experience in using this measure/ The measure is not used previously								4.3				4.3									4.3	4.3				4.3								21.5
B34	The need for additional staff or employees to control or calculate this measure			17																								4.3							21.3
B35	Considering the required data as confidential information																							4.3	8.5										12.8
B36	The cost of implementing the measure might be more than any realized savings/ The cost of collecting data															4.3																			4.3
Total Responses Percentage for Each Measure		100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	

This can prove what has been concluded from the literature review, the main investigation, and the initial pilot study regarding the lack of a clear Construction Materials Management (CMM)-reporting system and CMM database in the J.C.I. Moreover, the results above can confirm and explain the rationales for the lack of a unified CMM benchmarking system to assess the performance of the CMM process in the J.C.I, which in turn confirms the necessity to develop a mechanism or a framework for continuously evaluating the effectiveness of CMM performance within the Jordanian building project. Thus, this may give a further indication for the contribution that is offered by this research to knowledge, and the significance of the research in terms of providing a basis for analysing and evaluating the continuous improvements that can be made on the CMM process (through the measures, documents, conditions and environments available within the J.C.I), which on its basis, in future, can establish the benchmark system for continuously evaluating the effectiveness of the CMM process.

7.2.3 Section 3 Analysis: Additional Measures:

The main intent of this section was to further survey the Jordanian large-scale concrete building projects for any measures that had not been identified during the main investigation within the selected case studies (site visits and interviews), or that are not listed within the set of proposed effectiveness measures. Similarly, the analysis of the section 3 responses follows the same manner as that one used for evaluating the original 33 measures within section 2; the respondents were asked to give a title, a description, and a point of measurement for any additional measure, besides answering the six assessment questions listed in section 2 for evaluating those additional measures.

Among the 47 functional experts, nine respondents identified five different additional measures. However, a comparative analysis that has been conducted by the researcher illustrates that those five additional measures were either included within the original list of proposed measures, incorporated within the list of practical measures developed from the main investigation, or they referred to the activities that are not considered among the integrated functions within the boundaries of the construction materials management process identified. One of the additional measures was very similar to or could be a redefinition of one of the original 33 proposed measures. Three of these measures were reformulation and redefinition for the practical effectiveness measures that have been established from the main investigation. The fifth additional measure was associated with the accounting activities. The examination and evaluation of those additional measures is summarised below;

1- Customer Satisfaction:

This additional measure was suggested by two functional experts. They described the measure as the percentage of the quantity, in volume or number, of the materials, items or equipments that were unsatisfied by the craft-workers and returned to their sources (main warehouse, store, or vendor), regardless of the causes. The measure was suggested to report the ability of the CMM process to secure the requested materials and items according to the requirements of the construction operations (craft-workers).

Comparative-analysis: a comparison of this measure with the set of the original proposed measure, clearly disclosed the similarity of the measure with the measure of 'Jobsite Rejections of Tagged Equipment (Q2)'. However, this measure includes all the unsatisfied and returned materials, and this has already been suggested through the discussion of the case studies' outputs within the main investigation, and it has been adopted to form a new measure (Q*) and listed within the P.E.Ms.

2- Ratio of disposed, destroyed, and lost Materials:

A warehouse-related functional expert proposed this measure to be included within the set of the effectiveness measures. This additional measure was proposed to report the ratio of the materials that have been disposed, destroyed, and lost during the construction process. This can occur in many cases, for instance, materials that were destroyed during their delivery, dismissed by a third party (consultant), field-stolen, or destroyed during the construction operation.

Comparative-analysis: a comparative analysis can clarify that the cases that led to disposing, destroying or losing materials can be listed under the causes of 'waste material'. Thus, this proposed measure refers, partially, to the measure 'Material Waste Ratio (C*), which has been developed through the main investigation analysis; it includes all the non-usable and surplus material into the waste category. It is worth mentioning that this measure (C*) is an expansion for the measure of 'Total Surplus (C8)' to include the entire surplus and non-usable, which in turn includes those materials and items that were disposed, destroyed, and lost during the construction operation.

3- Material Release Requisition (M.R.R) Ration:

Three respondents suggested this measure to be added to those used for evaluating the effectiveness of the CMM performance. They believe that this additional measure can assess the effectiveness of the performance of functions of 'Procurement' in accomplishing 'Materials Releases Requisitions' (M.R.Rs). The measure was described as the ratio of the number of the 'Materials Release Requisitions (M.R.R') that were performed by the 'Procurement Department' in a company's home office to the total number of M.R.Rs during a period of time.

Comparative-analysis: as it was defined earlier in Chapter VI, the purpose of the Materials Release Requisitions (M.R.R') is largely similar to the Requisitions for Quotations (R.F.Qs), which is to initiate the flow of activities to purchase and secure specified materials, and in some Jordanian organisations, the two terms can, interchangeably, be used. Therefore, this measure is very similar to the measure 'Home office Requisition Ratio (QN1)' (a redefinition), and it is possible to use the formula of QN1 to calculate this measure. As this additional measure cannot be considered as a new independent measure, there is no need to adopt it to contribute to forming the P.E.Ms.

4- Internal Material Request (I.M.R) Processing Time:

Two experts related to Field Control and Warehousing functions suggested this measure to assess the ability of the warehousing function to secure the materials requested on or before the time needed. The measure reports the ratio of the number of the Internal Material Requests (I.M.Rs) that were processed on or before the required date.

Comparative-analysis: this additional measure forms a part of the practical effectiveness measure 'Material Withdraw Request (MWR) Processing Time (T***)', which includes the activities of issuing both an Internal Material Request (I.M.R) and an External Material Request (E.M.R) to the craft-workers. T*** can be used to evaluate the 'Internal Material Request (I.M.R) Processing Time' separately. Therefore, there is no need to establish a new formula to process the proposed measure.

5- Workforce overtime:

One respondent, who came from a materials-planning background, saw that this additional measure 'Workforce Overtime' can provide an indication on the performance of the CMM process. This can be conducted through using the comparative accounting system "Planned budget versus Actual expenses", in other words, the percentage of the actual workforce overtime to the planned or estimated workforce overtime.

Comparative-analysis: the information about this measure is incomplete. Moreover, this additional measure seems to be more related to accounts payable or the accounting activities, which are out of the boundaries of the CMM process that were predefined in this research. The measure, therefore, is not considered for evaluating the effectiveness of the CMM process in this study.

In short, the responses of section 3 did not identify any new effectiveness measures that were not listed in the original 33 proposed measures or/and in the practical effectiveness measures (P.E.Ms). This leads to the conclusion that 'giving the opportunity to 47 functional experts with extensive experience and broad CMM-related expertise did not identify any additional measures that differ considerably from those which were established whether from examining the literature review (the proposed set of the effectiveness measures) or those developed from the outputs of the main investigation (the practical effectiveness measures)'. This basically indicates that the proposed set of effectiveness measures and the practical measures are an appropriate sample for the potential materials management effectiveness measures, and they could represent the population of the possible measures within the Jordanian Construction Industry.

In fact, confirmation of the appropriateness of the measures' sample (collecting a sufficient census of possible materials-related measures that can be used within the J.C.I) affirms the validity and reliability of the proposed effectiveness measures whether those contained within the set of the original 33 measures or those forming the list of practical effectiveness measures that can be used within the Jordanian building projects. This, in turn, indicates the validity of the E.CMM.P Framework developed.

7.2.4 Section 4 Analysis: Evaluation the Developed Practical Workflow Diagram of the CMM Process:

As mentioned previously, among the other objectives, the questionnaire basically aims to address the first stage of the validation process the 'formative evaluation', which was designed to assess the basic structure of the 'Developed E.CMM.P Framework' (the practical workflow diagram of the CMM process developed) before setting the final actual development. As part of the formative evaluation stage, this section is intended to evaluate the developed Practical CMM Process Workflow Diagram (PCMMP Workflow Diagram) which depicts the CMM process that is practiced in the J.C.I.

The evaluation process was designed to assess the ability of the developed CMM workflow diagram to embody/reflect what is currently practiced in the real-life of the CMM process within the large-scale concrete building projects in the J.C.I. Accomplishing this task was based on eliciting the views of the functional experts on the practical CMM process workflow diagram through examining the agreement degree of the participants on the next six evaluation statements;

1- PCMMP-Ev1: "in general, the practical CMM process (PCMMP) workflow diagram can reflect the real-life (current status) of managing the construction materials within the majority of the Large-scale Concrete Building projects within the J.C.I",
2- PCMMP-Ev2: "the proposed functions that forms the developed PCMMP Diagram are practiced by the majority of the contractor organisations for managing their building materials in the Jordanian building projects",
3- PCMMP-Ev3: "the proposed activities, which constitute (listed under) the functions of the developed PCMMP diagram, are principally similar to those that are involved in the completion of the majority of the CMM functions in the Jordanian building projects",
4- PCMMP-Ev4: "the proposed positions and sequence of the functions of the PCMMP diagram embodies the actual sequence for those functions that shape the CMM process in the majority of the Jordanian building projects",
5- PCMMP-Ev5: "the proposed internal and external outputs and inputs of the PCMMP's functions (relationships between the developed functions of the CMM process, and their relations with the external participants; Customers, vendors, and clients) are similar to those found in the majority of the CMM processes in the J.C.I.",
6- PCMMP-Ev6: "the overlaps that have been proposed between the developed functions in the PCMMP diagram can depict the actual overlaps which exist between the CMM process's functions, activities, and responsibilities in the majority of Jordanian building projects".

These six statements were designed to evaluate the structure and components (functions and activities) of the PCMMP workflow diagram, in terms of the extent of conformity to those that form the current CMM process implemented within the majority of the Jordanian large-scale concrete building projects. In addition, they evaluate how the functions' positions and sequence and their relationships and overlaps that were developed within the PCMMP diagram can embody those connecting the actual CMM functions within the Jordanian building projects. For achieving this evaluation stage, in this section, the participants were required to tick the box that best represented their assessment of the statements on the developed workflow diagram on a scale of **1** (strongly disagree), **2** (disagree), **3** (neutral), **4** (agree) and **5** (strongly agree).

Table 7.14 below highlights the overall rating from the respondents on the evaluation statements, using the responses percentages for each degree of agreement. In general, the findings show that, excepting the PCMMP-Ev3 feedback, all the feedback from the participants on the PCMMP diagram agreed with the contents of the evaluation statements; 'Strongly Agree', 'Agree' and 'Neutral'. The median score was 4 for all the statements' feedback. The Cronbach's alpha for the scale was 0.864 (>0.7), and the Chi-square test results for all the propositions were less than 0.05 ($p<0.05$). Both the high value of Cronbach's alpha and the results of the Chi-square test confirm the reliability and the validity of the propositions regarding evaluating the practical CMM process workflow diagram. One concludes that the entire evaluation statements in the scale is reliable.

The functional experts agreed that the PCMMP workflow diagram developed can, generally, represent the process of managing materials that is usually practiced within the Jordanian Large-scale Concrete Building projects, with 91.5% of them selected 'strongly agree' and 'agree' (44,7% and 46.8 respectively) for the PCMMP.Ev1 statement. They also indicated that the functions that form the developed PCMMP diagram are largely similar to those that are usually practiced by the majority of the Jordanian contractors for managing their materials in the building projects, where, 85.1% of the respondents ticked 'Strongly agree' and 'agree' for the second evaluation statement (PCMMP. Ev2). 70.2% of respondents ticked 'strongly agree' and 'agree' along with the fact that "*The proposed activities, which constitute (listed under) the functions of the developed PCMMP diagram, are principally similar to those that are involved in the completion of the majority of the*

CMM functions in the Jordanian building projects", however, the disagreement level about this statement was found with a very low percentage 4.3%.
In this context, from **Figure 7.7** below, one can clearly note that, although the rate of 'agree' responses gradually increased in the first three statements (46.8%, 48.9%, and 55.3% for PCMMP.Ev1, PCMMP.Ev2, and PCMMP.Ev3 respectively), the overall rating of agreement gradually decreased (91.5%, 85.1%, and 70.2% for PCMMP.Ev1, PCMMP.Ev2, and PCMMP.Ev3 respectively). This might refer to increasing the uncertainty level whenever the details about the diagram were more in-depth. This can also explain the increase in the responses of the 'Neutral' and 'Disagree' for PCMMP.Ev3 statement, where it is natural and logical that the uniqueness of a construction project leads to the difference in the detailed activities that are practiced in the CMM process from one project to another.

Table 7.14 can also demonstrate that the majority of the functional experts 'strongly agree' and 'agree' (87.2%) with the position and sequence of the functions within the PCMMP diagram, and they saw that this sequence can embody the realistic position and sequence of the CMM functions within the most Jordanian projects. 85.1% of the respondents chose 'strongly agree' and 'agree' to assess the statement of PCMMP.Ev5, which states that "the proposed internal and external outputs and inputs of the PCMMP's functions (relationships between the developed functions of the CMM process, and their relations with the external participants; customers, vendors, and clients) are similar to those found in the majority of the CMM processes in the J.C.I". For the last statement (PCMMP.Ev6) in this evaluation stage, the majority of respondents felt that 'the overlaps that have been proposed between the developed functions in the PCMMP diagram can depict the actual overlaps which exist between the CMM process's functions, activities, and responsibilities in the majority of Jordanian building projects', with 80.8% of them selected 'strongly agree' and 'agree' for assessing this statement.

In short; based on the above findings, it can be concluded that the majority of the respondents confirm that the developed PCMMP workflow diagram can embody and reflect what is currently practiced in the real-life of the CMM process within the large-scale concrete building projects in the J.C.I, which in turn confirm the validity and the reliability of the E.CMM.P Framework developed.

Table 7.14: The Evaluation of the Practical Construction Materials Management Process (PCMMP) Workflow Diagram Developed

LABEL	EVALUATION STATEMENT	RESPOSE SCORE %					Median	SIG	Std. Deviation
		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree			
PCMMP . EV1	In general, the practical CMM process's (PCMMP) workflow diagram, can reflect the real-life of managing the construction materials within the majority of the Large-scale Concrete Building projects within the J.C.I	0	0	8.5	46.8	44.7	**4**	0.001	0.640
PCMMP. EV2	The proposed functions that form the developed PCMMP Diagram are practiced by the majority of the contractor organisations for managing their building materials in the Jordanian building projects	0	0	14.9	48.9	36.2	4	0.015	0.689
PCMMP. EV3	The proposed activities, which constitute (listed under) the functions of the developed PCMMP diagram, are principally similar to those that are involved in the completion of the majority of the CMM functions in the Jordanian building projects,	0	4.3	25.5	55.3	14.9	4	0.000	0.741
PCMMP. EV4	The proposed position and sequence of the functions of the PCMMP diagram embodies the actual/ realistic sequence of those functions that shape the CMM process in the majority of the Jordanian building projects	0	0	12.8	53.2	34	4	0.003	0.657
PCMMP. EV5	The proposed internal and external outputs and inputs of the PCMMP's functions (relationships between the developed functions of the CMM process, and their relations with the external participants; Customers, vendors, and clients) are similar to those found in the majority of the CMM processes in the J.C.I	0	0	14.9	53.2	31.9	4	0.006	0.669
PCMMP. EV6	The overlaps that have been proposed between the developed functions in the PCMMP diagram can depict the actual overlaps which exist between the CMM process's functions, activities, and responsibilities in the majority of Jordanian building projects	0	0	19.1	46.8	34	4	0.0067	0.721

Cronbach's alpha = 0.864

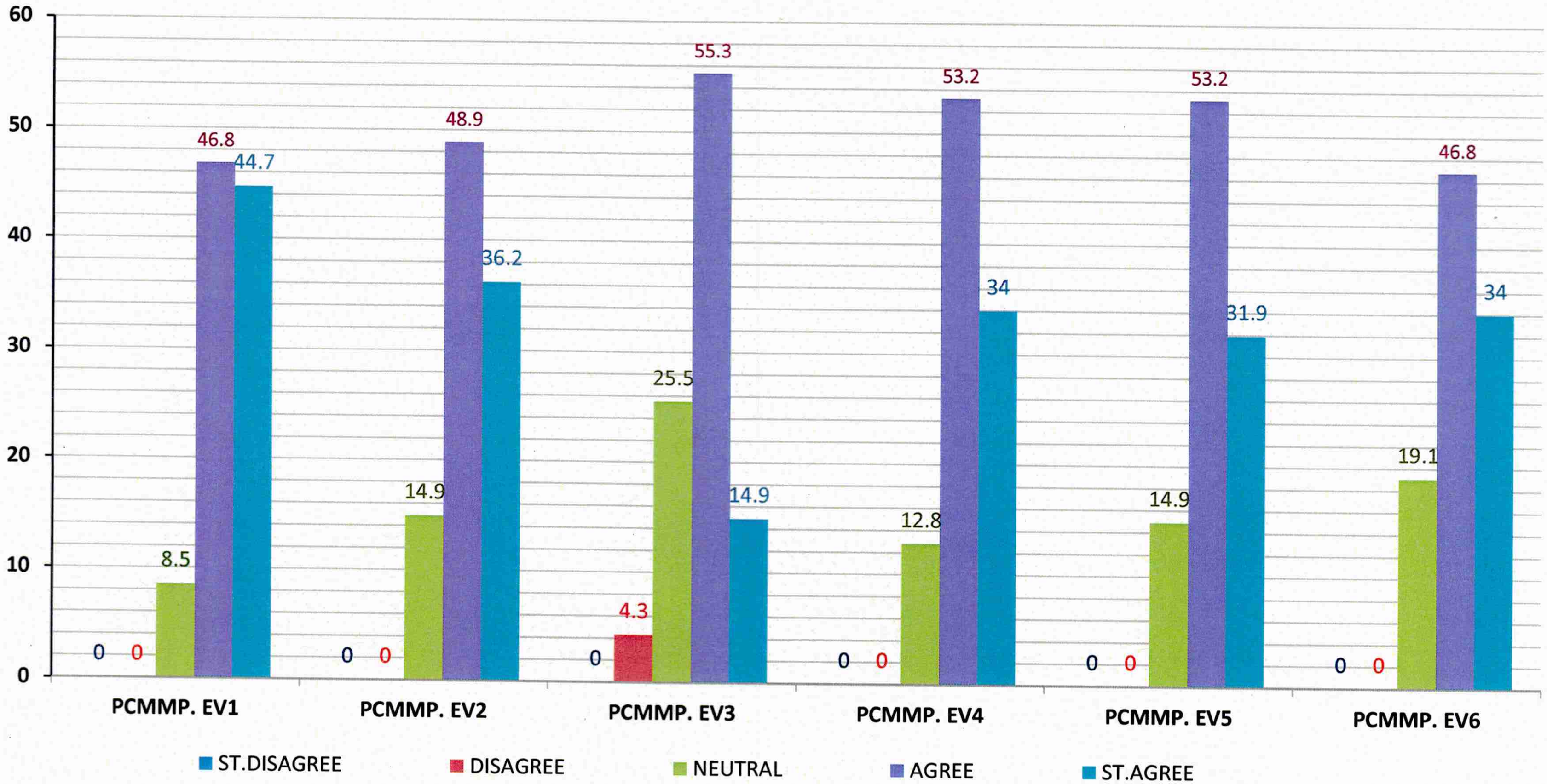

Figure 7.7: Graphically, the Evaluation of the Developed Practical Workflow Diagram of the Construction Materials Management Process (PCMMP Workflow Diagram)

7.3 SUMMARY OF THE CHAPTER:

Chapter VII presented the analysis of the quantitative data collected for this research project using the questionnaire technique. The main purpose of the questionnaire survey was to evaluate the proposed set of the measures of the Effectiveness of the CMM Performance (ECMMP) that has been developed from the literature review, and to evaluate the Practical Construction Materials Management Process (PCMMP) workflow diagram that has resulted from analysing the case studies' data. For realizing this purpose, 33 proposed effectiveness measures were assessed using three areas of evaluation; their utilization, importance in communicating effectiveness, and practicality to implement, in addition to discovering the significant barriers that could hinder practicing each measure in the Large-scale concrete building projects within the Jordanian Construction Industry (J.C.I). Based on this evaluation, the Key Effectiveness- Measures (K.E.Ms), which are ranked as the highest ten important and practical measures simultaneously, were explored. Moreover, the ability of the developed PCMMP workflow diagram to reflect what is currently practiced within the Jordanian building projects was evaluated.

In this chapter, a descriptive statistics analysis using 'Scores', 'Mean', and' Median' was used to explore the data collected. The mean score was used for ranking the propositions (effectiveness-measures) in the majority of the evaluation areas. A bivariate analysis was carried out to explore the relationship between the practicality and the importance of the measures; the Pearson's Chi-square and Cramer's V tests were used to identify the significant association between variables. Additionally, the validity and reliability of the used data were investigated using a number of statistical tests; Cronbach's alpha coefficient for testing the reliability of scales; Chi-square goodness-of-fit' to test the validity of items.

Based on the results obtained from the literature review process, analysing main investigation (case study), and the analysis of the questionnaire survey, the 'E.CMM.P' Framework for evaluating the effectiveness of the CMM performance within Large-scale concrete building projects in the Jordanian Construction Industry will be developed in the next chapter (Chapter VIII).

CHAPTER VIII:

DEVELOPMENT OF THE E.CMM.P FRAMEWORK

8.0 INTRODUCTION TO THE CHAPTER:

In the previous two chapters, the findings of the analysis of the qualitative and quantitative data collected were presented and profoundly discussed. **Chapter VIII** presents the main phases of the development of a framework for Evaluating the Effectiveness of the Construction Material Management Process Performance **(E.CMM.P Framework)** within the large-scale concrete building projects in the J.C.I. The framework development is based on coordinating and integrating the findings resulting from the review of literature, the cross-case studies analysis, and the questionnaire survey analysis. Developing the E.CMM.P framework accomplishes the fifth objective of the study; 'development of the E.CMM.P framework'.

The chapter provides an explanation for the phases and stages of the process of framework development. It begins with defining the main structure of the E.CMM.P framework; it then proceeds to the designing of the phases and sources of data for developing the framework. This is followed by explaining and addressing the phases and stages that were conducted for developing the E.CMM.P framework. The findings that were obtained from each phase are presented.

As a result of integrating the findings of the development phases, the actual final E.CMM.P framework is developed and graphically displayed. For the purpose of explaining the mechanism of implementing the developed E.CMM.P Framework within the CMM process or system of a building project or a contractor, an explanatory scenario of the E.CMM.P framework application is offered. Finally the chapter is summed up in the chapter summary.

8.1 STRUCTURE OF THE FRAMEWORK & SOURCE OF DATA:

According to Rouse (2005), a framework can be defined as a real or conceptual structure intended to serve as a support or guide for building up or using something. An operational framework is a structure used as the basis for a process being constructed; it depicts the operation of a process within certain functional boundaries (Plemmons, 1995;

TheFreeDictionary, 2014). The operational framework involves a set of functions, which represent the main elements, within an operating system, which represents the fundamental structure (skeleton) of the framework (Rouse, 2005; TheFreeDictionary, 2014) as well as the links that connect the elements within the basic structure and depict the transportation of the relevant information between the elements.

The development of an operational framework for evaluating the Effectiveness of the CMM Process Performance (the E.CMM.P Framework) is a result of integrating the Practical Effectiveness Measures (P.E.Ms) and placing them within the Practical workflow diagram of the CMM Process (the P.CMM.P workflow diagram) at the points of measurement, using an operational mechanism for communicating P.E.Ms within the practical CMM process diagram. Accordingly, the developed E.CMM.P framework consists of three key components:

- ***The Main Body, (the Basic Structure)*:** the practical workflow diagram for communicating the integrated functions and activities that form the CMM process within the large-scale concrete building projects in the Jordanian Construction Industry. This workflow diagram constitutes the main body (basic structure) of the E.CMM.P framework. The development of the practical workflow diagram of the CMM process (P.CMM.P workflow diagram) is mainly built on the findings resulting from the literature review process, in particular the 'typical CMM workflow diagram', and the analysis of the qualitative data collected including 'identifying the CMM related functions and activities that are practiced within the Jordanian building projects' (see **Sections 3.4** and **6.6.1.3**).
- ***The Main Elements*:** the set of measures that can be practically used for measuring and evaluating the effectiveness of the CMM performance in the large-scale concrete building projects in the J.C.I. These Practical Effectiveness Measures (P.E.Ms) represent the main elements of the E.CMM.P framework. They are established on the bases of the proposed set of the effectiveness-measures that has been developed from the literature review and the measures that are applied within the Jordanian projects; the cross-case study analysis has revealed these measures (see **Sections 4.4**, and **6.6.2.3**).
- ***The Operational Mechanism:*** they are processes together with a set of instructions for linking those practical effectiveness measures (the framework's elements) and

employing them within the practical framework of the CMM process (the framework's body) for the purpose of evaluating the extent of its performance effectiveness. This mechanism is designed to operate the E.CMM.P framework and to represent the nerves and tendons that link its body and elements together. The mechanism is developed on the basis of integrating the benchmarking procedures (Benchmarking Model) that were discussed throughout the literature review part (see **Section 4.5.2**).

It is evident that the main components of the E.CMM.P framework (basic structure, main elements, and operational mechanism) were developed gradually through a case study research; the findings are supported by an extensive literature review of the materials management processes and measures as well as the benchmarking techniques. Accordingly, the process of developing the E.CMM.P framework has been sequentially implemented throughout the research on six main stages that are classified into four phases. Each phase is concerned with the completion of a component of the developed E.CMM.P framework including conducting the framework validation process. *Phase I*: developing the workflow diagram of the CMM process practiced within the Jordanian projects; *phase II*: establishing a set of practical effectiveness-measures (P.E.Ms) that can be used within the Jordanian building projects; phase *III*: setting out an operational mechanism for communicating the framework's elements (P.E.Ms) within its main body (P.CMM.P workflow diagram), and designing the final E.CMM.P framework; phase IV: conducting the validation process, Which is presented in **Chapter IX**.

These phases are graphically depicted in **Figure 8.1** and discussed in the following sections.

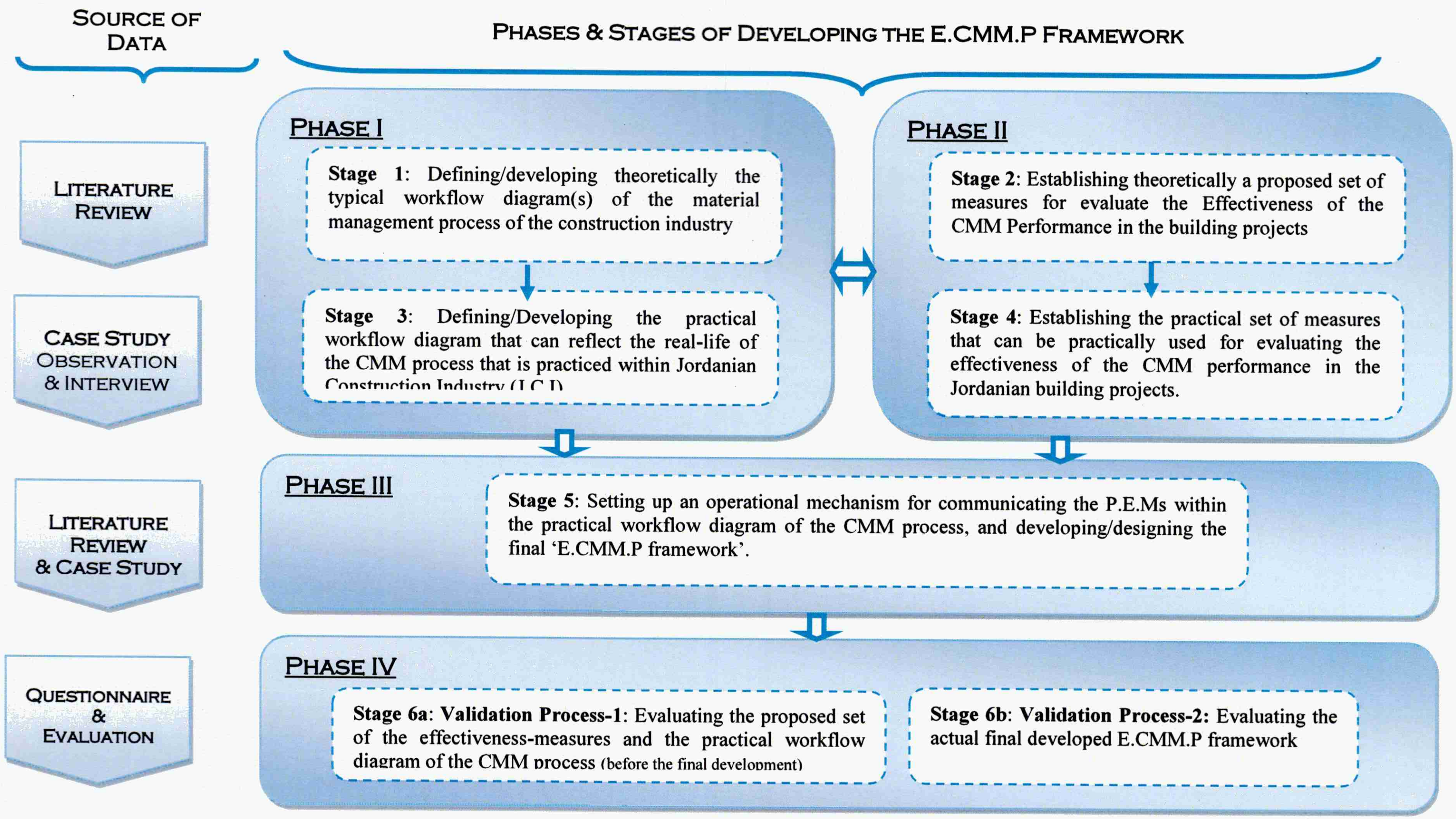

Figure 8.1: Figure 8.1: The Phases and Stages of the process of the Development of the E.CMM.P Framework, and the Data Sources employed

8.2 PHASE I: DEVELOPING THE PRACTICAL WORKFLOW DIAGRAM OF CMM PROCESS IN THE J.C.I:

Phase I is concerned with developing the 'structural body' of the E.CMM.P framework through developing the practical workflow diagram that can reflect the current realistic practices of the CMM process within the large-scale concrete building projects in the Jordanian Construction Industry (J.C.I). Accomplishing this phase has been realized through critically reviewing the literature and analysing the data collected using a case study research (main investigation) within two stages: Stage 1 and Stage 3 respectively.

The first stage in the Phase I (**Stage 1**) aims to define the typical workflow diagram for communicating the integrated functions and activities that shape the materials management process of a typical construction project. On the basis of the extensive literature review, the typical workflow diagram(s) of the materials management process in the construction industry was theoretically identified, as presented in **Figure 3.6** and **Sub-Figures 3.6.1-3.6.7** (see **Chapter III, Section 3.4**). This typical workflow diagram was used to interpret the typical materials management process within a typical construction project and to provide a comparative basis for developing the Practical Workflow Diagram of the CMM Process (PCMMP), which represents the structural body (basic structure) of the E.CMM.P Framework, as will be discussed in the following stage (stage 3) below.

The second stage for accomplishing phase I (**Stage 3**), which is the focus of this section, is to develop the practical workflow diagram of the CMM process that is practiced within the Jordanian building projects. Achieving this stage was based on an extensive discussion addressing the cross-cases analysis of the CMM processes that have been practiced within the six Jordanian building projects (the selected case studies), and on examining the extent of their conformity with the typical workflow diagram of the CMM process that was developed on the basis of the literature review process, in particular, those aspects that regarding the sequence of the functions and the existence and distribution of the activities and the terminologies used (see **Chapter VI, Section 6.6.1**). As a result of that comprehensive discussion, the practical workflow diagram of the CMM process within the Jordanian building projects was developed. It was found out that there is similarity between most of the activities, which were practiced within the selected case studies, and those that form the typical workflow diagram of the CMM process despite the existence of some differences in the distribution of the activities within the functions, the overlapping of some functions, and the presence of some new activities that emerged in these cases (see **Figure 6.6**). **Figure 8.2** illustrates the integrated workflow diagram for the main functions that form the Practical CMM Process.

In fact, the development of the Practical CMM Process (P.CMM.P) workflow diagram, including discussing the results of the cross-cases analysis, defining the functions and activities that form the P.CMM.P diagram, and investigating the similarities and differences between the typical and the developed CMM functions, are discussed and accounted for in detail in **Chapter VI, Section 6.6.1,** and the functions and activities that form the practical CMM process workflow diagram is detailed in **Figure 6.6**. The present section is only concerned with reviewing the process of developing the functions of the P.CMM.P workflow diagram, and graphically illustrating the activities that form each of those integrated CMM functions, as illustrated below.

As a result of discussing the cross-cases analysis, it was found out that the CMM process begins with the 'Planning' function in most cases, though some of its activities are beyond the scope of some contractors' work. Therefore, the 'Planning' function has been designated to be the first independent function in forming the CMM process that is practiced within the large-scale concrete building projects in the J.C.I. The function includes the activities that are similar to those included within the Planning function in the typical workflow diagram of the CMM process; they were found to be recursive in most cases (whether with the same name used (with Black Colour in Figure 6.6) or with some modifications to meet the common terminologies used (with Red Colour in Figure 6.6)), along with all the new related-activities, which emerged within this function in one or more than one of the case studies (with Green Colour in Figure 6.6); see **Figure 6.6**. The outputs of the function are submitted to the next function the 'Material Take-off and Design Interface'. A copy of the Project Material Management's Book is forwarded to the Project Team, as demonstrated in the diagram in **Figures 8.2** and **8.2.1**.

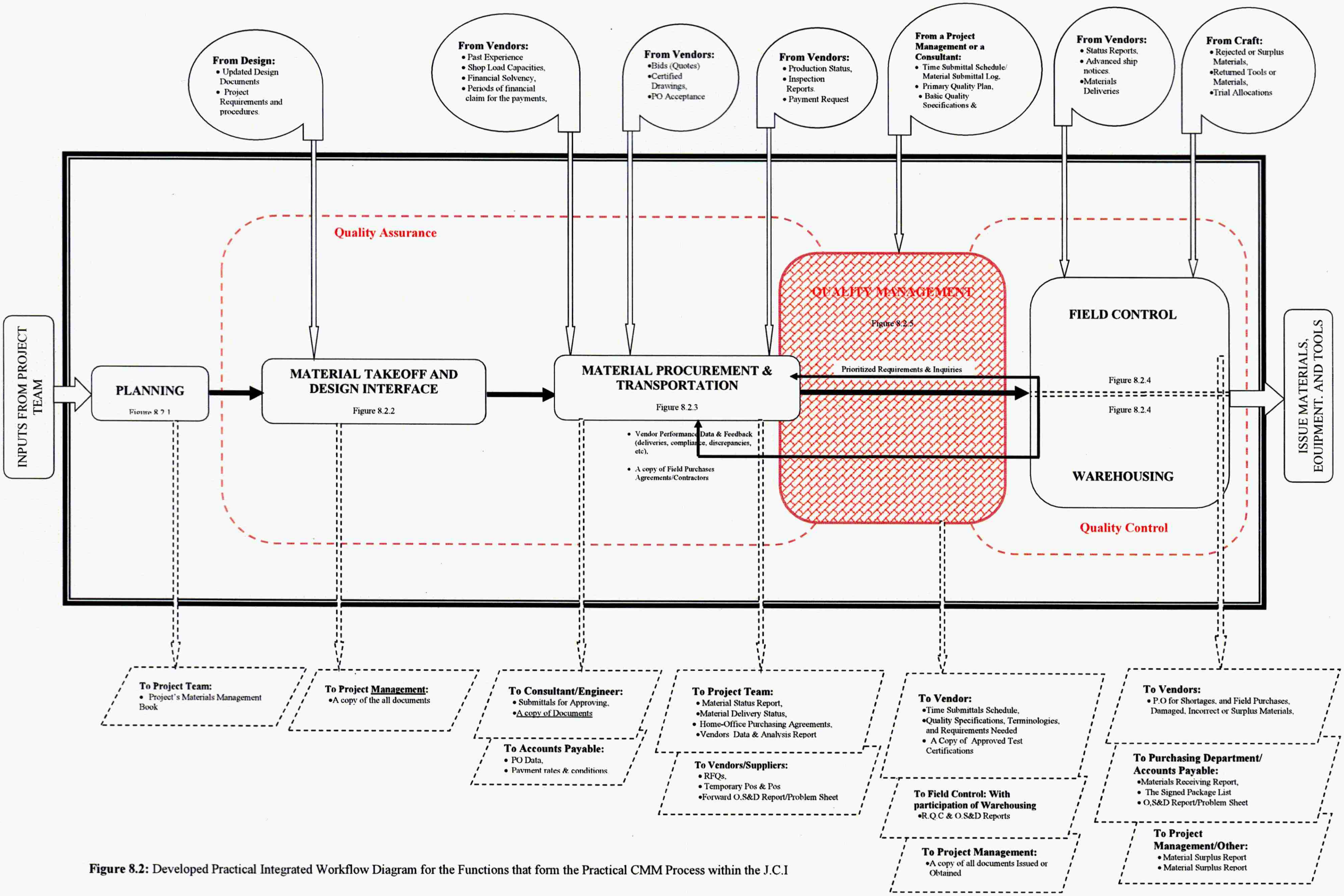

Figure 8.2: Developed Practical Integrated Workflow Diagram for the Functions that form the Practical CMM Process within the J.C.I

According to the logical sequence of the functions of the CMM process stipulated in most of the literature reviewed in this research and to what has been implemented within all the cases, the function that usually followed the 'Planning' function is that of the 'Take-off and Design Interface'. Reformatting the function of 'Material Take-off and Design Interface' to reflect the practical CMM process practiced within the J.C.I is somewhat similar to what happened to its predecessor (Planning). Although this function was combined with some activities of the 'Planning' function to form new functions in some cases (Cases E, and F), it emerged as an independent function in most cases (see **Figure 6.5**). Similarly, the common activities that were found in most cases, whether those are similar to the original activities that were listed in the typical CMM process or those which were exported from other functions (with Blue Colour in Figure 6.6), were designated to form the practical CMM diagram under the 'Material Take-off and Design Interface' function. In addition to some activities that were renamed to conform to the terminology used. Due to fact that this function is considered, in the Jordanian Construction Industry, as the basis for the entire CMM process, many of the new activities were found; the most common of them were nominated to participate in forming this function. The implementation of this function is based on the documents, data and inputs that are submitted by the 'Planning' function and 'design's team', while its outputs are usually forwarded to the following function (Material Procurement and Transportation) with a copy to the project management team, as displayed in **Figures 8.2** and **8.2.2**.

Based on what was concluded from the discussion of the cross-cases analysis (as detailed in **Section 6.6.1**), there is no physical appearance for the 'Vendor inquiry and Evaluation' function and the 'Expediting and Transportation' function as independent functions. All activities of the 'Vendor Inquiry' function in all the case studies and the majority of the activities of 'Expediting' function in most case studies were combined with those in the 'Purchasing' function within one function. Regardless of the name of the integrated function, which included the activities of these functions, performing its activities were the responsibility of a certain team in a definite department, whether it was called 'Purchasing', 'Logistics' or 'Material Procurement and Transportation'. For that reason, it was decided to combine the common activities of those functions under one function that would be called the 'Material Procurement and Transportation' function. Likewise, to form this function, the most common activities whether they were recognised among the original typical activities, which were listed in the typical CMM process, or those that were exported from other functions, were designated; some activities were renamed, new activities were added, and uncommon activities were omitted. The main inputs to this function include those that come from the previous function's outputs, various data from the external participants (vendors), and feedbacks from the functions of the 'Field Control' and 'Warehousing'. The function's outputs are forwarded to the followed functions (Field Control and Warehousing), in addition to, the relevant documents that are submitted to specific departments or teams (Project Team, Engineer, Vendors, and Account Payable). This function is illustrated graphically in the practical function diagram, **Figures 8.2** and **8.2.3**.

During the site observation and based on the cross-cases analysis, it became evident that there was, somewhat, overlap among the activities and the responsibilities of the 'Field Control' and the 'Warehousing' functions. Emphasis was placed on the inevitability of placing the Warehousing function, especially Site-Warehouse (Site-store) under the authority of the Field Control team that has direct connection with the Craft-workers and that was responsible for issuing Materials to them. Therefore, those two functions have been placed with no clear border between them, as revealed in **Figures 8.2** and **8.2.4**. The comparison with the typical CMM workflow diagram indicates that the majority of the activities that were practiced in the Jordanian building projects within the functions of 'Field Control' and 'Warehousing' are similar to those found in the typical CMM process (even if there are some changes in some activities' labels). New activities have been added to reflect the reality of practicing the functions within the J.C.I. In addition to the inputs, which are submitted from the function of the 'Material Procurement & Transportation', the required documents and data, which are requested from the vendors and sent from the craft, are submitted to the functions too. The main outputs of these functions are 'Issuing Materials, Equipment, Tools and orders to Craft-Workers', and participation in preparing and issuing the 'R.Q.C and O.S&D Reports', additionally, forwarding related-documents to the vendors, the project team, purchasing department and accounts payable, along with feedback to the previous function. The overlapping among the 'Warehousing' and 'Field Control' functions and the activities included can be graphically clarified in **Figure 8.2.4.**

The position of the 'Quality Management' function and the distribution of their activities within functions of the CMM processes that are applied in the Jordanian building projects have been totally changed from what has been proposed in the typical workflow diagram that was drawn on the basis of the literature review. The centre of the function, where the activities of Quality Assurance (QA) and Quality Control (QC) are intersected and overlapped, is stationed as interface between the 'Material Procurement and the Transportation' function on one hand and the 'Field Control and Warehousing' functions on the other hand. However, the activities of the 'Quality Management' function are changeable/distributed between the CMM process's functions. Its Quality Assurance's activities are irregularly distributed within the functions of 'Take-off' and 'Material Procurement and Transportation' (although some considerations regarding the QA could be taken within the planning function); they are usually managed by the participation of the personnel of these functions and the Quality Management and Follow-up team (at the Organisational Level). While its Quality Control activities are irregularly conducted within the functions of 'Material Procurement and Transportation', 'Field Control' and 'Warehousing'; they are performed by involving the Quality Management and the Follow-up team with the personnel of those functions (Material Procurement and Transportation', 'Field Control' and 'Warehousing').

Despite this significant change in the position of the practical Quality Management function, the majority of its activities are similar to those listed in the typical CMM process with slight changes in some activities' names to meet the Jordanian terminologies used, in addition to some new activities that emerged. The implementation of this function is essentially based on the project's quality specifications and requirements, time submittal schedule and the primary quality plan, which are usually sent by a consultant, a construction management organisation (client's representatives), or a project management team (contractor's team). The main outputs of the function are forwarded to the vendor, field controller, and the projects management department. The activities that are included in the centre Quality Management function are graphically demonstrated in **Figure 8.2.5,** while the distribution of its activities is exhibited in **Figures 6.6** and **8.2**.

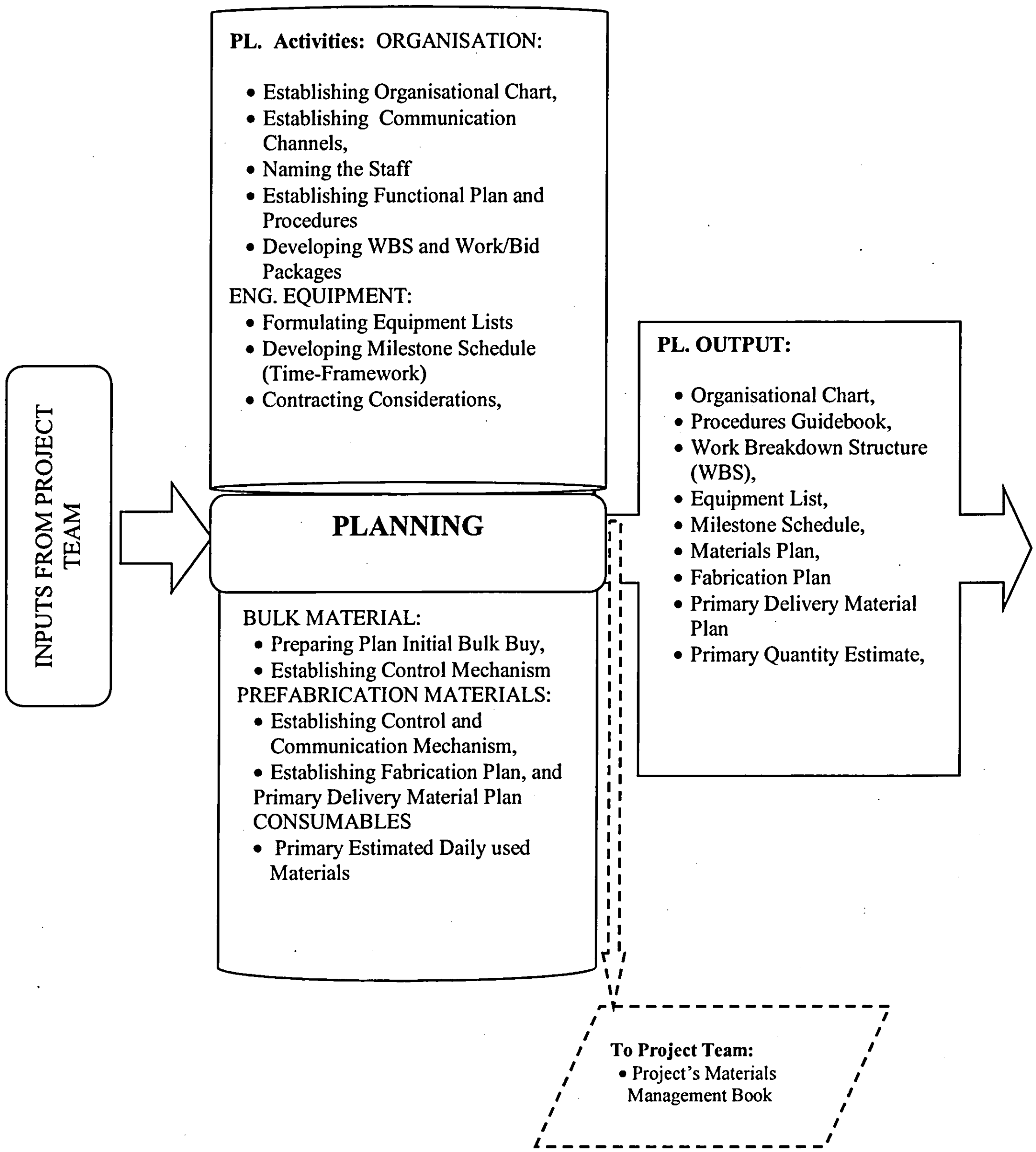

Figure 8.2.1: Developed Practical Planning Function Diagram

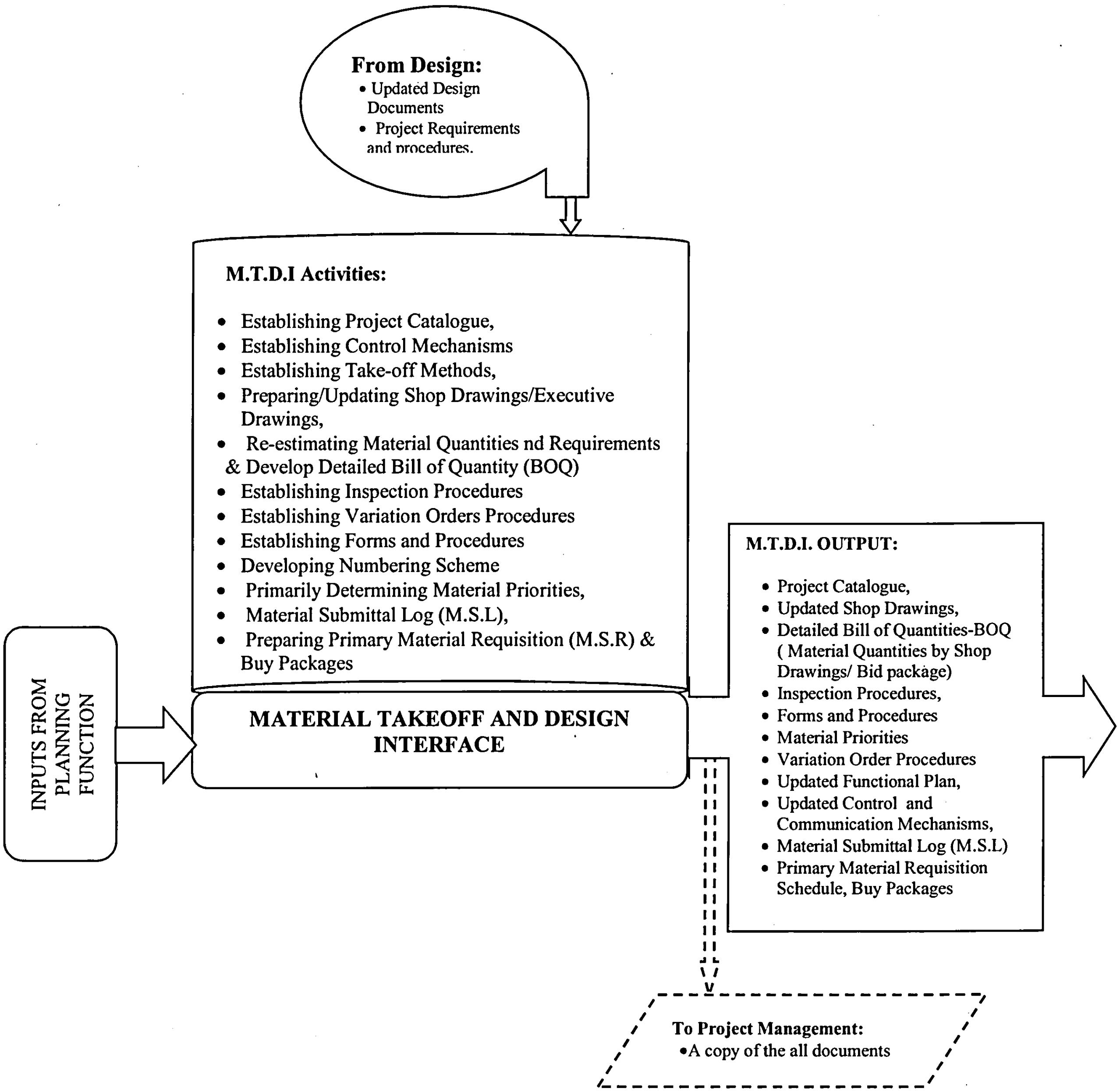

Figure 8.2.2: Developed Practical Material Take-off & Design Interface Function Diagram

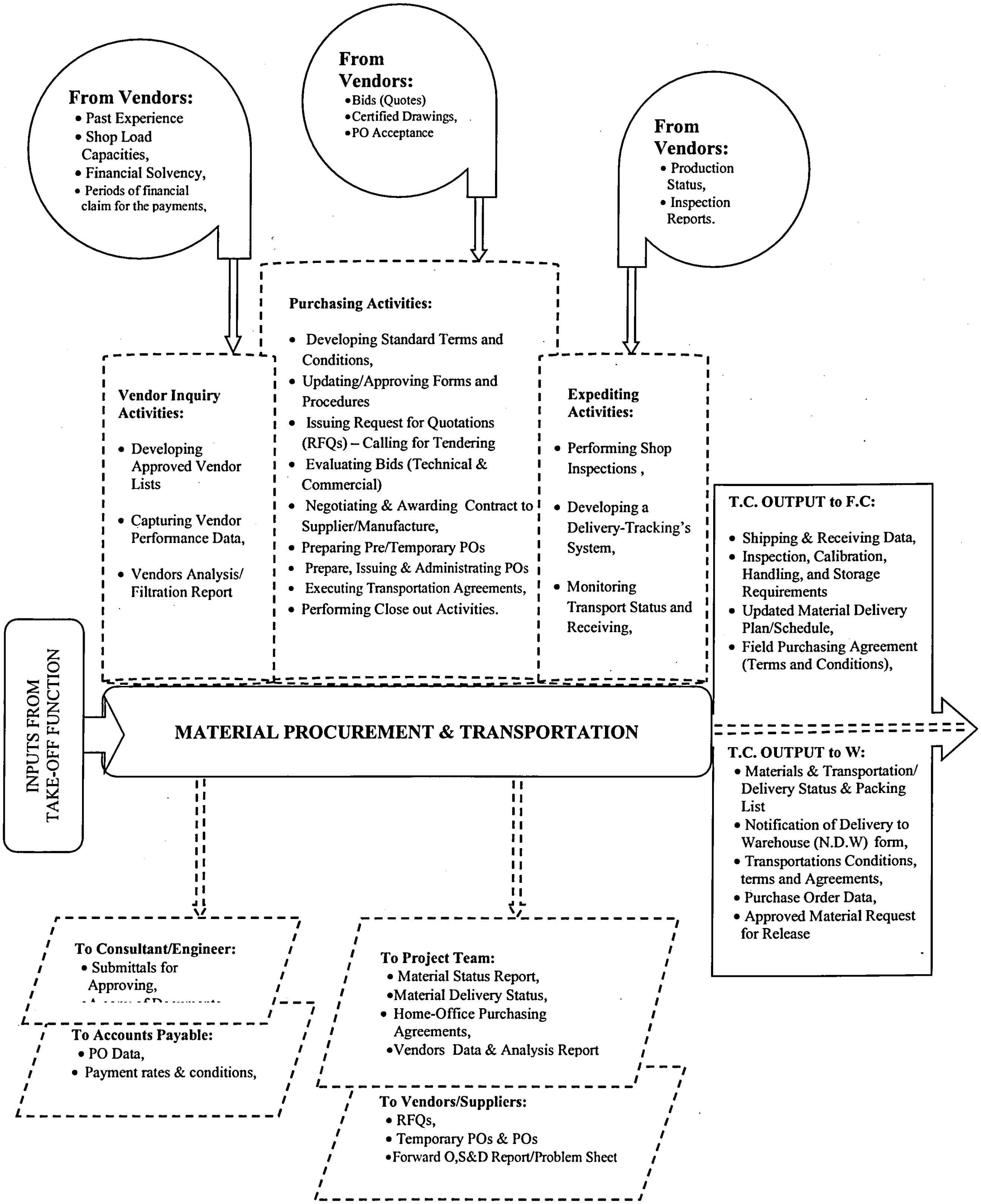

Figure 8.2.3: Developed Practical Material Procurement & Transportation Function Diagram

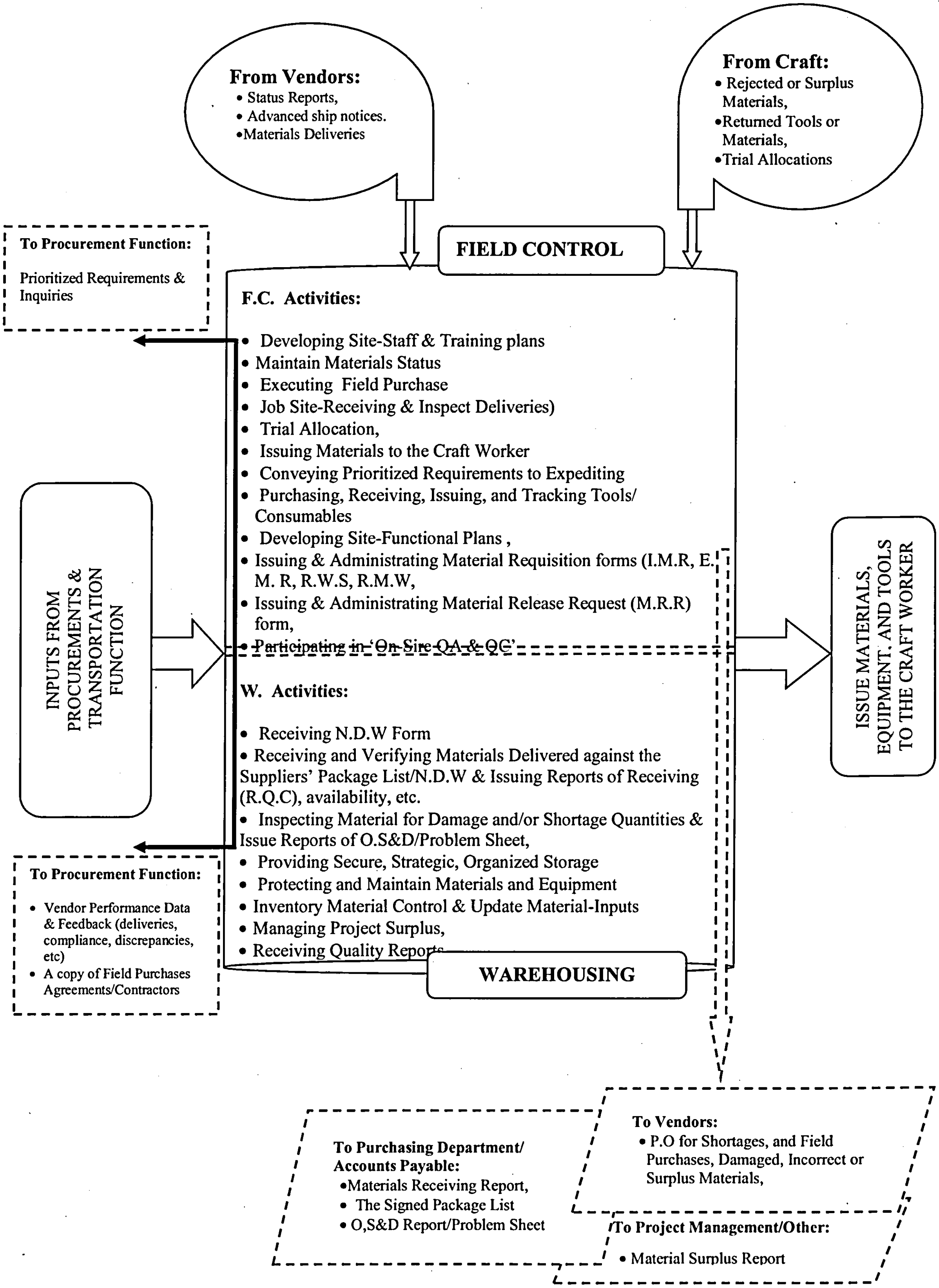

Figure 8.2.4: Developed Practical Field Control & Warehousing Functions Diagram

Figure 8.2.5: Developed Practical Quality Management Function Diagram

8.3 PHASE II: ESTABLISHING A SET OF PRACTICAL EFFECTIVENESS MEASURES (P.E.MS):

Phase II is intended to develop the 'main elements' of the proposed E.CMM.P framework. This was realized through establishing a set of Practical Effectiveness-Measures (P.E.Ms) that are and can be used for evaluating the effectiveness of the performance of the Construction Material Management process within the large-scale concrete building projects in the J.C.I. The achievement of this phase involves two main stages namely Stages 2 and 4, through implementing two data collection approaches; the literature review and qualitative approach (the main investigation).

Stage 2 is the *first stage* involved in conducting Phase II. This stage is concerned with theoretically establishing a proposed set of measures for evaluating the effectiveness of the performance of the materials management process in the construction industry. To determine this stage, an extensive literature review was carried out to identify and critically assess the material-related measures used in the construction industry. However, the lack of related literature, regarding measuring the materials management performance within the construction context, has led to expanding the literature investigation area to include an examination of the performance measurements that are used for the supply chain management and materials management processes within the manufacturing and construction industries and the industrial projects. As a result of examining different materials management-related measures and approaches that were specified during the review of literature, a set of thirty three **(33)** measures grouped under seven (7) different attributes were proposed to evaluate the effectiveness of the performance of materials management process within the construction projects (a set of the proposed effectiveness-measures), as explained in details in **Chapter IV**, and summarised in **Table 4.16**.

The set of the proposed effectiveness-measures is considered as a comparative basis for developing the Practical Effectiveness-Measures (P.E.Ms) that can be used for assessing the effectiveness of the CMM performance within the Jordanian building projects, which represents the main elements of the E.CMM.P framework developed, as illustrated in Stage 4 below.

Stage 4 *is* the *second stage* of Phase II; it embodies the core of the phase. Stage 4 endeavours to establish a set of measures that can be practically used for evaluating the effectiveness of the CMM performance within the large-scale concrete building projects in the J.C.I. For that purpose, a main investigation using the case study approach (site visits and interviews) was carried out on six on-going building projects that are currently executed in six Jordanian Governorates. The Cross-cases analysis technique was conducted within the six case studies to explore the effectiveness measures, approaches, or mechanisms that are presently in use within the cases for monitoring and evaluating the performance of the CMM process or system. Moreover, during the site visits and the interviews that were conducted within the case study research, the potentiality of applying the proposed effectiveness measures, which were established on the basis of the literature review, practically within the Jordanian building projects was discussed, and the obstacles that can hamper their application were defined (detailed discussion is provided in **Sections 6.6.2.2** and **6.6.2.3**). As a result of combining and consolidating the entire procedures and results included in Stage 4, a set of 26 Practical Effectiveness Measures (P.E.Ms), which can be used for evaluating the Effectiveness of the Construction Material Management's Performance (E.CMM.P) in the Jordanian Large-scale Concrete Building Projects, was established (see **Tables 6.6 and 8.1**).

In fact, the process of establishing the P.E.Ms, including examining the applicability of the proposed effectiveness-measures within the J.C.I, exploring the measures or approaches that are currently implemented to assess the CMM performance in the J.C.I, and reformulating those measures to reflect the effectiveness ratio, is discussed in detail in **Chapter VI, Section 6.6.2**. This section only addresses the review of the process of developing the P.E.Ms; besides classifying the P.E.Ms to facilitate their use within the E.CMM.P framework, as demonstrated below.

Based on discussing the findings that resulted from the cross-case analysis for the six case studies, it was concluded that although there is no certain standard or a visible unified set of measures for evaluating or quantifying continuously the effectiveness of the CMM performance in the J.C.I, numerous mechanisms, qualitative techniques, and some quantitative measures are practiced separately and irregularly to monitor and follow-up the performance of the CMM system within the Jordanian large-scale concrete building projects. These mechanisms and techniques were generally classified, within this research project, into three main approaches. **1)** Monitoring the Material-related Documents and

Reports, **2)** Examining the Ability of the CMM System to meet its objectives, and **3)** Observing the Efficiency of the Material-related Information System (Reporting System) (see **Section 6.6.2.1)**. It was noted that these approaches and techniques, largely, relied on monitoring and examining the system of transferring the relevant data and information. This is undertaken through following up the reporting system and the data enclosed. This could explicate the reason behind using the CMM-related documents and their reporting system for contributing in developing the E.CMM.P framework, as will be discussed and explained in the next phase (*Phase III*).

However, examining the applicability of the proposed set of effectiveness-measures within the Jordanian building projects, and discussing the comparison between them and the techniques and procedures practiced (during the interviews) revealed that: **1)** there were some measures that match, or that are largely similar to the proposed measures but they were used irregularly and separately (they are designated as *Exist-Measures*), **2)** some proposed measures were not practiced quantitatively or qualitatively within all the case studies selected (they are designated as *Not Exist-Measures*), **3)** the presence of some quantifiable techniques that are somewhat similar to the proposed measures, in terms of their purpose (they are designated as *Quantitative-Techniques*); **4)** the appearance of some alternative procedures that have been practiced qualitatively (non-measurable) to follow-up the performance of one or more function of the CMM system used (designated as *Qualitative-Techniques/Approaches*) and **5)** the appearance of some new measures or quantitative techniques that are different, in terms of their purpose, from the proposed measures; they have not been cited within the set of the proposed measures (they are designated as *New-Measures*).

The process of establishing a set of Practical Effectiveness Measures (P.E.Ms), which are/or can be used for evaluating the effectiveness of the performance of the CMM process within the Large-scale Concrete Building Projects in the J.C.I, was based on the following key actions: **I)** adopting the 'Existing-Measures' as proposed by the set of measures that were developed in the literature; **II)** approving the proposed measures that were not used in all case studies (the non-Exist-Measures) but they were found applicable within the Jordanian projects, **III)** reformatting and reformulating the 'Qualitative approaches' and 'Quantitative techniques' that were found applicable within the Jordanian projects, based on their possibility of calculation and the availability of the data and the documents needed, **IV)** deleting 'the non-Exist-Measures', and omitting the 'Qualitative' that were found impossible to be used within the J.C.I, whether because of the difficulty of their calculation, the lack of the required documents availability, or their incompatibility with or their absence from the Jordanian culture; and **V)** adding the 'New measures', which were exposed by the case study cross-analysis, with some modifications, if needed, to reflect the effectiveness format (Processing the measures' groups within these actions was explained in **Section 6.6.2.3**).

As a result of the implementation of phase II, a set of twenty six Practical Effectiveness Measures (PEMs) was established. Those measures, which will form the main elements of the developed E.CMM.P framework, include sixteen proposed measures, five measures resulting from reformulating and reformatting the qualitative and quantitative approaches used to whether embody one of the proposed measures or represent a new measure, and five new measures used within the Jordanian projects, as explicated in **Table 8.1**. As stated above, in order to understand the process of assessing the proposed effectiveness-measures and establishing the practical effectiveness-measures (P.E.Ms), extensive analysis and discussion are provided in **Chapter VI; Section 6.6.2**.

Table 8.1 provides a summary for the description of the twenty six Practical Effectiveness Measures (P.E.Ms) that were found whether based on the definitions that were found while reviewing the relevant literature, or that were obtained from the interviewees while analysing and discussing the main investigation outputs. This includes the measurement attribute, measure's code, measure's name, point of measurement (Measure's Location), the proposed definition for the measure calculation (formula), and a brief description of each P.E.Ms. In addition, the table includes the documents and reports that were observed during the site visits and that were suggested by the interviewees to be used for practicing these measures as they include the needed data and information.

The measures listed within **Table 8.1** are classified into two groups according to the desired low and high values: **Group A** (-) includes measures that are more desirable with low values, and that are considered best when they are as low as possible; and **Group B** (+) includes measures that are more desirable with high values, and that are considered best when they are as high as possible.

Table 8.1: The description of the Practical Effectiveness Measures (P.E.Ms) that can be used for Evaluating the E.CMM.P within the Jordanian Large-scale Concrete Building Projects

CATEGORIES ATTRIBUTES	CODE	MEASUREMENT TITLE	AREA/POINT OF MEASUREMENT	MEASURE DEFINITION	DOCUMENTS USED	SUMMING AS (+,-) Group A (-)	SUMMING AS (+,-) Group B (+)	MEASURES MEANING/DESCRIPTION	NOTES
ACCURACY	AC1	**Material Receipt Problems**	The interface between vendor and warehouse Function	➢ **AC1 reports** the data or information discrepancies associated with **a material delivery** that, if not detected and corrected, would cause inaccuracies in the project materials management database. ➢ This measure is the percentage of line items received without discrepancy.	• R.Q.C reports = DU10 • O.S&D reports = DU11 • Problem Sheet Form = DU12		×	➢ Material receipt problems occur when **shipping documents** or materials do not agree in specific areas with **the purchase order** or receiving report, ➢ Discrepancies may be identified on bills of lading, packing lists, POs, Advance Shipment Notices (ASNs), and other materials documentation (packing list, etc).	Those two can be Combined A1 + A2
	AC2	**Material Receipt Problems - Internal**	At the interface of the Vendor with the Warehouse Function.	➢ **AC2** reports the **accuracy** of internally generated material related data as determined at the point of receipt. ➢ AC2 is the **percentage** of line items received without internal discrepancy	• R.Q.C reports = DU10 • O.S&D reports = DU11 • Problem Sheet Form = DU12		×	➢ The problems associated with material receipt processing may **impact** the materials management **database system** by introducing erroneous or inaccurate data. ➢ Examples of discrepancies with internal origins may include (1) materials correctly purchased and delivered to the site without a PO number,(2) the commodity code on the PO is not in the materials catalog, and (3) the PO is not available to receive the materials against. ➢ The causes of discrepancy could be the difference between AC1 & AC2	
	AC3	**Warehouse Inventory Accuracy**	Within the Warehouse Functions	➢ This measure is determined by **comparing** through a **statistical sampling** the data in the materials database with **the physical assets** in the warehouse and controlled laydown areas ➢ AC3 is the **ratio of the number** of items that are found accurate to the number of random items to be counted (items that are used to form the random sample)	• Inventory Record/Database = DU14 • Warehouse Observation/System=DU15		×	➢ **AC3** measures **process quality** by reporting the accuracy of the information associated with the **warehouse** function. ➢ The inventory results indicate the accuracy of the materials management database system when compared with the physical asset count. Any difference between the **inventory records** and the **actual physical counts** constitutes a discrepancy. ➢ To calculate the **AC3**, it is essential to **carry out statistical** analysis in comparing the physical counts versus the system counts	This measure could be calculated for the entire items in the Warehouse
QUALITY	Q1	**Installing Equipments Rework**	At the Interface of Construction with the field control Function.	➢ **Q1** can be reported as a percentage of the total number of installing equipments identified as requiring rework (field modification) to the total number of installing equipments. Q1 may be reported as a cumulative and/or periodic measure. ➢ **Q1** reports the total number of installing equipments identified as requiring rework (field modification) divided by the total number of installing equipments, multiplied by 100 to provide a percentage ratio.	• Construction Status report = DU35 • Field Progressing Works Report = DU25 • Variation Orders (VOs) = DU36 • Daily & Monthly Reports = DU24	×		➢ **Q1** reports materials related **process quality** as a specific evaluation of design and supplier (fabrication) performance. ➢ Monitoring the Installing Equipment Rework (IER) may evaluate the **ability** of the design and materials management processes to **react** to design **changes** without impacting construction operations. ➢ The root cause of IER may relate to any number of sources such as, • design and fabrication accuracy, • owner/contractor changes (i.e. modifications), • Shipping constraints, or schedule acceleration, • Untimely deliveries/ schedule acceleration, • Materials not in right place when needed/ shipping constraint, • Non-compliance with specification, • Materials or equipments are not to project request. ➢ In the case of owner or contractor changes, evaluating IER provides feedback on the impact of earlier decisions. ➢ IER constitute major and critical elements of some construction projects and rework may significantly impact construction productivity. (*that is why Q1 can be measured related to value*)	
	Q2	**Jobsite Rejections of Tagged Equipment**	At the Interface of Construction Operation with the Field Control Function.	➢ **Q2** represents the **percentage** of all rejections of tagged equipment. ➢ **Q2** is calculated by dividing the total number of the rejected tagged equipment (or items) to the total number of the issued tagged equipments, multiplied by 100.	• Inspection Form = DU8 • Material Returned/Rejection Form = DU20 • Notifications of Return/Non-conforming Items = DU21 • Materials Inspection Request (M.I.R) = DU7	×		➢ **A rejection occurs** when Construction notifies the Field Control Function of return of the item, because the construction group considered it unfit in its current form. ➢ The ability of the design and materials management processes to provide tagged equipment in accordance with requirements is critical to maintaining efficient construction operations.	
	Q*	**Construction Operation Returns**	At the Interface between the construction Operations (Craft-workers) and the Field Control Function	➢ Similar to Q2, this measure (Q*) can be calculated through the ratio of the number of all material inspections that were rejected by the Warehouse, Field Control or Supervision team for all the materials and items used to the total number of inspections (M.I.R, Notification of Non-conforming Item, Materials Returned Rejected Forms, etc.).	• Inspection Form = DU8 • Material Returned/Rejection Form = DU20 • Notifications of Return/Non-conforming Items = DU21 • M.I.R forms = DU7	×		➢ This measure is very similar to the measure 'Jobsite Rejections of Tagged Equipment (Q2)', with some expansion to include all returned materials. ➢ The return of the materials by the construction operation can occur due to many reasons, for instance, wrong requisition, wrong order, wrong vendor shipment, wrong issuance, material damaged or defective, or other	
QUANTITY	QN1	**Home Office Requisition Ratio**	At the Interface of the Procurement Function with the Vendor.	➢ **QN1** reports the **percentage** of requisitions for quotations (RFQ) performed by the home office compared to the total number of request for	• RFQ forms within Comprehensive Monthly/Quarterly Report = DU1		×	➢ The **QN1** ratio serves as an **indicator** of the degree of economizing transaction activities by performing RFQs (Requisitions for Quotations) in the home office.	

CATEGORIES ATTRIBUTES	CODE	MEASUREMENT TITLE	AREA/POINT OF MEASUREMENT	MEASURE DEFINITION	DOCUMENTS USED	SUMMING AS (+, -) Group A (-)	Group B (+)	MEASURES MEANING/DESCRIPTION	NOTES
				quotations (RFQs) during a period of time.				➢ For this **measure**, an requisition submitted in an actionable format is considered the source of a RFQ. ➢ The **purpose** of a requisition is to initiate the flow of activities to purchase and receive specified materials.	
	QN2	**Home Office Purchase Order Ratio**	At the Interface of the Procurement Function with the Vendor.	➢ **QN2** reports the **percentage** of purchase orders (POs) performed by the home office compared to the total number of POs transactions during a period of time	• PO forms within Comprehensive Monthly/Quarterly Report = DU2		×	➢ The **NQ2** ratio **indicates** the proportion of POs transmitted from the home office and serves as an indicator of PO activity performed by the home office.	
	QN5	**Commitment – Field**	At the Interface of the Procurement Function with the Vendor.	➢ **QN5** reports the **percentage** of the **value** of materials and tagged equipment committed by **the field compared** to the total commitment value during a specified time period.	• Field Works Report = DU25 • Field POs = DU23 • Daily & Monthly Reports = DU24		×	➢ This is a companion measure to Commitment – Home Office (QN4)	This information/ or documents could be available in field control function
	T2	**Bid/Evaluate/Commit Lead Time**	The First Measure **T2a** is at the Interface of the Vendor with the Procurement Function. The Second measure **T2b** is taken at the Interface of the Procurement Function with the Vendor.	➢ **T2** is the **average duration** reported in days to bid, evaluate, and commit (BEC) to the purchase of materials. ➢ **T2** uses a ratio format to report/communicate the **average duration and planned** duration.	• Using Documents related to the RFQs and the POs; DU1, DU2	×		➢ The measure is bounded by the receipt of the vendor's response to the RFQ until the issuance of the PO. ➢ The measure focuses on the sequence of activities within the control of the Purchasing Function. The average BEC durations may be segregated by materials grouping (piping, steel, controls, etc.) or by discipline (civil, electrical, mechanical, etc.) or by process.	
	T5	**Commodity Vendor Timeliness**	At the Interface of the Vendors with the Warehouse Function.	➢ **T5** is the **ratio**/percentage of vendor deliveries that were delivered on time in regards to the '**promised delivery date**' and the '**actual delivery date**'. ➢ **Calculating** 'T5' requires determining the number of on time deliveries and the total number of deliveries during a specified period of time.	• Materials Delivery Status = DU6 • R.Q.C reports = DU11		×	➢ '**On Time Delivery**' should be defined in an organisation or a project; e.g., it could be established that materials received within two days are considered on time, while materials received after that are considered late deliveries. ➢ The **chronological** determination of same day or next day is midnight (0000 hours). ➢ This measure reports the percentage of on time deliveries, but may also represent several subcategories, for example, one to three days late and three or more days late.	Some people believes that the on time promised deliveries is the on-time planned deliveries.
	T6	**Commodity Timeliness**	At the Interface of the Vendors with the Warehouse Function.	➢ **T6** is the **percentage** of deliveries made **on or before** the 'actual delivery date' when compared to the '**required delivery date**'. ➢ **Calculating** 'T6' requires determining the number of deliveries made on time or before the required delivery date and the total number of deliveries during a specified period of time	• Material Delivery Status (MDS) Report = DU6 • Receiving Reports, i.e R.Q.C reports = DU11		×	➢ The **chronological** determination of same day or next day is midnight (0000 hours). ➢ **T6** is reported as the **percentage** on time, but may represent two or more subcategories, for example 'one to three days late' and 'three or more days late'.	
TIMELINESS	T7	**Materials Withdraw Request (MWR) Lead-time**	At the Interface of Construction with the Warehouse Function.	➢ **T7** measures the lead time allowed for the issuance or delivery of materials by reporting time, ➢ **T7** is the difference between MWR date and the need or requested delivery date. ➢ The measure is reported as **a ratio** of the average MWR lead-time and the planned MWR lead-time.	• Material Receipt = DU9 • Delivery Status Report = DU6 • Internal Materials Requests/ Request Material from Site-Store (RMS/I.M.R) Form = DU4 • External Materials Requests/ Request Material from warehouse (EMR/RMW) Form = DU5 • Milestone Schedule and Delivery Plan = DU31	×		➢ **The MWR date** is the date an authorization is issued to the warehouse to withdraw specific materials from inventory. ➢ **The lead time indicates** the ability of construction operations to request material as the work package start date approaches, and, thereby, minimize the amount of time craft workers wait for materials. ➢ **Accountability** is maintained as the withdrawals are issued to individuals in the warehouse or delivered to project material drop sites.	
	T*	**Procurement Processing Time**	The Interface between Vendor and Procurement function.	➢ 'T*' reports the percentage of **average** actual procurement processing time in days to the **planned** procurement processing time in days	• Using Documents related to the RFQs and the POs; DU1, DU2 • &Temporary POs=, DU3	×		➢ **Average actual procurement processing time is the average duration bounded by the transmission of the request for quotation (RFQ) until the issue of the temporary purchase order for the vendor/supplier'** ➢ The duration encompasses the RFQ, bid evaluation, negotiation and award, and issuance of the Temporary PO.	
	T**	**Purchase Orders (PO) to Material Receipt and Updated in the System Duration**	The First measure location **T**a** is at the Interface of the Procurement Function with the Vendors. The Second location **T**b** is at the Interface of the Vendor with the Warehouse Function.	➢ **T**** is based on merging two measures T3+T4 in one measure in some projects. ➢ **T**** is the **ratio** of the **average** processing time duration from issuing PO to receiving and updating materials in the warehouse system inventory to the **planned** processing time duration	• PO forms = DU2 • Receiving Quality Control (R.Q.C) reports = DU10 • Warehouse/Inventory Record/Database = DU14	×		➢ **T**** is the measurement of the processing time from issuing PO to receiving and updating materials in the warehouse system/inventory, ➢ **T**** uses a ratio format to communicate the average actual duration and the planned duration. ➢ Due to the fact that the average duration is calculated based on each PO line item, the measure could be the sum of issuing to receive and update durations divided by the total number of receipts.	
	T***	**Materials Withdraw Request (MWR) Processing time – Internal**	Within the Field Control and the Warehouse Functions	➢ **T***** is reported as the percentage of the Material Withdraw Requests (MWRs) that were processed on or before the required date, during a period of time.	• Material Receipts = DU9 • Internal Materials Requests (RMS/I.M.R) = DU4 • Material Request Schedule = DU26 • Daily/Monthly Reports = DU24 • Receiving Quality Control (R.Q.C) reports = DU10		×	➢ **T***** can evaluate the effectiveness of the warehousing function's performance in terms of its ability to meet the requirements of the construction operations, ➢ The average duration of the fulfilment of a request/order bounded by issuing whether an Internal Material Request (I.M.R) or External Material Request (E.M.R) until the issue of the required materials to the craft, ➢ Counting the MWR processing time (From issuing IMR to sign the material receipt by the foramen or the person who requested it).	

CATEGORIES ATTRIBUTES	CODE	MEASUREMENT TITLE	AREA/POINT OF MEASUREMENT	MEASURE DEFINITION	DOCUMENTS USED	SUMMING AS (+, -) Group A (-)	Group B (+)	MEASURES MEANING/DESCRIPTION	NOTES
					• Warehouse/Inventory Record/Database = DU14 • Signed Package Lists = DU37				
COST	C3	**Freight Cost Percent**	Within the Procurement (Expediting and Transportation) Function.	➤ **C3** reports the **percentage** of freight costs as a percentage of material expenditures.	• The M.D.S Report = DU6 • Document related to Materials Financial Reports and Statements of Cash flows Reports = DU33 • Schedule of the general expenses = DU34	×		➤ The **total freight cost** is divided by **materials expenditures** for the time period. ➤ The results may be combined and reported as a cumulative or a six-week rolling average to compare more readily with industry average.	
	C4	**Express Deliveries Percent**	At the Interface Between the Vendor and the Warehouse Function.	➤ **C4** reports the **percentage of express deliveries** made to the project warehouse by dividing the number of express deliveries and the total number of deliveries for a specified time period.	• M.D.S Report = DU6 • Material Status Report = DU16 • Monthly Report (Urgent Deliveries) = DU24	×		➤ Express deliveries are those deliveries where a **premium price** is normally paid for a quick response type transport of materials or equipment. ➤ This measure **reflects the ability** to plan and utilize **standard modes** of transportation and delivery.	
	C5	**Construction Time Lost**	Between Construction Operations and the Field Control Function.	➤ **C5** is the percentage of **construction time lost** due to the impact of materials, as estimated by construction supervisors. ➤ **To calculate C5**, it is essential to determine the total amount of materials-caused lost and the total amount of construction time	• The daily & monthly reports = DU24 • Daily labour sheets = DU28 • Time Record: Inactivity Timesheet for Machineries = DU38 • Material Delivery Plan (Milestone) = DU31 • Consultant Status Report = DU32 • Equipment Utilization reports = DU39	×		➤ **C5 reflects** the direct impact of the materials management process upon construction operations. ➤ The percentage of time lost due to materials is usually reported and collected using daily **labour sheets**. Feedback to the Field Control function is recommended on a weekly basis.	➤ The construction time lost is usually calculated and reported by the Project's Consultant/Engineer for Identify the reasons of delay for the issues of Complaints and disputes.
	C8	**Total Surplus**	Within the Warehouse and Field Control Functions.	➤ **C8** reports the **percentage** value of unused materials in relation to the total purchase cost of materials.	• Material Returned/Rejection Form = DU20 • Notifications of Return/Non-conforming Items = DU21 • Inventory Record/ Warehouse System = DU14.15 • Material Status Report = DU16 • Site Material Status Report = DU19 • Availability Report = DU17	×		➤ **The value of unused materials** is determined before being coded for return (restocking) or disposition by third parties or facility operations and maintenance.	➤ Sometimes the surplus could be resulted because of good using and saving for the requested materials on the site
	C*	**Material Waste Ratio**	Between Construction and Field Control Function	➤ C* reports the percentage of the value of the materials that is considered as waste (surplus and unused materials) compared with the total materials costs.	• Material Returned/Rejection Form = DU20 • Notifications of Return/Non-conforming Items = DU21 • Inventory Record/ Warehouse System = DU14.15 • Material Status Report = DU16 • Site Material Status Report = DU19 • Availability Report = DU17	×		➤ This measure is similar to the measure 'Total Surplus', the only difference is that the all material waste is included into the surplus category. ➤ the material waste includes both the surplus and non-usable material	
	C**	**Material Waste Management**	Between Construction and Field Control Function	➤ The measure 'Waste Management (C**)' can be calculated by dividing the actual material waste value by the planned waste material value (Expected to be waste).	• Inventory Record/ Warehouse System = DU14, DU15 • Material Status Report = DU16 • Site Material Status Reports within Daily and Monthly Reports = DU19 • Design documents related to material utilization & Waste management=DU27 • Notifications of Return/Non-conforming Items = DU21 • Materials Availability Report = DU17 • Material Returned/Rejection Form = DU20	×		➤ Planned Value of Waste Material is the expected value of waste materials.	
AVAILABILITY	AV1	**Material Availability**	At the Interface of the Warehouse Function with Construction Operations.	➤ **AV1** is calculated through dividing the total number of material line **items issued** by the total number of material line **items requested**. ➤ **AV1** can also be calculated through dividing the total number of material line **items issued** by the total number of material line **items required**	• Materials requests (MRS & MRW form) = DU4, DU5 • Inventory Reports/ Record = DU14 • Releases Record = DU29 • Site Receipt/ Material Issuances = (DU9, DU29) • Materials Availability Reports = DU17 • Material Flow Schedule = DU22		×	➤ **AV1 represents** the ability of the materials management process to issue or deliver properly scheduled and communicated material requirements to construction operations prior to what is commonly recognized as the activity early start date (ESD) or the field need date (FND). ➤ **AV1** is commonly associated with those materials and equipment items with need dates that have been established and updated on a regular basis.	
	AV2	**Stockout Analysis**	Within the Warehouse Function.	➤ **AV2** is the ratio of the total number of line items that a **warehouse is unable to issue** to the craft-workers divided by the total number of line items	• Section of Out of Stock Materials in Materials Status Report/ = DU16 • Materials Availability Reports = DU17	×		➤ **V2** is commonly **associated** with **bulk material** items and may be used as an aggregate measure for **nine stockout** situations. These causes may be identified as the stockout situation occurs and used to calculate	

CATEGORIES ATTRIBUTES	CODE	MEASUREMENT TITLE	AREA/POINT OF MEASUREMENT	MEASURE DEFINITION	DOCUMENTS USED	SUMMING AS (+, -) Group A (-)	Group B (+)	MEASURES MEANING/DESCRIPTION	NOTES
				requested.	• Inventory Record = DU14 • Store Shortfalls List = DU18			percentages for each subgroup ➢ The categories are: Ahead of schedule, MIN/MAX low, Inventory: Inventory, Not short, Takeoff errors, Field takeoff: Field, Already issued and Other: Nonspecified causes. **See (Plemmons, 1995) P63**	
Flexibility	F₁	Delivery Flexibility	The First measure location **F1a** is at the Interface of the Vendor with the Warehouse. The Second location **F1b** is at the Interface of Warehouse Function with Construction Operations	➢ **Delivery flexibility** can be expressed as the **percentage** of slack time by which the delivery time can be reduced. ➢ Delivery flexibility can also be measured as the proportion of excess slack across all jobs (j)	• Executive, design and planning documents and reports = DU13 • Milestone Schedule and Delivery Plan = DU31		×	➢ J could be the material line item or job in the system.. ➢ This is the ability to move planned delivery dates forward. This ability allows the supply materials/materials management to accommodate rush orders and special order. ➢ An example of high delivery flexibility is just in time, when suppliers deliver the products to the customer at the right quantity, place, and time. (Sanchez and Perez, 2005)	
	F3	Volume Flexibility	The First measure location F3a is at the Interface of the Procurement Function with Vendor. The Second location F3b is at the Interface of Warehouse Function with Construction Operations	➢ The **volume flexibility** measure 'F3' measures the proportion of demand that can be met by the materials management system. ➢ This proposed measure 'F3' depends on dividing the **average** of demand volume that can be met by the materials management system to the total **planned** demand volume or the required demand volume	• Material Status Report = DU16 • Materials Availability report = DU17 • The Bill of Quantities = DU30 • Material Requests = DU4, DU5 • Warehouse/Inventory Record/Database = DU14		×	➢ **Volume flexibility** is likely to be an important response to uncertainty in highly cyclical industries, (Sanchez and Perez, 2005) ➢ Volume flexibility is the ability to adjust capacity to meet changes in customer quantities. (Duclos, 2003) ➢ For the development of a supply chain volume flexibility measure, it is interested in how much of the demand can be met considering only the range of volumes that are profitable. ➢ Demand volume could be units (number of units)	

8.4 PHASE III: SETTING OUT AN OPERATIONAL MECHANISM AND DESIGNING THE FINAL E.CMM.P FRAMEWORK:

Phase III, in fact, aims to design the final form of the E.CMM.P Framework. This can be realized through achieving the only stage involved in this phase; 'Stage 5'. **Stage 5** aims to set up an operational mechanism for operationalizing the E.CMM.P Framework for monitoring and evaluating the effectiveness of the CMM performance within the Jordanian building projects. This operational mechanism is a set of interrelated activities and instructions that are designed to operationalize (run) the E.CMM.P framework through linking the framework's elements (P.E.Ms) and integrating them within its main body (P.CMM.P workflow diagram) at the points of measurement. The accomplishment of this phase is based on the findings of two adopted research methods; literature review findings for identifying the suitable mechanism for operating the framework, and the findings of the main investigation (cross-case analysis) for modifying and tailoring the mechanism to fit the Jordanian large-scale concrete building projects.

8.4.1 Setting up the Operational Mechanism:

The basic idea of defining an operational mechanism, for operating the developed E.CMM.P framework, is mainly based on investigating benchmarking that was conducted during reviewing the relevant literature (see **Chapter IV-Section 4.5**). The numerous definitions of benchmarking, which have been obtained from the literature and introduced in **Section 4.5**, confirm the potentiality of using the benchmarking techniques for comparing the performance of similar business units, operating units, or operating processes for the purpose of monitoring and evaluating the effectiveness of their performance. Among those definitions were those that were introduced by Stukhart (1995, p188) "*Benchmarking is the means by which company performance can be measured, or by which a company can be judged*"; and by Anand and Kodali (2008), benchmarking is an activity that looks inward or outward of an organisation to find the best practice and the highest performance and then measures the actual business operations against those goals, to help this organization improve its performance. Initially, those definitions made the researcher think seriously about the use of 'benchmarking', and search for an operational mechanism through which the E.CMM.P framework can be operated; in particular, the benchmarking models.

According to Stukhart (1995), for any benchmarking to be effective, standards must be made available; this could be difficult to achieve by many companies in the construction industry because the construction companies rarely reveal their detailed data. This could confirm the fact that unlike the manufacturing industry, formal benchmarking activities are not widely applied within the construction industry (Lema and Price, 1995). This could also account for the lack of scholarly references to benchmarking or the existence of benchmarked data within the construction industry (Fisher, Miertschin and Pollock, 1995; Plemmons, 1995) (for more explanation, see **Section 4.5.3**). This is also confirmed by what was concluded from the main investigation; the lack of standards or a set of unified measures for benchmarking (see **Section 6.6.2**).

However, Plemmons (1995) and Kozak (2006) stress that regardless of the lack of benchmarking standards in the construction industry, comparing performance information is not unique to the manufacturing and service industries; moreover, the construction-related literature indicates that information is available for firms and individuals to compare their organisational and project performance. This can indicate the possibility of performing an internal benchmarking process within a construction company through collecting data on its own performance and evaluating them so as to make improvements through comparing its performance with that of the pervious time (the previous years) or the different stages of the project(s). The use of internal benchmarking within the construction organisation was recommended by Kozak (2006) and Plemmons (1995), among others, who believe that the readily available data and information and the lack of problems associated with confidentiality or the nondisclosure of data makes the internal benchmarking process the easiest to perform (for more details about the definition of internal benchmarking, see **Section 4.5.1**). Consequently, it was decided to adopt the internal benchmarking in the current research project as the basis for establishing the operational mechanism of the E.CMM.P Framework.

On the grounds that the process of benchmarking should be applied in a model, a framework for action, or a formal set of procedures, with flexibility for modification to meet the individual needs (Plemmons, 1995; Elmuti and Kathawala, 1997), the efforts, in this phase, were focused on identifying a benchmarking model that can help depict those steps or procedures that together describe the functionality of the operational mechanism and the steps that should be taken while performing benchmarking evaluation. While examining the relevant literature, it was found that several benchmarking models were developed or adopted for use primarily within the manufacturing and service-related industries (see **Section 4.5.2**). However, despite the fact that the core of the different benchmarking models is similar, most of the authors have tailored their approaches or models to their own practices and experience (Partovi, 1994). All this encouraged the researcher to select a benchmarking model and to modify it to be used as an operational mechanism.

Based on a careful examination of the benchmarking models utilized for manufacturing and service industries, Plemmons (1995) presented a proposed benchmarking model for construction industry (see **Figures 4.6** and **4.7**). This benchmarking model is considered as the most recent and important attempt for benchmarking the materials management process using a series of measures that can be collected to the best of my knowledge. Central to the proposed model is a third-party benchmarking mechanism (called Benchmarking Clearinghouse) to support the collection and dissemination of performance data and best practices. With the help of Bell, Plemmon (1995) managed to establish a mechanism for integrating Clearinghouse within the typical companies' benchmarking procedures. The proposed purpose of Clearinghouse, in Plemmons's model, is the efficient and effective collection and dissemination of comparative performance data and information for the CMM process, as illustrated in **Figures 4.6** and **4.7** and described **in Section 4.5.3**. The majority of the recent studies and researches concerning measuring the performance of the CMM process rely on Plemmons and Bell Model. Therefore, this model is adopted, in the present research project, to lay down the basis for the operational mechanism of the E.CMM.P framework.

The proposed operational mechanism of the E.CMM.P framework has been developed based on the Plemmons and Bell Model with introducing some modifications on some elements of the model to suit the main proposed purpose of the operational mechanism in the current study, in addition to set and designate operating procedures that reflect employing the P.E.Ms for evaluating the CMM process within the large-scale concrete building projects. The operational mechanism of the developed E.CMM.P framework is proposed graphically in **Figure 8.3**.

Figure 8.3 presents the diagram of the operational mechanism that depicts the interrelated actions and procedures for communicating the developed practical effectiveness-measures (the E.CMM.P framework's elements), and for integrating and employing them within the developed practical workflow diagram of the CMM process (the E.CMM.P framework's body) for the purpose of monitoring and evaluating the effectiveness of the performance of the CMM process that is practiced within the Jordanian building projects.

The basic elements and procedures of the proposed operational mechanism, which were drawn from the literature review conducted by the researcher (see **Section 4.5)**, reflect actions associated with the *four* common steps, on the basis of which the majority of the companies' routine benchmarking activities were superimposed; these are involved with '*Planning*', '*Collecting*', '*Analysing*', and '*Improving*'. These *four* activities, which are called the benchmarking activities, are outlined by the most benchmarking models, in particular the Xerox Benchmarking model; besides, they are adopted by Plemmons and Bell (1995), Al-Khalil et al. (2004), among others.

However, because of the 'Benchmarking Clearinghouse', which was proposed by Plemmons and Bell (1995) during developing their benchmarking model (see **Section 4.5.3**), does not exist in the strategies of the J.C.I, a unit, called the 'Measurement and Follow up Unit', was proposed by the researcher to be integrated within the operational mechanism in the current research. Basically, the purpose of this unit is, somewhat, similar to the 'Benchmarking Clearinghouse'; it is mainly designated to be engaged in the systematic collection and dissemination of the related process performance information and data for the CMM process within the building projects of an organisation. This unit can be located in a construction contractor organisation within a department such as, the 'Planning and Follow-up Department' or with the 'Quality Management Unit'.

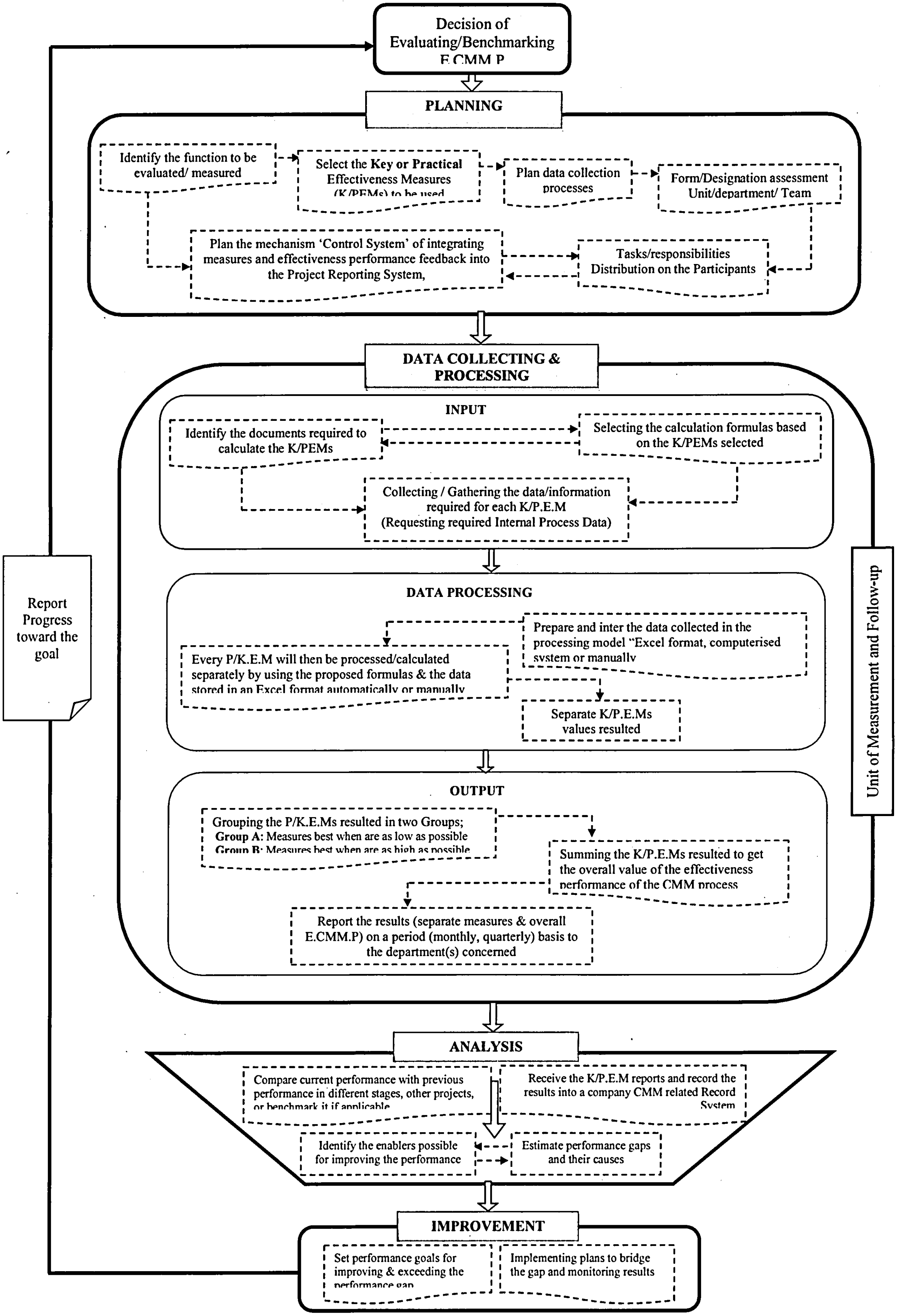

Figure 8.3: Operational Mechanism of Operationalizing the Practical Effectiveness-Measures within the E.CMM.P Framework

The name and the location of the unit, in fact, are proposed by the researcher based on his knowledge and observation while conducting the case study research. It is the researcher`s belief that the unit's name reflects the purpose of the unit, and that its location is the most appropriate place, based on the researcher's point of view that allows the unit's team or operator in his capacity, to access the whole data and information needed for operating the P.E.Ms within the CMM process in the majority of the Jordanian building projects (see **Chapter VI**). The unit name and location is not compulsory; additionally, there is flexibility for modification to suit the functional structure of a contractor company, as recommended for the internal benchmarking by Partovi (1994), Plemmons (1995), Elmuti and Kathawala (1997), and Anand and Kodali (2008).

Moreover, from the findings of the cross-case analysis, the importance of the information and reporting system used for evaluating the performance of the CMM process within the Jordanian building projects was highlighted (see **Section 6.6.2**); therefore, the report system is also integrated within the proposed operational mechanism. Regarding the proposed procedures of the operational mechanism (included under the benchmarking activities), they were mainly developed from the common benchmarking procedures that were found in the literature and descried in **Section 4.5**. However, those procedures were modified, tailored, and detailed to fit the purpose of the proposed operational mechanism, and to meet the process of the CMM within the Jordanian large-scale concrete building projects. These proposed procedures can be modified to meet the individual requirements, operation conditions, and functional structure of a contractor company. Describing these proposed procedures and explaining how they are designed, integrated, and used within the E.CMM.P framework will be made in some detail in the next sections.

8.4.2 Designing the E.CMM.P Framework:

As stated earlier, the development of the framework for Evaluating the Effectiveness of the CMM Process Performance (E.CMM.P Framework) comes as a result of incorporating its three main components; the 'Basic Structure (Main Body)': the practical workflow diagram of the CMM process (P.CMM.P diagram), the 'Main Elements': Practical Effectiveness Measures (P.E.Ms) or the Key Effectiveness Measures (K.E.Ms), and the 'Operational Mechanism': the set of interrelated procedures and instructions for linking the basic structure with the main elements. After accomplishing those main components based on the findings of the three phases discussed above, the next stage is designing the E.CMM.P framework, which follows two steps;

***Step1*:** integrating the Practical Effectiveness-Measures (P.E.Ms) within the practical CMM process diagram (P.CMM.P workflow diagram) through placing each measure at its point of measurement (Measure's Location) as defined in **Chapters IV** and **VI** and summarized in **Tables 4.16** and **8.1**. Each measure is indicated by a symbol that carries its code inside an oval at its own measurement point within the practical CMM process diagram, as clarified in **Figure 8.4**.

***Step2*:** setting the operational mechanism for connecting P.E.Ms (or could be just the K.E.Ms) within the P.CMM.P diagram. This is performed through placing the activities of the operational mechanism (Planning, Collecting, Analysis, and Improvement) and their procedures, sequentially, within the P.CMM.P workflow diagram. Each activity with its procedures is placed within a proposed area that can include one or more of the CMM function(s). The area of each activity is proposed by the researcher to be higher or lower (down) the concerned CMM function that is expected by its staff or department to be able to perform the proposed procedures of this activity. Those activities and their procedures are linked together with the practical effectiveness measures by the reporting and information system, using documents and reports that were observed during the site visits and suggested by the interviewees to be used for practicing these measures as discussed in **Chapter VI**, summarized and labelled in **Table 8.1**. Each group of P.E.Ms that are located in the same location within a CMM function is communicated and connected with the set of documents and reports that proposed for practicing these measures (see **Figure 8.4.**).

Based on performing the above two steps, a framework has been developed to integrate the practical effectiveness-measures within the practical workflow diagram of the CMM process, allowing an operational mechanism to communicate and operationalize those uniform measures within the workflow process (E.CMM.P Framework), as graphically depicted in **Figure 8.4**. **Figure 8.4** presents the main components that form the developed E.CMM.P Framework for Evaluating the Effectiveness of the CMM Process Performance in the large-scale concrete building projects within the Jordanian Construction Industry

(J.C.I). The detailed E.CMM.P Framework, including the Practical CMM functions and activities, the Practical Effectiveness-Measures (P.E.Ms), and the activities and procedures of the operational mechanism, is presented in **Appendix L**.

It is worth pointing out that the Key Effectiveness Measures (K.E.Ms), which are ranked as the highest ten important and practical measures simultaneously (see **Table 7.12**), can be applied instead of the all 26 Practical Effectiveness Measures (P.E.Ms) to establish a miniature and simplified framework to facilitate the process of measuring the effectiveness of the CMM performance within a project or company. This framework would include the main measures that can reasonably reflect the extent of the effectiveness of the performance of the CMM process that is intended to be evaluated.

In order to understand the mechanism of operating the E.CMM.P framework (including the roles of the operational mechanism activities) and illustrating the importance of the E.CMM.P framework in monitoring and evaluating the effectiveness of the CMM performance, an explanatory scenario is presented in the next section.

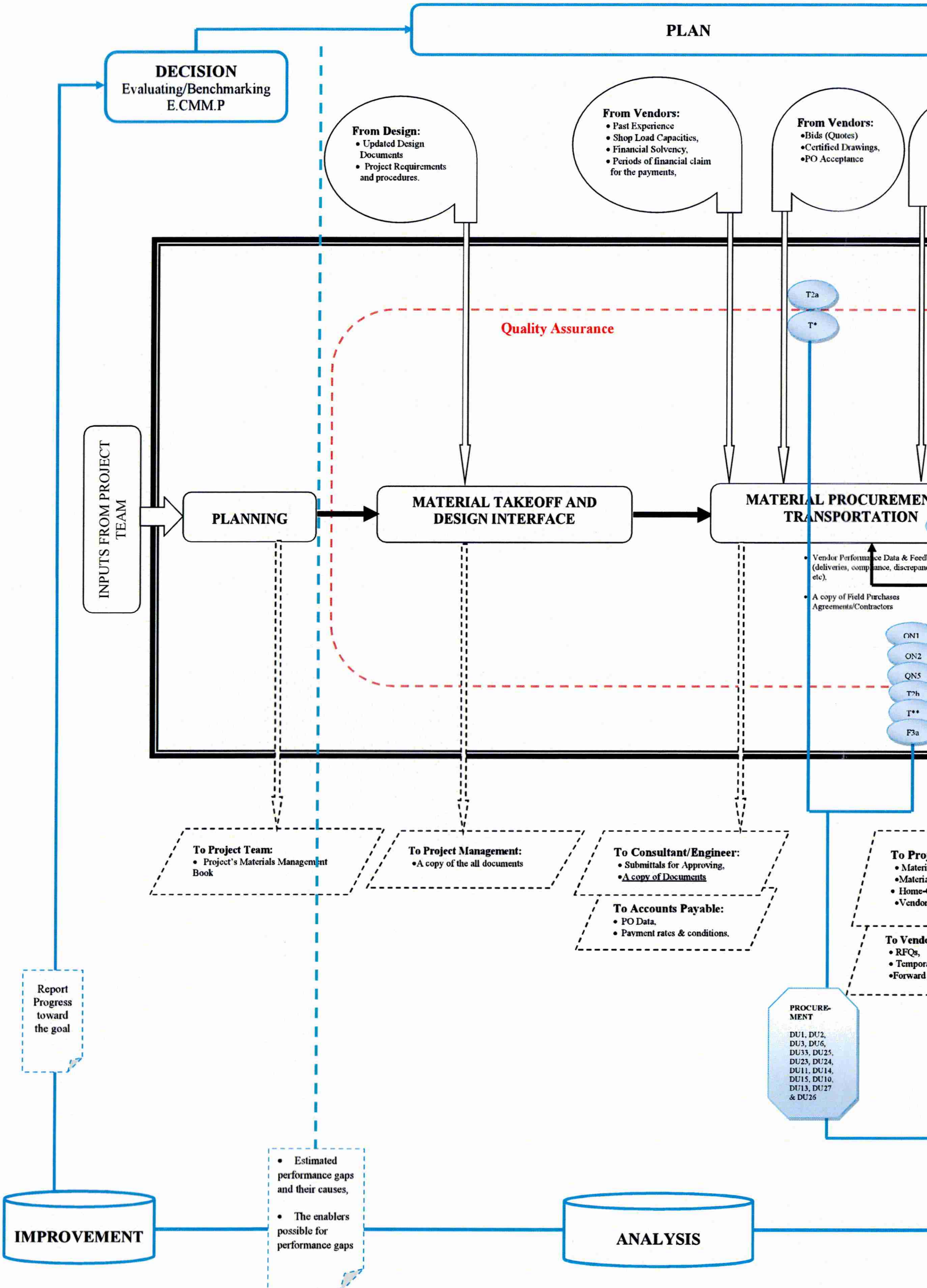

Figure 8.4: The Developed E.CMM.P Framework

8.4.3 An Explanatory Scenario for the E.CMM.P Framework Application:

This section provides a scenario for explaining the mechanism of implementing the developed E.CMM.P Framework within the CMM process or system of a building project or a contractor company. The scenario focuses on mechanism for operationalizing the Practical Effectiveness-Measures (P.E.Ms) into a CMM process for evaluating the effectiveness of its performance. The scenario also illustrates how the E.CMM.P framework could assist a project management-related staff or department in evaluating the performance of its current CMM system or process, and monitoring the impact of the continuous improvements that can be made on this system or process.

This scenario supposes a first class Jordanian building contractor firm has adopted and incorporated the E.CMM.P framework within its CMM system or CMM process of one or more of its large-scale concrete building projects. The scenario also assumes that the concerned CMM-related planning department within the 'Organisational Level' of this contractor decided to monitor the impact of applying a new strategy or technique that has been already applied to the CMM system (let's say, apply a new computerised system), or to investigate a defect that has been identified in performing of a CMM function (e.g. a Field Control function), based on the material-related reports. According to the E.CMM.P framework, the process of evaluating the effectiveness of the performance of that CMM function, or of monitoring the impact of applying the new technology will follow, sequentially, the following activities and procedures;

PLAN:

It is the first activity after that a manager, team, or department, who is usually responsible for one or both of the functions 'Planning' and 'Take-off' (e.g. the Planning & Following up Department), takes a decision to evaluating the CMM process; this interprets locating 'Making Decision' within the area of the 'Planning' function.

The first procedure under the 'Plan activity' is to identify which function of the CMM process is to be monitored or evaluated (the area of evaluation); let's say Field Control. Based on the evaluation area, the related Practical (or Key) effectiveness measures

(K/P.E.Ms), which fit the area of evaluation, are selected. The selected measures are those that are specified and allocated for evaluating the concerned function (their point-measurements are located within the area of evaluation). For example, if the area of evaluation selected is between the vendor and the 'Field Control', measures such as, AC1, AC2, C4, T**, or T6 would be selected; if the evaluation area selected is between the 'Field Control' and 'Construction Operation' (Craft-workers), the staff of planning action would select measures such as, Q2, C5, C*, T7, or Q*. After identifying the P.E.Ms that will be used, the following procedure involve planning the data collection process; for example, reporting-based (using the relevant documents, forms, and reports) or observation-based (using site visits and performance monitoring); internal or external data collection. This is followed by the procedures of forming and designating the unit or team that will be responsible for collecting and processing the required data, and then distributing the tasks and responsibilities on the participants. According to this research, it will be a unit called the 'Measurement and Follow up Unit' in this scenario. The final proposed procedure within the planning activity is to plan or define a mechanism 'Control System' for integrating measures and effectiveness-performance feedback into the 'Project Reporting System' (e.g. with daily, monthly or technical reports...etc.).

The majority of the procedures that are included under the 'Plan' activity are the responsibilities for the personnel within the functions of the 'Take-off' and 'Material Procurement', which are considered by the majority of Jordanian projects as the ones in charge of the most of the executive decisions and actions regarding planning and designing activities for materials management; this could be the main reason behind locating the 'Plan' activity within the area between the functions of 'Material Take-off' and 'Material Procurement', as demonstrated in **Figure 8.4**.

DATA COLLECTION & PROCESSING:

This activity involves procedures primarily associated with collecting and processing the required data and information. The activity relies on the data submitted by the previous activity 'Planning', and it is carried out by the 'Measurement and Follow up Unit', which has been already designated by the planning activity. As proposed earlier in **Section 8.4.1**, this unit could be located under the position of the 'Quality Management' function or department, as shown graphically in **Figure 8.4**. The rationale behind choosing this location is that, as derived from the cross-cases analysis, the staff of the 'Quality Management' function monitors most reports and feedbacks within the CMM process; besides, it has the authority to ask other personnel to submit the reports or documents needed. This enables the team or the operators of the 'Measurement and Follow up Unit' to access the majority of the data and information required for performing their job. From the researcher point of view, this function might be a supervisory one rather than an operational one; consequently, it could be more impartial and neutral.

This activity could be implemented on four stages; Input, Data Processing, Output, and Reporting (dissemination); each stage has a number of procedures as follows:

1. **INPUT:** this stage is concerned with identifying the required calculation formulas (equations) based on the P.E.Ms (or the K.E.Ms) that were selected by the planning activity team. Subsequently, the data and information that are required for calculating those measures are determined. These internal process data is gathered by requesting the documents, reports and forms that include the required data and information from the concerned department personnel to transfer them to the 'Measurement and Follow up Unit'; those procedures are represented graphically through the lines drawn between a set of the measures and the 'Measurement and Follow up Unit' through crossing the set of the documents required, (see **Figure 8.4**). Finally, the gathered data will be transferred to the next stage; data processing,
2. **DATA PROCESSING:** this stage includes preparing and entering the collected data, which were received from the previous stage, into a 'processing model', e.g. an Excel format, computerised database or manual system. Based on that, each selected P.E.Ms (or K.E.Ms) then is processed (calculated) separately by using their specific formulas and the data that are automatically stored in an Excel format, or manually. Finally, the values of the P.E.Ms (or K.E.Ms) are submitted separately to the next stage,
3. **OUTPUT:** This is the last stage in the activity of 'Data collection and Processing'; within this stage, the separated K/P.E.Ms values will be assembled into two groups: Group A^- & Group B^+, as illustrated in **Table 8.1**;
    - *Group A*: Measures best when they are as low as possible
    - *Group B*: Measures best when they are as high as possible

This is followed by summing K/P.E.Ms values, depending on their classification, to obtain the overall value of the effectiveness of the performance of the concerned CMM function (e.g. the Overall E.CMM.P Value = AC1 + AC2 + T6 - T** - C4).

Finally, reporting is the last procedure in the 'output stage'. Here, the results, whether the separate measures values and the overall value of the E.CMM.P, are submitted to the department or team, who was responsible for the establishment of this activity and its unit, within the 'Planning' activity. The selected effectiveness-measures, outputs, and the relevant information and data will be submitted either directly or on a period basis (monthly, quarterly), in a simple and structured format using the CMM report system. The activity's outputs will be used to conduct the next activity 'Analysis'.

ANALYSIS:

Based on the data outputs that were obtained and reported by the previous activity 'Data Collecting and Processing', the concerned department or team (who is in charge of accomplishing this activity) will carry out the next procedures and tasks: 1) Receiving the K/P.E.M values, which are included within the specific reports and incorporated into the company CMM related-Reports, and recording the values of the 'K/P.E.Ms into a 'P.E.Ms (or K.E.Ms) Performance Log'; 2) Comparing and calibrating the current K/P.E.Ms value with the previous K/P.E.Ms values that were calculated and obtained whether for; the different project stages, within the same stage or the period in other projects, before applying the new system or improvement, or with a relevant standard benchmark if applicable; and 3) Estimating the gaps in performance and their causes, and 4) identifying the potential enablers that can improve the performance of the CMM function or the entire CMM process.

The implementation of the 'Analysis' activity could be the responsibility of the same team or department that performs the 'Plan' activity, as they are responsible for creating the 'Measurement and Follow-up' unit' for performing the ' Data Collection and Processing' activity. This interprets locating the 'Analysis' activity within the same area where the 'Plan' activity is located (see **Figure 8.4)**. The outputs of this activity, including the estimated performance gaps and the enablers proposed for improving, will be forwarded to the next activity 'Improvement'.

IMPROVEMENT:

This is the last activity in the operational mechanism. The accomplishment of this activity depends on the output of the previous activity, the estimated performance gaps, the causes of the performance gaps, and the potential enablers that can improve the performance. The main procedures of this activity include setting the performance goals for improving and bridging the performance gap, implementing plans to bridge the gap and monitoring results, and developing a system for reporting progress toward the goal. Those tasks seem to be related to the 'Plan' context more than to other activities; thus, they could be carried out by the department or the team that is responsible for one or both the CMM functions 'Planning' or 'Material Take-off'; this might allow for positioning the activity of 'Improvement', either, within the area of 'Plan' activity, or under the Planning' Function '; where the action of 'Making Decision' is located; as shown in **Figure 8.4**.

To sum up, the explanatory scenario above can illuminate the importance of the developed E.CMM.P framework in providing a structured approach to continuously assess the effectiveness of the performance of a single function or the entire process of managing the building materials within the Jordanian large-scale concrete building projects. The importance of E.CMM.P Framework can manifested in the benefits of adopting this framework by the Jordanian building contractors for enhancing, continuously monitoring, evaluating, and analysing the impact of the continuous improvements that can be implemented within the CMM process. Moreover, the framework can provide a comparative assessment through evaluating the effectiveness of the CMM performance for the different stages of the project execution, different periods, or for the different projects. This greatly enables a CMM-related administrator to estimate the effectiveness-performance gaps and to identify their causes; thus choosing the suitable improvement course. Based on the relevant literature reviewed, the pilot studies conducted, and the cross-cases analysis performed, the lack of a standard benchmark was confirmed, regarding the performance of the CMM process that can be used for comparison. However, continuously recording the outputs and assessing the values of effectiveness of the CMM performance (K/P.E.Ms) can be a basis for creating a CMM performance database internally within a contractor organisation or externally within a construction-related organisation, such as, the Jordanian Construction Contractor Association (JCCA). This can also provide a basis to identify the best practice CMM process or performance within the

Jordanian building projects. Moreover, this mechanism could become later a standard benchmark for the performance of the CMM process in the Jordanian Construction Industry (J.C.I).

Given the similarity in the culture, weather, geographical nature, style and the type of the buildings, and building materials used in the vast majority of the Arab countries, one cannot exaggerate if one asserts that this framework might offer a basis for establishing a benchmarking mechanism that can be implemented within the entire Arab region (Arab Construction Industry, A.C.I).

8.5 SUMMARY OF THE CHAPTER

This chapter presented the process of development of the E.CMM.P framework. The chapter started with introducing the six stages of developing the framework, which were categorized into four main phases; *phase I*: developing the workflow diagram of the CMM process practiced within the Jordanian projects; *phase II*: establishing a set of Practical Effectiveness-Measures (P.E.Ms) that can be used within the Jordanian building projects; *phase III*: setting out an operational mechanism and designing the final E.CMM.P framework; *phase IV*: conducting the framework validation process (this is presented in the next chapter). The chapter then proceeds to a detailed explanation of the first three phases of developing the framework; *phases I, II, and III.*

The chapter sought to enhance understanding of building the framework based on the research data sources that were obtained from the findings of the literature review process and the outputs of the data collection techniques. As a result of consolidating the findings of the development phases, the mechanism of operationalizing the practical effectiveness-measures for evaluating the performance of the CMM process with the Jordanian large-scale concrete building projects was graphically designed in an operational framework format; 'The Final Developed E.CMM.P Framework'.

The next chapter (Chapter IX) will present the '*phase IV*: conducting the framework validation process'. It will focus on explaining the validation process of the developed E.CMM.P Framework, including summarizing the 'Formative Evaluation' stage, and explaining and discussing, in detail, the 'Summative Evaluation'.

CHAPTER IX:

THE E.CMM.P FRAMEWORK VALIDATION

9.0 INTRODUCTION TO THE CHAPTER:

Many aspects are considered to ensure research validation: using multiple data collection approaches (Triangulation), conducting interviews and filling up the questionnaires by highly experienced professionals and functional experts, employing electronic software for analysing the data collected and conducting pilot studies among many others (see **Sections 5.6.3.1** and **5.6.3.2** for more details about the research validity and reliability). In **Chapter IX**, efforts are concentrated on presenting and discussing the fourth and final phase of developing the E.CMM.P framework; '*Phase IV*: conducting the 'framework validation process'. The chapter begins with introducing the aim and objectives of the validation process, and then providing a summary for the process of conducting of the first stage of the framework validation process (the Formative Evaluation), and the findings obtained. The chapter then proceeds to report, in detail, the final stage of the validation process (the Summative Evaluation), including outlining the evaluators profiles, presenting the responses received from the evaluators, and analysing the comments and suggestions made by the evaluators.

9.1 THE VALIDATION AIM AND OBJECTIVES:

The validation process mainly aims to assess the applicability and appropriateness of the developed 'E.CMM.P Framework' for communicating the integrated CMM Functions and operationalizing their Practical Effectiveness Measures (P.E.M) to monitor and evaluate the effectiveness of the CMM performance within the large-scale concrete building projects in the Jordanian Construction Industry. The specific objectives of this validation process can be summarised in the following points:

- To examine and evaluate the acceptability and adaptability of the concept of the framework (measuring and benchmarking the effectiveness of the performance of the CMM process) within the Jordanian Construction Industry.
- To assess the usability and suitability of the E.CMM.P framework, and its applicability for implementation as a practical management tool within the Jordanian building projects and contractors; evaluating the ease of the framework to be used, and the availability of the required data.

- To obtain expert validation and to determine whether the framework needs any modification to promote its operationality (implementation arrangements) or effectiveness, through obtaining professional comments and recommendations,
- To assess the probable benefits of using the framework to enhance monitoring and evaluating the continuous improvements in the CMM process within the different stages of the project or between projects, and its importance with respect to providing a basis for establishing a standard benchmark.

9.2 THE E.CMM.P FRAMEWORK VALIDATION PROCESS:

The validation of the developed E.CMM.P framework is the final stage in developing the framework (*Stage 6*). According to Faulkner (1998), Gediga, Hamborg and Duntsch (1999), Anumba and Scott (2001), Binti-Kasim (2008), and Ali (2011) evaluation plays a significant role in the process of a framework development. They assert that the main role of evaluation is to detect errors as early as possible in the development cycle, and to eliminate any problems that could be presented in a final developed framework. Accordingly, the validation process of the E.CMM.P framework includes evaluating the main body (P.CMM.P workflow diagram) and the main elements (P.E.Ms) of the E.CMM.P framework, and evaluating the actual final developed framework. The evaluation process, in the current research, was carried out on two evaluation stages, in terms of the time they take place in the framework development cycle, using two types of evaluation activity; 'Formative Evaluation' is implemented during the framework development stages whereas 'Summative Evaluation' occurs after the E.CMM.P framework has been developed, as discussed below.

9.2.1 The Framework Formative Evaluation:

This is the first stage of the framework validation process; it was undertaken during the development cycle before the final design of the developed framework is made. The framework formative evaluation is intended to assess the main components of the E.CMM.P framework that were developed based on the findings that resulted from the framework development phases: Phases I and Phase II (see previous chapter). This is based on attempting to obtain wider experts' notions and opinions about whether the practical CMM diagram can reflect the realistic practice of the CMM processes within the

Jordanian building projects, and on exploring the extent of usability of the proposed effectiveness-measures and their applicability to those projects.

The formative evaluation focused on evaluating the thirty-three effectiveness-measures that were proposed for assessing the effectiveness of the CMM performance which were developed on the basis of the literature review process. The evaluation areas for the proposed effectiveness-measures involved the utilization of measures (past, current in use, and potential), their importance in communicating the effectiveness and their applicability, in addition to identifying the significant barriers related to measures implementation, and the exploration of any additional measures used. Moreover, formative evaluation endeavoured to assess the practical workflow diagram that depicts the CMM process practiced in the J.C.I, which has been developed out of the findings of the cross-cases analysis, in terms of its ability to reflect what is currently practiced in the real-life of the CMM process within the Jordanian large-scale concrete building projects.

A 'Group Administrated Questionnaire' survey was conducted to gather a wider responses from the functional experts in the Jordanian Construction Industry (J.C.I). Out of a total of **52** questionnaires that were handed to the construction professional experts, **47** completed questionnaires that were used in the analysis. The data collected from the questionnaire survey was prepared, sorted, classified, and then entered into statistical software package (SPSS 19) for analysis. Finally, this was followed by discussing the outputs and obtaining the findings. The sampling size, the design, and the conducting and analysing process of the questionnaire survey were provided in **Sections 5.5.3.3, 5.6.1.3**, and **7.1** respectively.

In fact, the analysis of the data collected and the discussion of the findings derived are presented in details in **Chapter VII**. In this section, some noticeable findings derived from the formative evaluation are re-reported and summarised below,

- The diversity of the respondents' positions and their expertise, which covers a broad range of CMM-related experiences, together with their long experience of working in areas related to material management within the Jordanian building projects, indicate that very well experienced respondents have participated in the formative evaluation (see tables and figures in **Section 7.2.1**). This indicates that the information gathered was reasonably reliable, and that they provided more realistic assessment of the CMM process in the Jordanian Construction Industry (J.C.I) and an in-depth evaluation of the effectiveness measures that are proposed to assess its performance. This can consequently increase the validity and reliability of the results, and thus the validity and reliability of the entire research project.

- Regarding the similarity between the results of the questionnaire survey and what has been discovered by the main investigation (the Case Study Technique) concerning the measures' utilization and practicality, it was found out that the vast majority of the measures, which were ranked among the ten mostly used and practical measures, are those found in current use within one or more than one of the selected case studies; they are included within the set of 'Practical Effectiveness Measures' that can be used for evaluating the E.CMM.P for the large-scale concrete building projects in the J.C.I (see tables and figures in **Section 7.2.2**). This could offer a further support for the validity and reliability of the outcomes of the main investigation (regarding the framework's elements) that are employed for developing the E.CMM.P framework, which thus confirms the validity and reliability of the framework that has been developed based on those outcomes.
- Giving the opportunity to 47 functional experts with extensive experience and broad CMM-related expertise to add any new measures did not identify any additional measures that differ considerably from those established whether from the literature review (the proposed set of the effectiveness measures) or developed from the outputs of the main investigation (the practical effectiveness measures), (see **Section 7.2.3)**. This basically indicates that the proposed set of effectiveness measures along with the practical measures is appropriate sampling for the potential materials management effectiveness measures; they could represent the population of the possible measures within the Jordanian Construction Industry. This indication confirms the validity and reliability of the effectiveness measures, which, in turn, confirms the validity of the E.CMM.P Framework developed.
- As discussed in **Section 7.2.4**, the outcomes of evaluating the developed PCMMP workflow diagram, in terms of its ability to reflect the CMM process that is practiced within the J.C.I, conclude that the majority of the respondents confirm that the developed PCMMP workflow diagram can embody and reflect what is currently practiced in the real-life of the CMM process within the large-scale concrete building

projects in the J.C.I, which in turn confirm the validity of the E.CMM.P Framework developed.

In short, the confirmation of the reliability and validity of the findings involved in developing the components of the E.CMM.P framework (PCMMP diagram and P.E.Ms), in addition to a number of reliability and validity statistical tests conducted (Cronbach's alpha and Chi-square), can significantly contribute to validating the final developed E.CMM.P framework, which will be detailed in the next section.

9.2.2 The Framework Summative Evaluation:

The summative evaluation of the final E.CMM.P framework developed is the final phase of the research project design which is the focus of the *Phase IV* and this section. It aims to accomplish the objectives of the validation process that are mentioned above through evaluating the developed framework in terms of its usability and applicability, assessing the barriers impeding the implementation of the framework, the likely benefits of using the framework, and the availability of the data and documents necessary for operationalizing the framework.

According to Fellows and Liu (2008) and Ali (2011), there are a number of different methods to be applied for validating such frameworks, among the most common are: 1) practically implementing the framework in the place that needs to be applied, 2) presenting the framework in the workshop and inviting people highly-experienced in the relevant field to discuss the framework and provide feedback, and 3) sending the framework to highly-experienced professionals and experts in the relevant area. The first approach needs permission from a contractor company to practice the framework within its CMM system, which is very difficult to obtain; additionally, this approach is time consuming and it could be more suitable for models than frameworks. With regard to the second approach, despite presenting the framework's components and the final framework in some non-relevant conferences and seminars (see **Section 9.2.2.3**), organising a relevant workshop or seminar for presenting the developed framework, and inviting the CMM-related experts for discussion and feedback was considered to be time consuming and costly; it is also difficult to invite those experts together for a workshop. Additionally, there are no workshops or seminars that are presently planned. The third method, sending the framework to experts in the relevant area, is a widely practised approach among those researches dealing with construction management, building project management, and construction materials management; they are found to provide good results; among them are Bhutto (2004), Binti-Kasim (2008), Fapohunda (2009), Obiajunwa (2010), and Ali (2011). This was also recommended by Inglis (2008) and Higham (2014), since it avoids any bias that could be made in the event of using an interview approach. Considering the busy schedules of the participants, this approach allowed them to review the framework at their own time, in addition to allowing them to consult their relevant documents and colleagues while reviewing the framework (Ali, 2011). Accordingly, the method of 'sending the developed framework to experienced professionals and experts for the validation' is adopted in the current research project.

For the purpose of validating the framework for evaluating the effectiveness of the performance of the CMM process within the Jordanian large-scale concrete building projects, selected senior and highly experienced individuals in the Jordanian construction sector were contacted. In order to ensure that the evaluation of the framework will be sufficiently strong, the selection of the respondents was based on the following criteria: they have (i) to be professionally qualified in construction management, (ii) to have a long working experience in the Jordanian Construction Industry, (iii) to have a good knowledge in managing the construction materials within the Jordanian large-scale building projects, and (iv) to have the willingness and desire to participate in this validation process.

Based on the above criteria, seven individuals were selected to evaluate the E.CMM.P framework, including highly experienced professionals, functional experts, and senior material-related managers. A copy of the developed E.CMM.P framework along with some explanatory documents, including the scenario of using the framework, was sent to each of the seven respondents. However, only five individuals (Validators/ Evaluators) kindly returned the feedback with a response rate of 71.4%, (see **Table 9.1** for more details).

Table 9.1: Details of Evaluators who participated in Summative Evaluation

Evaluator ID	*Position*	*Details*
I	Senior Consultant of JCI	Co-Founder and Managing Director for one of the first corporations of construction management and planning consultancy in Jordan, 40 years experience in managing and supervision large-scale construction projects. He is one of the decision makers in the J.C.I. He participated in the Pilot Study II
II	Senior Construction Manager	30 years experience in the Jordanian Construction Industry, 18 years of involving in the issues of controlling and managing construction materials. He is one of the Keys-of-Contact of the research
III	Consultant - Projects Director	Nearly 25 years experience in construction industry, more than 15 years working consultant organisation in the field of projects management, He participated in the main investigation.
IV	Project Manager	30 years experience in J.C.I, and about 20 years of them in managing high-rise and complex concrete building projects, He participated in the main investigation.
V	Senior Academician	More than 25 teaching subjects related to construction management and materials management, in addition to participating in consulting large-scale construction projects. He is one of the Keys-of-Contact of the research

9.2.2.1 Feedback and Analysis:

Generally, very positive and encouraging feedback was received from the expert evaluators within the second stage of the E.CMM.P framework validation process (Summative Evaluation). The selected evaluators clearly expressed their opinion and provided some suggestions to further modify and improve the proposed framework. The views, suggestions, and comments from each evaluator along with follow-up actions and analysis are presented below;

FEEDBACK AND COMMENTS FROM EVALUATOR (I):

Generally, no one can deny that there is a need for monitoring the performance of the CMM process, and I believe that applying the E.CMM.P framework in the Jordanian contractor companies will be very useful for periodical and systematic evaluation for the *performance of their CMM functions. It could also provide very good basis for establishing a standard benchmarking relating to CMM performance that can be used within the Jordanian Construction Industry. I totally agree with adopting this mechanism to be used within the J.C.I. However, I have some comments regarding the implementation issues;*

- *I think that applying such framework requires setting up an implementation strategy, whether within the framework within a contractor organisation or when it is widely implemented it within the J.C.I. This could involve the relevant public and private associations and organisations, such as, the Jordanian Construction Contractors Association (JCCI), and the Board of the National Building Code.*
- *Considering the framework application scenario, the framework is straightforward and easy to follow and apply, but I suggest preparing a handbook that is specially written for the process of evaluating the effectiveness of the CMM performance. This handbook would serve as a procedural framework and a resource document for implementing the developed framework. The handbook could include definitions for the measures used, step-by-step plan for implementing the framework within a contractor company, and some other explanatory information.*
- *I believe that implementing the framework for benchmarking among contractors or different projects through evaluating the effectiveness of the CMM process could be greatly based on sharing competitive information and data that would be used as comparative data between the contractor organisations. This might rarely occur within the Jordanian construction companies, and I think extraordinary steps should be taken to increase the acceptance among the construction contractors through ensuring the security of the competitive data and promoting the trust between the contractors. For that purpose, I think that the evaluation process should be conducted under the auspices of an independent governmental or academic institution.*

ANALYSIS OF FEEDBACK AND COMMENTS OF THE EVALUATOR (I):

- The framework recommended an operational mechanism for implementing the developed framework within a building project or a contractor, which provides interrelated actions and procedures for the use of the effectiveness-measures for evaluating the performance of the CMM process within Jordanian large-scale concrete building projects. This could represent an implementation strategy for the framework within a company or project. It is important to develop a comprehensive implementation strategy for incorporating the framework into the relevant institutions within the Jordanian Construction Industry. However, adopting the framework by a relevant public institution, such as JCCA to oblige the contractors to apply it needs more investigations in future researches.

- In fact, the developed E.CMM.P framework is provided with a description for the measures used, operational mechanism, and application scenario which could serve as resource document for implementing the framework. Detailed handbook is very useful for providing project managers or/and the evaluation team with the required information and instructions of using the effectiveness-measures and applying the framework. However, issuing a handbook is usually conducted within the plan of disseminating and distributing the framework, which could be placed under the implementation strategy, rather than within the process of framework development.
- The developed framework was built on adopting the internal benchmarking technique as a basis for establishing the operational mechanism of the framework. Within this technique, a building company collects data on its own CMM process performance and evaluation so as to make improvements through comparing the performance of its CMM process with that of the previous times (past years), with the different stages of its project, or among its projects. Readily available data and information and the lack of problems associated with confidentiality or the non-disclosure of data enables this technique to implement the framework without resorting to share competitive information and data between the contractors.

In summary, the evaluator (I) acknowledged that:

- The framework is straightforward and easy to follow and apply.
- The framework is very useful for providing structured procedures for evaluating the effectiveness of the performance of the CMM process that can be implemented periodically.
- The developed framework provides a good basis for establishing a unified benchmarking for the performance of the CMM process in the J.C.I.
- The concept of the framework is accepted within the J.C.I.

FEEDBACK AND COMMENTS FROM EVALUATOR (II):

The suggested workflow diagram of the CMM process, which on the basis of which the E.CMM.P framework is developed, covers the major integrated functions and activities that could form the CMM process within the most Jordanian building projects. I acknowledge that the effectiveness-measures are well conceived and that the data and information required for the proposed equations are readily available. Following is the feedback for the proposed framework;

- *I observed that although the major functions of the construction materials management process are included into the CMM workflow diagram, some sub-functions were missed, such as function of 'Material Delivery' that could include materials shipping and receiving.*
- *The proposed framework provides an understandable operational mechanism for operationalizing the framework, which includes a clear procedures and instructions for the use of the effectiveness-measures to evaluate the performance of the CMM process within the framework. However, I think that the team who has the authority to perform the activity of 'Plan' should also include individuals from 'CMM Planning' function or department. Accordingly, the proposed location of the 'Plan' activity within the operational mechanism should be expanded to include the CMM 'Planning' function besides the functions of 'Material Take-off' and 'Material Procurement'.*
- *The suggested framework is limited; it is only dedicated to evaluate the CMM performance within the Jordanian large-scale concrete building projects, which, I believe, represent an important segment of the investment projects in the Jordanian construction sector, in particular, when a large number of Arab investors tended to invest in the kingdom after the so-called Arab Spring Events. However,*
- *I would suggest that the developed framework also accommodate (ingest) the existence of the small and medium-scale building projects, which represent wide range of the projects in the Jordanian Construction Industry. This would increase the scope of benefit from this framework within the Jordanian construction sector.*

ANALYSIS OF FEEDBACK AND COMMENTS OF THE EVALUATOR (II):

- The framework was proposed for enhancing the evaluation and monitoring of the performance of the CMM process rather than for supplying materials processes. For that reason along with the purpose of simplifying the framework and making it more effective, the developed framework focused on the main functions that were found to be commonly used within the vast majority of the building projects. Nevertheless, this does not mean ignoring the sub-functions of the CMM process; the majority of the CMM sub-functions and activities have been incorporated into/within the main CMM functions as activities. Regarding materials delivery, activities such as, ,developing material delivery plan', 'developing a delivery tracking system', 'monitoring transport status and receiving', and 'preparing shipping and receiving data', have been included under the function of the 'Material Procurement and Transportation'.

- The locations of the operational mechanism's activities have been proposed based on the procedures involved underneath. Considering the procedures that are included under 'Plan' activity, one can note that the majority of them are procedural and executive decisions related to planning and designing activities, which are usually the responsibility of 'Material Take-off' and 'Material Procurement' functions. However, the proposed locations for the mechanism activities are not obligatory, and the framework provides flexibility for a change to fit the functional structure of a contractor company; this will not affect the aims or the operational mechanism of the developed framework.
- The E.CMM.P framework has been developed on the basis of the workflow diagram of the CMM process, which represented the basic structure for the framework. The process of managing the construction materials within small building projects in Jordan, or elsewhere, does not have standardized procedures or particular criteria that can characterize its own composition. The functions and activities of managing materials within the small projects usually depend on the contractors' strategies and the persons' behaviour and talents. Moreover, the influence of the lack of proper materials management within the large-scale projects is enormous comparing to that of small projects.

In summary, the evaluator (II) acknowledged that:

- The suggested framework provides CMM workflow diagram that covers the major integrated functions and activities that could form the CMM process within the most Jordanian building projects.

- The effectiveness-measures are well conceived and practical to be implemented within the Jordanian large-scale projects, as the most documents and reports needed for practicing these measures are available
- The proposed operational mechanism, which is used for operationalizing the framework, is clear and embraces a group of the procedures and instructions that clearly explain the use of the effectiveness-measures to evaluate the performance of the CMM process within the framework.

FEEDBACK AND COMMENTS FROM EVALUATOR (III):

The research project is very rational and logical, and the framework is very beneficial; it has been built on thorough and coherent findings. The established effectiveness-measures are very extensive and they address a wide range of the aspects and issues related to the performance of materials management into the Jordanian building projects, which indeed need to be monitored, measured, and evaluated. I strongly agree with most activities and procedures that form the operational mechanism; they are applicable, viable, and straightforward to be incorporated within the reporting system of the majority of the Jordanian first class construction contractors. I am happy to suggest integrating the E.CMM.P within my organisation affirming of the following;

- *The operational mechanism of the E.CMM.P framework should be operated by an independent team or unit, which is directly subjected to the projects management department with the contractor organisational level or the project's consultant, instead of the suggested unit. This can support the impartiality and transparency with respect to collecting the data, and they can strengthen the reliability and credibility of the results.*
- *As the operational mechanism of operating the effectiveness-measures would normally be operationalized internally, preparing and submitting the relevant reports should become a routine activity with minimal additional efforts. Consequently, I think that it is essential to propose a simple, an unified, and a systematic format for reporting the effectiveness of the performance of the CMM process. (Effectiveness-measures). This report, which can be called 'E.CMM.P Report', would contain comparative information on materials management performance that would be described in generic terms, and the effectiveness-measures that would be coded by unified and featured symbols.*

ANALYSIS OF FEEDBACK AND COMMENTS FROM EVALUATOR (III):

- The unit of 'Measurement and Follow up' has been mainly proposed to be engaged in the systematic collection and dissemination process within the framework for conducting those procedures associated with collecting and processing the related CMM process performance data and information, and disseminating the relevant outputs. The location of the unit was proposed within the area where the 'Quality Management' function is located to allow its team to access most of the required data; as the personnel of this function have an authority to monitor and investigate most reports and feedback related to the performance of the CMM process and to request any documents or data needed. The unit's location is not compulsory and can be re-positioned according to the distribution of the responsibilities and activities of the CMM functions, and to commensurate with the functional structure of a contractor company. The developed E.CMM.P framework recommended that this unit should be impartial and neutral, but it should follow to contractor departments, as the purpose of the framework is to monitor the performance of the CMM process to identify the required improvements rather than to judge the performance of the contractor.
- The E.CMM.P framework stresses setting a simple and structured format for reporting the effectiveness-measures and relevant performance information and data; it proposes incorporating reporting the selected effectiveness-measures, the evaluation results, and the relevant information and data within the project reporting system. This is stipulated in a number of procedures within the framework's operational mechanism that stipulates procedures such as those of 'Plan the mechanism 'Control System' of integrating measures and effectiveness performance feedback into the Project Reporting System' (in the plan activity), and report the results (separate measures & overall E.CMM.P) on a period (monthly, quarterly) basis to the department(s) concerned. Moreover, the proposed framework confirms the importance of using the coding system for effectiveness-measures, data, and documents, and using generic terms for the CMM functions and activities. This code would be used on all project(s) reports and communications; it would also serve to disassociate relevant performance data from the project information. This can be noted from the use identification code for the P.E.Ms (such as, AC1, Q2, T6… and so on), and for the required documents (such as, DU1, DU2, DU3,…etc.).

In summary, the evaluator (III) acknowledged that:

- The research project is significant and that it provides a good contribution to society and knowledge.
- The framework is very helpful and it is built on thorough and coherent findings.
- The operational mechanism and procedures underneath are applicable to the most Jordanian first class construction contractors.
- The established effectiveness-measures cover a wide range of the CMM activities that the extent of their performance can express the performance of the CMM process.
- It is possible to adopt the framework by the concerned organisations.

FEEDBACK AND COMMENTS FROM EVALUATOR (IV):

Generally, the concept of the proposed framework is a very good starting point for the building contractor to benchmark and evaluate the performance of their CMM system; it is also applicable within the Jordanian building projects. I am really impressed by using the diagram technique for designing the E.CMM.P framework; a diagram that is often better than using many words, it helps to better understand the framework. I can follow the E.CMM.P framework, CMM workflow diagram, and the sub-diagrams of the CMM functions, and I can understand what they are portraying. I must commend your ability to put and portray the entire CMM process and the necessary mechanism, including activities and procedures, for operationalizing the effectiveness-measures into the CMM process within one framework, on a piece of paper. The following are some questions and queries that came to my mind when I was reading the framework design report;

- *The process of supplying and managing the building materials usually involves number of participants including owner, contractor, and vendor or/and supplier. The performance of each of those participants can influence the performance of the materials management process within a building project. From reviewing the effectiveness-measures, particularly, the purpose of these measures, I observed that you focused on measuring and evaluating the performance of the CMM process from the contractor side. I'm wondering whether the performance of the vendor has been calculated or considered in evaluating the performance of the entire CMM process.*
- *In the same context of the previous question, the large-scale building projects are usually implemented by a main contractor and number of sub-contractors underneath. So, my question is that; Have you considered the existence of the sub-*

contractor as an important element into the process of executing a building project, while developing the E.CMM.P framework, particularly, establishing the proposed effectiveness-measures?

- *I acknowledge that the CMM workflow diagram into the proposed framework depicts the most common functions and activities that can be practiced within the Jordanian large-scale building projects. However, one of the well-known features that characterise the construction projects is 'uniqueness'. This can lead to some changes in the process of the CMM from one project to another, including omitting a function or some activities that exist in your framework, or adding an additional function or activities that are not cited in your framework. My query is that, do you think, the proposed framework is flexible enough to accept any changes that can occur on the structure of the CMM process without affecting the functionality of the framework?*
- *In the context of the uniqueness of the construction projects, owing to the natural of the project and the environment surrounding, the type of the materials, items, and equipment used can differ from one project to another. This difference could be very apparent and visible within the materials that are imported for specific requirements (certain desires or needs) or those that are used for the finishing works. I'm wondering if you took the types of materials into your consideration when developing the framework.*
- *The 26 practical effectiveness measures (P.E.Ms) or even the 33 proposed measures do assess the performance of a good number of the functions and actions related to the CMM process, and they can be practiced within the Jordanian projects. In addition, the use of all these measures for evaluating the performance of the CMM process could provide more accurate index. However, the question to be raised is whether it is necessary to integrate all these measures to evaluate the CMM performance? I think, for effective use for the framework and for minimizing the time spent for collecting data, there is a need to rank the practical effectiveness-measures in order to indentify the most important measures, and then select number of them to evaluate the effectiveness of the CMM performance.*

ANALYSIS OF FEEDBACK AND COMMENTS FROM EVALUATOR (IV):

- The framework has been developed for the purpose of evaluating the construction materials management process, which is defined as 'controlling the movement of materials within a contractor organisation' (see **Section 2.8** and **Figure 2.7**). Based on this definition, the workflow diagram of the CMM process was developed to include the functions and activities that are practiced for managing the building materials within a contractor organisation. Accordingly, the developed framework focused on evaluating the effectiveness of the performance of those functions that form the process of the CMM. However, the performance of the vendors is prepared, analysed and evaluated within the functions of the CMM process ('Material Procurement-Vendor Inquiry', 'Field Control', and 'Warehousing'), and the outputs are incorporated into the framework as feedback. Moreover, number of the effectiveness-measures are located as the interface between the vendor and many CMM functions, such as, AC1, AC2, T6, T*, C4, and most measures of 'Quantity' attribute.
- The framework has been proposed for evaluating the performance of the CMM process within the Jordanian building projects that are mainly implemented by the main contractor who, largely, responsible for supplying and managing all the required materials on-site of project. The sub-contractors are considered as tools utilized to implement certain job or parts of the project under the authority of the main contractor, but they have no authority to supply building materials, or to set their own plan or strategy to manage the materials. Moreover, the purpose of the framework is to evaluate the performance of the CMM functions and activities regardless of who is the contractor's department or the team that carried out those functions or activities.
- The E.CMM.P framework was, basically, built on the typical workflow diagram of the CMM process for a typical building project, which then on its basis, the practical CMM workflow diagram within the Jordanian project was built. The development of these two diagrams was based on the findings resulting from the in-depth literature review and critical cross-cases analysis. Thus, the developed CMM workflow diagram that is considered as the basic structure of the framework could reflect the major functions and the activities that can form the majority of the building projects.

Moreover, it is very possible to introduce some modifications on the framework to suit the changes that can occur on the sequence or the form of the functions.

- The framework has been proposed to evaluate the effectiveness of the performance of the CMM process within the skeleton stage of the large-scale concrete building projects. Thus, the term 'materials', in this research work, refers to those raw materials, component parts, consumables, and equipment used for implementing that stage of the concrete projects, with some emphasis on some wide-used materials such as; 'Concrete' (as bulk materials), 'Reinforcement Structural Steel' (as fabricated materials), and 'Insulation/Isolation Boards' (as engineered materials). Among many rationales for this selection, which are highlighted in Chapters One and Three, are that the Arab Construction Industry is a concrete-based and that a large percentage of the materials, which are used in these projects, are exploited during the skeleton stage. In fact, this customization helps in facilitating the development of a typical and unified workflow diagram for the CMM process.
- The E.CMM.P framework is constructed on the basis 26 practical effectiveness-measures (P.E.Ms) that are found practical to be implemented within the Jordanian building projects. However, the framework and its proposed operational mechanism gives the operator the freedom to choose the measures that suit his/her aim(s) for conducting the evaluation process, or those that suit the function or the activity that is intended to be measured. With regard to the ranking order of measures, ranking the measures has been established in the first stage of the framework validation process (Formative Evaluation). At that stage, the proposed effectiveness-measures were ranked in terms of three aspects; 1) their utilization (whether they were used in the past or are currently in use), 2) their importance in communicating effectiveness, and 3) their practicality to be implement within the J.C.I, the analysis and the obtained results are presented in **Section 7.2.2**. Moreover, examining the association between the importance and practicality of the measures concluded that eight of the ten highest ranked measures considered important have also been ranked among the ten highest as being practical to implement, even though they are in a slightly different sequence. Those measures, which are ranked as the highest ten important and practical measures simultaneously, can be considered as the Key Effectiveness Measures (K.E.Ms); they can be adopted and used within the E.CMM.P framework instead of the 26 P.E.Ms, for the purpose of minimizing the time and effort spent in

collecting and processing the relevant data and information (see **Table 7.12** and **Figure 7.6**).

In summary, the evaluator (IV) acknowledged that:

- The E.CMM.P framework concept is very helpful; it serves as a good source or technique for the building contractors to benchmark the performance of their CMM process.
- The framework is applicable within the Jordanian building projects.
- The use of the diagram technique for development is very effective.
- The proposed workflow diagrams and mechanism that form the framework are understandable; they are also easy to be followed.
- The CMM workflow diagram within the proposed framework includes the most common functions and activities that can be practiced within the Jordanian large-scale building projects.
- The proposed effectiveness-measures can evaluate the performance of a good number of the functions and actions related to the CMM process within the Jordanian projects, moreover, they can provide an accurate index.

FEEDBACK AND COMMENTS FROM PARTICIPANT (V):

I have reviewed the developed framework and read the attached development reports, and I generally find it a very good piece of work, which can open the door for the concerned experts, academicians, and professionals to search on very important issue that was absent in the Jordanian construction field; 'measuring the effectiveness of the performance'. The E.CMM.P framework proposes a new idea and methodology for evaluating the performance of the CMM process, which I believe it can bring about unexpected improvements in managing the building materials within the Jordanian building projects if adopted properly. This piece of work would be very valuable for new graduate engineers as it provides them with a good basis to understand the CMM process and the methods of assessment, and for experienced CMM professionals to assist them to evaluate and improve their current CMM system. I strongly confirm that incorporating the E.CMM.P framework can be managed within the Jordanian construction organisations, as it is compatible with the process of the CMM used and information system; besides the data required are easy to obtain. The comments I have made below are mostly suggestions.

- *For effective implementation of the developed E.CMM.P framework within the Jordanian Construction Industry, a great deal of education is required, in particular in aspects like the importance of evaluating the CMM process and the mechanism and methodologies to do so.*
- *I would suggest training course is provided by the designated evaluating CMM team or department that serves those who could be involved in the evaluation process. The topics of this training course(s) could include the importance of evaluating the performance of the CMM process, the meaning and location the effectiveness-measures, mechanism of collecting and analysing the required data, and the means of integrating the measure and the framework feedback into the current materials management reporting system that is used within the contractor organisation or the building project.*
- *I agree with the most effectiveness-measures that you have proposed for evaluating the performance CMM, and I believe that the majority of them can provide a good indicator for the performance of one or more activity of the CMM process. I also believe that most of the equations, which have been proposed for calculating those measures, reflect the descriptions of their measures, however, I think more clarification for these equations is required, particularly, describing and explaining, with some detail, the terminologies used in those equations.*
- *The existence of effectiveness-measures' formulas and the operational mechanism for operationalizing those measures within the CMM process for evaluating its performance made me think in establishing computerized system or a software for quantitatively measuring the performance of the CMM process. This computerized system could facilitate the process of evaluating the CMM process routinely, and help a contractor to record and integrate the measures values into the company's database, and then to conduct a benchmarking process whether internally through comparing between the contractor' projects or externally between the contractors.*
- *Establishing a specific team(s) for performing and following up the process of evaluating the performance of the CMM process (the application of the framework) can augment the effectiveness of implementing the E.CMM.P framework within both the organisational-level of a contractor and the field-level of the project. However, you have to be aware that this can increase the number of the project management staff that can affect, even slightly, the usual project budget.*

- *Could you summarize in one word, what the key criterion or indicator for measuring the performance of the construction material management process is? I will be excited to read the answer in the final version of your research work.*

ANALYSIS OF FEEDBACK AND COMMENTS FROM EVALUATOR (V):

- In fact, there is an urgent need for education concerning the assessment of the performance of the CMM process in the Jordanian Construction Industry. This can be managed either through introducing the relevant subjects within the special curriculum in construction management sections, or through offering private training courses into the concerned contractors' organisations or projects. The training course would serve to initiate similar performance-assessment activities within the industry by introducing uniform measurement terminology and methodologies to the performance-assessment participants. This will help in disseminating the process of evaluating the performance of the CMM systems into the culture of the Jordanian Construction Industry. However, the process of educating and training the concerned people within the JCI could be futuristic step, which can be part of the implementation strategy of the E.CMM.P framework, and it can be managed during the stage of operationalizing the framework.
- The developed framework proposed simple formulas that can be used for quantifying the performance of the CMM process using effectiveness format. These proposed formulas have been developed in accordance with the descriptions of their measures that have been obtained either from the literature review or the findings of the cross-cases analysis. Consequently, the terminologies that are used in the structure of these formulas are generic terms, which can be found among those usually used in the engineering- related academic terminology and within the projects in the construction industry. Furthermore, the definitions of these measures, including describing the measures' attributes, the point of measurement, measures' names and codes, a definition and brief description for each effectiveness-measure, and the documents and reports to be used for practicing these measures, have been detailed in the research project (**Chapters IV, VI** and **Appendix Q**), and summarized in the Table of P.E.Ms (see **Table 8.1**).
- The use of the E.CMM.P framework as a basis for building a computerized system for quantifying the effectiveness of the performance of the CMM process is one of

the importance aspects of the research project and its contribution to the society. This computerised system can help a contractor to monitor the performance of its CMM system and to build a relevant database that can manage documenting the effectiveness-measurement outputs, introducing visualization for the fluctuation of the CMM performance, and benchmarking the performance of the CMM process within different stages of a project or within similar projects.

- The framework proposes establishing a unit called 'Measurement and Follow up' engages in the mechanism of operationalizing the E.CMM.P framework. This unit is designed to carry out the procedures that have been proposed to collecting and processing the relevant data and information. The designated team that is already involved in this unit or in the entire operational mechanism is among the staff who is already involved in the work of the concerned contractor or project. Therefore, there is no need for engaging extra individuals to operationalize the framework, and in case there is need for designating an additional staff, this will not significantly influence the project budget compared with the benefits that can be obtained by adopting the framework.
- 'Effectiveness'. In this research project the effectiveness was adopted to be the process measure for evaluating the performance of the CMM process. Effectiveness is defined as a measure that weighs up the performance process by building a comparison between actual outputs and planned or targeted outputs. The adoption of the effectiveness was justified by many rationales (see **Chapter IV-Section 4.1.2**), among those is its ability to utilize the existing project data to benchmark the performance of the materials management process within the project and across the corporate boundaries.

In summary, the evaluator (V) acknowledged that:

- The research work is very informative study with a very good starting point to carrying out research on the field of materials management in the construction industry.
- The E.CMM.P framework provides a new idea and methodology for evaluating the performance of the CMM process, which will have a good effect in improving the management of the building materials within the Jordanian building projects.

- Integrating the framework within the Jordanian construction organisations can simply be managed, due to the fact that it is compatible with the process of the CMM used, and the availability of the needed information and data.
- The majority of the effectiveness-measures offer a good indicator for the performance of one or more CMM activity.
- The proposed formulas and equations of the effectiveness-measures reflect the descriptions that have been developed for the measures of the performance of the CMM process.
- The E.CMM.P framework can serve as the basis for establishing a computerized system that will help the Jordanian contractors in several aspects.

9.2.2.2: Summary of the findings of the Framework Summative Evaluation:

Overall, the above feedback that has been received from the highly experienced experts in the Jordanian Construction Industry was remarkable and encouraging. The feedback confirmed the applicability of the E.CMM.P framework to evaluate the effectiveness of the performance of the CMM process within the Jordanian large-scale concrete building projects. It also confirmed that applying the framework within the Jordanian contractor organisations will be very useful for the periodical and systematic evaluation of the performance of their CMM functions and activities. Based on the comments, suggestions and opinions made by the participants (evaluators), it is concluded that the concept of the E.CMM.P framework would be acceptable and the preferred mechanism for evaluating the materials management effectiveness within the Jordanian Construction Industry; it provides a good basis for establishing a unified and standard benchmarking for the performance of the CMM process in the industry.

9.2.2.3: Some Actions related to Research Validation:

During the accomplishment of the PhD research project, various actions and activities have been carried out by the researcher whether for promoting the skills of the researcher, for accomplishing the research, or for the processes of the data collection. Among those are actions and activities that might be related to the validation of the E.CMM.P framework, as presented below:

- The second pilot study (Pilot II) was conducted prior to performing the data collection process in the Kingdom of Jordan (see **Section 5.6.5.1** for more details).

Pilot study II included organising a meeting (small conference) with some expert professionals (the research Keys-of-Contact) and decision makers related to the Jordanian Construction Industry (J.C.I) including the chairman of the Jordanian Construction Contractors Association (JCCA), the Assistant Secretary of the Jordanian Engineers Association (JEA), and a Senior Consultant of JCI, in addition to some guests on Skype. The meeting included 30 minutes presentation on the research objectives, the concept of measuring the effectiveness of the performance of the CMM process, and the proposed effectiveness-measures that resulted from the literature review process. During the discussion, which was followed the presentation and lasted for more than two hours, the comments and questions focused primarily on the concept of evaluating the performance of the CMM process and on the possibility of benchmarking the effectiveness-measures within the Jordanian Construction Industry. This meeting provided the first impression on the acceptance of the concept of measuring the performance of the CMM process; the concept and measures were acknowledged as being essential; they are needed to monitor and evaluate the performance of the CMM process within the Jordanian building projects (see **Appendix I**). Some of the comments of the participants were incorporated into the current proposed E.CMM.P framework.

- During the individual interview with the chairman of the Jordanian Construction Contractors Association (JCCA) as one of the decision-makers, he invited the researcher to attend a conference that discussing the experience of the application of the 'National Building Code'. This conference included many of the construction related people, such as; the construction contractors, construction consultant companies, construction engineers and decision-makers such as, the Minister of Public Works and Housing of Jordan, and others. In this conference, the researcher exploited the opportunity to present his research to the construction-related people, including the construction decision makers and code related specialists; he also tried to perform the following actions; I) Examining the acceptance of integrating a mechanism of benchmarking the CMM performance within the J.C.I; II) investigating the existence of any standards for management of the building materials, any certain set of measures or mechanism for evaluating the CMM effectiveness, and any standard or criteria for the project size classification. The feedback that was obtained from the conference influenced the design of the data collection process and pointed out some considerations that have been taken while developing the E.CMM.P framework, (see **Appendix M**).

- Among many of the participations by the researcher in the different construction-related conferences, the research outputs, including the components of the E.CMM.P framework and the final actual developed framework, have been presented in two conferences as follows;
    - A paper entitled as "Investigating and Evaluating the Effectiveness of Construction Materials Management Performance on Large-scale Concrete Building Projects in the Arab Region" was presented in the 'Development & Society Faculty Research Conference' that took place in Sheffield on 10 June, 2014. This paper aimed to present the main components of the E.CMM.P framework; the workflow diagram of the CMM process, which represents the basic structure of the developed framework, and the effectiveness-measures, which represent the main elements of the developed framework. The feedback and comments of the attendees were remarkable; it recommended dividing the process of developing the framework into phases to facilitate the follow-up of progress in developing the framework (see the abstract of the paper in **Appendix N**).
    - A poster entitled as "Evaluating the Performance of Materials Management Process on Concrete Building Projects in the Arab Region" was also presented in the 'First Libyan Forum on Higher Education: a Vision for the Future' that was held in London on 5-6 June, 2014. The poster was intended to present the final E.CMM.P framework. The feedback from the attendees was very encouraging; it recommended investigating the applicability of the E.CMM.P framework within the Libyan Construction Industry (L.C.I), and it stressed on simplifying the shape of the E.CMM.P framework by presenting each CMM function separately, and; see a copy of the poster in **Appendix O**.

9.3 SUMMARY OF THE CHAPTER

This chapter focused on reporting the industry validation of the framework for evaluating the performance of the building projects in the Jordanian Construction Industry. The validation process included two evaluation types that were conducted on two stages through the framework development cycle: 1) *Formative Evaluation* which was carried out before developing the final actual framework using a 'Group Administrated Questionnaire' survey that involved 47 functional experts in the Jordanian Construction Industry (J.C.I). It has sought to obtain wider expert's notions and opinions to assess the compatibility of the practical CMM diagram with the real-life CMM process that is practiced within the Jordanian building projects, and to explore the extent of usability of the proposed effectiveness-measures and their applicability in those projects in the Jordanian Construction Industry (J.C.I). 2) *Summative Evaluation* which assessed the final E.CMM.P framework in terms of its appropriateness and applicability, the barriers impeding the implement of the framework, the likely benefits of using the framework, and the availability of the data and documents necessary for operationalizing this framework. For accomplishing the summative evaluation, a copy of the developed E.CMM.P framework along with some explanatory documents, including the scenario of using the framework, were sent to five experienced professionals and experts (evaluators), who are involved in the Jordanian Construction Industry. The selection of this approach was justified and the criteria of selecting those evaluators were identified. In the feedback section, the evaluators' comments and the feedback were presented and analysed, and the outcomes of the summative evaluation stage was described.

The outcomes of the formative evaluation confirmed that; i) the proposed set of effectiveness measures is an appropriate sampling for the potential materials management effectiveness measures, and they could represent the population of the possible measures within the Jordanian Construction Industry; and that ii) the developed PCMMP workflow diagram can embody and reflect what is currently practiced in the real-life of the CMM process within the large-scale concrete building projects in the J.C.I. The feedback, which was obtained from the summative evaluation, was very positive and encouraging; it confirmed that the E.CMM.P framework is applicable within the Jordanian large-scale projects, and if adopted and applied correctly, the CMM process will be improved and practiced more effectively. Finally, the E.CMM.P framework may not only bring about improvement in managing the materials within the Jordanian building projects but it may also lay down a basis for standard benchmarking regarding the performance of CMM process in the Arab Construction Industry.

CHAPTER X:

CONCLUSION

10.0 INTRODUCTION TO THE CHAPTER:

Chapter X is the final chapter of the thesis. It summarizes the main conclusions drawn from the study and makes further recommendation. The chapter begins with a brief summary of the research and demonstrates how the research aim and objectives were achieved through accomplishing the phases that were designed to develop the E.CMM.P framework. The significance of the research and its contribution to knowledge are highlighted. The chapter also presents the main limitations of the study and concludes with some recommendations for further research.

10.1 KEY CONCLUSIONS:

The basic idea of the research initiated from the urgent need to propose a mechanism or a framework for measuring the effectiveness of the performance of CMM process in the Jordanian large-scale concrete building projects in order to provide a basis for analysing and evaluating the impact of the continuous improvements that can be made to this process. To realize this purpose, the aim of the research has been formulated to "*establish a set of uniform measures for evaluating the effectiveness of construction materials management performance and to develop a framework for their use within the large-scale concrete building projects in the Jordanian Construction Industry*". Several specific objectives are associated with achieving this aim; they include:

1- Critically reviewing the existing literature on materials management processes, and identifying, theoretically, the typical workflow diagram(s) of the materials management process in the construction industry,
2- Identifying and assessing the material-related measures used within the construction industry (or may be with other industries) to establish a proposed set of measures to evaluate the effectiveness of the performance of the Construction Materials Management (CMM) process in construction projects,
3- Developing a practical workflow diagram for communicating the integrated functions and activities that form the CMM process within the large-scale concrete building projects in the Jordanian Construction Industry (J.C.I),
4- Evaluating the proposed set of measures, and determining the Practical Effectiveness-Measures (P.E.Ms) that can be applied within the CMM process in the Jordanian large-scale concrete building projects,

5- Developing and validating a framework that operationalizes the P.E.Ms for evaluating the Effectiveness of the CMM Performance (E.CMM.P Framework) within the large-scale concrete building projects in Jordan.

It is the author's conviction that the aim and objectives have been met and that the research main question has been answered through adopting a mixed eclectic approach that involved several research activities including the literature review, main investigation (case studies; interviews-based analysis), the questionnaire survey, and the framework validation as illustrated diagrammatically in **Figure 5.10** and discussed in **Section 5.6**.

The specific activities undertaken in this research, with respect to the research objectives, are mainly designed to develop a framework for **E**valuating the **E**ffectiveness of the **C**onstruction **M**aterial **M**anagement **P**rocess **P**erformance (E.CMM.P Framework) within the large scale concrete building projects in the J.C.I. The development of the E.CMM.P framework was carried out sequentially throughout the research on six main stages that were classified into four phases, presented in **Chapter IX**. Each phase is concerned with accomplishing a component for the developing E.CMM.P framework including conducting the framework validation process. *Phase I*: developing the workflow diagram of the CMM process practiced within the Jordanian projects; *phase II*: establishing a set of practical effectiveness-measures (P.E.Ms) that can be used within the Jordanian building projects; phase *III*: setting out an operational mechanism for communicating the framework's elements (P.E.Ms) within its main body (P.CMM.P workflow diagram), and designing the final E.CMM.P framework; phase IV: conducting the validation process. The achievement of the research objectives through the accomplishment of these phases is summarised below;

Objective 1: Critically reviewing the existing literature on materials management processes and identifying, theoretically, the typical workflow diagram(s) of the materials management process in the construction industry.

The review of the existing literature on construction materials management practice identified the typical workflow diagram(s) for communicating the integrated activities and functions that form the materials management process of a typical project within the construction industry. On the basis of the extensive literature review, the most common integrated functions that are used through the life cycle of various construction projects and that are regarded as commonalities between the majority of the CMM processes that are reported in this research (see **Chapter III** and **Table 3.4**), eight integrated CMM functions were identified as applicable to a typical construction project. The functional workflow diagram technique was adopted to communicate the process inputs, integrated functions, activities and outputs within the identified functional boundaries, and to achieve the expected level of coordination of the CMM process.

As result of utilizing the findings of the literature review regarding the diagrams of the CMM process, putting into practice the eight integrated functions within the functional boundaries of the CMM process identified, and applying the workflow diagram technique adopted, the typical workflow diagram of the CMM process was identified to represent the typical materials management process for a archetypal construction project, as discussed in **Chapter III** and shown in **Figure 3.6.**The boundaries of the CMM process in the diagram depicts the workflow and sequence of the functions within the CMM process; **1)** 'Planning' is nominated as the first function in the CMM diagram that received the primary process input in the form of material related information from the project team. This function is then followed by **2)** 'Material Take-off, **3)** Vendor Inquiry and Evaluation, **4)** Purchasing, **5)** Expediting and Transportation, **6)** Quality management, **7)** Warehousing and **8)** Field Control together with their activities. The end process boundary is defined by the primary process output that is linked to issuing materials to the primary customer who is involved in construction operations and who represents those craft-workers for whom the materials are issued.

Objective 1 accomplishes the *first stage* in **Phase I** of developing the framework for Evaluating the Effectiveness of the CMM Process Performance (the E.CMM.P Framework) (**Phase I**: **Stage 1**; see **Figure 8.1**). This workflow diagram was used to interpret the typical materials management process within a typical construction project, and to provide a comparative basis for developing the 'Practical Workflow Diagram of the CMM Process (PCMMP)', which represents the structural body (basic structure) of the E.CMM.P Framework, as discussed in **Chapter VIII**.

Objective 2: ***Identifying and assessing the material-related measures used within the construction industry (or may be within other industries), and establishing a proposed set of measures to evaluate the effectiveness of the performance of the Construction Materials Management (CMM) process in construction projects.***

The process of literature review was also designed to identify the measures that are used for evaluating the effectiveness of the CMM performance. It was essential to define the 'performance' as measurement criterion and 'effectiveness' as process measurement, which are considered, from numerous perspectives, as better criterion and measure for evaluating the CMM process (see the justifications in **Section 4.1.1** and **4.1.2**). Based on the analytical literature review, 'Performance' in this study was summarized as an analysis of both effectiveness and efficiency in achieving the task required; it is used to measure the extent of improving the effectiveness, efficiency, and quality of a business process. 'Effectiveness', in the study, is defined as "the extent to which the outputs of the materials management process meet the needs and expectations of its primary customer, construction".

Objective 2 was designed to accomplish the *first stage* of achieving **Phase II (Phase II: Stage 2**; see **Figure 8.1**). This stage is concerned with theoretically establishing a proposed set of measures for evaluating the effectiveness of the performance of the CMM process. The process of establishing or developing a set of proposed effectiveness measures for evaluating the CMM performance is essentially based on identifying, critically assessing, and then adopting material-related measures used in the construction industry. However, due to the lack of related literature, regarding measuring the materials management performance within the construction context, the literature investigation area was expanded to cover examining the performance measures that are used for the supply chain management and materials management processes within the manufacturing and construction industries and the industrial projects. The process focused on modifying these measures to fit the building/construction context; these include removing the duplications and the organisational measures that were not directly associated with the materials management, reformatting some measures into the effectiveness format, and modifying other measures that were adopted form other sectors or industries to fit the building/ construction sector.

As a result of the process of examining different materials management-related measures and approaches that were reported in the literature, and that were considered as key measures that can best communicate effectiveness (the most important, practical and frequent measures used in different industries), a set of **thirty three** (33) measures grouped under **seven** (7) different attributes was proposed to evaluate the effectiveness of the performance of materials management process within the construction projects, as explained in details in **Chapter IV**, and summarised in **Table 4.16**. In this study, the set of the proposed effectiveness-measures is considered as a comparative basis for developing the Practical Effectiveness-Measures (P.E.Ms) that is used for assessing the effectiveness of the CMM performance within the Jordanian building projects; it represents the main elements of the E.CMM.P framework developed (*Stage 4*).

Objective 3: Developing a practical workflow diagram for communicating the integrated functions and activities that form the CMM process within the large-scale concrete building projects in the Jordanian Construction Industry (J.C.I),

A main investigation using the case study approach was conducted to achieve partly the third objective of this research. The case study research was principally based on regular site visits and semi-structured interviews that were conducted to collect the required data from six on-going Jordanian large-scale concrete building projects located in six different Jordanian Governorates. The site visits to the six case study projects included a number of field tours and organisations' home-offices, while the semi-structured interviews were conducted with 14 high experienced personnel involved in the six case study projects. The diversity in the type, work-stage, and location of the projects selected was deliberate in order to provide an opportunity to explore the different approaches to practicing the CMM process and to depicting a more realistic picture that can reflect the real-life of the CMM process practiced within the large-scale concrete building projects in the J.C.I. Details of the case studies' selection, procedures of implementation and the key findings were presented in **Chapter V** and **Chapter VI** respectively.

Objective 3 was set to achieving the *second stage* of **phase I (Phase I: Stage 3**; see **Figure 8.1**) through investigating the current practices of CMM process within the J.C.I, and re-shaping the typical workflow diagram of the CMM process to reflect the real-life CMM processes that are practiced within the Jordanian large-scale concrete building projects. Realizing *stage 3* was based on a wide discussion addressing the cross-cases analysis regarding the CMM processes that have been practiced within the six case studies projects, and on examining the extent of their conformity to the typical workflow diagram of the CMM process that was developed on the basis of the literature review process **(Figure 3.6)**, in particular, those aspects that take into consideration the sequences of the functions, the existence and distribution of the activities, and the terminologies used (see **Chapter VI, Section 6.6.1**).

In general, the case studies revealed that there are no certain standards, uniform mechanisms or binding written policies in contracts regarding the process of managing building materials in the construction projects in the J.C.I. As a result of the comprehensive discussion, the practical workflow diagram for communicating the integrated functions and activities that form the CMM process within the Jordanian large-scale concrete building projects was developed (see **Figure 8.2** and **Figures 8.2.1** to **8.2.5**). This practical workflow diagram of the CMM process represents the structural body (the basic structure) of the E.CMM.P Framework. Furthermore, it was found out that there is similarity between most of the activities, which were practiced within the selected case studies, and those that form the typical workflow diagram of the CMM process despite the presence of some differences in the distribution of the activities within the functions, the overlapping of some functions, and the occurrence of some new activities that emerged in these cases (see **Chapter VI; Figure 6.6**).

Objective 4: Evaluating the proposed set of measures to determine the Practical Effectiveness-Measures (P.E.Ms) that can be applied within CMM process in the Jordanian large-scale concrete building projects,

Objective 4 was concerned with completing the *second stage* of **phase II (Phase II: Stage 4**; see **Figure 8.1**). The main investigation was also to achieve partly objective four through using the case study approach that was carried out on the six on-going building projects. The Cross-cases analysis technique was conducted within the six case studies to explore the effectiveness measures, approaches, or mechanisms that are currently in use within the cases for monitoring and evaluating the performance of the CMM process, to examine the potentiality of applying the proposed effectiveness-measures, which were established on the basis of the literature review, practically within the Jordanian building projects, and to define the barriers that can hinder their application (detailed discussion is provided in **Sections 6.6.2**).

Based on discussing the findings that resulted from the cross-case analysis for the six case studies, it was concluded that despite the presence of a number of qualitative techniques and some quantitative measures, which are practiced irregularly to monitor and follow-up the performance of the CMM system, there is no certain standard or an observable unified set of measures for evaluating or quantifying continuously the effectiveness of the CMM performance within the Jordanian large-scale concrete building projects. However, examining the applicability of the proposed set of effectiveness-measures within the Jordanian building projects, and discussing the comparison between them and the techniques and procedures practiced revealed that there were some measures that match, or that are largely similar, to the proposed measures, that there were some quantifiable techniques somewhat similar to the proposed measures in terms of their purpose, that there appeared to be some alternative procedures practiced qualitatively to follow-up the performance of one or more function of the CMM system used, and that there were some new measures or quantitative techniques that were not cited within the set of the proposed measures.

The establishment of the set of Practical Effectiveness Measures (P.E.Ms), which are/or can be used for evaluating the effectiveness of the performance of the CMM process within the Large-scale Concrete Building Projects in the J.C.I, was based on five main actions: **I)** adopting the 'Existing-Measures' as proposed by the set of measures that were developed in the literature; **II)** approving the proposed measures that were not used in all case studies ('Existing-Measure') but they were found applicable within the Jordanian projects; **III)** reformatting and reformulating the 'Qualitative approaches' and 'Quantitative techniques' that were found possible to be formulated for quantified use (to reflect the effectiveness of the CMM performance quantitatively) to represent either the original proposed measure or a new measure; **IV)** omitting 'the non-Exist-Measures', the 'Qualitative' and the 'Quantitative' techniques that were found impossible to be quantitatively used within the J.C.I; and **V)** adding the 'New measures', which were practiced within one or more of the case studies, with some modifications to reflect the effectiveness format.

As a result of the implementation of **phase II**, a set of twenty six Practical Effectiveness Measures (PEMs) was established. Those measures, which will form the main elements of the developed E.CMM.P Framework, include sixteen proposed measures, five measures resulting from reformulating and reformatting the qualitative and quantitative approaches used, and five new measures that were in use in the Jordanian projects, as explicated in **Table 8.1**, and explained in **Chapter VI, Section 6.6.2.3**.

Objective 5: Developing and validating a framework that operationalizes P.E.Ms for evaluating the Effectiveness of the CMM Performance (E.CMM.P Framework) within the large-scale concrete building projects in Jordan,

Objective 5 covered the last two phases for the development of a framework for Evaluating the Effectiveness of the Construction Material Management Process Performance (E.CMM.P Framework) within the large-scale concrete building projects in the J.C.I; **Phase III**-*Stage 5*: setting up an operational mechanism and designing the final E.CMM.P framework; **Phase VI**-*Stage 6*: the framework validation process.

The development of the (E.CMM.P Framework) comes as a result of incorporating its three main components: 1) the 'Basic Structure (Main Body)': the practical workflow diagram of the CMM process (P.CMM.P diagram); 2) the 'Main Elements': the practical effectiveness measures (P.E.Ms); and 3) the 'Operational Mechanism': the set of interrelated procedures and instructions for linking the main elements within the basic structure. These main components of the E.CMM.P framework were developed gradually based on the outcomes the case study research and the findings are supported by the extensive literature review; they are validated through a questionnaire survey, and through obtaining feedback from the highly experienced professionals and functional experts.

The design of the E.CMM.P Framework was based on coordinating and integrating the findings of the first two phases through the two main steps within **Phase III**:

Step1: integrating the Practical Effectiveness-Measures (P.E.Ms) within the practical CMM process diagram (P.CMM.P workflow diagram), which were developed out of the findings of the case studies, through placing each P.E.M at its point of measurement (Measure's Location) as defined in **Chapters IV** and **VI** and summarized in **Tables 4.16** and **8.1**.

Step2: setting the operational mechanism for connecting the P.E.Ms (the framework's main elements) and operationalizing them within the P.CMM.P workflow diagram (the framework's main body) through integrating the activities of the operational mechanism (Plan, Data Collection and Processing, Analysis, and Improvement) and their procedures (identified by the literature review), sequentially, within the P.CMM.P workflow diagram.

As a result of performing the above two steps, including integrating the P.E.Ms and placing them at the point of measure within the practical workflow diagram of the CMM process, and then applying the operational mechanism for communicating those measures within the practical diagram, a framework for communicating the integrated CMM functions and operating the practical effectiveness-measures for evaluating the effectiveness of the performance of the CMM process within the Jordanian large-scale building project (E.CMM.P Framework) has been developed (see **Figure 8.4**).

Phase VI-*Stage 6* was concerned with conducting the framework validation process, which is mainly designed to assess the applicability and appropriateness of the developed 'E.CMM.P Framework' for monitoring and evaluating the effectiveness of the CMM performance within the large-scale concrete building projects in the J.C.I. The validation process comprised evaluating the main body, the (P.CMM.P workflow diagram), the main elements (P.E.Ms) that form the E.CMM.P framework, and the actual final developed framework through two evaluation stages; 'Formative Evaluation' and 'Summative Evaluation':

1- Formative Evaluation was carried out during the development stages and before the final actual development of the framework was made. The evaluation feedback was derived from the results of the 'Group Administrated Questionnaire' survey, which was conducted to gather wider responses from **47** functional experts in the J.C.I. The evaluation focused on evaluating the thirty-three effectiveness-measures that were developed on the basis of the literature review process, in terms of their utilization, importance in communicating the effectiveness, and applicability within the J.C.I. Moreover, the formative evaluation endeavoured to assess the practical workflow diagram, which was developed from the findings of the cross-cases analysis, in terms of its ability to reflect what is currently practiced in the real-life of the CMM process within the Jordanian large-scale concrete building projects. The main outcomes of the formative evaluation indicated that the proposed set of effectiveness measures along with the practical measures is an appropriate sampling that could represent the population with respect to the possible measures within the JCI. The outcomes of evaluating the developed PCMMP workflow diagram concluded that the majority of the respondents confirm that the practical workflow diagram can embody and reflect what is currently practiced in the real-life of the CMM process within the large-scale concrete building projects in the J.C.I. This indication confirms the validity and reliability of the outcomes of the main investigation involved in developing the E.CMM.P framework, which, in turn, confirms the validity of the E.CMM.P Framework developed (details are provided in **Chapter VII** and **IX**). Moreover, based on this evaluation, the Key Effectiveness-Measures (K.E.Ms) that can represent the main effectiveness-measures that can be used to evaluate the performance of the entire CMM process and reasonably reflect the extent of its effectiveness, were explored.

2- Summative Evaluation aimed to assess the final developed framework in terms of its applicability and appropriateness for evaluating the performance of the CMM process within the J.C.I, the likely benefits of using the framework, and the availability of the data and documents necessary for operationalizing the framework. This evaluation technique was based on sending a copy of the developed E.CMM.P framework along with some explanatory documents to the five selected seniors and highly experienced professionals and experts (Evaluators) in the Jordanian construction sector (see **Table 9.1**). Generally, the feedback that was received from the evaluators was remarkable and encouraging. It confirmed the applicability of the E.CMM.P framework to evaluating the effectiveness of the performance of the CMM process within the Jordanian large-scale concrete building projects. Based on analysing the evaluators' feedback, it was concluded that practicing the framework by the Jordanian contractors would be very useful for the periodical and systematic evaluation of the performance of the CMM processes and systems, and that the J.C.I could take advantage of it.

Based on the discussion above, it is evident that the research achieved its main aim "to establish a set of uniform measures for evaluating the effectiveness of construction materials management performance and to develop a framework for their use within the large-scale concrete building projects in the Jordanian Construction Industry", through fulfilling its main five objectives that were designed to cover the four phases of developing the E.CMM.P Framework. The significance of the research and its contribution to the body of knowledge is summarised in the next section.

10.2 THE SIGNIFICANCE AND CONTRIBUTION TO KNOWLEDGE:

As mentioned in **Section 1.4**, various literature studies illustrated the importance of materials management and highlighted how it became the process that determines the project success in construction as it does in manufacturing (see **Section 3.2.2**). Moreover, the fact that materials are the major cost component in any construction project and that their value represents 50-60% of the project's cost can serve as a good indicator of the importance of the materials management process, and consequently, it can identify the importance of evaluating the effectiveness of its performance.

The significance of the study emerges from its contribution to bridging the gap(s) that can be found in the previous studies, knowledge, or practical professional life. Based on the in-depth review of the related literatures and through critically examining the previous studies (see **Chapter IV**), one can realize the extent of the significance of this research and its essential contribution to knowledge. The significance of a research can be revealed by the extent of the contribution that it can make to knowledge, society, and/or to the research methodology. The contribution of this research can be summarised in the following points:

- As it was demonstrated from the literature review, the first pilot study conducted, and the case studies investigated, there is a pressing need for measuring the performance of the materials management process to provide a basis for following up, assessing and analysing the impact of any improvement or change on the materials management process and the overall construction industry. However, although there are some references on measuring the supply chain management performance in the manufacturing industry, they are still very limited to the construction industry, and they might be absent from the field of building materials management (where no relevant references could be found). Therefore, this research provides an original approach to develop a set of uniform measures for measuring the effectiveness of the construction materials management performance in the construction-building field, embracing the widest type of construction projects, and thus representing a major contribution to knowledge.
- Developing a 'Framework for Communicating the Integrated CMM Functions and operationalizing the Practical Effectiveness Measures' (E.CMM.P Framework)

illustrates the creation of a mechanism for monitoring, analysing, and evaluating the effectiveness of CMM performance within the building projects. Moreover, this demonstrates flexibility as a measurement's attribute, added to the other six attributes of measurement, which were previously adopted for measuring the effectiveness performance in the construction industry, thus contributing to knowledge.

- From the site visits, whether those were paid in Libya (the first pilot study) or those conducted in the Kingdom of Jordan, in particular, the discussions that were made with the decision makers in Libya and Jordan, it can be concluded that there is no such study regarding the assessment of the performance of the CMM process in Libya and Jordan (Grifa, 2010; Al-Tarawnh, 2012; and Qagish, 2012,). Additionally, there is no official standard or a particular approach used in the majority of the Arab construction projects for evaluating the effectiveness of CMM performance (Ibid.). This finding was confirmed by the data collected from the case studies in Jordan. In view of that, it can be noted that this study is the first of its kind to be conducted in the Jordanian, or may Arab, Construction Industry (J/A.C.I), and it will be beneficial to society, especially given that this study has been designed to fit and accommodate the Jordanian Construction Industry (J.C.I) taking into account the Jordanian environment, including the building and management methods, culture and terminologies, and thus providing a contribution to society.
- As it was stated in **Section 1.4**, the majority of studies, which were conducted on the construction industry, used only empirical approaches. According to Boyer and Swink (2008), Singhal et al. (2008), and Tangpong (2011), there is a growing consensus that the use of multiple research methods (whether in one study or across different studies on related topics) is critical to the development of the operation and the supply chain management field as different methodological approaches have different strengths and limitations (e.g., Babbie, 1995). Therefore, the body of research that has applied multiple research methods is less susceptible to systematically biased findings (Boyer and Swink, 2008). In line with that finding, multiple research methods are applied in this research whereby a set of updated measures on the CMM performance was developed from the critical analysis of the comprehensive literature review process (the proposed measures), and then was examined and tested empirically within the case study technique (the Site Visit, Interview & Questionnaire). This gives the

research additional unique value and provides further support to the research validity and reliability.

- With regard to the practical benefits that can be attained for the building contractors, Hassan (2005, p62) believes that 'the key competitive edge is to promote knowledge-based approach to management through the process of continuous development supported by learning, adopting and adapting innovations, and measuring performance'. In this context, applying the developed E.CMM.P framework for measuring quantitatively the effectiveness of CMM performance can help a contractor organisation in several aspects, such as:
  - monitoring the impact of any improvements or new strategies that can be implemented, and evaluating the effectiveness of the CMM performance through the different stages of the project,
  - quantifying the differences in performance, and documenting why those differences exist and identifying the defect areas,
  - comparing between its projects (internally), comparing its projects with other projects (externally), calibrating the industry rates or the best-in-class performance (benchmark) if applicable,
  - identifying the steps necessary to realize the higher levels of performance, and
  - recording the measuring-results values within a database; it becomes possible to develop a benchmark(s) that can be used internally (to compare between the project's stages within a project, or between projects within an organisation).

- The research findings and the E.CMM.P framework represent a basis for developing a standardised benchmark(s) for benchmarking the CMM performance internally, externally and internationally, in addition to forming a basis for building a computerised system to facilitate performance monitoring of the CMM process.
- The research findings, whether those resulting from the literature review or from the data collection analysis, provide a foundation for additional work to further enhance the materials management practices, and to encourages Arab researchers to enter the field and create more developed techniques for monitoring and evaluating the CMM process from different dimensions.

10.3 LIMITATIONS OF THE RESEARCH:

Despite the time constraints, the lack of the related-resources and references and the difficulty involved in accessing the data required, the researcher managed to carry out the research study. The main limitations encountered are the following:

- The research is confined to the Jordanian Construction Industry.
- For more reliable and valid research findings, the study considered only the large-scale projects, where functions and activities of the CMM process can be clearer and standardized, with more emphasis on the concrete building projects where the majority of the main construction materials are used.
- The majority of the research data were obtained from the main building contractors-first class organisations, who are primarily responsible for managing the majority (if not all) of the functions and activities of the CMM process in most Jordanian construction projects, and they have specific criteria and arrangements for managing their CMM process.
- In order to avoid the complexity involved in managing various types of materials and to facilitate the development of a typical and unified workflow diagram for CMM process, the materials, which were applied in this study, were customized to just include materials used within the skeleton stage: 'Concrete' that represented the bulk materials, 'Reinforcement Steel' that represented fabricated materials, and 'Insulation/Isolation Boards' that represented engineered materials.
- In order to set boundaries to this study, the CMM process was limited to those functions and activities primarily associated with materials management-related data, which were adopted from the most notable construction materials management handbooks and references (such as, Construction Industry Institute (CII), Plemmons, 1995, and others, see **Chapter III**). The functions associated with accounting or the accounts payable activities were excluded from the integrated functions of the CMM system.
- Due to the limitation of time, the lack of the availability of the required samples, and the difficulty involved in accessing the essential data, the majority of the data obtained through the main investigation was based on six on-going large-scale concrete building projects that were selected as case studies. The research data was mainly obtained from the field observation (site visits), 14 high expertise material-related professionals involved in semi-structured interviews, and 47 CMM-related

experts and professionals who were delegated by their organisations to participate in the questionnaire survey. Those participants were responsible for and involved in at least one of the CMM functions or activities within the 30 different under-construction building projects, which were executed by 26 first class building contractor-organisations.

- Time and financial constraint did not permit the study to validate the findings and conclusions of this thesis empirically (by conducting an empirical research) through testing the practical effectiveness measures and the E.CMM.P Framework in the real world. This was the main reason behind the lack of involving the mathematical equations of the measures within the thesis, and only providing the formulas' definitions of these measures.

Based on the limitation of this study, there are recommendations for further study, as summarized below.

10.4 RECOMMENDATIONS FOR FURTHER RESEARCH:

This study developed a framework to evaluate the effectiveness of the performance of the CMM process within the Jordanian large-scale concrete building projects. The limited scope of the research project could not allow the researcher to entirely cover all the matters related to the CMM process topics. There are additional topics worthy of further study, and the scope for others to build on this work exists. Hence, for further research, the following topics are recommended:

- Further improvement can be made to the E.CMM.P framework: different functions and activities involved in the CMM process need more attention in order to construct more realistic workflow diagram for the CMM process; additional research is needed to explore extra effectiveness-measures that can make the evaluation of the CMM process more accurate.
- It is recommended that developing a mechanism or measures that pursue to determine the factors influencing materials management process performance.
- It is recommended to give adequate time and financial resources for conducting a wider investigation; involving bigger number of building projects (case studies) and larger size sample, in addition to fully evaluation of the E.CMM.P framework by

allowing more participants to be involved to provide constructive suggestions that aim to improving the structure of the framework and enriching the contents.

- It is important to test the developed E.CMM.P framework in real situations (real life cases) through integrating the framework within the CMM system of a contractor to determine the efficiency and effectiveness of the framework. Moreover, more investigation is required by industry practitioners to examine the impact of integrating the framework into the overall process of materials management.
- The use of the proposed equations for the effectiveness-measures and the operational mechanism to build a computerised system (computer aided design) is desired. This would enhance the usefulness of the framework and facilitate continuous monitoring of the performance of the CMM process; hence, it facilitates the commercialisation of the E.CMM.P framework.
- Due to the similarity between the Arab countries with regard to the culture, weather, the building style, and the building materials used, it is recommended to expand the area of the research to include the whole Arab region, and to continue to develop a standardised benchmark(s) (Benchmark mechanism) for benchmarking the CMM performance at the national level (within the J.C.I), externally (within the Arab region), and internationally (within the construction industry worldwide), through using these research findings as a basis.

10.5 CONCLUDING REMARKS:

The current research proved that effectiveness-measures can be determined for the CMM process in building projects. Based on the extensive evaluation conducted, it can be stated that the concept of the E.CMM.P framework and the proposed mechanism for evaluating the materials management effectiveness would find acceptance within the Jordanian Construction Industry. This would provide a good basis for establishing a unified and standard benchmarks for the performance of the CMM process in the industry.

The present research yielded much valuable information to the construction managers who desire to experiment with, or quantify the impact of, any new strategy, new technology, or any process changes that could be applied on their CMM system. By implementing the E.CMM.P framework, a construction manager can compare the performance differences between projects or between the stages of a project. The significance of the research and its contribution to knowledge can be realized in improving the effectiveness of the CMM process, which will result in significant cost and time savings for the building projects.

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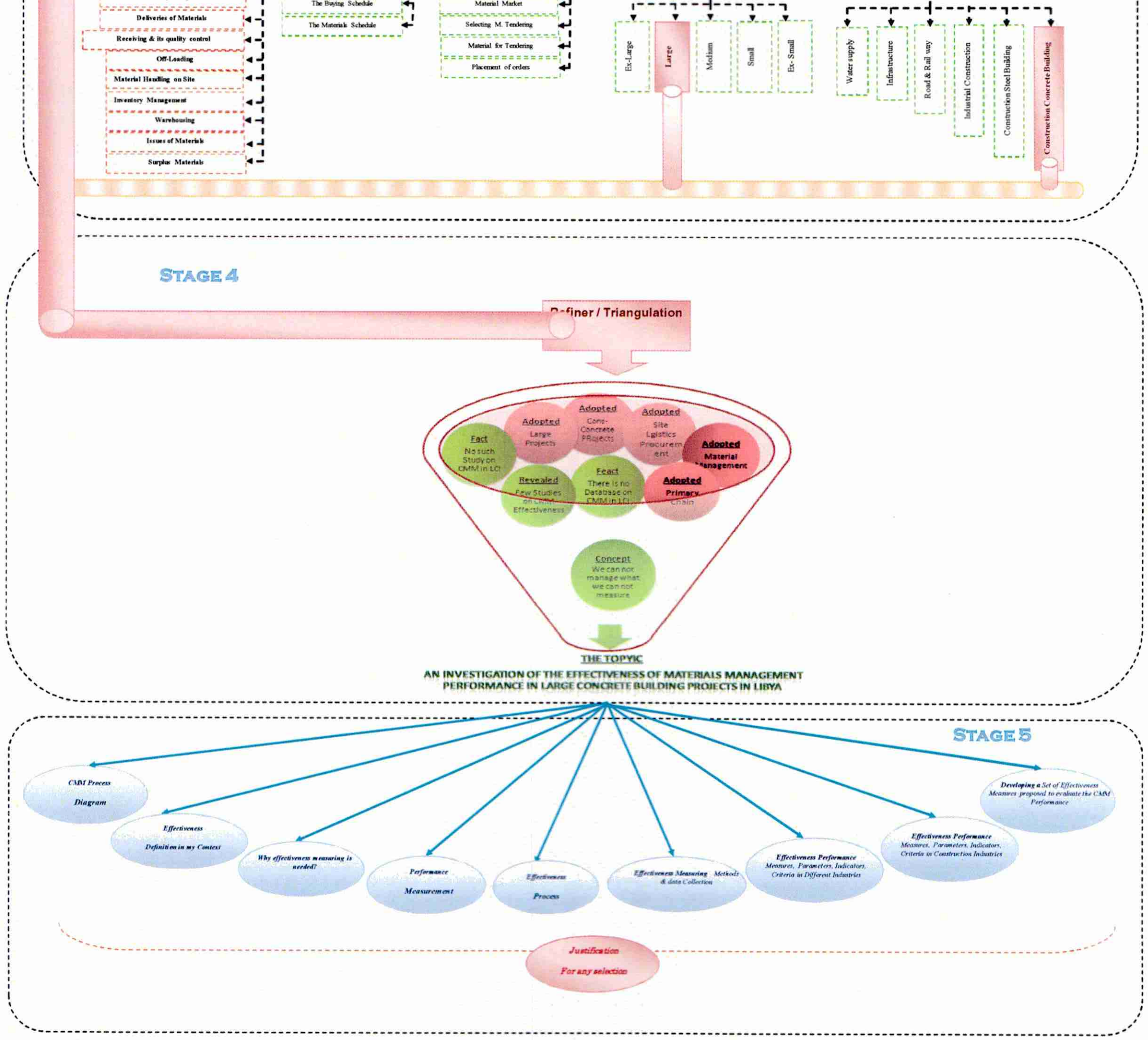
APPENDIX A:

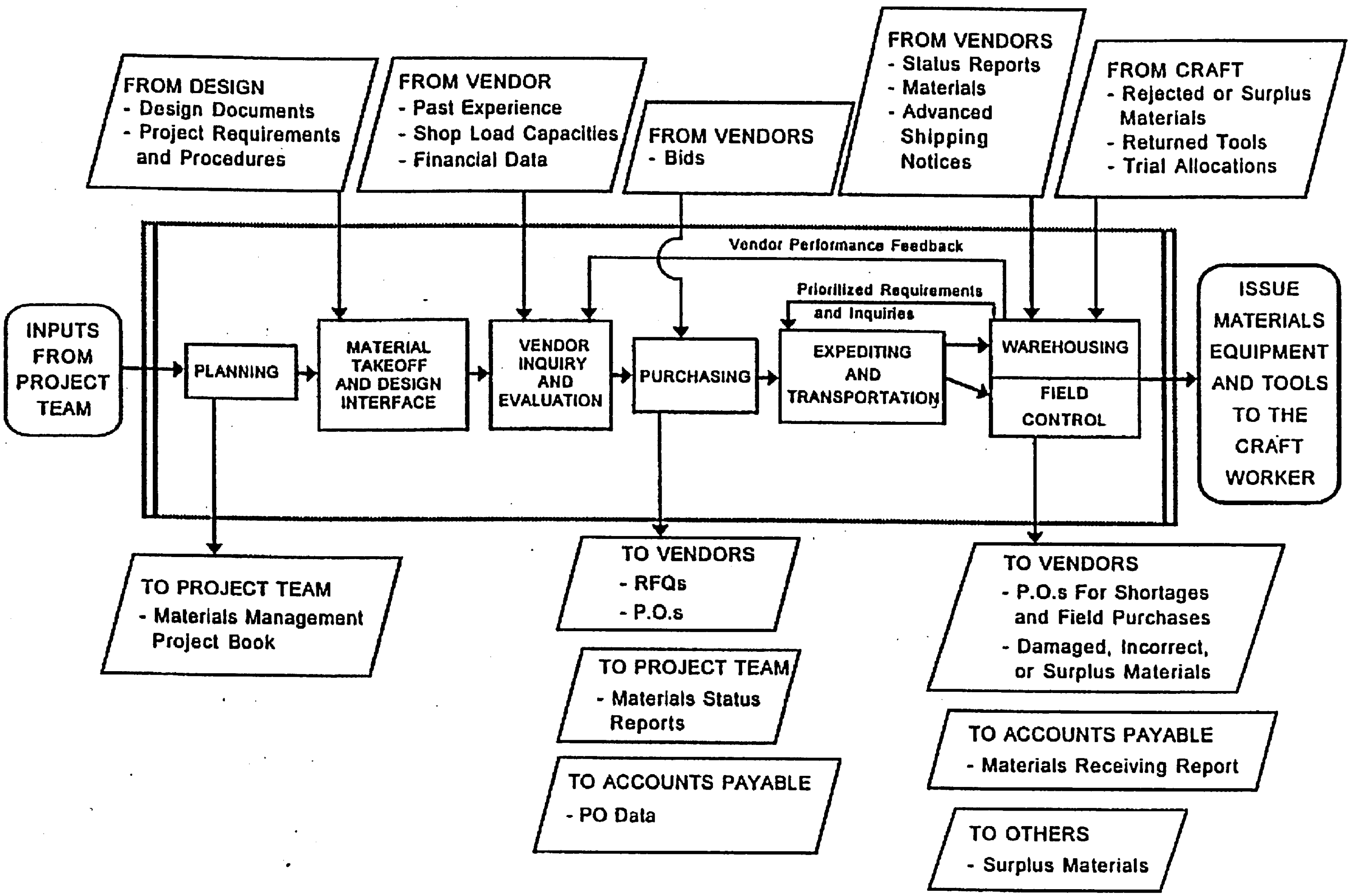
LITERATURE REVIEW PROCESS PLAN DIAGRAM


Deliveries of Materials
Receiving & its quality control
Off-Loading
Material Handling on Site
Inventory Management
Warehousing
Issues of Materials
Surplus Materials
The Buying Schedule
The Materials Schedule
Material Market
Selecting M. Tendering
Material for Tendering
Placement of orders
Ex-Large
Large
Medium
Small
Ex- Small
Water supply
Infrastructure
Road & Rail way
Industrial Construction
Construction Steel Building
Construction Concrete Building
STAGE 4
Refiner / Triangulation
Fact
No such Study on CMM in LCI
Adopted
Large Projects
Adopted
Cons-Concrete Projects
Adopted
Site Logistics Procurement
Adopted
Material Management
Revealed
Few Studies on CMM Effectiveness
Fact
There is no Database on CMM in LCI
Adopted
Primary Chain
Concept
We can not manage what we can not measure
THE TOPIC
AN INVESTIGATION OF THE EFFECTIVENESS OF MATERIALS MANAGEMENT PERFORMANCE IN LARGE CONCRETE BUILDING PROJECTS IN LIBYA
STAGE 5
CMM Process Diagram
Effectiveness Definition in my Context
Why effectiveness measuring is needed?
Performance Measurement
Effectiveness Process
Effectiveness Measuring Methods & data Collection
Effectiveness Performance Measures, Parameters, Indicators, Criteria in Different Industries
Effectiveness Performance Measures, Parameters, Indicators, Criteria in Construction Industries
Developing a Set of Effectiveness Measures proposal to evaluate the CMM Performance
Justification
For any selection

Appendix A-1

APPENDIX B:

PLEMMONS'S CMM PROCESS DIAGRAM


FROM DESIGN
- Design Documents
- Project Requirements and Procedures
FROM VENDOR
- Past Experience
- Shop Load Capacities
- Financial Data
FROM VENDORS
- Bids
FROM VENDORS
- Status Reports
- Materials
- Advanced Shipping Notices
FROM CRAFT
- Rejected or Surplus Materials
- Returned Tools
- Trial Allocations
Vendor Performance Feedback
Prioritized Requirements and Inquiries
INPUTS FROM PROJECT TEAM
PLANNING
MATERIAL TAKEOFF AND DESIGN INTERFACE
VENDOR INQUIRY AND EVALUATION
PURCHASING
EXPEDITING AND TRANSPORTATION
WAREHOUSING
FIELD CONTROL
ISSUE MATERIALS EQUIPMENT AND TOOLS TO THE CRAFT WORKER
TO PROJECT TEAM
- Materials Management Project Book
TO VENDORS
- RFQs
- P.O.s
TO PROJECT TEAM
- Materials Status Reports
TO ACCOUNTS PAYABLE
- PO Data
TO VENDORS
- P.O.s For Shortages and Field Purchases
- Damaged, Incorrect, or Surplus Materials
TO ACCOUNTS PAYABLE
- Materials Receiving Report
TO OTHERS
- Surplus Materials

APPENDIX C:

THE SPSS CODE BOOK

SPSS Code Book

ITEM NO	FULL VARIABLE NAME	SPSS VARIABLE NAME	CODING INSTRUCTIONS
1	Respondent Current Position/ Title	Position	1= Material Manager/ Administrator 2= Material Officer/ Coordinator 3= Warehouse Manager/Storekeeper 4= Purchasing/Procurement Manager 5= Project Manager 6= Logistic Manager/Coordinator 7= Construction Site Manager 8= Planner 9= Quality Manager/ Coordinator 10= Engineer/ Architect 11= Other Position; please specify..............................
2	Years of Construction Experience within the JCI	Ex.Years	1= <5 years 2= 5- 10 years 3= 11- 15 years 4= 16- 20 years 5= 21-25 years 6= >25 years
3	Years of Working on Behalf of the Current Organisation/Company	W.Years	1= <5 years 2= 5- 10 years 3= 11- 15 years 4= 16- 20 years 5= 21-25 years 6= >25 years
4	Years of management or responsible project experience in the area related to materials management	M.Years	1= <5 years 2= 5- 10 years 3= 11- 15 years 4= 16- 20 years 5= 21-25 years 6= >25 years
5	Type of your organisation	Org.Type	1= Contractor 2= Sub-Contractor 3= Client 4= Consultant 5= Supplier 6= Other, please give details...
6	Type of Construction Project	Pro.Type	1=.Industrial Building Project 2= Residential / Housing Building Project 3= Institutional Building Project 4= Commercial Building Project 5= Heavy Civil Building 6= Other, please give details..............................
7	Type of Contract	Cont.Type	1= Fixed Price (Lump Sum) 2= Unit Price (Re-measured Based) 3= Cost Plus (Actual cost + Profit) 4= Cost Reimbursable (Variation) 5= Other, please give details..............................
8	Perspective Choose to Answer	Perspect	1= Planning & Administration

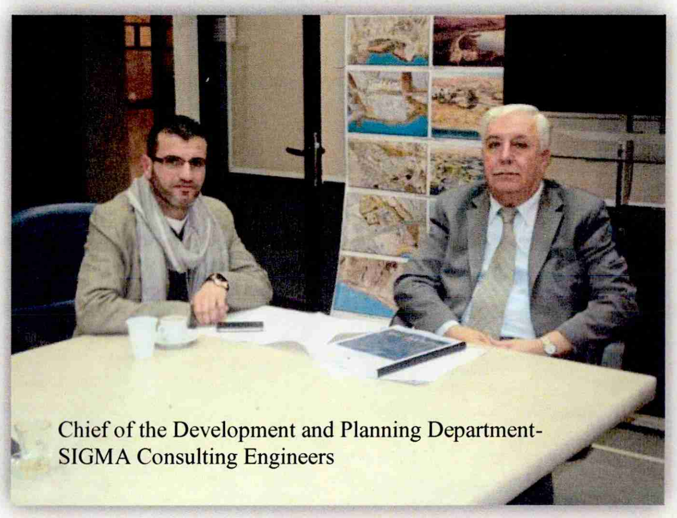
ITEM NO	FULL VARIABLE NAME	SPSS VARIABLE NAME	CODING INSTRUCTIONS
	the Questionnaire		2=Material Takeoff & Material Control 3=Vendor Inquiry & Evaluation 4=Purchasing (Organisational Level - Home Office) 5=Purchasing (Construction Level - Filed) 6=Transportation & Expediting 7=Quality Control 8=Warehousing (Organisational Level - Home Office) 9=Warehouse (Construction Level – Site Store) 10= Field Control 11=Other; please specify................................
9	Estimated Cost of the Current Project	Est.Cost	1= <£15 m 2= £15 - 25 m 3= £26 - 35 m 4= £36 - 45 m 5= £46 - 55 m 6= >£ 55 m 7= If > £100 m, please give details.................
10	Size of the Current Project?	Pro.Size	1= Small –Scale Project 2= Medium-Scale Project 3= Large-Scale Project 4= Huge Project 5= Other Size; please specify................................
11	The Measure. Used in the Past	'M'. Used 1 to 33	1= Yes 2= No
12	The Measure. Currently in Use	'M'. Using 1 to 33	1= Yes 2= No
13	The Measure. Would like to be Used	'M'. W.Use 1 to 33	1= Yes 2= No
14	The Importance of the measure in communicating the effectiveness of the materials management process	'M'. Important	**IMPORTANCE SCALE** 1= Not Important 2= Slightly Important 3= Moderately Important 4= Very Important 5= Extremely Important
15	The practicality of the measure to be implemented	'M' .Practical	**IMPORTANCE SCALE** 1= Not Practical 2= Slightly Practical 3= Moderately Practical 4= Very Practical 5= Extremely Practical
12	Evaluation of the Practical CMM Process's (PCMMP) Workflow Diagram	E.PCMMP	**AGREEMENT SCALE** 1 = Strongly Disagree, 2= Disagree, 3= Neutral, 4= Agree, 5= Strongly Agree

APPENDIX D:

THE RESEARCH KEYS-OF-CONTACT

Dean of Faculty of Engineering and Technology
(Academics: JU)

Assistant Secretary of the Jordanian Engineers Association
(Jordanian Engineers Association)



Chief of the Development and Planning Department-
SIGMA Consulting Engineers

Contractor's Project Manager
Private Construction Company

Owner's Construction Manager
(Public Construction Company)

Client's Project Manager
(Construction Management Firm)

Appendix D-1

APPENDIX E:

PICTURES THAT DOCUMENT THE SITE VISIT PROCESSES

Case Study A:

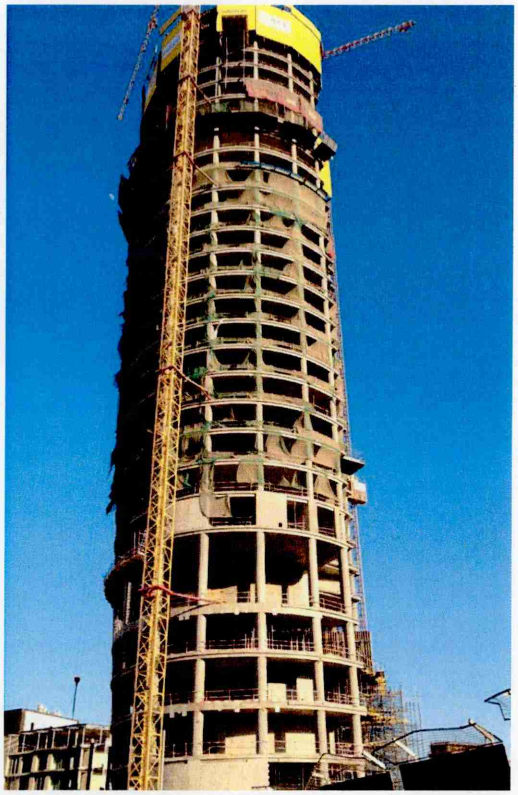
Case Study B:

Case Study C:

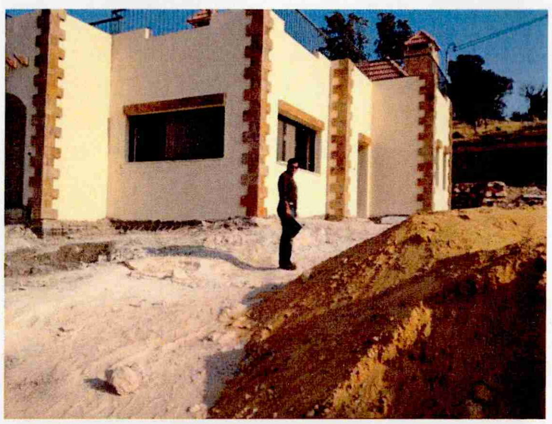
Case Study D:

Case Study E:

Appendix E-2



Case Study F:



APPENDIX F:

THE MAIN SUBJECTS AND QUESTIONS OF THE INTERVIEW

1.0- Personal Questions:

1.1- What is your name if you do not mind? Please
1.2- what is your qualification? Please
1.3- What is your current job/ position? Please
1.3.1- What are your functions and responsibilities in this project?

1.4- How many years of experience do you have? Please
1.5- What is the kind of construction project are you managing now? Please
1.6- How your job(s)/task(s)/role(s) in the project are related to materials management?
1.6.1 How long have you been involved in managing materials on construction sites?
1.6.2 Years of management or responsible project experience in the area of materials management.

1.7- How long have you worked in projects on behalf of Jordanian Construction Industry (JCI)? Please

2.0- The Organisation's background & General Overview:

2.1- What is the main activity(s) of your organisation? Please
2.2- What is the current project, which your organisation is carrying out on behalf of JCI? Please
2.3- What is the value of the contract, which is currently being executed by your organisation/company? Please
2.4- What is the value average of construction contracts, which have been executed by your organisation in behalf of Jordanian Construction Industry? Please
2.5- What is the type of project's Contract? Please
2.6- Is there a standardized classification to classify projects in terms of their size
2.6.1 If not, how do you classify your current project in terms of its size?

3.0- A Process of Construction Material Management (CMM):

3.1- According to your experience, could you provide us with an overview about managing the construction materials within the large-scale building projects in Jordan? This does not mean assessing or providing the detailed procedures of materials management process.
3.2- Does your organisation have specific procedures, system or written policies (whether it is own or adopted from elsewhere), in managing its construction materials?
3.3- Does your company have a specific department (Planning, Purchasing, or other divisions) for managing materials in its projects?
3.4- In your current project, could you explain in details, how you are managing your materials, from planning (as the first function) to the function of issuing materials to a craft-workers? If you like, you can give us a story of supplying an item or a material.
3.5- After looking on (reviewing) and discussing the typical CMM workflow diagram;
3.5.1 How far do you think the attached CMM Workflow Diagram(s) (functions, sub-functions & activities) match the CMM process that is currently in use in your project or company?
3.5.2 What are the differences and similarity? Please
3.5.3 In case there are differences, how do you manage functions and activities of CMM? And what are the alternative(s)?
3.5.4 What do you think about the positions and the sequence of the typical CMM functions, and the inputs and outputs feedbacks (Feedbacks Transpiration)?

3.6- With the exception of function No 8 (Quality Management Function), the diagram with the other seven integrated functions is similar to what has been developed by Plemmons in 1994 and it is used in many construction industries.
3.6.1 Is the function of quality management one of the functions that form your CMM system?
3.6.2 Within the sequence of the functions of the typical CMM workflow diagram, 'where do you think, the functions the quality management function should be placed?'
3.7- Regarding the modification that have been done on the positions of the 'Field Control' and 'Warehousing' Functions (replacing the sequence of Field Control Function with Warehousing Function), what do you

think about this modification?; and do you think that that the relationship should be between the craft worker and warehousing directly or the craft worker and the field control?

3.8- Who are, generally, the responsible for managing the building materials?

3.8.1 **Who typically manages the activities/Functions that form the materials management's process/system?**

3.8.2 Who typically purchases the majority of the following types of materials;

- Bulk materials
- Engineered materials
- Tagged Items

4.0- Effectiveness Measures of CMM Performance:

4.1- How you can check and evaluate the impact of any improvements, changes, or applications, which could be applied to the CMM process, in order to identify the extent of their effectiveness, suitability, and their need for more improvement or replacement?

4.1.1 What are the mechanisms or approaches used for monitoring those improvements and evaluating the performance of the CMM system used?

4.1.2 How the effectiveness of materials management performance can be measured within the large-scale building projects in JCI?

4.1.3 Do you have any specific mechanism or approach that can let you know the extent of the effectiveness of CMM performance?

4.1.4: If yes, What are the mechanism and measures that have being used for measuring the effectiveness of CMM performance in your project?

4.3- After reviewing and discussing the set of 33 measures for evaluating the CMM performance;

4.3.1 In the past, have you used one or more of these or similar measures?

4.3.2 Currently, are you using one or more of these or similar measures?

- If no, what are the alternatives that are used for monitoring the operation materials management function(s)?
- Do you think there is a potentiality to apply this measure, in terms of the availability of the required documents and the ability to collect data?; and How practical would these measures be to implement?

4.3.3 Please identify any significant barrier(s) you feel would be associated with implementing these measures (one by one).

4.3.4 How important is these measures in communicating the effectiveness of the materials management process? How practical would these measures be to implement?

4.4- Open discussion on the measures under the flexibility attribute.

5.0- Terminology:

5.1- What is the documentary cycle, which is implemented/applied in managing the materials management?

5.2- How does the responsibilities and authorities of managing materials move from a department or function to another in your organisation?

5.3- Is there naming or designation for the person or team who is responsible for conducting the CMM process?

Thank you very much

APPENDIX G:

THE QUESTIONNAIRE SURVEY

PART (I): RESPONDENT PROFILE SHEET:

Instructions:
For the following questions please tick (✓) the appropriate response (s) and fill for details:

Personal Information	Organisation Information
Q1.1-Name: .... **Q1.2- Your Current Position/ Title:** ☐ 1- Material Manager/ Administrator ☐ 2- Material Officer/ Coordinator ☐ 3- Warehouse Manager/Storekeeper ☐ 4- Purchasing/Procurement Manager ☐ 5- Project Manager ☐ 6- Logistic Manager/Coordinator ☐ 7- Construction Site Manager ☐ 8- Planner ☐ 9- Quality Manager/ Coordinator ☐ 10- Engineer/ Architect ☐ 11- Other Position; please specify................................ **Q1.3- Years of Construction Experience within the JCI:** ☐ 1) <5 years ☐ 2) 5- 10 years ☐ 3) 11- 15 years ☐ 4) 16- 20 years ☐ 5) 21-25 years ☐ 6) >25 years **Q1.4- Years of management or responsible project experience in the area related to materials management:** ☐ 1) <5 years ☐ 2) 5- 10 years ☐ 3) 11- 15 years ☐ 4) 16- 20 years ☐ 5) 21-25 years ☐ 6) >25 years **Q1.5- From What Perspective Do you Choose to Answer the Questionnaire:** ☐ 1- Planning & Administration ☐ 2- Material Takeoff & Material Control ☐ 3- Vendor Inquiry & Evaluation ☐ 4- Purchasing (Organisational Level - Home Office) ☐ 5- Purchasing (Construction Level - Filed) ☐ 6- Transportation & Expediting ☐ 7- Quality Control ☐ 8- Warehousing (Organisational Level - Home Office) ☐ 9- Warehouse (Construction Level – Site Store) ☐ 10- Field Control ☐ 11- Other; please specify................................	**Q1.6- Name of your Current Organisation/ Company:** .... **Q1.7- The type of your organisation:** ☐ 1- Contractor ☐ 2- Sub-Contractor ☐ 3- Client ☐ 4- Consultant ☐ 5- Supplier ☐ 6- Other, please give details.. **Q1.8- On What the Type of Construction Project, Do you Currently Work?** ☐ 1- Industrial Building Project ☐ 2- Residential / Housing Building Project ☐ 3- Institutional Building Project ☐ 4- Commercial Building Project ☐ 5- Heavy Civil Building ☐ 6- Other, please give details................................ **Q1.9- Under What the Type of Contract, Do you Currently Work?** ☐ 1- Fixed Price (Lump Sum) ☐ 2- Unit Price (Re-measured Based) ☐ 3- Cost Plus (Actual cost + Profit) ☐ 4- Cost Reimbursable (Variation) ☐ 5- Other, please give details................................ **Q1.10- What the Estimated Cost of your Current Project:** ☐ 1) <£15 m ☐ 2) £15 - 25 m ☐ 3) £26 - 35 m ☐ 4) £36 - 45 m ☐ 5) £46 - 55 m ☐ 6) >£ 55 m ☐ 7) If > £100 m, please give details................. **Q1.11- What is the Size of your Current Project?** ☐ 1- Small –Scale Project ☐ 2- Medium-Scale Project ☐ 3- Large-Scale Project ☐ 4- Huge Project ☐ 5- Other Size; please specify................................

PART (II): EVALUATION OF PROPOSED EFFECTIVENESS MEASURES:

Instructions:
After completing Part (I) of questionnaire (Respondent Profile Sheet), answer the following questions for each effectiveness measures that located in the next Table. The Labels, which are shown on the workflow diagram of CMM process attached with the cover-page (Appendix A), correspond to suggested measurement points. While answering these questions, feel free to make comments directly on the diagram.

Your feedback is appreciated

The Full text of This Part Questions:

Question 2.1 (Q2.1):
In the Past, have you used this or a similar measure?

Question 2.2 (Q2.2):
Currently, are you using this or a similar measure?
If yes, Skip question 3)

Question 2.3 (Q2.3):
Given the opportunity and the ability to collect the data, would you consider using this measure to monitor operations or identify problems with the materials management function (s) under your control?

Question 2.4 (Q2.4):
How important is this measure in communicating the effectiveness of the materials management process?

Question 2.5 (Q2.5):
How practical would this measure be to implement?

Question 2.6 (Q2.6):
In the space provided, please identify any significant barrier (s) you feel would be associated with implementing this measure.

Descriptions & Questions:
The next table includes the description of each measure; what the measure is, what it might be used for, and the location of measurement point(s). Measures are grouped into seven categories: Accuracy, Quality, Quantity, Timelines, Cost, Availability, and Flexibility.

CATEGORIES ATTRIBUTES	CODE	MEASUREMENT TITLE	AREA/POINT OF MEASUREMENT	MEASURES MEANING/DESCRIPTION	Q2.1: Used in the Past		Q2.2: Current in Use		Q2.3: Would Use		Q2.4: Importance					Q2.5: Practical To Implement					Q2.6: Any Significant Barriers/
					Yes	No	Yes	No	Yes	No	Not 1	Slightly 2	Moderately 3	Very 4	Extremely 5	Not 1	Slightly 2	Moderately 3	Very 4	Extremely 5	
ACCURACY	AC1	Material Receipt Problems	The interface between vendor and warehouse function	➢ AC1 reports the data or information discrepancies associated with a material delivery that, if not detected and corrected, would cause inaccuracies in the project materials management database. ➢ This measure is the percentage of line items received without discrepancy. ➢ Material receipt problems occur when shipping documents or materials do not agree in specific areas with the purchase order or receiving report (bill of lading, packing list, Pos, and others.																	
	AC2	Material Receipt Problems - Internal	At the interface of the Vendor with the Warehouse Function.	➢ AC2 reports the accuracy of internally generated material related data as determined at the point of receipt. ➢ The problems associated with material receipt processing may impact the materials management database system by introducing erroneous or inaccurate data. ➢ Examples of discrepancies with internal origins may include (1) materials correctly purchased and delivered to the site without a PO number,(2) the commodity code on the PO is not in the materials catalog, and (3) the PO is not available to receive the materials against. ➢ The causes of discrepancy could be the difference between AC1 & AC2																	
	AC3	Warehouse Inventory Accuracy	Within the Warehouse functions	➢ AC3 measures process quality by reporting the accuracy of the information associated with the warehouse function. ➢ This measure is determined by comparing through a statistical sampling the data in the materials database with the physical assets in the warehouse and controlled laydown areas. ➢ The inventory results indicate the accuracy of the materials management database system when compared with the physical asset count. Any difference between the inventory records and the actual physical counts constitutes a discrepancy. ➢ To calculate the AC3, it is essential to carry out statistical analysis in comparing the physical counts versus the system counts. (Darweesh, 1999)																	
QUALITY	Q1	Installing Equipments Rework	At the interface of Construction with the field control Function.	➢ Q1 reports materials related process quality as a specific evaluation of design and supplier (fabrication) performance. ➢ Q1 reports the total number of installing equipments identified as requiring rework (field modification) divided by the total number of installing equipments, multiplied by 100 to provide a percentage ratio.. ➢ In the case of owner or contractor changes, evaluating IER provides feedback on the impact of earlier decisions. ➢ IER constitute major and critical elements of some construction projects and rework may significantly impact construction productivity. *(that is why Q1 can be measured related to value)*																	
	Q2	Jobsite Rejections of Tagged Equipment	At the interface of Construction operation with the field control Function.	➢ Q2 represents the percentage of all rejections of tagged equipment. ➢ A rejection occurs when Construction notifies the Field Control Function of return of the item, because the construction group considered it unfit in its current form. ➢ The ability of the design and materials management processes to provide tagged equipment in accordance with requirements is critical to maintaining efficient construction operations.																	
QUANTITY	QN1	Home Office Requisition Ratio	At the interface of the Purchasing Function with the Vendor.	➢ The QN1 ratio serves as an indicator of the degree of economizing transaction activities by performing RFQs (Requisitions for Quotations) in the home office. ➢ QN1 reports the percentage of requisitions for quotations (RFQ) performed by the home office compared to the total number of request for quotations (RFQs) during a period of time. ➢ For this measure, an requisition submitted in an actionable format is considered the source of a RFQ. ➢ The purpose of a requisition is to initiate the flow of activities to purchase and receive specified materials.																	
	QN2	Home Office Purchase Order Ratio	At the interface of the Purchasing Function with the Vendor.	➢ QN2 reports the percentage of purchase orders (PO) performed by the home office compared to the total number of PO transactions during a period of time. ➢ The NQ2 ratio indicates the proportion of POs transmitted from the home office and serves as an indicator of PO activity performed by the home office.																	
	QN3	Average Line Items Per Release	At the interface of the Purchasing Function with the Vendor.	➢ QN3 is the ratio of the average line items per release and the planned number of line items per release. ➢ the measure might be reported in ratio format to communicate average and planned values. ➢ The NQ3 measure provides a general indication of the throughput for a given amount of effort to generate a release. The objective would be to maximize the line items per release. ➢ This measure could report actual versus planned releases in a periodic or cumulative format.																	

CATEGORIES ATTRIBUTES	CODE	MEASUREMENT TITLE	AREA/POINT OF MEASUREMENT	MEASURES MEANING/DESCRIPTION	Q2.1: Used in the Past		Q2.2: Current in Use		Q2.3: Would Use		Q2.4: Importance					Q2.5: Practical To Implement					Q2.6: Any Significant Barriers/ I
											Not	Slightly	Moderately	Very	Extremely	Not	Slightly	Moderately	Very	Extremely	
					Yes	No	Yes	No	Yes	No	1	2	3	4	5	1	2	3	4	5	
	QN4	Commitment – Home Office	At the interface of the Purchasing Function with the Vendor.	➢ QN4 reports the **percentage** of material and tagged equipment committed by **the home office compared** to the total commitment **value** during a specified time period. ➢ This is a companion measure to Commitment - Field (QN5)																	
	QN5	Commitment – Field	At the interface of the Purchasing Function with the Vendor.	➢ QN5 reports the **percentage** of the **value** of material and tagged equipment committed by **the field compared** to the total commitment **value** during a specified time period. ➢ This is a companion measure to Commitment – Home Office (QN4)																	
	QN6	Electronic Data Interchange (EDI) Purchases	At the interface of the Purchasing Function with the Vendor.	➢ QN6 is the **percentage** of purchases made using **electronic data interchange** (EDI) applications to the **total value** of purchases. ➢ The contribution of EDI is important to the materials management **strategy**. ➢ The total value of purchases is used to monitor the utilization of EDI computer-to—computer linkages. ➢ Changes in the measure should **reflect** paper reduction, clerical time savings and purchase order cycle time reductions.																	
	QN7	Sole Source Purchases	At the interface of the Purchasing Function with the Vendor.	➢ QN7 is the **ratio** of materials purchased via **sole source** to the total amount of purchases for a specified period of time. ➢ Sole source transactions would include purchases from key vendors who have negotiated override agreements.																	
	QN8	Minority Suppliers	At the interface of the Purchasing Function with the Vendor.	➢ QN8 is the **percentage** of total commitments for materials purchased via minority suppliers. ➢ For the purpose of **defining the term**, minority suppliers will encompass small, disadvantaged, minority, and women owned enterprises. ➢ This measure allows **monitoring** of **periodic** and **cumulative** percentages to achieve strategic business objectives.																	
TIMELINESS	T1	Procurement Lead Time	The interface between vendor and of purchasing function	➢ **T1** is the project **ratio** of the average procurement lead time in days and the planned procurement lead time. ➢ It uses a ratio format to report average **actual and planned values**. ➢ **Average procurement lead time** is the average duration bounded by the transmission of the request for quotation (RFQ) until the receipt (assigned) **acceptance** of the purchase order from the vendor. The **duration encompasses** the RFQ, bid evaluation, negotiation and award, and issuance of the PO. ➢ The **duration reflects** the completeness of the RFQ information, the need for additional negotiation, delays, the efficiency of bid evaluation, the mechanism of issuing the PO and receiving the acceptance copy.																	
	T2	Bid/Evaluate/Commit Lead Time	The first measure **T2A** is at the interface of the Vendor with the Purchasing Function. The second measure **T2B** is taken at the interface of the Purchasing Function with the Vendor.	➢ **T2** is the **average duration** reported in days to bid, evaluate, and commit (BEC) to the purchase of materials ➢ It uses a ratio format to report **average duration and planned duration.** ➢ The measure is bounded by the receipt of the vendor's response to the RFQ until the issuance of the PO. ➢ The measure focuses on the sequence of activities within the control of the Purchasing Function. The average BEC durations may be segregated by material grouping (piping, steel, controls, etc.) or by discipline (civil, electrical, mechanical, etc.) or by process.																	
	T3	Purchase Orders (PO) to Material Receipt Duration	The first measure location **T3A** is at the interface of the Purchasing Function with the Vendors. The second location **T3B** is at the interface of the Vendor with the Warehouse Function.	➢ **T3** is the **average duration** from the issuance of the PO until the receipt data of material(s). ➢ It uses a ratio format to communicate the **average duration and the planned duration.** ➢ **Average duration** is calculated based on each PO line item. Therefore, the measure is the sum of the issuance—to— receipt duration divided by the total number of receipts (this is for just calculation of Average duration).																	
	T4	Material Receiving Processing Time	Within the Warehouse and the Field Control functions.	➢ **T4** reports the **percentage** of materials received by the warehouse that is processed within two time periods, **same day**, and by **next day** ➢ **The processing time starts** when a shipping document is time/date stamped by the warehouse receiving activity, and a copy is returned to the transport carrier. **The processing time ends** when the material is updated to a received status within the materials management system. ➢ The chronological determination of same day or next day is midnight (0000 hours). ➢ This measure may be used in conjunction with overtime cost and workhours of craft labour assigned to the warehouse.																	
	T5	Commodity Vendor Timeliness	At the interface of the Vendors with the Warehouse Function.	➢ T5 reports the **percentage** of vendor deliveries that were delivered on time in regards to the **promised delivery date** and the **actual delivery date.** ➢ The **chronological** determination of same day or next day is midnight (0000 hours).																	
	T6	Commodity Timeliness	At the interface of the Vendors with the Warehouse Function.	➢ **T6** is the **percentage** of deliveries made **on or before** the actual delivery date when compared to the **required delivery date.** ➢ The **chronological** determination of same day or next day is midnight (0000 hours).																	
	T7	Materials Withdraw Request (MWR) Leadtime	At the interface of Construction with the Warehouse Function.	➢ **T7** measures the lead time allowed for the issuance or delivery of materials by reporting time is the difference between MWR date and the need or requested delivery date. ➢ The measure is reported as a **ratio** of the average MWR leadtime and the planned MWR leadtime. **The MWR date** is the date an authorization is issued to the warehouse to withdraw specific materials from inventory. ➢ **The lead time indicates** the ability of construction operations to request material as the																	

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											Not	Slightly	Moderately	Very	Extremely	Not	Slightly	Moderately	Very	Extremely	
					Yes	No	Yes	No	Yes	No	1	2	3	4	5	1	2	3	4	5	
				work package start date approaches, and, thereby, minimize the amount of time craft workers wait for materials. ➤ Accountability is maintained as the withdrawals are issued to individuals in the warehouse or delivered to project material drop sites. ➤																	
COST	C1	Average Manhour/Workhour per Material Takeoff (MTO)	Within the Material Takeoff and Design Interface Function	➤ C1 reports the average number of workhours required to generate a material takeoff (MTO) for a single drawing sheet. ➤ The measure is reported as a ratio of the average number of workhours and the planned number of workhours. ➤ The measure does not differentiate between manual and computer assisted MTOs, but it should include the effort associated with manually checking the final results. ➤ The average is(could be) determined by dividing the total number of identified MTO manhours by the total number of MTOs produced during the time period.																	
	C2	Average Manhour/Workhour per Purchase Order (PO)	Within the Purchasing Function	➤ C2 reports the average number of manhours required to generate a purchase order (PO) during the time period. ➤ The measure is reported as a ratio of the average number of workhours and the planned number of workhours to generate a PO. ➤ The generation of a purchase order is associated with a series of activities or tasks deemed necessary by management and the contract requirements. Therefore, each PO represents certain amount of workhours.																	
	C3	Freight Cost Percent	Within the Expediting and Transportation function.	➤ C3 reports the percentage of freight costs as a percentage of material expenditures. ➤ The total freight cost is divided by materials expenditures for the time period. ➤ The results may be combined and reported as a cumulative or a six-week rolling average to compare more readily with industry average.																	
	C4	Express Deliveries Percent	At the interface Between the Vendor and the Warehouse Function.	➤ C4 reports the percentage of express deliveries made to the project warehouse by dividing the number of express deliveries and the total number of deliveries for a specified period. ➤ Express deliveries are those deliveries where a premium price is normally paid for a quick response type transport of materials or equipment. ➤ This measure reflects the ability to plan and utilize standard modes of transportation and delivery.																	
	C5	Construction Time Lost	Between Construction Operations and the Field Control Function.	➤ C5 is the percentage of construction time lost due to the impact of materials as estimated by construction supervisors. ➤ C5 reflects the direct impact of the materials management process upon construction operations. ➤ The percentage of time lost due to materials is usually reported and collected using daily labour sheets. Feedback to the Field Control function is recommended on a weekly basis.																	
	C6	Payment Discounts	Within the Purchasing Function	➤ C6 reports the percentage of payment discounts correctly taken within the discount period. ➤ The measure indicates the missed discount opportunities and may have specific application in an electronic environment where the billing and payment information is entered and transmitted electronically. ➤ The measure reports work process improvements in terms of reducing the payment cycle, it may include: electronically comparing invoices; barcoding of documents; making payment through Electronic Funds Transfer EFT; implementing summary bills; or reducing the paper based verification system.																	
	C7	Warehouse Safety Incident	Within the Warehouse function.	➤ C7 reports the incident rate associated with warehouse function. ➤ The measure reports the percentage of warehouse lost time incidents compared to the total number of incidents for the project.																	
	C8	Total Surplus	Within the Warehouse and Field Control Functions.	➤ C8 reports the percentage value of unused materials in relation to the total purchase cost of materials. ➤ The value of unused materials is determined before being coded for return (restocking) or disposition by third parties or facility operations and maintenance.																	
AVAILABILITY	AV1	Material Availability	At the interface of the Warehouse Function with Constrution Operations.	➤ AV1 represents the ability of the materials management process to issue or deliver properly scheduled and communicated material requirements to construction operations prior to what is commonly recognized as the activity early start date (ESD) or the field need date (FND). ➤ It is calculated by dividing the total number of material line items issued by the total number of material line items requested. ➤ AV1 is commonly associated with those materials and equipment items with need dates that have been established and updated on a regular basis.																	
	AV2	Stockout Analysis	Within the Warehouse function.	➤ AV2 is the ratio of the total number of line items that a warehouse is unable to issue to the craft worker divided by the total number of line items requested. ➤ This measure is commonly associated with bulk material items and may be used as an aggregate measure for nine stockout situations. These causes may be identified as the stockout situation occurs and used to calculate percentages for each subgroup ➤ The categories are: Ahead of schedule, MIN/MAX low, Inventory: Inventory, Not short, Takeoff errors, Field takeoff: Field, Already issued and Other: Nonspecified causes. See (Plemmons, 1995) P63																	

CATEGORIES ATTRIBUTES	CODE	MEASUREMENT TITLE	AREA/POINT OF MEASUREMENT	MEASURES MEANING/DESCRIPTION	Q2.1: Used in the Past		Q2.2: Current in Use		Q2.3: Would Use		Q2.4: Importance					Q2.5: Practical To Implement					Q2.6: Any Significant Barriers/
											Not	Slightly	Moderately	Very	Extremely	Not	Slightly	Moderately	Very	Extremely	
					Yes	No	Yes	No	Yes	No	1	2	3	4	5	1	2	3	4	5	
Flexibility	F1	**Delivery Flexibility**)	The first measure location F_D **A** is at the interface of the Vendor with the Warehouse. The second location F_D **B** is at the interface of Warehouse Function with Construction Operations	➢ J could be the material line item or job in the system.. ➢ This is the ability to move planned delivery dates forward. This ability allows the supply materials/materials management to accommodate rush orders and special order. ➢ Delivery flexibility can be expressed as the percentage of slack time by which the delivery time can be reduced ➢ Delivery flexibility can also be measured as the proportion of excess slack across all jobs (j). ➢ An example of high delivery flexibility is just in time, when suppliers deliver the products to the customer at the right quantity, place, and time. (Sanchez and Perez, 2005)																	
	F2	**Changes Flexibility**	At the interface of Construction with the field control Function.	➢ Monitoring F2 may evaluate the **ability** of the design and materials management processes to **react** to design **changes** without impacting construction operations. ➢ F2 also **indicates** the flexibility of construction material management system to react any changes without impacting the cost of field construction phase. ➢ The root cause of these changes could be; • design and fabrication accuracy, • owner/contractor changes (i.e. modifications), • Shipping constraints, or schedule acceleration. • Untimely deliveries/ schedule acceleration, • Materials not in right place when needed/ shipping constraint, • Materials or equipments are not to project request. ➢ In the case of owner or contractor changes, evaluating F2 provides feedback on the impact of earlier decisions.																	
	F3 .	**Valume Flexibility**	The first measure location F_D **A** is at the interface of the Vendor with the Warehouse. The second location F_D **B** is at the interface of Warehouse Function with Construction Operations	➢ **Volume flexibility** is likely to be an important response to uncertainty in highly cyclical industries. (Sanchez and Perez, 2005) ➢ The volume flexibility measure, **F3**, measures the proportion of demand that can be met by the supply chain system/ materials management system ➢ Volume flexibility is the ability to adjust capacity to meet changes in customer quantities. (Duclos, 2003) ➢ For the development of a supply chain volume flexibility measure, it is interested in how much of the demand can be met considering only the range of volumes that are profitable. ➢ Demand volume could be units (number of units)																	

PART (III): ADDITIONAL MEASURES:

Instructions:

Suggest effectiveness measures not cited in the previous section, and evaluate these measures by filling the answers for the next questions;

The Full text of This Part Questions:

Question 3.1 (Q3.1):
In the Past, have you used this or a similar measure?

Question 3.2 (Q3.2):
Currently, are you using this or a similar measure?
If yes, Skip question 3)

Question 3.3 (Q3.3):
Given the opportunity and the ability to collect the data, would you consider using this measure to mentor operations or identify problems with the materials management function (s) under your control?

Question 3.4 (Q3.4):
How important is this measure in commutating the effectiveness of the materials management process?

Question 3.5 (Q3.5):
How practical would this measure be to implement?

Question 3.6 (Q3.6):
In the space provided, please identify any significant barrier (s) you feel would be associated with implementing this measure.

CATEGORIES/ ATTRIBUTES	MEASUREMENT TITLE	AREA/POINT OF MEASUREMENT	MEASURES MEANING/DESCRIPTION	Q3.1: Used in the Past		Q3.2: Current in Use		Q3.3: Would Use		Q3.4: Importance					Q3.5: Practical To Implement					Q3.6: Any Significant Barriers/ Notes
										Not	Slightly	Moderately	Very	Extremely	Not	Slightly	Moderately	Very	Extremely	
				Yes	No	Yes	No	Yes	No	1	2	3	4	5	1	2	3	4	5	

PART (IV): EVALUATION OF THE PRACTICAL CMM PROCESS'S (PCMMP) WORKFLOW DIAGRAM DEVELOPED:

Instructions:

As part of the validation process, please look at the developed Practical Workflow Diagram of the CMM Process that practiced in the J.C.I/A.C.I below, and provide your assessment on the workflow. To do so, please tick (✓) the box that best indicates your level of agreement with each of the statement below, where:
I= Strongly Disagree, 2= Disagree, 3=Neutral, 4=Agree, 5= Strongly Agree

1- In general, the practical CMM process's (PCMMP) work flow diagram, can reflect the real-life of managing the construction materials within the majority of the Large-scale Concrete Building projects within the A.C.I,

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
[ ]	[ ]	[ ]	[ ]	[ ]

2- The proposed functions that form the PCMMP Diagram are practiced by the majority of the contractor organisations for managing their building materials in the Arabic building projects,

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
[ ]	[ ]	[ ]	[ ]	[ ]

3- The proposed activities, which constitute (listed under) the functions of the PCMMP diagram below, are similar to those are practiced within the majority of the CMM processes in the Arabic building projects,

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
[ ]	[ ]	[ ]	[ ]	[ ]

4- The proposed position and sequence of the functions of the PCMMP diagram embodies the actual/ realistic sequence for those functions that shape the CMM process in the majority of the Arabic building projects,

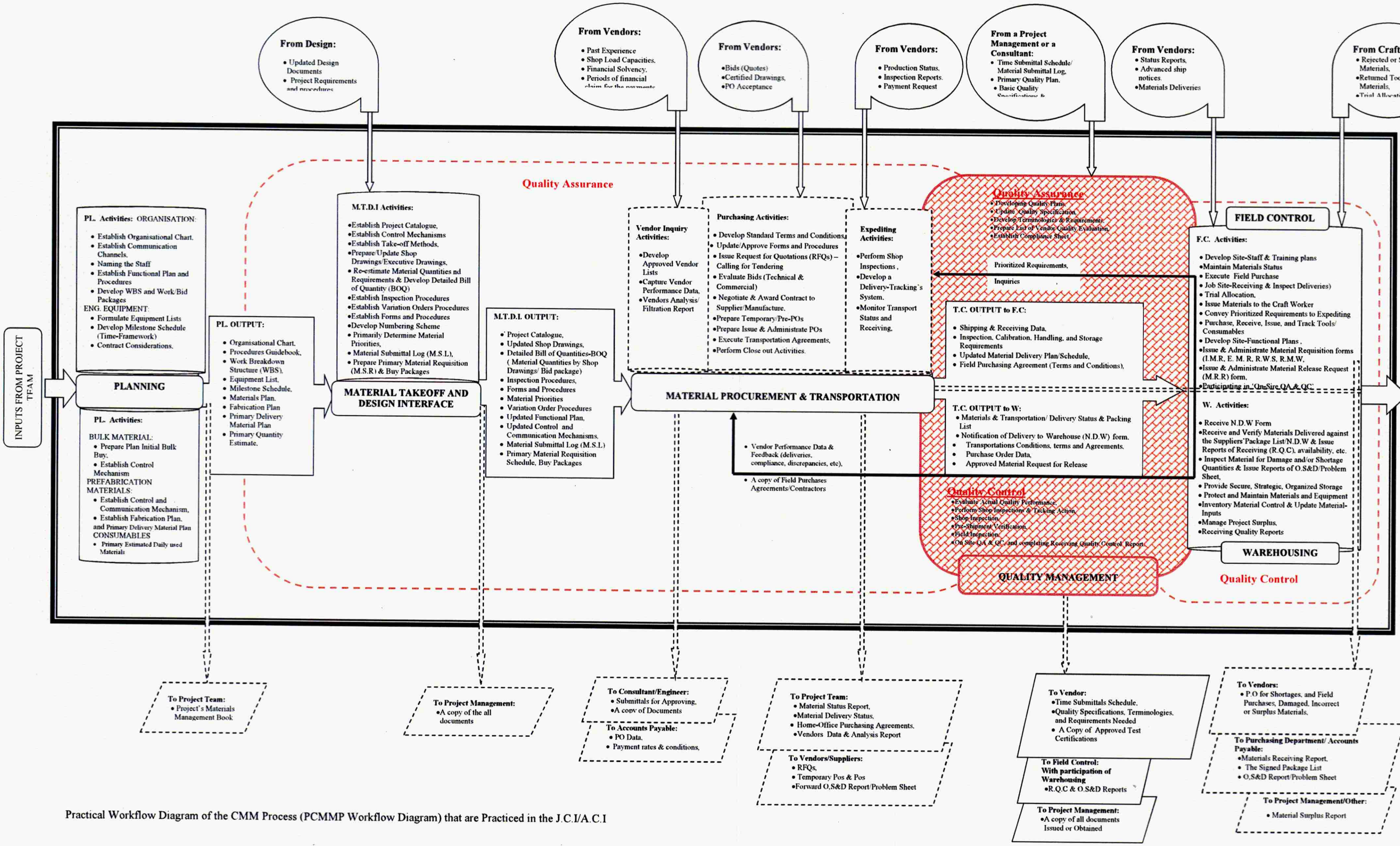
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
[ ]	[ ]	[ ]	[ ]	[ ]

5- The proposed internal and external outputs and inputs of the PCMMP's functions (relation between the functions of the CMM process, and their relation with the external participants; Customers, suppliers, vendors, and clients) are similar to those found in the majority of the CMM processes in the A.C.I.,

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
[ ]	[ ]	[ ]	[ ]	[ ]

6- The overlaps that have been proposed between the functions in the PCMMP diagram can depict the overlaps which are exist between the CMM process's functions, activities and responsibilities in the majority of Arabic building projects.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
[ ]	[ ]	[ ]	[ ]	[ ]



Practical Workflow Diagram of the CMM Process (PCMMP Workflow Diagram) that are Practiced in the J.C.I/A.C.I

Appendix G-10

PART (V): GENERAL NOTES, SUGGESTIONS & RECOMMENDATION:

Instructions:

In the space provided below, please state your notes, suggestions, and recommendations about the general overview of the research purpose and significant, CMM process in the Arabic Region, CMM process diagrams, the mechanisms used for evaluating the performance the CMM process;

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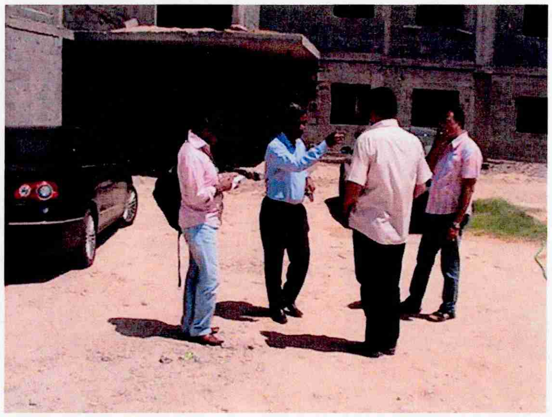
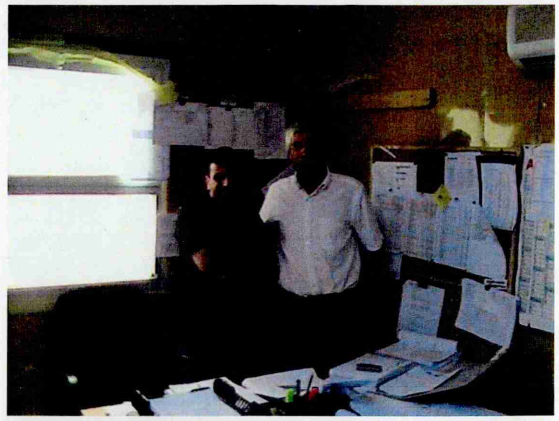
Thank you very much indeed

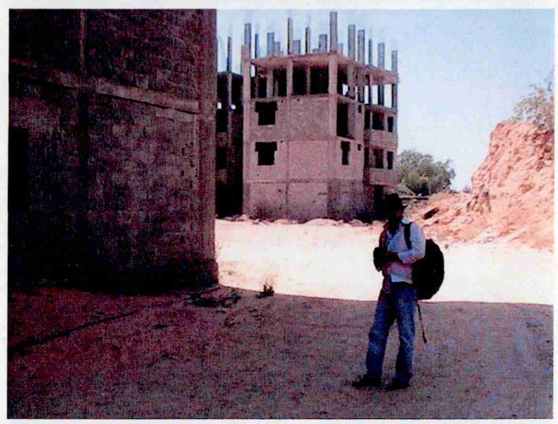
For your cooperation

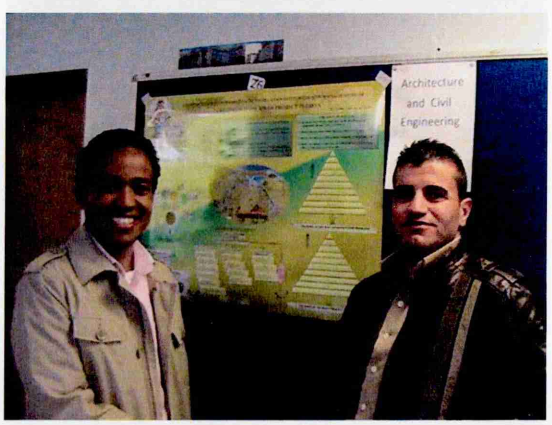
APPENDIX H:

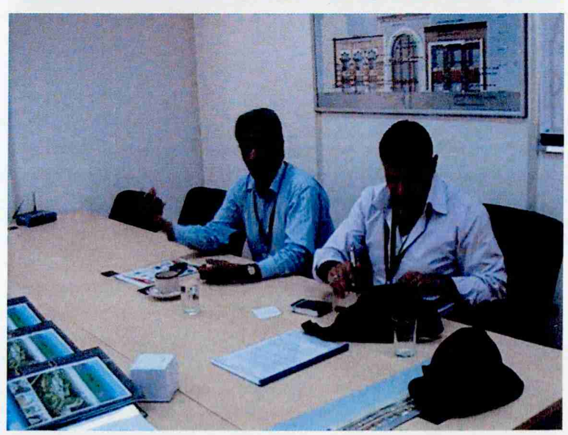
PICTURES THAT DOCUMENT THE PILOT STUDY I









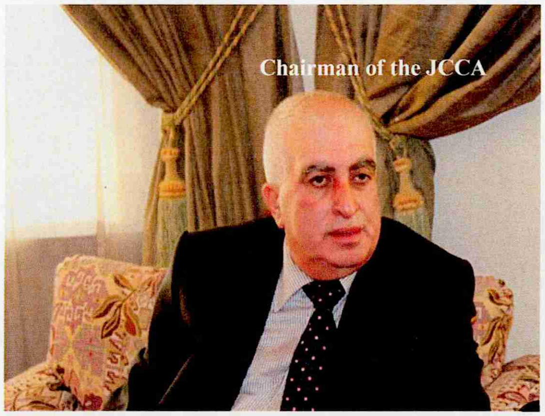


Appendix H-1

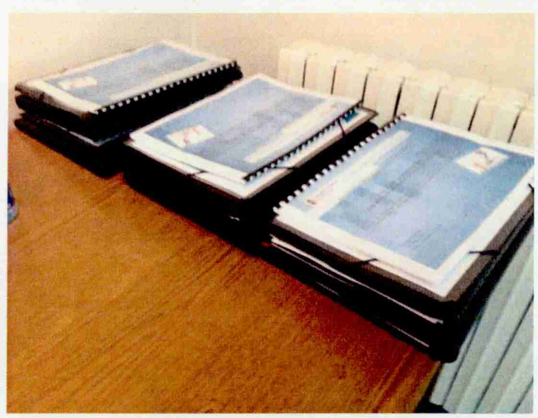
APPENDIX I:

PICTURES THAT DOCUMENT THE PILOT STUDY II

INDIVIDUAL INTERVIEWS WITH THE JCA DECISION:



MEETING FOR PILOT STUDY II:



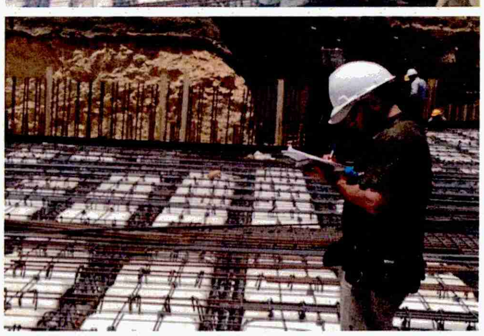
APPENDIX J:

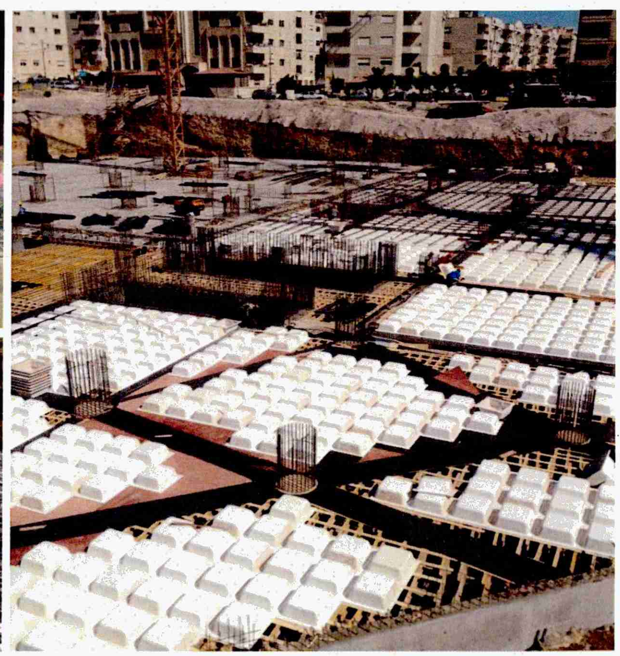
CASE STUDIES' REPORTS: PRESENTING THE CASE STUDIES OUTCOMES

1 CASE A: THE CANCER CENTRE BUILDING PROJECT:

1.1 Project Description/Background:

The project is a large-scale building project, which is considered as the biggest health centre for cancer in Jordan; it is composed of three basements and two 15 floor towers. The total gross built-up area is about 84752.92 m^2. One tower serves as an outpatient facility and the other as in-patient. The project is to be implemented on phases; the current phase is the implementation of the skeleton works including the primary works of electronic and mechanical first fix. The estimated cost of these skeleton works is 24.500.000 J.D = £22,789,370. The completion rate of the skeleton works is 10.5%, which means the project is at the beginning stage.





1.2 Organisation Profile:

The concerned company is a first class company (according to JCCA classification), which has a good experience in building hospitals all over Jordan. The main activity of the company is to execute a wide range of large-scale and complex public and private projects in the field of engineering and construction, in particular hospitals and health facilities. It is the main contractor for implementing the skeleton works of this project. Under the contactor`s responsibility, two sub-contractors work: one for shuttering works (wood framework) and another for reinforcement steel works (Steel Installation).

1.3 The Data Collecting Process:

Nine site visits were made within seven weeks (each one lasted for full time workday); including a tour to the construction site, company's warehouse, company's home-office, purchasing department and the stores on the site. The site visit process included monitoring the processes of requesting and supplying materials and reviewing material-related documents, daily and monthly reports, inspections forms, internal and external material requests, purchasing orders, drawings submittal, and the documentary cycle. The guided tours usually followed the logical flow of information and the material request process on the project site, which usually initiates from and ends at the field-operations level. This involved holding short meetings with those who were responsible for carrying out this process; they introduce each other during the project site tours (a craft-worker on a site, a foreman, a procurement officer, a warehouse manager, a project planner, a quantity surveyor, and a concrete supplier). During these visits, the related documents are reviewed, the emphasis is placed on understanding and documenting the approaches of requesting materials, the flow of the required documents, field activities, the mechanism used for evaluating the performance of the CMM process, and on obtaining the common industry-based terminology.

During the site visits, two semi-structured interview sessions took place with the Project Manager (PM) and the Construction Site Manager (CSM) within the contractor-field team of the project, and Warehouse Manager within the organisational level. The interviews, in total, lasted about four hours (2:13h+1:35h), which included one tow interview session on the site office and one in the Projects Management Department that included demonstrating the current material management system.

1.4 Lessons Learnt from the Site Visit and the Reviewed Documents:

Based on analysing the data collected and the notes recorded during the activities carried out within the site visits, the main lessons learnt are summarised under the following titles;

1- General Overview and CMM-Related Departments and Responsibilities:

Generally, although there is no particular or written policy used for managing the construction materials within the organisation, there could be general procedures, which are familiar to the majority of the construction companies within the JCI. Numerous participants contribute to the CMM process, but the scope of their involvement and responsibilities widely overlapped with others and it was not clearly defined; neither was it stipulated in the contractual document. However, these responsibilities could be drawn from the project team structure, as shown in **Figure J.1.**

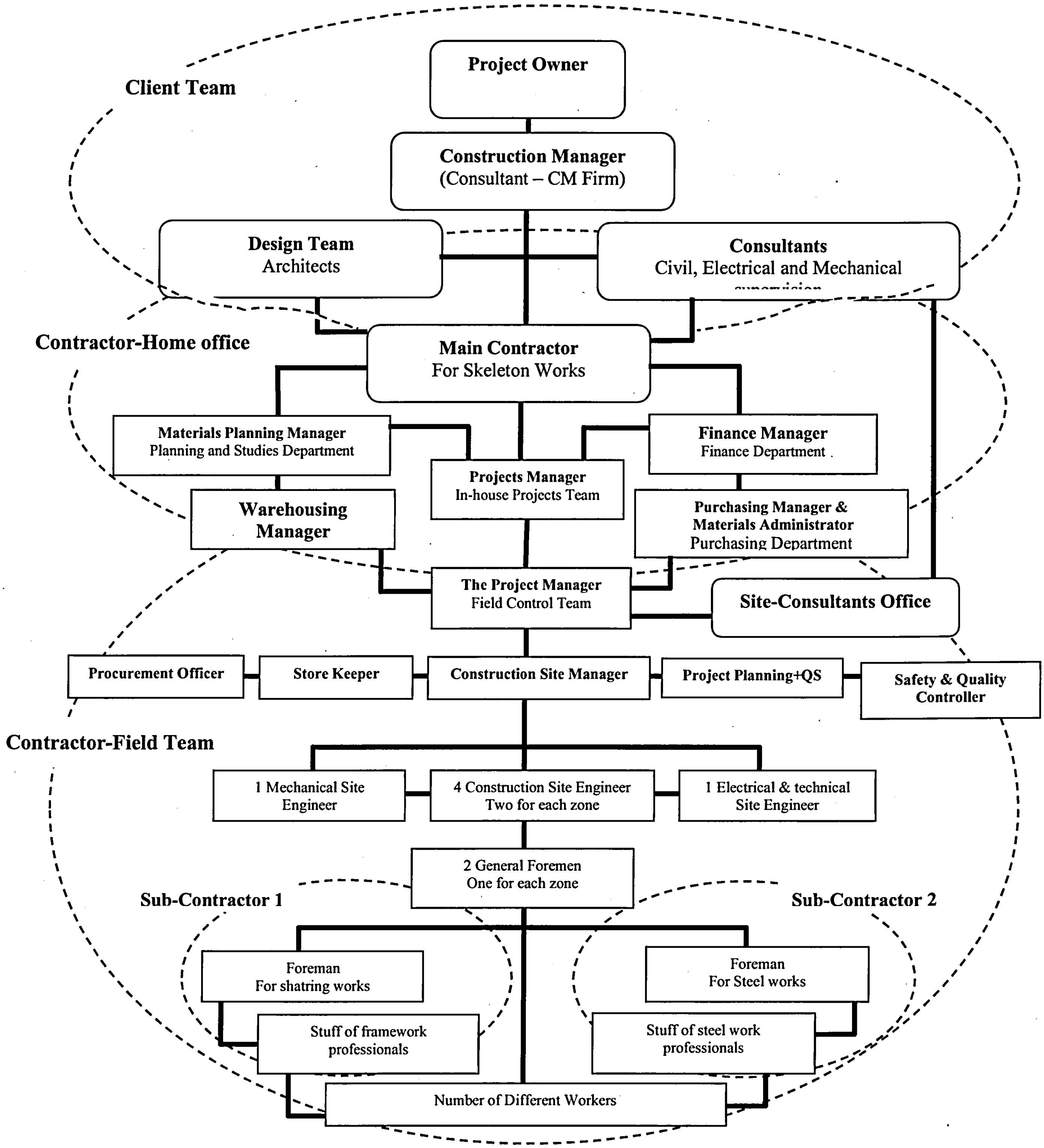


Figure J.1: The Project Team Structure as Related to CMM Process – Case Study A

The CMM process starts with a general planning and projects management department within the home-office (Head-office) of the company, whose team is responsible for planning the entire implementation process for building projects, including the CMM process. The planning function is conducted by this department with the participation of the project management team at the client level. The purchasing department within the head-office, which has a good knowledge about the local and international building materials markets, is responsible for managing the procurement process for all the projects. The materials administrator of the department along with the PM within the field team are responsible for selecting and evaluating the majority of the suppliers and for sending the Vendor Analysis Reports to the Projects Management department and the consultant for approving the issue. Both the material administrator and the project manager are also responsible for the entire process of purchasing, buying small items and securing bulk materials on the site. However, Field Purchasing could be carried out for some consumable materials (daily used). Additionally, the warehousing department exists in the company, which is competent in storing materials, inventory, and following-up the site-stores.

2- A Process of Building Materials Requesting:

The process of requesting materials begins from the customer who needs these materials or equipment. Since the customer in the CMM process is a Craft-worker on a site, the process of requesting materials initiates from the field-operations level; it commonly includes the following sequential steps;

a) A foreman and a procurement officer prepare a list of the materials needed for a week of work,

b) The required material list is sent to the CSM and discussed with the procurement officer and the storekeeper, in order to check their need priority and the availability in the site-store,

c) If the materials are available in the store, they are ordered by processing an internal material request form that is called the Request Materials from the Store (R.M.S),

d) In case the materials are unavailable in the store, the CSM along with the procurement officer reports to the PM by sending the list attached to the availability report,

e) The PM reports to the main warehouse in the company home-office (usually by phone) to make sure that the materials are available

f) In case the materials are available in the warehouse, an external material request is processed by filling a Request Material from, a Warehouse (R.M.W) form, and sending it to the material administrator for signature and then forwarding it to the warehouse department. Based on that, the materials can be released and delivered by the company's lorries to the site,

g) In case the materials are not available in the warehouse, the PM along the procurement officer report to the material administrator in the company home-office using an internal purchasing order that is called Pre-Purchasing Order (P.PO),

h) The purchasing department team then prepares and sends the PO to the supplier, who is already identified in the previous stage,

i) In case the quality of the material is already approved by the consultant, the materials are delivered to the site according to the assigned transportation agreement,

j) In case there is no quality approval, a specimen is usually sent to the consultant with the Material Inspection Request (M.I.R) form, before delivering materials to the site,

k) The procurement officer follows up the delivery, tracks the materials to the site and prepares the Material Delivery Status (M.D.S) report,

l) Receiving materials, which is considered the beginning point of the physical materials control at the job-site, is usually conducted by the storekeeper, procurement officer, and quality controller. They ensure that all materials received and inspected are in compliance with purchasing orders, standards and specifications. Based on that, they prepare related-received reports; Quality Control (R.Q.C) reports, and Over, Short and Damaged (O.S&D) List/Reports,

m) Finally, the storekeeper/ warehouse manager issues the required materials, and keeps copies of the material request documents for inventory control issues. He also prepares, with other project's participants, many related reports, such as, the Material Status Report, Inventory Control Report, and so on.

These are the main hierarchy and common procedures that are generally followed for requesting materials. However, this hierarchy depends on the type, quantity and the availability of the materials needed. For instance, the craft-workers and foremen can request consumed materials (daily used materials) directly from the site-store. The storekeeper can issue these materials to the field participants and forward a copy of R.M.S form to the construction site manager. The construction site manager can request any materials available in the Site-Store; the PM can order some materials such as, concrete, steel, chemical liquids and materials with low cost and/ or quantity by issuing PO directly to the supplier, which is already named, with forwarding a copy to the materials administrator.

3- Examples and Notes of the CMM process witnessed:

During the data collection process, efforts were concentrated on the process of managing the construction materials in general. However, since the concrete and steel represent the most widely used bulk and fabricated materials (respectively) in the skeleton works, more emphasis was placed on the process of managing and requesting these materials.

Requesting Concrete Material (Bulk Material);

- The used concrete, in this case study, is ready-made concrete; the concrete is mixed out of the site, and it is ordered from a particular concrete supplier.
- Based on the site reports, the construction site manager (CSM) and his execution team determine the parts that are ready to be casted.
- The CSM prepares a Request for Inspection & Approval (R.I.A), which is sent along with the sketch drawing to the consultant office (a copy is sent to the Project Manager PM) for approving the issue
- After R.I.A is approved, CSM prepares the Request for the Concrete Pour (R.C.P) , which is sent to the consultant (a copy to the PM) for approving the quantities and qualities of the concrete,

- After that, CSM with the procurement officer prepare the Purchasing Order (PO) and send it to the PM to sign it after confirming the quantity and the exact time of casting.
- The procurement officer asks the concrete supplier by phone to deliver the required mixed concrete until the PO is sent,
- The concrete supplier is already identified at the beginning of the project; he is well-known by the contractor and has good relationship with him.
- The procurement officer is responsible of tracking the delivery of materials and organising when, where and how the concrete pump will be sited to provide the concrete to the site, and to prepare the Materials Status Report (M.S.R),
- During casting the concrete, the quality controller with the third party (Quality Testing Laboratory/Centre) make the required in-site tests (cube, slump test, etc.).
- As the site is surrounded by three roads, authorisation/permission from the traffic police is required, and sometimes the casting concrete could be performed at night. (as there is less the road conjunction),

Requesting Steel Material (Fabricated Material);

- The steel material is manufactured and shaped in the steel factory out of the site; it is brought to the site for ready use,
- The quantity surveyor, within the project planning team at the project-field level, prepares the steel sheet, which is called the Reinforcement Steel Schedule (R.S.S) from the shop drawings for the particular part of the building, which is under implementation,
- The R.S.S, which contains the bending shape and the quantities of steel, should be reviewed and approved by the project management team (CSM and PM) before being sent to a steel manufactory to be fabricated,
- Based on the RSS, the steel manufactory supplies the shaped steel to the storage area on the site,
- The procurement officer follows up delivering the material to the site, and preparing Materials Delivery Status Report
- The storekeeper and the procurement officer receive the steel material and confirm the quantity and quality of materials by matching them with the RSS,
- Copies of RSS are sent to the civil site engineers and the steel foreman to order the material as it is needed.

4- Terminology:

The most common CMM process-related terminologies, forms, reports and documents that were recognised in this case study are;

- Request for Inspection & Approval: (R.I.A)-Form
- Request for Concrete Pour: (R.C.P)-Form
- Purchasing Order: (PO)-Form
- Pre-Purchasing Order: P.PO-Form

- Material Status Report: (M.S.R)-Report
- Material Delivery Status Report: (M.D.S)-Report
- Internal Request Materials = Request Materials From the Store: (R.M.S)-Form
- Variation Order: (VO)-Form
- External Request Materials = Request Materials from Warehouse: (R.M.W)-Form
- Material Inspection Request: (M.I.R)-Form
- Internal Materials Receipt: (IMR)-Receipt
- Steel Sheet = Reinforcement Steel Schedule: (R.S.S)

5- Observed Actions:

- Many Variation Orders (VOs) were issued in the project because of the changes in designs. Those changes lead to changes in material specifications or quantities, such as, increasing the thickness of a slab; cancellation of some ground beams work, and changes in the diameter of some HD UPVC pipes.
- Earlier requisition is made by the CSM for some materials, such as, manufactured steel and wood sheets) for saving time,
- A Primary computerised system has been used; using Excel Microsoft Office for inventory, Primavera for planning, and e-mail for sending some electronic documents.
- In some cases, the PM and the Material Administrator select the suppliers based on their history, price, and material specifications. The supplier should be accepted and approved by the consultant

1.5 The Key Interview Outputs:

A semi-structured interview was conducted with the PM and the CSM within the contractor-field team. Although the interviews addressed some general CMM-Related issues, they focused on discussing and exploring the functions and activities that form the CMM process practiced in the case studies. They examine the mechanisms currently in use for evaluating the CMM performance, and identifying the set of effectiveness-measures that are and/or can be used for evaluating the performance of the CMM process.

1- Functions and Activities of the construction Materials Management Process:

In order to facilitate presenting the functions and activities that shape the CMM process practiced in this case study, the currently implemented functions and activities were determined, discussed and compared with those that form the typical workflow diagram of the CMM process (developed from the literature review). This is intended to explore the differences and similarities between the typical and practical CMM processes including determining which of the activities exist, which exist under another name or function, which is non-existent along with the alternatives, as summarised in the next table.

NO	FUNCTIONS	ACTIVITIES	EXIST	EXIST UNDER OTHER NAME	INCLUDED UNDER OTHER FUNCTIONS	NOTCE & ALTERNATIVES	FUNCTION OUTPUT	FEEDBACKS
1	**PLANNING**	**ORGANISATION**:					1- Organizational structure for project management. 2- Procedures Guidebook 3- Work Breakdown Structure (WBS)	1- This function implemented in Organisation Level. 2- The Project Mat Management Book Catalogue to the pr team (project manager) 3- The function's output t function of take-of Design Interface Team,
		Establishing Responsibilities	*Exist*	*Tasks/Job/Responsibilities Distribution (Assignments)*		➤ *The overlap is usually expected* ➤ *Here the job boarders for each member are assigned*		
		Establishing Communication Channels	*Exist*			*Not official*		
		Developing Staffing and Training Plans	*Exist*	*Naming the Staff*		➤ *No training; as basically, they should be qualified* ➤ *it exists in somewhat*		
		Developing Functional Plans and Procedures	*Exist*			*These procedures are developed by the CM company, and imposed on all the project participants*		
		Developing WBS and Work/Bid Packages	*Exist*			*This exists even before the work on site commencement (WBS)*		
		ENGINEERED EQUIPMENT:					1- Equipment List 2- Milestone Schedule 3- Delivering Materials Plan	
		Formulating Equipment Lists	*Exist*			➤ *Usually carried out for the main equipment used for completing work, for example, Cranes, Templates concrete columns, and Waffle (fibber frame for roofing),* ➤ *This could occur in other stages, such as, stage of fixing equipment (Medical devices) or Finishing & decoration stage. But in the Skeleton work, it doesn't exist (as the little number of engineered materials are used.*		
		Developing Milestone Schedule Milestone is the time period specified to end a specific work	*Exist*			➤ *Based on the project Timetable, the general milestone schedule is developed.* ➤ *Based on the Milestone Schedule for implementing the project, the milestone schedule for delivering building materials can be established*		
		Contract Considerations	*Exist*			*In skeleton stage, this activity concerns the fabricated materials*		
		BULK MATERIAL:					1- Primary quantity estimate, 2- Delivering Materials Plan	
		Quantity and Update Requirements			*Take-off*	➤ *It is ok for quantities, but not for exact date required.* ➤ *In the planning stage, it could be Preliminary process.*		
		Plan Initial Bulk Buy	*Exist*			*It is a basic process, because on this activity, I can determine the cost of materials.*		
		Establishing Control Mechanism				*For the majority of bulk materials like concrete, there is no specific control mechanism. It could be later established within site works, because the sit-work can only identify the mechanism that should be used.*		
		PREFABRICATION MATERIALS:					1- Delivering Materials Plan	
		Developing Tag Numbering Scheme			*Take-off*	➤ *The tagged items are not too much visible in the Skeleton works.* ➤ *The main fabrication of the material in the skeleton stage is the fabricated steel, which does not need tagging.*		

NO	FUNCTIONS	ACTIVITIES	EXIST	EXIST UNDER OTHER NAME	INCLUDED UNDER OTHER FUNCTIONS	NOTCE & ALTERNATIVES	FUNCTION OUTPUT	FEEDBACKS
						➢ In the Skeleton stage, in the site-store, this could occur for the engineered materials or for other project stages, such as, Finishing & decoration stage. ➢ In the Skeleton work, it doesn't exist (as the little number of prefabricated materials indicated)		
		Establishing Control and Communication Mechanism	*Exist*			Paper work & Using E-mail		
		CONSUMABLES					1- Daily used Material Lists	
		Developing Quantity Requirements	*Primary Estimate*	*Daily used Materials Lists*				
2	**MATERIAL TAKEOFF & DESIGN INTERFACE** Design Interface could mean preparing shop drawings	Establishing Project Catalog, Coding Systems		*Establish Project Catalog*		Project Catalog can exist, sometimes it can be one of the output of Planning function.	1- Bill of Quantities (BOQ), 2- Materials, quantities package, bid package, 3- Inspection procedures, 4- Materials Priority, and 5- Variation Orders Procedures. **Extra Activity;** Preparing the Shop Drawings	1- This function implemented in Organisation-Level a with the project manage team in the Field-Level. 2- From Project T (Updated design docun and project procurements 3- The function's outputs t function of Vendor Inq and Evaluation, 4- Materials' quan package, bid package t project team (Pr Manager),
		Establishing Control Mechanisms	*Exist*					
		Establishing Take-off Methods	*Exist*			It is one of the quantities, the surveyor's responsibilities to appoint calculating method(s) and units used.		
		Determining Quantities, Consolidating Requisitions		*Developing or updating the Bill of Quantity (BOQ)*		➢ Again, it is one of the quantities surveyor and project manager's responsibilities ➢ Especially, for the Materials that are purchased from overseas.		
		Determining Craft Preferences		*The Materials Priorities*				
		Establishing Inspection Procedures	*Exist*			Considering that, steel and cement are already approved in the JCI, only site tests are made.		
		Establishing Change Management Procedures		*Establishing Variation in the Order Procedures*		Changes in this case mean those who lead the change, the materials' quantities, qualities, or delivering approaches. This is called VO changes.		
3	**VENDOR INQUIRY AND EVALUATION** In JCI, the vendor is usually the supplier. In some cases, the manufacture is the vendor and the supplier one else (may who delivers materials).	Developing Approved Vendor Lists	*Exist*		*within Purchasing Function*	➢ In the skeleton stage, the number of vendors or suppliers is limited, so this function is not a big issue. Therefore, it could be included under the purchasing function. ➢ These activities are exactly in the tendering process, which is usually included under the purchasing function. ➢ Sometimes, for some specific materials, a vendor or a supplier could be assigned in the contract. In this case, one must supply one's materials from this vendor or supplier (Sole Source).	1- Approved vendor lists, 2- Vendors Filtration report; Including Vendors' CV (Performance Data)	1- This function is implement the Purchasing & Departments in Organisation-Level along the project Manager in the Level. 2- From the vendors; experience, shop load capa financial data (Fina solvency), and period or dur for financial claim for the payment 3- This function was not separated from the purch function. In fact, there is n borders between this fun and the purchasing fun (combined). 4- The feedback (Ve Analysis/filtration Report) Project Team
		Capturing Vendor Performance Data	*Exist*					
		Providing Performance Feedback		*Vendors Analysis/filtration Report*				

NO	FUNCTIONS	ACTIVITIES	EXIST	EXIST UNDER OTHER NAME	INCLUDED UNDER OTHER FUNCTIONS	NOTCE & ALTERNATIVES	FUNCTION OUTPUT	FEEDBACKS
4	PURCHASING	Establishing Forms and Procedures			*This could be considered within the Take-off function*		*1- Purchasing order data,* *2- Home office purchasing agreement* *3- field procurement and subcontract purchase agreements (terms and conditions)* *4- Payment rates and conditions* *5- Transportation agreement & terms,*	*1- This function implemented in Purchasing Department i Organisation-Level a with the project Manage Team in the Field Level.* *2- **From**; the input from ve inquiry or its alternative,* *3- **To**; The output Transportation & Rece Function,* *4- **To** Project team; Mate Status Report,* *5- **To** Vendor; RFQ(s) & PO* *6- **To** Accounts Payable; Data*
		Developing Standard Terms and Conditions	*Exist*			➢ *It is carried out at the stage of pricing the tender.*		
		Issue Request for Quotations (RFQs)	*Exist*	*Call for Tenders*				
		Evaluating Bids (Technical & Commercial)	*Exist*					
		Preparing Purchase Orders		*sometimes Both are called ''Issue Purchase Orders(PO)''*		➢ *Two of the activities are combined in one activity, which is called Issue Purchase Orders* ➢ *Purchasing Manager /Materials Administrator, Project Manager (PM), or Construction Site Manager (CSM) along with the Procurement Officer could perform this activity, it depends on the type and quantities of the required materials.* ➢ *However, the majority of PO procedure starts from the field control/CSM and Project Manager and then completes by purchasing department.* ➢ *In some cases, the PM can purchase some materials (Field Purchasing) without reference to the General Purchasing Department, but he should forward the invoices to the department.*		
		Administering Purchase Orders						
		Performing Close Out activities	*There is no activity naming like this*					
5	EXPEDITING & TRANSPORTATION *This function in some companies could be named as Transportation and Receiving Control*	Establishing Expediting Plans	*Not*			*In the process of ordering the steel (steel is formed by the manufactory). This function is applied by the project manager or Procurement Officer (Field-Level), who periodically telephones the steel manufactory to make sure that preparing the order is going on well.* *✱This kind of expediting is called routine status reporting.*	*1-The output to the project team (Material & Transportation/ Delivering Status Reports)* *2-output to Warehousing Function (output to the project team (Material & Transportation/ Delivering Status Data)* *3- Output to the Field Control (Shipping and Receiving Data, Inspection, handling and storage required), this could be oral or by phone.* *But this is performed by the function of <u>Transporting and receiving control</u>*	*1- The modification, w has been made by us, o feedback with Field Co and Warehousing, and o was agreed on* *2- **From** vendor; Produ status, inspection rep payment request.* *3- **From** Warehouse and control functions (Prio requirements & Inquiries)* *<u>This function may be c Transporting and Rece Control.</u>*
		Performing Shop Inspections	*Exist*		*with purchasing function*	➢ *This can be written in the contract for some specific materials. It can include visiting materials shops or manufactories at the beginning of the vendor inquiries function, for example, visiting the steel manufactory or mechanical items shop.*		
		Establishing Communication Mechanism	*Not*					
		Executing Transportation Agreements			*The agreement is already made with the supplier earlier; it could be made within the Purchasing Function or Transportation*			

NO	FUNCTIONS	ACTIVITIES	EXIST	EXIST UNDER OTHER NAME	INCLUDED UNDER OTHER FUNCTIONS	NOTCE & ALTERNATIVES	FUNCTION OUTPUT	FEEDBACKS
					Control Function			
		Performing Route Surveys	*Not*					
		Monitoring Production and Transportation Status		*Tracing Materials Delivery Control*	*Function of purchasing*	➢ *In skeleton works/stage, monitoring production does not really exist. It could exist for some specific materials (electronic and mechanical items), however, it depends on the contractors terms.* ➢ *The process of Monitoring transportation status is included within Transportation and Receiving Control,* ➢ *Tracking Materials is usually done by the procurement officer or the construction site manager*		
6	**FIELD CONTROL** *He advised to feedback goes to the project team (Listen)*	Maintaining Materials Status	*Exist*				*1- To the Craft-workers; Issuing materials, equipment and tools,* *2- To Project Team at the Organisational-Level: a copy of all the output documents*	***From Field Craft;*** *1- Rejected or surplus mater* *2- Returned Tools,* ***From Vendors;*** *1- Status reports,* *2- Advanced Ship* *3- Notices and* *4- Materials delivers Report* • *The field control and warehouse functions are somewhat combined and th field control should have al data on the warehouse.* • *As the relationship should between the craft-workers a the field-control, the field control should be placed before warehousing to;* o *empower the field control control the issuing and th movement of materials.* o *for quality control issues,* o *and to facilitate sending s materials directly to the s*
		Executing Field Procurement		*Field Purchase/ procurement*				
		Receiving and Inspecting Material Deliveries	*Exist*					
		Trial Allocations	*Exist*					
		Issuing Materials to the Craft Worker	*Exist*					
		Conveying Prioritized Requirements to Expediting		*Materials Priorities List/Report*				
		Purchasing, Receiving, Issuing, and Tracking Tools/ Consumables	*Exist*	*Field Purchase/ procurement*		*it is usually for some consumable/daily used materials*		
7	**WAREHOUSING**	Receiving Report (OS&D, availability, etc.)	*Exist*			Report of Insert Materials to the site store *a copy of the Packing List that is signed (when receiving materials) sent to the project Manager*	*With the involvement of the field control* *1- To Vendors, P.Os for Shortages,* *2- To Vendors also, Damaged, Incorrect or Surplus Materials* *3- To accounts Payable;*	• *This function is implemen by the Storekeeper in the Fi Level for the site-store & by Warehouse Team in the Organisation Level.* • *Vendor Performances Feedback is sent by Warehousing to the Vendo*
		Providing Secure, Strategic, Organized Storage	*Exist*					
		Protecting and Maintaining Materials and Equipment	*Exist*					
		Inventory Materials		*Inventory Control*				
		Management Project Surplus	*Exist*			➢ *It is usually the responsibility of the*		

NO	FUNCTIONS	ACTIVITIES	EXIST	EXIST UNDER OTHER NAME	INCLUDED UNDER OTHER FUNCTIONS	NOTCE & ALTERNATIVES	FUNCTION OUTPUT	FEEDBACKS
						Projects Senior Manager (Contractor-Home office Level) or the CM Company, which represents the owner (Client- Level). ➢ *There are three approaches to managing the surplus;* *1- Agreement with the supplier or the vendor for returning the surplus of materials* *2- Sending the surplus back to the main warehouse,* *3- Co-ordinating with another project, which may need the surplus, to obtain the surplus* ➢ *Reducing the surplus; could be by requesting materials as needed.*	*Materials Receiving Report,* *With the involvement of the field control* *1- Issuing materials, equipment and tools to the craft-worker,* *2- Surplus Materials*	*Inquiry directly, which is usually sent (with more det about the vendor and alternatives) to Project Team/Manager* • *A copy of any feedbacks, which are sent from warehousing to Vendor, Accounts and Others, goes the project Manager*
8	QUALITY MANAGEMENT	**Quality Assurance (QA):**					*To Vendor;* • *Time Submittals* • *Quality Specifications, Terminologies, and requirements* • *Test Certifications* *To Vendor Inquiry and Evaluation/Purchasing;* • *Quality Plan,* • *Vendors Quality Appraisal.* *To Field Control:* • *R.Q.C List/Report or O.S&D Reports (Over, Short and Damaged Reports)* *To PM's Team* • *A copy of all above .*	*It should be located between transportation from one side and warehousing and field control from another side.* *From Project Team;* • *Time Submittals* *Quality Specifications*
		Developing Quality Plans including; • Evaluating the need for in-plant inspection, • Evaluating the level of Inspection, • Deciding; in-house or contracted inspector.				*Construction Management (CM) Company responsibility*		
		Developing Quality specification				*CM Company responsibility*		
		Determining terminologies and requirements			*Updated in Take-off function*	*CM Company & Contractor-home office responsibility*		
		Preparing list of vendor quality evaluation			*Vendor Inquiry in Purchasing*			
		Quality Control (QC):						
		Evaluating actual quality performance & taking actions on the differences	*Exist*			*Consultant Office & Contractor-home office responsibility*		
		Shop Inspections	*Exist*			*Depends on the type of materials*		
		Pre-Shipment verification						
		Field Inspections	*Exist*					
		On-site QA &QC: Completing and receiving quality control list/report		*Site-Inspection of Documents and Materials Quality*		*Responsible for the warehousing team and consultant*		

2- The Mechanisms/Approaches Currently in Use for Evaluating the CMM Performance;

No specific mechanism for measuring the effectiveness of CMM performance has been used in this case study. However, some qualitative (non-quantified) approaches have been applied to monitor the extent of the effectiveness of the current CMM system. The most significant, visible and feasible mechanism, which can indicate the effectiveness of CMM performance, has been based on following up the project's reports. This mechanism is practiced as follows;

a) Following up and documenting reports such as, the Daily/Monthly reports, Materials Delivery Status reports, Receiving Quality Control (R.Q.C) reports, Over, Short and Damaged (O.S&D) List/Reports, and Inventory-Site store reports,

b) Formation of a committee within the Field Level; it includes the CSM, Procurement Officer, Site-Storekeeper, and Quantity Surveyor. The committee reviews, examines and evaluates reports and documents of POs, requests, transportations, receiving, quality tests, and storage.

c) The committee prepares a comprehensive report that includes evaluating the CMM process by providing a;

- Comparison between; (1) the planned schedules and the actual works on the site, (2) the actual and planned procurement lead time, (3) the actual and estimated materials cost, (4) the actual and estimated waste of materials, and (5) the actual and required quality of materials used.
- Examining and evaluating the POs issued, RFQs processed, shipping certificates, signed releases, test documents, rejections of non-conforming items, and the volume of the surplus,
- Highlighting the expected reasons behind any delays or problems

d) This report is sent and discussed with the Project Manager, who in turn, transfers it to the Purchasing Department or the Project Management Department in the Contractor-Home Office (the Organisation Level),

e) In some cases, monthly or quarterly meetings are held; they invite the PM, CSM, Procurement Officer, Materials Administrator, a representative of the CM's company, and a representative of the consultant office, in order to discuss related-issues and to develop solutions and make recommendations and decisions.

3- A Set of Measures for the Effectiveness of the CMM Performance;

To facilitate presenting the results of this section, the measures used in this case study were determined, discussed and compared with the proposed set of measures that has been developed in the literature review process. This aims to identify the existing measures (Exist), the non-existent ones (Non-Exist), the existing Similarities, and the Alternatives, as summarised in the next table.

ATTRIBUTES	CODE	MEASUREMENT TITLE	EXIST	EXIST SOMETHING SIMILAR	ALTERNATIVES	NOTCE
ACCURACY	AC1	**Material Receipt Problems**			*Quality Control (R.Q.C) reports, Over, Short and Damaged (O.S&D) List/Reports*	*These reports provide the number of receipt with discrepancies, and the discrepancies description. But it is not for measuring the CMM process effectiveness.*
	AC2	**Material Receipt Problems - Internal**			*R.Q.C reports, O.S&D List or Reports, Material Status on the Site*	
	AC3	**Warehouse Inventory Accuracy**		*Periodic review of the inventory/ Regular Inventory Control*		*Monitoring the accuracy of the data documenting process for construction material, by comparing the inventory records and the actual physical counts*
QUALITY	Q1	**Installing Equipment Rework**			*Construction Status Report: The section of the Progress of Fixing/Installing equipment on the site*	*Providing CSR which is a very important measure*
	Q2	**Jobsite Rejections of Tagged Equipment**		*Counting the Notifications of Return/non-conforming Items*	*For this, Material Inspection Request (M.I.R) and Material Returned/Rejection Forms are used*	➢ *In some cases; counting the Inspections Forms that rejected the total number of Inspections Forms* ➢ *It is the most practical measure*
QUANTITY	QN1	**Home Office Requisition Ratio**			*Monthly/Quarterly Report includes the number of performed RFQs, and total PO transmitted to the home-office*	*Listing and Checking the number of performed RFQs and POs. This is within reports for monitoring, but not as unit of measurement*
	QN2	**Home Office Purchase Order Ratio**				
	QN3	**Average Line Items Per Release**	*Not*			*The documents, which usually resulted from the Planning function and the Take-off function, do not include the planned number of line items per release"*

ATTRIBUTES	CODE	MEASUREMENT TITLE	EXIST	EXIST SOMETHING SIMILAR	ALTERNATIVES	NOTCE
	QN4	**Commitment – Home Office**	*Not*			
	QN5	**Commitment – Field**	*Not*			
	QN6	**Electronic Data Interchange (EDI) Purchases**	*Not*			*The EDI technology is not commonly used*
	QN7	**Sole Source Purchases**	*Not*			*Some materials are purchased by sole source; for example, supplier of steel is assigned in the contract. (this could be called Sole Brand)* *Although it is good way to purchase, and good to be measured, it is not measured in JCI.*
	QN8	**Minority Suppliers**	*Not*			*Some daily used materials are purchased, within field purchasing function, from Local market. However, they are not measured.*
TIMELINES Shipping Documents are called Packing List in JCI	T1	**Procurement Lead Time**	*Not*		➢ *According to PO duration, the processing time could be monitored, followed up and controlled, but without any measurement or calculation.*	
	T2	**Bid/Evaluate/Commit Lead-time**	*Not*			
	T3	**Purchase Orders (PO) to Material Receipt Duration**	*Not*			
	T4	**Material Receiving Processing Time**	*Not*			
	T5	**Commodity Vendor Timeliness**			*Monitoring Delivery Status Report*	
	T6	**Commodity Timeliness**	*Exist*			
	T7	**Materials Withdrawal Request (MWR) Lead-time**		*Measuring Materials Withdrawal*	*Delivery Status Report, Internal & External Materials Requests (RMS*	*1- It is very important.* *2- Usually we measure the difference between MWR date and*

ATTRIBUTES	CODE	MEASUREMENT TITLE	EXIST	EXIST SOMETHING SIMILAR	ALTERNATIVES	NOTCE
				Request (MWR) Processing Time	*& RMW)*	*the date of receiving the materials on the site/by the craft.* *3- The point of measurement could be interfaced between Craft and Warehouse, Craft Field Control, or Field Control and Warehouse,*
COST	C1	**Average Man-hour /Work hour Per Material Take-off (MTO)**	*Not*			*They are performed/conducted by monthly salaried employees*
	C2	**Average Man-hour /Work hour Per PO**	*Not*			
	C3	**Freight Cost Per cent**	*Exist*			*This issue is always negotiable with the suppliers. Try to make it the smallest percentage. It is sometimes the responsibility of a supplier.*
	C4	**Express Deliveries Per cent**	*Exist*		➢ *This is Reported in Materials Delivery Status as Urgent Deliveries, POs, and in Monthly Reports*	➢ *In order to evaluate the ability of construction operations, to request materials with sufficient time, or to purchase them from the vendor to secure the materials* ➢ *Using Materials Delivery Status* ➢ *It could be considered as a flexibility measure*
	C5	**Construction Time Lost**	*Exist*			➢ *In order to identify the causes of delay for the purpose of matters of the complaints and claims between a contractor, a supplier and an owner, the construction time lost due to the impact of the materials is monitored, and its percentage to the construction time is calculated.* ➢ *In the daily & monthly reports,*

ATTRIBUTES	CODE	MEASUREMENT TITLE	EXIST	EXIST SOMETHING SIMILAR	ALTERNATIVES	NOTCE
						the construction time lost is usually recorded ➢ *Construction Time Lost is estimated by the supervisor team (auditors) and the site team*
	C6	**Payment Discounts**	*Not*			*There are seasonal financial reports that include the actual and planned/estimated price for each item or material.*
	C7	**Warehouse Safety Incident Rate**	*Not*			
	C8	**Total Surplus**	*Exist*			➢ *It is one of the best indicators for the extent of the effectiveness of the CMM system used* ➢ *Using Notifications of Return/Non-conforming Items, Inventory Record/ Warehouse System, Site Material Status Report, and Availability Report*
AVAILABILITY	**AV1**	**Material Availability**	*Exist*	*It is calculated as the percentage of issued materials to the requested materials.*		*It is essential to identify the extent of the effectiveness of a warehouse performance to deliver or issue the materials as required or scheduled, and consequently on the basis of which, one can evaluate fully the materials management process. For this calculation, documents, such as Materials requests (MRS & MRW form), Inventory Reports, which include the materials issued within the period, and Releases Records, are used.*
	AV2	**Stock out Analysis**			*Following up the material*	*This can also indicate the flexibility*

ATTRIBUTES	CODE	MEASUREMENT TITLE	EXIST	EXIST SOMETHING SIMILAR	ALTERNATIVES	NOTCE
					availability & Reporting the materials that cannot be issued.	*of the CMM system/process to late engineering changes.* *Within the Materials Status Report, there is a section called Out of Stock Materials, which tells us about materials that cannot be issued, Inventory and Record*
FLEXIBILITY	**F1**	**Delivery Flexibility**			*Within The Delivery Time Schedule, the overlapping between delivery lead times and other project functions; lead times and slack time can be determined. For that, the Delivery plan, Millstone Schedule, and Material Submittal Log could be used.*	➢ *The action itself usually happens but it is not measured* ➢ *<u>Example on that:</u>* *When the consultant (Engineer) later discovered a mistake in the width of a wall, after he gave us permission for casting concrete, this led to examining the ability to move the concrete delivery date forward by coordinating it with the supplier, examining the delivery milestone schedule, and identifying the potential options to overlap the activities' lead-time, slack time, and the delivery time*
	F2	**Changes Flexibility**	*Not*		➢ *Difficult to be calculated* ➢ *Construction Status Report and Materials*	➢ *<u>Example on that:</u>* *After requesting the built and cut reinforcement steel (Formed Steel), a mistake in the length of steel bars was discovered. Therefore, it was necessary to look for an approach to save the amount of the formed steel. What happened was that part of the*

ATTRIBUTES	CODE	MEASUREMENT TITLE	EXIST	EXIST SOMETHING SIMILAR	ALTERNATIVES	NOTCE
					Status Report	*steel was re-formed on the site and used somewhere else in the roof; another part was kept in the store to be used in the next floor.* ➢ *This often happens on the site* ➢ *the identification of the direct and indirect cost of the rework that is performed in the field due to the impact of materials, in order to calculate F2, is a very difficult job''.* ➢ *This flexibility could give indication for the ability of the PM, CSM, Materials administrator or site team to react to changes*
	F3	**Volume Flexibility**			➢ *It is not quantitatively calculated, though, the required data for this measure could be available in Materials Status Report; and the Bill of quantities which includes,* *1-The volume of the required demand,* *2-The volume demand that has been already met* ➢ *Reporting the volume of the required demand and the volume demand that has been already met*	➢ *<u>Example on:</u>* *In some cases, the supplier can be unable to provide the project with the materials, which are needed for a particular demand volume and at specific time with specific specifications. In order to adjust the change in the demand volume and to secure the required demand volume, the contractor usually chooses more than one supplier for an item or material, and this helps to secure the item from others, when one supplier is unable to secure the entire demand value,*

4- Responsibility Matrix for Materials:

In Case Study A, the CMM is an integrated process; it includes many project participants: PM, CSM, Quantities Surveyor and even crafts. The responsibility matrix, as shown in **Table J.1**, illustrates the distribution of responsibilities within the organisations and departments that participate in the CMM process. However, two specific individuals (or groups), which are named in this case study, are in charge of procuring materials;

1- One is responsible for carrying out the purchasing process (for the all the projects of the organisation) at the organisational-level that is called the Purchasing Department, which is headed by **Purchasing Manager/Materials Administrator**

2- Another group could be of the project's members or engineers, who exist in each project headed by **Procurement Officer**. S/he is responsible for securing the required materials for his/her project including, tracking materials delivery, following up the documentary cycle, and participating in receiving materials.

Table J.1: Responsibility Matrix for Managing Materials in the Case Study A

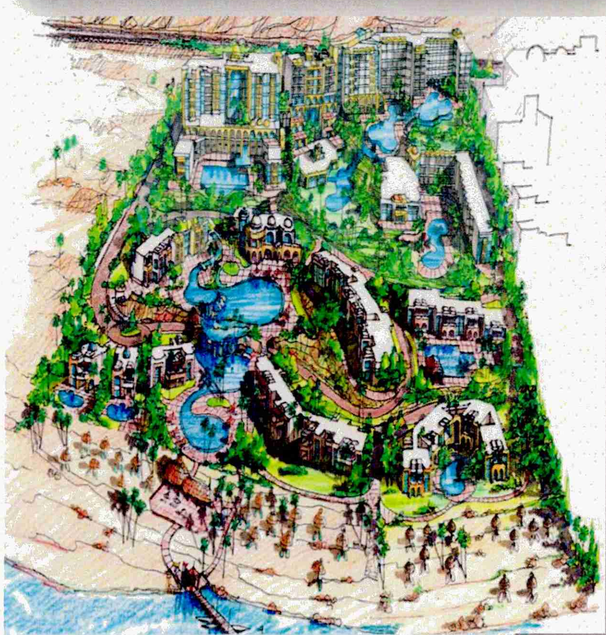
	CLIENT LEVEL			CONTRACTOR LEVEL							
	PROJECT OWNER			CONTRACTOR-HOME OFFICE				CONTRACTOR-FIELD TEAM			
FUNCTION	CM organisation	Consultants/ Engineering	Design Team	Planning Team	Purchasing Team	Projects Management Team	Warehousing Team	Project Management Team	Construction Site Management Team	Materials Team	Quality Team
Planning	A	E		I,E		A		C		C,E	
Materials Take-off & Design Interface	A	E	E					I,E	C		
Vendor Inquiry & Evaluation		A			I,E	A		C,E		C	
Main Purchasing					E	A		C	I	C	
Field Purchasing					A			A,C	I,E	E,C	
Expediting & Transportation								A	I,E	C,E	
Field Control		A						A	C,E	I,E	E
Warehousing							I,E	A		C,E	C
Quality Management		E						E	C		I,E,C

Keys of Actions: **I**=Initiate; **A**=Approve; **E**=Execute/Prepare; **C**=Coordinate;

2 CASE B: PRESIDENTIAL RESORT & FIVE STAR HOTELS:

2.1 Project Description/Background:

The project is an establishment of five star hotels and a tourist resort on the seashore of the Dead Sea zone. It is the first integrated tourist hotel complex in the region with a capacity of (383) keys. The project is located within the main hospitalization zone, with famous salts and mud extracted from the Dead Sea to provide the best therapeutic services to patrons. The project is built on 55300 m^2; it contains two five star hotels, two royal buildings, two president villas, different models of residential chalets (5 star plus), therapeutic health centre (Clinic Spa), and works of landscape of bodies of water, green spaces, facilities and VIP guests services. The estimated cost of the building works is about100,000,000 $ = £65,856,630. It is in the middle stages of the implementation of skeleton works (65% of concrete skeleton works).



2.2 Organisation Profile:

The concerned organisation in this case is the main consultative (Construction Management) company, which represents the clients; it is considered as one of the well-known consultative companies in the Arab World. This organisation has mainly designed and managed the building project, and it is responsible for managing and following up the entire implementing process, including the delivery of materials to ensure keeping up with the time schedule, the required qualities and specifications. The main contractor for implementing the skeleton works is a first class company working on behalf of the JCI. The main activity of the contractor is engineering and construction works. All the executing team, including the engineers, foremen, craft-workers, is contractor-in house.

2.3 Data Collection Process Conducted:

Seven site visits (within five weeks) are made including a visit to the planning department in the main consultative office, to a project administrator office, and five full time workday tours in the construction site. Those visits included discussions with some material-related officials in the consultant-head office, including a senior manager and a planning manager, and in the consultant-site office, including project administrator. Additionally, discussions with those involved contractor-field team, construction site manager and laboratory manager. During the site tours, many material-related documents were reviewed; the material requisition process was observed and followed up, and notes were recorded. Two semi-structured interviews were conducted with the project administrator (from the consultative office side) and the construction site manager (from the contractor side). The interviews lasted about five and half hours in total (3:45 h + 1:42h) within two days.

2.4 The Process of CMM Practiced:

1- General Overview and CMM-Related Departments and Responsibilities:

Although the selection of the majority of materials is subject to certain specifications, standards and tests required under the contract, managing these materials is not subject to a particular written policy. Since the project has special specifications and needs, special materials need to be imported from overseas. Thus, a plan is developed for managing these materials from the early stages before the tendering stage. In the current case study, the main consultant manages and governs the majority of the implementation process, including some CMM functions setting up the initial plan and time schedule, preparing the primary bill of quantities (BOQ) and material catalogue, determining particular vendors for some materials, arranging inspection procedures, and establishing the forms used for requesting materials. The planning team of the project management department at the contractor-head office level (organisational level) updates these components in conformity with its own CMM system. It develops the final version of the CMM plan (the delivery plan, receiving system, handling ways and equipment, storage requirements), milestone schedule, BOQ, inspection tests and procedures, site movement layout, and identifies the procedural matters, the lists of site materials related staff, forms, facilities, equipment used and so on. These documents are submitted by the contractor to the consultant for approval. The purchasing department at the organisation level is responsible for preparing a list of selected vendors, issuing RFQ, biddings, evaluating, issuing PO and purchasing materials. In this case, the main warehouse is on the site, and its team is responsible for receiving, inspecting and storing materials, in addition to the inventory issue. Field purchasing is conducted by the PM, CSM along with the materials coordinator of this project. The quality team, that is included in the quality and laboratory department, is responsible for quality control on the site.

As stated above, part of the consultative company's responsibilities is the management of the construction material process; therefore, the focus in this case is on the consultative company team on the construction field. **Figure J.2** demonstrates the structural supervision and project management from the consultant viewpoint.

2- Process of Requesting Building Materials:

After preparing and approving the shop drawings, a copy of these drawings is sent to the PM and his team (CSM, site engineers and site technicians). According to the shop drawings, the BOQ and the materials required, the process of requesting materials usually follows the procedures below;

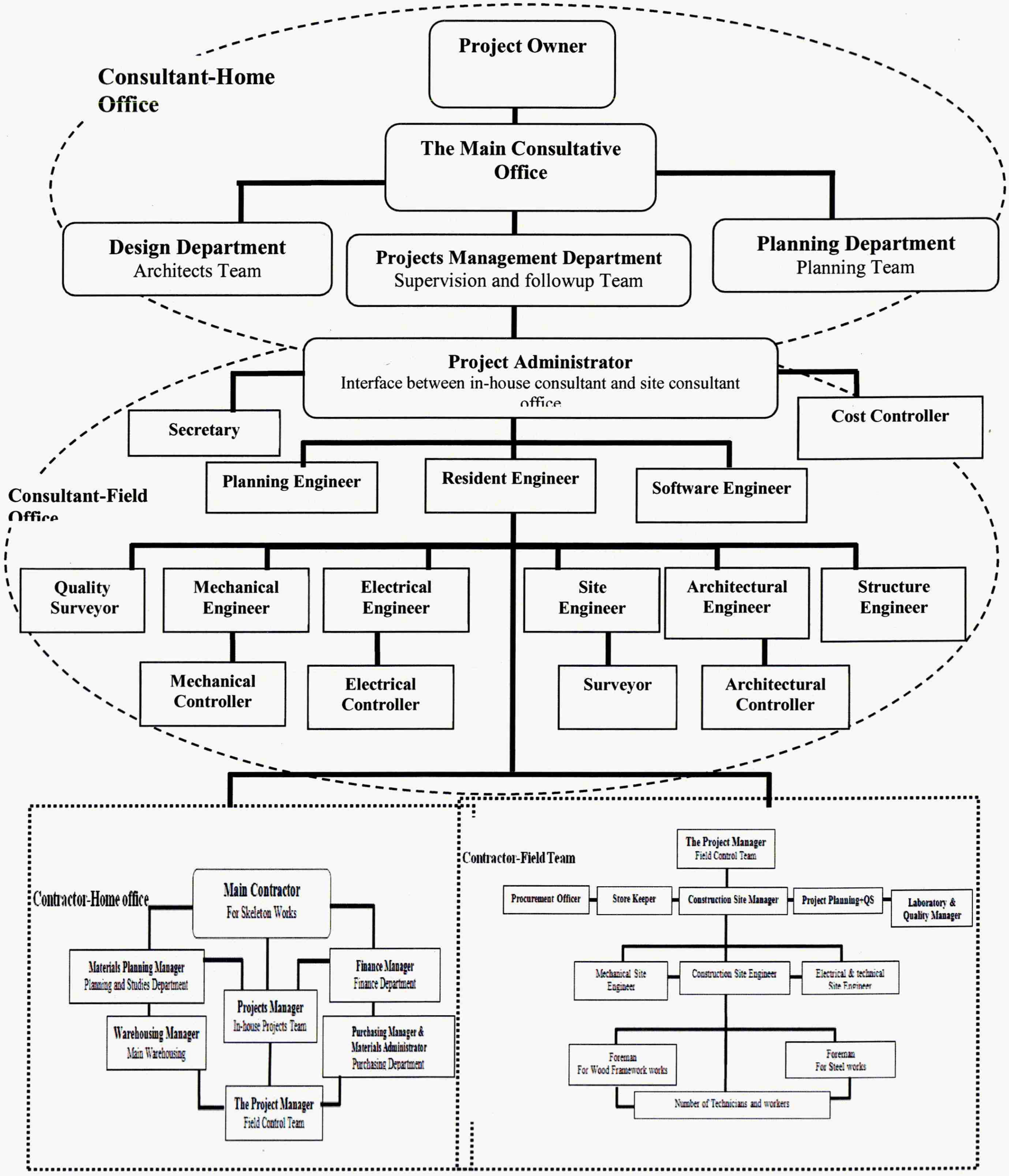


Figure J.2: The Consultative Office and the Project Supervision Team Structure

a) The CSM and the materials coordinator within the contractor-field level determine the materials that are needed at a certain time (during the next week or month). This includes the types, quantities, and specifications of these materials,

b) This list is sent to the PM, who along with the quantity surveyor reviews, signs and sends it to the field-warehouse for preparing the required materials, recording them in the inventory system as ready to be submitted and then issuing the materials as needed on the site,

c) In case the required materials are available, the CSM can request the materials as needed on the site by the Internal Materials Request (I.M.R) form.

d) In case the required materials are unavailable in the field-warehouse, the warehouse manager informs the PM, who asks CSM to prepare the Pre-Purchasing Order (P.PO),

e) The CSM, the quality surveyor and the materials coordinator prepare the P.PO with the required materials for the total section of the building and discusse with the warehouse manager the ability to store the requirements. The P.PO along with the availability report is sent to the purchasing department within the organisational level.

f) In case the vendor (supplier) is determined and approved by the consultant, the purchasing department prepares the PO and sends it to the vendor; a copy is forwarded to the consultant office,

g) In case the vendor has not been determined yet, the purchasing department sends RFQ to the particular vendors cited in the approved list, and then the purchasing manager and the PM evaluate the bids and select the vendor. After that, the PO is sent to the selected vendor. However, this case rarely happens at the stage of the skeleton works; as only dealing with 3-4 items, such as steel, concrete, insulation materials and bricks, where the specifications, suppliers and requirement inspections of these materials are already identified.

h) The Materials Submittal Transmittal (M.S.T) form and the specimen of the required material are sent to the consultant for quality approval issues,

i) After obtaining the required approvals, the supplier delivers the materials to the site-warehouse according to the assigned transportation agreement,

j) The materials coordinator follows up the deliver, tracks the materials to the site and prepares the Materials Delivery Status report,

k) Receiving materials is the responsibility of the material coordinator, the storekeeper, and the site laboratory team. They prepare related- receiving reports; Quality Control (R.Q.C) reports, Over, Short and Damaged (O.S&D) List/Reports,

l) The final stage is performed by the field-warehouse manager; it includes issuing materials to the site, documenting copies of the material-related documents, updating the inventory, and preparing the Materials Status and Inventory Control Reports.

These are the main procedures for requesting materials. The PM has the authority for the field purchasing of materials such as, concrete, steel, and daily used materials by preparing and sending PO directly to the supplier, who is already identified and approved. Moreover, the CSM and the foremen can request any daily materials from the site-warehouse by filling the I.M.R form, and forwarding a copy to the PM.

3- Functions and Activities that Form the CMM Process in the Case Study;

Based on the site tours, wide discussions with participants and the findings of reviewing the literature, the main practical functions and activities that form the CMM process within this case study were explored, and the significant differences and similarities within the typical CMM workflow diagram were recognised. The main findings of this section are summarised as follows;

a) Only seven functions were identified; they shape the CMM process within this case, where the function of 'Vendor Inquiry & Evaluation' was considered as an activity included under the 'Purchasing' function.

b) As expediting is not really needed for the skeleton works' materials, the function of 'Expediting and Transportation' was called 'Transportation Control', and it was conducted under the Purchasing and Field Control functions,

c) The consultative company, which represents the project's owner, has an authority (by the contract) to control and/or participate with the contractor in some activities that are included in certain functions such as, planning, take-off, and quality management,

d) The field control and warehouse functions are combined, and the field control obtained all data in store,

e) The majority of the quality assurance's activities are the responsibility of the consultant,

f) The centre of the Quality Control Activities has been interfaced between the Transportation function (from one side) and the Field Control and Warehousing functions (from the other side). However, some of its activities are interchangeable between the functions,

g) Although the majority of the activities and functions exist as named in the typical CMM functions, some activities exist but under other names (**Red**), such as,

NO	*Typical Activity's Name*	*New/used Activity's Name*
1	Establishing Responsibilities	*Establishing Organisational Structure*
3	Determining Quantities, Consolidating Requisitions	*Developing Bill of Quantity (BOQ)*
5	Financial Data	*Financial Solvency,*
7	Preparing Purchase Orders	*Pre-Purchase Orders*
8	Administering Purchase Orders	*Issuing and Administrating PO*
9	Prepare list of vendor quality Evaluation	*Vendor Quality Appraisal*
9	Inventory Materials	*Inventory Control*
10	Executing Field Procurement	Executing *Field Purchase*
11	Receiving and Inspecting Material Deliveries	*Job Site (receiving & inspecting)*
12	Issuing Materials to the Craft Worker	*Internal Issuing Materials*

h) Some activities exist, but are included under different functions (**Blue**); such as,

NO	*Activity's Name*	*Activity's typical Function*	*Activity's current Function*
1	Establishing Communication Channels	Planning	*Material Take-off & Design Interface*
2	Developing Staffing and Training Plans	Planning	*Field Control*
3	Developing site-Functional and Plans and Procedures	Planning	*Field Control*
4	Updating Quantity Requirements	Planning	*Take-off & Design Interface*
5	Establishing Forms and Procedures	Purchasing	*Take-off & Design Interface*
6	Executing Transportation Agreements	Expediting & Transportation	*Purchasing*

i) New activities have emerged in this case study **(Green)** such as,

NO	*New Activity*	*Function Listed Below*
2	Preparing Shop Drawings,	Material Take-off & Design Interface
3	Identifying Material Priorities	Material Take-off & Design Interface
4	Establishing Variation Orders(VOs) Procedures	Material Take-off & Design Interface
5	Vendors Analysis Report	Purchasing
6	Developing a Delivery-Tracking's System,	Expediting
7	Participating in 'On –site QA & QC'	Field Control & Warehousing
9	Surplus Materials Report	Output of Field Control & Warehousing
	Primary Delivery Plan	

Based on the above points, the practical workflow diagram of the CMM process within the case study B has been developed as shown in the next figure. **Figure J.3** illustrates how materials management is practiced in this case study, including the functions and activities that formed the CMM process, inputs, and outputs of the functions, and the feedbacks between those functions.

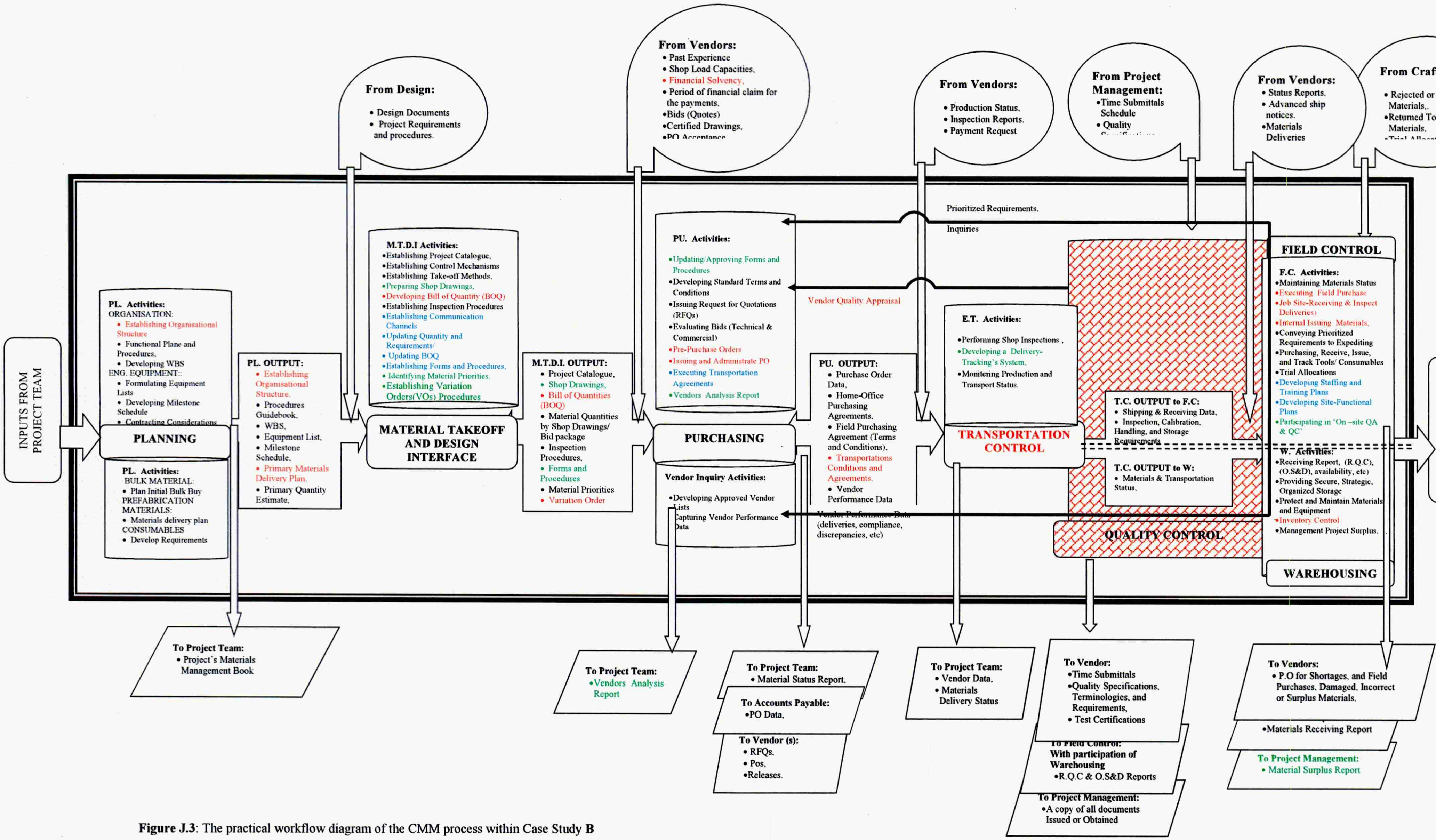


Figure J.3: The practical workflow diagram of the CMM process within Case Study **B**

2.5 The Measurement of the CMM Performance:

1- The Mechanisms/Approaches Currently in Use for Evaluating the CMM Performance;

There is no set of measures or specific approaches for evaluating the performance of the CMM process. In this case, however, more qualitatively mechanism has been used for assessing the performance of the CMM process. This mechanism is based on the discovery of any irregularities and mistakes that can indicate the inaccuracy or unsuitability of the current CMM system. The techniques applied to implement this mechanism are mainly built on monitoring and scrutinizing all the CMM-related documents, and it mainly follows the next actions;

f) Mentoring and examining the technical, financial and administrative reports, site reports, inspection lists, receiving documents, RFQs, POs, requests, release, and the entire materials-related documentary cycle,

g) Determining any irregularities, mistakes, delays, and unplanned procedures, with an emphasis on the following actions;

- Slowness in processing the required documents that should be issued by each function of the CMM process, (Time, Quantity),
- Delay in the procedures of moving the documents and obtaining the feedbacks from one function to another, (Time, Quantity),
- Lack of the accuracy and completeness of documentation required from the output of every function, (Accuracy),
- Poor documentation of the documents circulating between the CMM departments and functions; the documented actions do not match reality (Accuracy, Quantity),
- The number of rejections of nonconforming items after and prior to shipment (Quality),
- How the priorities of material allocation are adjusted to the work requirements (Field Control),
- Poor hierarchy (Lines of command) in managing the materials within the organisational level in the contractor-in-house or field level on the site (Quality)

h) Investigating the causes of these problems and assigning a person, team or department to be in charge of studying these problems,

i) Finally, making decisions for improvement, changes, or replacement of that system

These procedures could be performed by the planning and follow-up the department within the organisational level of the contractor.

2- A Set of Measures for the Effectiveness of the CMM Performance;

In this project, there is no uniform or specific set of measures applied for assessing the effectiveness the CMM performance. However, when discussing the proposed set of measures with the interviewees, and comparing the set with the actual actions practiced, it was discovered that some measures existed but used separately; some scholars used techniques that are similar to the proposed measures, while others applied some alternatives to follow up the performance of the CMM process. These are summarised below;

a) Measures are existent, but they are practiced separately, even if for the purpose of monitoring and following-up the CMM performance but not for quantitative measurements.

NO	*The Measure's Code*	*Its Attribute*	*Notes*
1	AC1	Accuracy	Using R.Q.C, O.S&D Reports
2	AC2	Accuracy	Receipt's Problem Sheet
3	AC3	Accuracy	
4	Q2	Quality	Using Notifications of Return/non-conforming Items
5	C3	Cost	Materials Financial Statements
6	C5	Cost	Using Daily labour sheets,
7	C8	Cost	The reason could be saving materials (considering as +/_). Using Material Returned/Rejection Form, Inventory Record, Material Status Report, Availability Report
8	AV1	Availability	Using Materials requests (MRS & MRW form), Releases, Site Receipt, or Availability Reports
9	F3	Flexibility	Using Material Status Report and Material Requests,

b) Techniques, which are similar to the proposed measures; they aim to evaluate the performance of the same functions that are measured by the proposed measures, even though they not from quantitative method.

NO	*The Technique Practiced*	*The Similar Measure/ Attribute*	*Notes*
1	Listing the number of the RFQ performed	QN1/ Quantity	Using RFQ forms
2	Listing the number of the PO performed	QN2/ Quantity	Using PO forms
3	Reporting the percentage of the value of materials purchased by the field to the total value of the purchased materials during a specific time	QN5/ Quantity	Using Field POs, Field Works Report
5	Listing and recording quantities and types of the materials that were unavailable in the Warehouse when they were requested by the craft-workers on the site.	AV2	Using Material Availability Report

c) Alternatives that are practiced to monitor and follow-up the performance of the CMM process,

NO	*A Measure/Attribute*	*The Alternative*
1	T5/Timelines	Following-up the Material Delivery Status (MDS) Report
2	T6/Timelines	Following-up the Material Delivery Status (MDS) Report
3	C4/Cost	Mentoring the number of express delivers by M.D.S Report
4	C6/Cost	Monitoring and comparing the actual materials' cost with planned materials' cost
5	F1/Flexibility	Updating the material delivery-related activities in the milestone schedule to move planned delivery dates forward
6	F2/Flexibility	Monitoring the ability of the construction team to modify the delivered materials to react to any change without impacting the cost of the field construction phase, using Construction Works Reports and Materials Status Report

d) Some new measures that emerged in this case;

NO	*The New Measure*	*Attribute*	*Notes*
1	Counting the MWR processing time	T7/ Timelines	From issuing IMR to sign the material receipt
2	Measuring the processing time from issuing PO to Receiving and updating materials in the warehouse system	T3&T4/ Timelines	T3&T4 combined
3	Measuring the Procurement processing time from submitting RFQ until issue the PO	Time	Procurement processing time
4	The percentage of the value of the materials considered as a waste to be compared with the total material costs	Cost	West=Unused Materials +Surplus

e) Some measures do not exist due to one or more of the following reasons;

- The difficulty involved in their calculation; QN3, C7, T1
- The irrelevance in the skeleton works, QN7, QN8 could be in the finishing works
- Lack of their importance; QN4, C1, C2, where employees are paid monthly salaries,
- Unused; QN6; EDI technology is not used in this project,
- The difficulty involved in their calculation within the Skeleton works, as the majority of the materials used in this stage are bulk materials and installing equipment is not essential or a frequent job, Q1.

2.6 Terminology:

This section presents the most recognisable terminologies, forms, reports and documents related to the CMM process in the present case study, in addition to the responsibilities of the project's participants while implementing the functions of the CMM process:

- Material Submittal Transmittal: (M.S.T)-Form
- Request for Concrete Pour: (R.C.P)-Form
- Purchasing Order: (PO)-Form
- Pre-Purchasing Order: P.PO-Form
- Materials Status Report: (M.S.R)-Report
- Materials Delivery Status Report: (M.D.S.R);Report
- Internal Materials Request (I.M.R) form: (I.M.R)-Form
- Variation Order: (VO)-Form
- Internal Materials Receipt: (IMR)-Receipt
- Steel Sheet = Reinforcement Steel Bars: (R.S.B)

Responsibility Matrix of Materials:

The matrix below represents the responsibility matrix, which illustrates the distribution of the responsibilities within the organisations and departments that participate in the CMM process of this project. However, in this case study, the PM, CSM, and the Materials Coordinator are the most responsible individuals for managing the building materials. The Materials Coordinator is assigned to participate in the CMM process; he coordinates between the vendors and the site, inspecting materials in the house-supplier, tracking deliveries, following-up documentary cycle, and participating in receiving the material process.

Table J.2: Responsibility Matrix for Managing Materials in the Case Study B

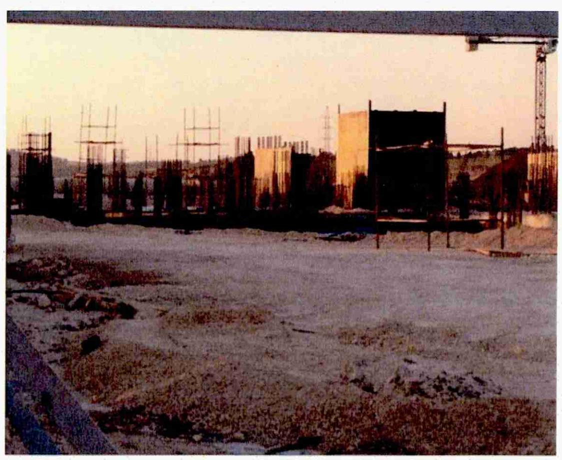
	CLIENT LEVEL		CONTRACTOR LEVEL							
	PROJECT OWNER		CONTRACTOR-HOME OFFICE			CONTRACTOR-FIELD TEAM				
FUNCTION	In- house Consultative office	Site Consultative office	Planning Team	Purchasing Team	Projects Management Team	Project Management Team	Construction Site Management Team	Materials Team	Site Laboratory Team	Site-Warehouse
Planning	I,A	E	I,E		A	C		C,E		
Materials Take-off & Design Interface	A	E				I,E	C			
Vendor Inquiry & Evaluation		A		I,E	A	C,E		C		
Main Purchasing				E	A	C	I	C		
Field Purchasing				A		A,C	I,E	E,C		
Expediting & Transportation						A	I,E	C,E		
Field Control		A				A	I,E	C,E	E	
Warehousing						A		C,E	C	
Quality Management	I	E				E	C	C	E	

Keys of Actions: I=Initiate; A=Approve; E=Execute/Prepare; C=Coordinate;

3 CASE D: HUGE IKEA STORE PROJECT:

31 Project Description/Background:

The project involves the construction of a huge commercial building comprising a 35,000 m^2 three-storey building. The first storey is designed for services including restaurants that can cater to about **600 people, coffee shops, spaces for families and people with special needs, children's play area, and a** 1020-space parking area. The second and third storeys contain the IKEA store, which is considered as one of the largest IKEA retailer stores in the Middle East. The primary estimated value of completing the project is approximately 55,000,000 JD = £51,159,811. The project is at the beginning stage (11.5 % of the skeleton works).



3.1 Organisation Profile:

The main contractor for establishing this project is a leading construction company in JCI. It is the result of the partnership between a well- known building company and a pioneering supplier of building materials, which possesses a number of subsidiaries in different business such as ready mix concrete, reinforcement steel, crushed stones and cement factories. The organisation experience and resources that are acquired over the years cover a wide spectrum of construction works, ranging from heavy civil construction projects such as huge shopping malls and towers, paper factories, steel factories, water treatment plants, sewage treatment plants, and industrial plants, to small projects designed according to client's requirements (ATCCO, 2014). The contractor is responsible for all the building and civil works of the project, including the skeleton works and the supply of all the construction materials required (Supply and Apply), without any participation of the subcontractors or external suppliers.

3.3 Data Collection Process Conducted:

To compensate for the period of the suspension of the project due to technical reasons, it was necessary to speed up the pace of work on the site. This led to the unavailability of the majority of concerned staff due to their preoccupation with executing the works. Therefore, it was decided to speed up the process of gathering data, where all the data needed of case D was collected through three full-time work- day visits and one interview session (within a week) The site visits are intended to observe the CMM process applied and to understand the mechanism used for evaluating the CMM performance through short discussion with some of the CMM-related people in the site. The semi-structured interview session, which lasted more than three and half hours (3:46) with the PM and CSM, concentrated on questions related to the CMM functions and activities that are practiced, and on the methods used for evaluating or controlling the effectiveness of the CMM performance inside the Case Study D.

3.4 The Process of CMM Practiced:

1- General Overview and CMM-Related Departments and Responsibilities:

Considering the fact that the executor and supplier of this project are under the umbrella of a single company, many of the CMM functions and activities overlap or they may fade due to the lack of need. This is somewhat similar to the technique of the sole source purchase (non-competitive purchase/procurement). Some functions do not exist, such as the function of 'Vendor Inquiry and Evaluation'; some activities fade, such as the activities of issuing RFQs, Bid, Evaluating and committing (B,E & C), and the transportation agreements; the role of some functions shrink, such as the expediting function.

The CMM process, in case D, is mainly based on the following functions;

1) Within the planning function, it involves setting up a plan for conducting the quality assurance activities, delivering the materials to the site, utilizing them;

2) Within the take-off function, it establishes the project catalogue, determining quantities, updating the BOQ and developing Quality Specification;

3) Within the logistics function; it secures the materials and equipment needed, coordinates between the internal suppliers, main warehouse and sites, monitores production, executes material deliveries' plane, and carries out 'Sole Source Purchases' (for Skeleton works);

4) Within the warehousing function, it protects, maintains materials and manages the project surplus;

5) Within the quality control function, it evaluates actual quality performance, performing shop inspections, and field Inspection;

6) Within the field control function, it receives and inspects material deliveries and quality reports, maintains materials status, issues materials to the craft-workers, and conducts on –site QA & QC with the participation of the quality control team and storekeeper.

The role of the consultant is limited to controlling, inspecting, and approving all the materials and equipment, in addition to following up the process of quality assurance and control.

Figure J.4 illustrates the organisational structure of the project management in case study D. It is obvious how the logistics department within the contractor organisational level controls the majority of the CMM process;

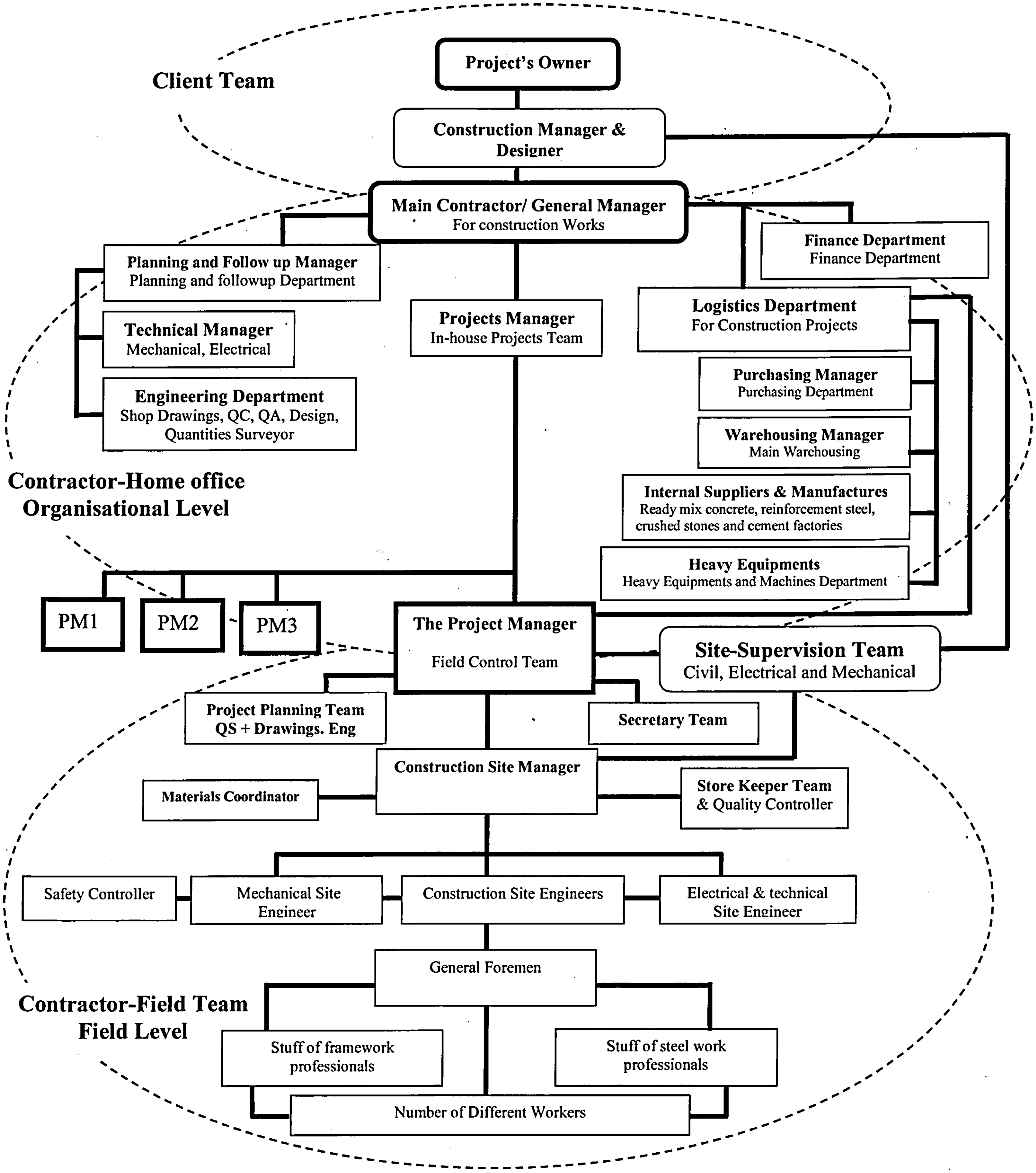


Figure J.4 the Project Team Structure as Related to CMM Process in Case Study D

2- Process of Requesting Building Materials:

Since the suppliers (internal vendors) are the contractor-in house, the process of ordering materials differs slightly from its predecessors. The subsequent procedures are those followed to request the concrete and steel materials.

Requesting Concrete (Bulk Material):

The concrete used in this case is ready-mixed concrete, which is prepared out of the site by the internal concrete supplier, belonging to the main contractor; it was already identified in the earlier stages. Requesting this materials mainly follows the steps below:

a) The CSM and the civil site engineer identify the parts that are ready to be casted and the date of casting them based on the daily site reports and the notifications of his/her team on the field,

b) The CSM, and his/her team calculate the quantities of the concrete needed based on the shop drawings and the modifications on the site,

c) The CSM and the material coordinator prepare the Request for Concrete Pour (R.C.P) form, which is sent along with the sketch of the part(s) that need casting to the PM within the field level,

d) The PM and the quantity surveyor in the field level review and sign the R.C.P form and send it to the consultant office for inspecting and approving the wooden frameworks and reinforcement steel, and for approving the type and quantities of the concrete,

e) The approved copy of the R.C.P form, which is signed by the consultant, is sent to the logistics department within the organisational level of the contractor,

f) The logistics department sends the R.C.P form to one of the concrete manufactures/suppliers within the contractor organisation for supplying the required concrete to the site according to the type, quantity, specification, and the date that are listed in the R.C.P form,

g) The material coordinator coordinates between the supplier and the site to determine when, where and how the concrete trucks and pumps will be positioned for pouring the concrete,

h) During casting the concrete, the quality controller with the third party (Quality Testing Laboratory/Centre), already assigned by the consultant, performs the in-site tests required (cube, slump test, etc.),

i) Finally, a receipt of receiving the concrete on the site is signed by the material coordinator or a civil engineer,

j) For fast tracking, some of the procedures, which are within the contractor departments, can be implemented by phone until the paper cycle is completed.

Requesting Steel (Fabricated Material):

The steel material is prepared and shaped out of the site in the steel workshop, which belongs to the contractor; it is then brought to the site ready to use. The specifications and quality of the steel are already approved by the Jordanian Institution for Standards and Metrology (JISM). Ordering this material needs to follow the following steps:

- **a)** Based on the shop drawings and updated executive sketches (in case there are modifications), the CSM and the civil site engineer with the participation of the steel foremen, prepare Bar Bending Schedule (B.B.S) for the specific parts of the building,
- **b)** The B.B.S, which contains the bending shape and quantities of steel, is sent to the PM at the field level, who in turn reviews the B.B.S with his quantity surveyor, signs and submits it to the logistics department,
- **c)** The logistics department sends the B.B.S to the steel workshop to prepare the required steel, which in turn supplies the shaped steel to the storage area on the site according to the type, quantity, specification, and the date that are listed in the B.B.S form,
- **d)** The material coordinator follows up delivering the material to the site, prepares with the site-storekeeper the storage-location and publishes the Materials Delivery Status Report,
- **e)** The storekeeper and material coordinator receive the steel material and confirm the quantities and types of materials by matching the received materials with the B.B.S,
- **f)** Copies of B.B.S Packing List are sent to the civil site engineers and the steel foreman to order the material as it is needed.
- **g)** The specifications and quality of the steel are already approved by the Jordanian Institution for Standards and Metrology (JISM),

As a rule, requesting the majority of the materials used for the completion of the skeleton works almost follow the same practice. In case that some of these materials are unavailable in the site store, the External Material Requests (E.M.R) are submitted to the logistics department, which in turn sends them to the main warehouse (or an internal supplier) for supplying them to the site. Within the skeleton stage, a small number of materials can be purchased from the local markets/suppliers that are well known by the contractor (sole-source). This is done by the purchasing section under the logistics department (Contractor-organisational level).

3- Functions and Activities that Form the CMM Process in the Case Study:

The key functions and activities, which formed the process of managing the majority of building materials in Case D are outlined below;

- **a)** As result of the fact that material suppliers belong to the main contractor, the functions of the 'Vendor Inquiry & Evaluation' and 'Purchasing' are not predominantly involved in the formation of the CMM process, which is practiced in case D,
- **b)** The logistics function replaces the above two functions (Vendor Inquiry & Evaluation' and 'Purchasing'), and it is essentially responsible for securing and supplying the materials and equipment needed by the internal suppliers, factories and the main warehouse to the site, including, monitoring production and transportation status, internal shop inspection, preparing and

executing material deliveries' plan, giving permission/authorisation for issuing materials to the site, and purchasing materials (those are unavailable in the warehouse) from the local sole source,

c) Expediting activities are included under the responsibilities of the functions of Logistics and Field Control, which are limited to monitoring production and following up the process of transportation, handling, downloading, tracking, and shop inspection,

d) The field control and site-warehouse functions are somewhat combined, and the field control has the authority for managing the site-store. Therefore, the vision which says that the warehousing function is under the authority of field control is reasonable,

e) The decision of the disposition of the surplus material, whether, returning them back to the main warehouse or using them in other projects, is taken by the logistic department at the organisational level with the participation of the PM in the field level,

f) The technology of intranet is adopted by Case D, in order to communicate and send the CMM-related documents between the logistics department at the organisational level of the company and their internal suppliers, manufactories, workshops, heavy equipment sections and main warehouse. In addition, some basic programs are used for the purpose of helping in planning, preparing construction drawing, and controlling the inventory,

g) While the majority of the quality assurance activities are conducted within the functions of Planning and Take-off, the quality control is an interface between the Logistics function (from one side) and the Field Control and Warehousing functions (from the other side),

h) Some of the quality management activities are conducted with the participation of the consultant,

i) Although the activities of the three functions (Vendor Inquiry, Purchasing, Expediting) do not partially exist, the majority of the activities of the rest of the functions exist, may be under different names or subsumed under different functions,

j) Some activities exist but under other names (**Red**);

NO	*Old Activity's Name*	*New Activity's Name*
1	Developing Staff and Training Plans	*Naming the Staff*
2	Plan Initial Bulk Buy	*Planning Initial Bulk Supply*
3	Developing Quantity requirements of Consumables	*Primary Estimated Daily used Materials*
5	Procedures Manual	*Procedures Guidebook,*
7	Determining Quantities, Consolidating Requisitions	*Developing Bill of Quantity (BOQ)*
8	Inventory Materials	*Inventory Control*
9	Receiving and Inspecting Material Deliveries	*receiving & Quality Control*

k) Some activities are included/listed under different functions (**Blue**);

NO	*Activity's Name*	*Activity's Old Function*	*Activity's New Function*
1	Monitoring Production and Transportation status	Expediting	*Logistics*
2	Developing Numbering Scheme	Planning	*Take-off & Design Interface*
3	Establishing Forms and Procedures	Purchasing	*Take-off & Design Interface*
4	Developing Quality Plan	Quality Management/QA	*Planning*
5	Updating Quality Specification	Quality Management/QA	*Planning*
6	Updating Terminology and requirements	Quality Management/QA	*Take-off*
7	preparing and executing material deliveries' plane	Expediting	*Logistic*
8	Provide Performance Data	Expediting	*Field Control & Wearhousing*

l) New activities have emerged in this case study (**Green**);

NO	*New Activity*	*Function Listed Below*
1	Establishing Fabrication Plan	Planning
2	Preparing Shop Drawings,	Material Take-off & Design Interface
3	Determining Material Priorities	Material Take-off & Design Interface
4	On –site QA & QC	Field Control
5	Material Surplus Report	Output of Field Control & Warehousing
6	Updating,/Approving Forms and Procedures	Logistics
7	Securing the Materials and Equipment needed	Logistics
8	Coordinating between the internal suppliers and the site	Logistics
8	Giving permission/authorisation to the main warehouse for issuing materials to the site	Logistics
9	Executing Sole Source Purchases (Skeleton works)	Logistics
10	Tracking the deliveries	Field Control
11	Developing Variation Orders Procedures	Take-off

By re-organising the functions and activities graphically on the basis of the findings above, the practical workflow diagram of the CMM process, which is applied in case study D, can be drawn as in **Figure J.5:**

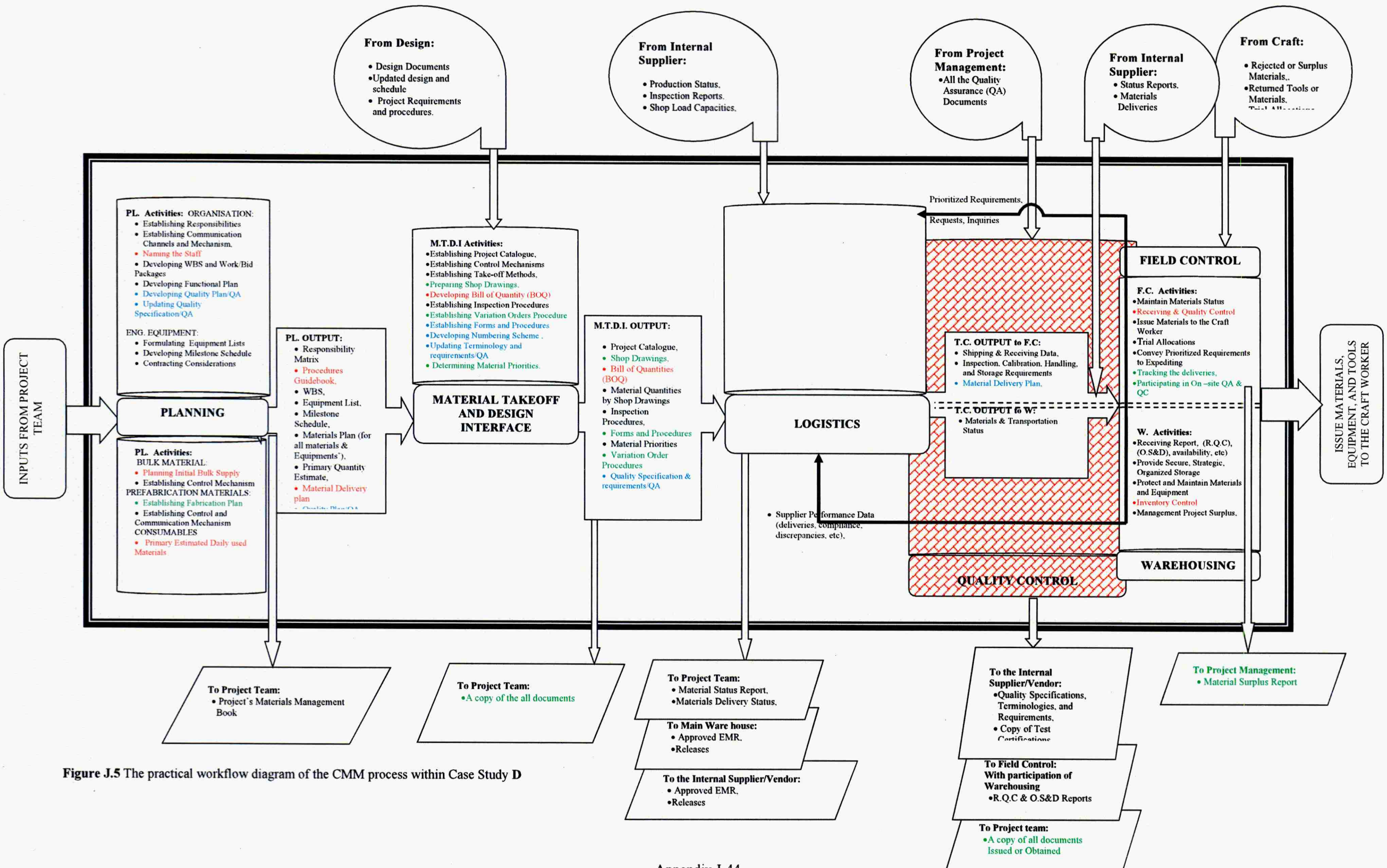


Figure J.5 The practical workflow diagram of the CMM process within Case Study **D**

3.5 The Measurement of the CMM Performance:

1- The Mechanisms/Approaches Currently in Use for Evaluating CMM Performance;

Assessing the performance of the CMM process in this case basically relies on two main criteria. The first criterion is based on evaluating its information system in terms of transferring timely and correctly the requests, reports, feedbacks, and inquiries from and to the right place, and on the extent of the speed of the response. The second criterion is evaluating the process of delivering materials to the site, as to whether or not it is in time with the correct quantity and quality. Although there are some quantitative techniques, more qualitative mechanism has been used to meet these objectives, which is designed to monitor information sharing (communicating of information between participants), information quality (accuracy, adequacy, timeliness, and credibility of information exchange), and delivery dependability (the capability of providing on time the type and volume of materials required by the construction operation). For the operation of this mechanism, the following techniques were used;

j) Monitoring and examining frequently the order fulfilment lead time; this is performed by monitoring the dates of issuing the External Material Request (E.M.R) by the field operation and the activity early start date (ESD) or the field need date (FND),

k) Evaluating periodically the efficiency of the used intranet through monitoring and examining the information exchange between the logistics department within the organisational level and the internal suppliers and manufacturers; for this purpose, the following practices have been employed;

- Filling a periodical Checklist that asks about how accurate, adequate and timely the information that is exchanged between the departments by those who use the intranet is,
- Monitoring the applications of Request for more Information (R.F.I) that are submitted by the internal suppliers and manufactories to the logistics department,
- Monitoring the re-submit, re-request or re-send E.M.R forms to the suppliers, in addition to evaluating the streamlines of ordering, receiving and other paperwork from suppliers,

l) Evaluating frequently the responsiveness of the internal suppliers and manufacturers to provide the required materials to where they are needed, by examining the date of receiving the E.M.R by a supplier and the date of releasing materials,

m) Monitoring and examining periodically the delivery dependability through the following considerations;

- Considering the formal and informal complaints of the field-operation, which are derived from the periodical checklist,
- Following-up the field operations, the flexibility in supplying different types of items and the equipment in order to meet the changing field operation needs,
- Examining the deliveries to know the extent to which they supply the right type, quantity, and quality of materials at the right time and the right place. This is done by checking R.Q.C, O.S&D Reports,

The mechanism of evaluating the performance of the CMM process is usually implemented by the Planning and Follow-up Department within the organisational level of the contractor.

2- A Set of Measures for the Effectiveness of the CMM Performance;

Due to the fact that the majority of the project suppliers are the contractor-in house, many of the effectiveness measures of the CMM performance either do not exist or are replaced by using other approaches,

a) Measures are existent, but they are practiced separately, even if they are for the purpose of monitoring and following up the CMM performance and not for quantitative measurements;

NO	*The Measure's Code*	*Its Attribute*	*Notes*
1	AC2	Accuracy	Using R.Q.C, O.S&D Reports
2	C5	Cost	For identifying the causes of delay, Using A Copy of the Monthly supervisor/ Consultant Report
3	C8	Cost	The reason could be the saving materials (considering as +/_), using Site Material Status Report, Availability Report

b) Actions/Techniques, which are similar to the proposed measures, aim to evaluate the performance of the same functions that are measured by the proposed measures, even if they are not from the quantitative method;

NO	*The Technique Practiced*	*The Similar Measure/ Attribute*	*Notes*
1	Periodic inventory inspection	AC3/Accuracy	Financial Reports and Statements of Cash flows
	Counting the number of notifications of return/non-conforming items	Q2/Quality	Material Returned/ Rejection Forms
2	Measuring Delivery Expenses	C4/Cost	
3	Listing the deliveries that are not made on or before the required delivery date (delayed deliveries)	T6/Timelines	Using the M.D.S Report

c) Alternatives that are practiced to monitor/follow-up the performance of the CMM process;

NO	*A Measure/Attribute*	*The Alternative*
1	Q1/Quality	Following-up the Construction Reports including equipment required for rework
2	T5/Timelines	Following-up the Material Delivery Status (MDS)Report
3	T7/ Timelines	Following-up the process of Internal Material Request
4	F1/Flexibility	Updating the material, delivery-related activities in the milestone schedule (Time Schedule) to move planned delivery dates forward using the milestone schedule and Delivery Plan

d) Some new measures that emerged in this case;

NO	*The New Measure*	*Attribute*	*Notes*
1	Measuring the processing time from issuing E.M.R to receiving and updating materials in the warehouse system	Time/T3+T4	E.M.R and Receiving Materials Receipt

e) The rest of the proposed measures do not exist due to one or more of the following reasons;

- There is no need for them, because the majority of the suppliers of the skeleton-related materials are the contractors-in house, AC1, C3
- The difficulty of their calculation, T1, F2
- The irrelevance in the skeleton works,
- Lack of their importance, C7
- Unused in the JCI, C1, C2, C6, QN6, QN7,
- They are not measured in the case, F3, AV1, AV2

3.6 Terminology:

The terminologies in Case D are rather similar to its peers. However, the most recognisable term is that of the logistics department, which is in charge of performing the majority of the activities of the CMM process. Additionally, the Materials Coordinator is the most recognisable CMM-related name, who is responsible for coordination between the internal supplier and the site, performing supplier-in house inspection, tracking deliveries, following-up documentary cycle, and participating in receiving the material process.

Responsibility Matrix for Materials:

The responsibility matrix, as exposed in **Table J.4** below, demonstrates the distribution of the responsibilities for managing the CMM functions in case D.

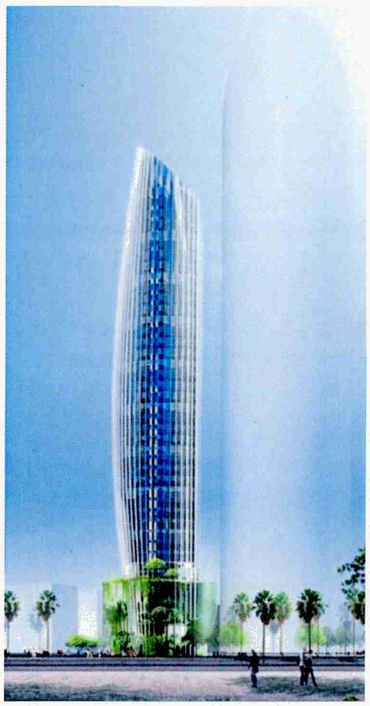
Table J.3: Responsibility Matrix for Managing Materials in the Case Study D

	CLIENT LEVEL		CONTRACTOR LEVEL							
	PROJECT OWNER		CONTRACTOR-HOME OFFICE				CONTRACTOR-FIELD TEAM			
FUNCTION	In- house Consultative office	Site Consultative office	Planning Team	Purchasing Team	Projects Management Team	Warehousing Team	Project Management Team	Construction Site Management Team	Materials Team (Material Officer)	Site-Store Team
Planning	**A**		**I,E**		**E**		**C**			
Materials Take-off & Design Interface		**A**			**I,E**		**E**	**C**		
Vendor Inquiry & Evaluation										
Main Purchasing				**I,E**	**A**	**C**			**C**	
Field Purchasing										
Expediting & Transportation						**C**	**A**	**I,E**	**C,E**	
Field Control					**A**		**I, E**	**E**	**C**	**C**
Warehousing						**I,E**	**A**	**C**	**C**	**E**
Quality Management (QA+QC)		**C**			**I**	**E**		**E**	**C**	**E**
		Keys of Actions: **I**=Initiate; **A**=Approve; **E**=Execute/Prepare; **C**=Coordinate;								

4 CASE E: THE HOTEL-TOWER PROJECT:

4.1 Project Description/Background:

The project is a five star hotel-tower, consisting of seven basements, and 49 floors above the ground floor lobby at 188 m high. It is considered as the highest concrete building in Amman. The 65000m^2 built-up area is distributed among seven basements for car parking and central service plant rooms as well as complementary facilities to the hotel's Conference Centre and Ballroom. Six Podium floors covering the site area are for concessions, forming part of the hotel's basic requirements (Restaurants, Health Centre, Spa, Swimming pool, Special dining Juice bar). A pool deck is located on the seventh Floor above a great feature structure identified as the Lantern; it represents a distinguished architectural element in the Project. The 425 keys of the hotel's rooms and suites are accommodated in 39 floors above podium, served by four technical floors. The estimated cost of the construction works is about 64,000,000 JD = £59,531,416. The project is at the middle stages: 63% of skeleton works of the project).






4.2 Organisation Profile:

The project is implemented by an Arab construction company, which is classified by JCCI as a first class construction contractor. It has been operating for half a century through a comprehensive regional network all over the Middle East. The organisation, whose track record is a prestigious list of efficiently delivered projects, is specialist in establishing heavy, civil engineering and construction projects, ranging from power generation and desalination plants, to factories, resorts, hotels, hospitals, and intricately sophisticated smart buildings. It is the main contractor for executing this project and it is accountable for all the building and civil works, including skeleton, superstructure, and infrastructure works. Among the tasks entrusted to the main contractor is the implementation of the skeleton works, including securing the required materials from the local suppliers and vendors and managing building materials in its main warehouse and within the site (ACC, 2014).

4.3 Data Collection Process Conducted:

Based on the plan of research data collection, and similar to the rest of the previous case studies, the main techniques used are site visits and an interview session. The site visit technique included five half-day field tours for three weeks, short discussions with CMM-related individuals, and surveying of some relevant documents. Due to the preoccupation of the concerned staff most of the time, a three hour-interview session was held with the Executive Project Director (PM) and the Warehouse Manager. The main aim of those two data collection techniques was to understand the practice of CMM within the project, to document the mechanism of materials requisition and their movement within the site, and to examine the approaches or techniques used for measuring or evaluating the effectiveness of the CMM performance.

4.4 The Process of CMM Practiced:

1- General Overview and CMM-Related Departments and Responsibilities:

Generally, the process of managing the building materials within the organisational level of the contractor in planning and take-off phases is similar to the typical CMM process. However, the construction management (CM) company and the consultative office, who represent the client, have an authority to control and monitor some of the activities within those two phases, including developing functional plans and procedures, drawing milestone schedule, establishing control mechanism, developing numbering scheme, material priorities, and establishing inspection procedures. Nevertheless, in Case E, the system of managing and requesting building materials within the field level slightly differs from the others whereby, the process of CMM within the field level is characterised by using special computerised software called SMS (Stock Management System); it is operated through intranet. SMS is responsible for organising the process of requesting building materials since it is ordered to be issued to the craft-workers on the site, in addition, it connects and transmits the documentary cycle (Requests, receipts, reports, confirmations) between the PM, site staff, and the personnel of the site-stores (sub-stores) and the main warehouse.

Figure J.6 below highlights the most recognisable/relevant departments and sections that participate in managing the building materials in this project.

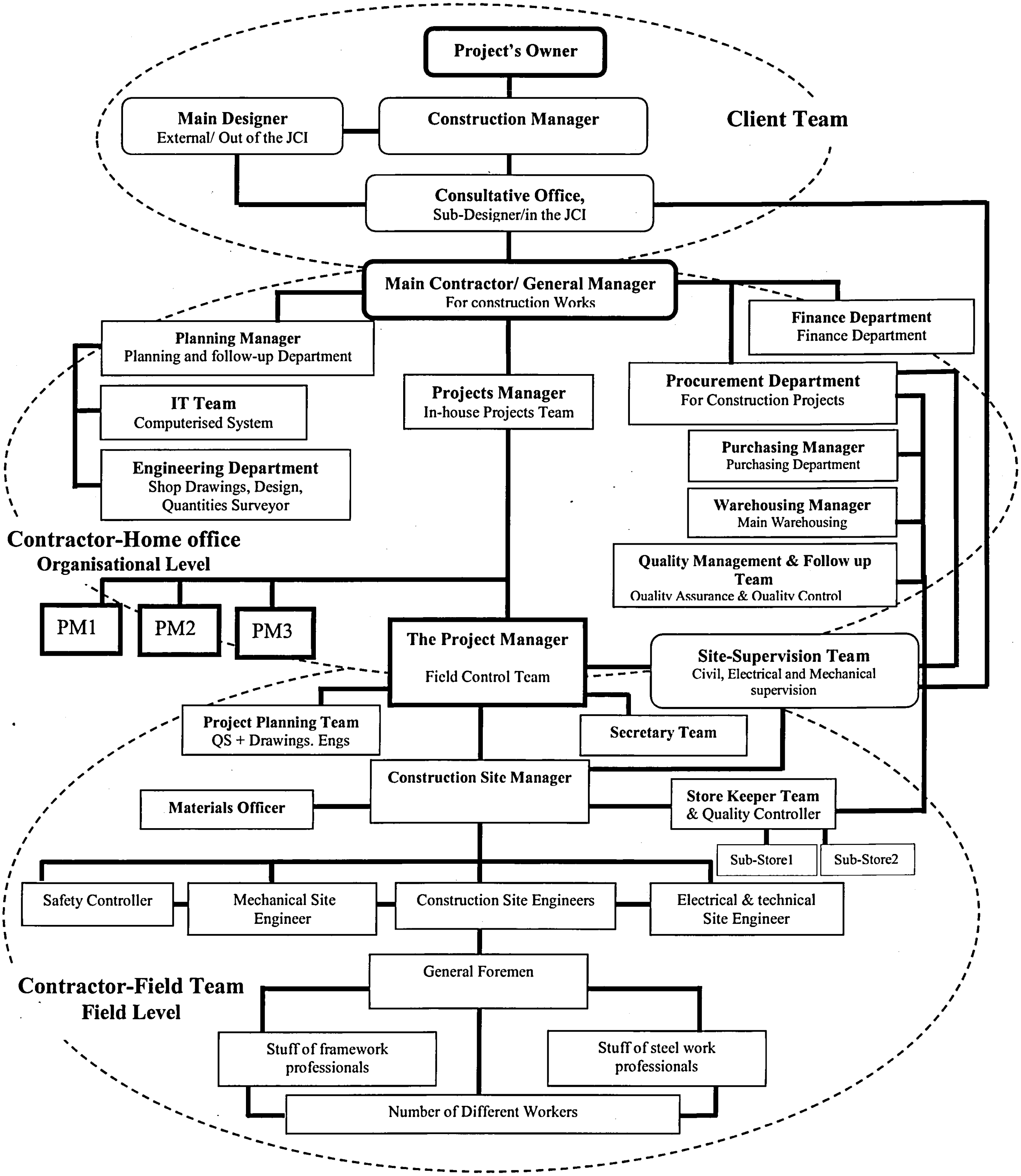


Figure J.6: The Project Team Structure-Related to CMM Process in Case Study E

2- Process of Requesting Building Materials:

The practice of requesting building materials in Case E is slightly similar to its peers, except in that in this case study, the material order procedures and documents moves between the concerned staff electronically through the intranet (SMS). The next procedures are typical steps that are practiced within Case E to request building materials from the time when they are requested to be secured on the site;

a) Any material order or request, in its first phase, is requested by the trade worker, who usually asks a foreman for securing the items required,

b) The foreman, based on the request, fills in the Internal Material Request (I.M.R) and gives it to the site engineer, who in turn, hands the hard copy to the building storekeeper (one of the sub-stores on the site), who inserts the request data into the system (SMS), to be converted into an electronic copy of I.M.R. It is then sent through SMS to the Construction Site Manager (CSM),

c) On the SMS interface, the I.M.R emerges to the CSM; more information could be obtained about the items requested by browsing electronically the 'Material Status' and 'Availability' reports through the SMS. Based on this information, CSM can sign and confirm the I.M.R electronically,

d) Based on the confirmation of I.M.R by the CSM, the storekeeper can release the required material to the trade worker, and the Material Site Receipt Form (M.S.Rt) should be documented within the SMS,

e) In case the required material is not available in the sub-store (site-store), the storekeeper notifies electronically through the SMS the CSM and the PM,

f) The CSM and his/her team (including the storekeeper) prepare a request for the materials required for a period of time. This is carried out by filling a hardcopy of the Material Stock Requisition Form (M.S.R), which involves a list of the materials required, their description, quantities needed, need-dates, and their Cost-Code, which is then sent to the PM,

g) The PM office (including quantities surveyor) updates the data of the M.S.R form into the electronic form of Material Release Request (M.R.R) (this is to keep the form recorded within the system), which is sent electronically through the intranet (SMS) to the main warehouse personnel and a copy to the CSM,

h) The main warehouse provides and delivers the required material to the job site or a sub-store; the personnel receive and update the materials in the system, and then issue the Material Receipt and O,S&D Reports,

i) In case the required materials are not available in the main warehouse, there are two situations;

- When the suppliers are identified from the take-off stage and approved by the consultant, the PM sends the M.R.R through the SMS to the purchasing section within the procurement department, which in turn requests the required materials from the pre-selected supplier/vendor by submitting a PO,
- When the suppliers are not determined, the PM and his/her team prepare and send electronically a Temporary-PO (Pre. PO) to the purchasing section, which in turn, based on the Temporary-PO, selects suppliers, negotiates, and awards the contract. After approving the contract by the CM/consultant, the Temporary-PO becomes PO,

j) According to the PO, the supplier delivers the required materials or items to the main warehouse, the job site or sub-store according to the transportation agreement,

k) Once the required materials are shipped to the main warehouse, the PM, within 24 hours, fills and sends electronically the Notification of Delivery to Warehouse (N.D.W) form to notify the warehouse personnel that certain material will be delivered to the warehouse for storage,

l) Once the required materials are delivered, the warehouse personnel or the site-store team verify the material received against the N.D.W or S.R.F (respectively), they then stamp and forward the Packing Slip to the Procurement Department (Purchasing Section)/Accounts for payment purpose (a copy is sent to the supplier/vendor). The warehouse personnel or the site-store team also notifies the PM by phone of all material received and stored at the warehouse or the sub-store,

m) In case there are any discrepancies in the material quantities, damages to the material or the materials are not delivered, the warehouse personnel or the site-store team prepare and issue O.S&D report and forward it through the SMS to the PM and purchasing section to be forwarded to the supplier/vendor,

n) After conducting on site-QA and QC research by the warehouse team, the warehouse manager/storekeeper with the quality control team issues R.Q.C reports, which are sent to the project management team

The above course of actions is the general process used for requesting typical materials and items. In case E, the field purchases are not conducted, whereas the entire materials and items are purchased through the purchasing section within the procurement department.

Because the concrete that was used in Case E, was readily mixed by a concrete supplier and the used steel is also supplied ready-shaped by a steel manufactory, the process of requesting these materials is similar to its predecessors.

3- Functions and Activities that Form the CMM Process in the Case Study:

The existence of the Construction Management (CM) Company, which represents the client, within the organisational structure of this project reduces the size of activities included under the planning function whereas some of these activities are carried out by the CM Company and the others are conducted by the contractor within the phase of Estimating and Taking-off. Therefore, there are noticeable differences in the allocation of activities within the CMM functions, as outlined below;

a) There is no noticeable emergence of the function of Planning within the CMM process that is practiced by the contractor (Case Study E),

b) The 'Estimating and Taking-off' function is carried out by the PM team and the CSM Team; it includes the following activities:

NO	Activity's Name	Situation in the Typical CMM	Notes
1	Estimating, Bid & Commit and Develop WBS	Planning	*For the project*
2	Establishing Control and Communication Mechanism	Planning & Take-off	
3	Developing Project Catalog and Coding system	Take-off	*Cost-Code for each item*
4	Updating Functional Plans, Forms and Procedures	Planning & Purchasing	
5	Developing the engineering Drawings (Shop Drawings) and the Site Layout		
6	Establishing Take-off Methods	Take-off	
7	Developing the detailed BOQ for the all materials	Take-off	*Determine Quantities and Requirements*
8	Developing Time-Framework of when materials are needed	Planning	*Develop Milestone Schedule*
9	Preparing Buy Packages for Major Materials	Planning	*Plan Initial Bulk Buy*
10	Preparing Pre-Requisition for the commodities		
11	Determining the Materials Priorities	Take-off/Field & warehousing	
12	Issuing Material Stock Requesting (M.S.R)	New	

c) The 'Vendor Inquiry and Evaluation's' activities are distributed within/under the 'Procurement Materials' function and 'Warehousing' Function,

d) The functions of 'Purchasing and Expediting and Transportation' are combined into the function of 'Procurement Materials', which is carried out by the procurement department-purchasing section and the PM team; it includes the following activities;

NO	Activity's Name	Situation in the Typical CMM	Notes
1	Developing Approved Vendor List	Vendor Inquiry & Evaluation	
2	Capturing Vendor Performance Data	Vendor Inquiry & Evaluation	
3	Preparing Temporary Purchase Order	Purchasing	*Pre-Purchase Order*
4	Evaluating Bids, Negotiate, and Award Contract to a Supplier/Manufacture	Purchasing	
5	Requesting & Approving Submittals from suppliers	Purchasing (RFQ)	*Conducted by the PM team*

NO	Activity's Name	Situation in the Typical CMM	Notes
6	Issuing PO	Purchasing	
7	Establishing and executing Transportation Agreements	Expediting & Transportations, Planning	
8	Monitoring Production and Transportation Status	Expediting & Transportations,	
9	Procuring Material		
10	Forwarding O,S&D Sheet to the Supplier/Manufacture to resolve problems		

e) The 'Field Control and Warehousing' functions are somewhat combined, and all the data of the warehouse and sub-stores should be updated in the intranet (SMS) by the knowledge of the field control team,

f) There are slightly differences in the activities between delivering and storing materials directly on the site (sub-stores) and delivering the material to workshop for fabrication (Pre-Fab) or to the main warehouse, however, the key activities that form the 'Field Control' functions are as listed below;

NO	Activity's Name	Situation in the Typical CMM	Notes
1	Issuing Material Release Request (M.R.R) form	New	*It could be scheduled in advance*
2	Maintaining Material Status	Field Control	
3	Tracking, Receive & Inspect Material Deliveries	Field Control	*With participation of warehouse personnel*
4	Trial Allocation by using the Intranet (SMS)	Field Control	*With participation of warehouse personnel*
5	Issuing Material to the craft Worker	Field Control	
6	Conveying Prioritised Requirements to Expediting	Field Control	

g) Although, many activities of 'Field Control' and 'Warehousing' functions are combined, the most recognisable/noticeable activities for the 'Warehousing' function are;

NO	*Activity's Name*	*Situation in the Typical CMM*	*Notes*
1	Receiving and Verifying Materials Received against the Supplier's Package List/ N.D.W form		*With participation of Field Control personnel*
2	Inspecting Material for Damage or/and Shortage of quantities		*With participation of Field Control personnel*
3	Receiving, Availability and O,S&D Reports	Warehousing	*With participation of Field Control personnel*
4	Providing Secure, Strategic, Organised Storage	Warehousing	
5	Protecting and Maintaining Materials and Equipment	Warehousing	
6	Receiving N.D.W form		*From the PM, Sub-stories, or Fabrication Area*
7	Inventory Materials , and update materials data into the intranet (SMS)	Warehousing	
8	Signing the Package List and sending it to Accounts Payable		
9	Material Project Surplus	Warehousing	*With participation of Field Control personnel*
10	Providing the Vendor/Supplier Performance Feedback	Feedback	*Vendor Inquiry & Evaluation*

h) The 'Quality Management' team with the participation of the personnel of the 'Take-off and Procurement' functions perform all the quality assurance activities.

i) The Quality Management team with the participation of the personnel of the 'Field Control' and 'Warehousing' functions perform all the quality control activities,

j) Managing the building materials within Case E is mainly designed to use the intranet technology (Stock Management System), which is a program that organises the movement of the procedures and documents electronically between the CMM participants; it is based on using the Cost-Code of each item, equipment, and material.

Based on the functions and activities presented above, the CMM process, which is practiced within the case study E, can be simulated graphically through the practical workflow diagram below in **Figure J.7**,

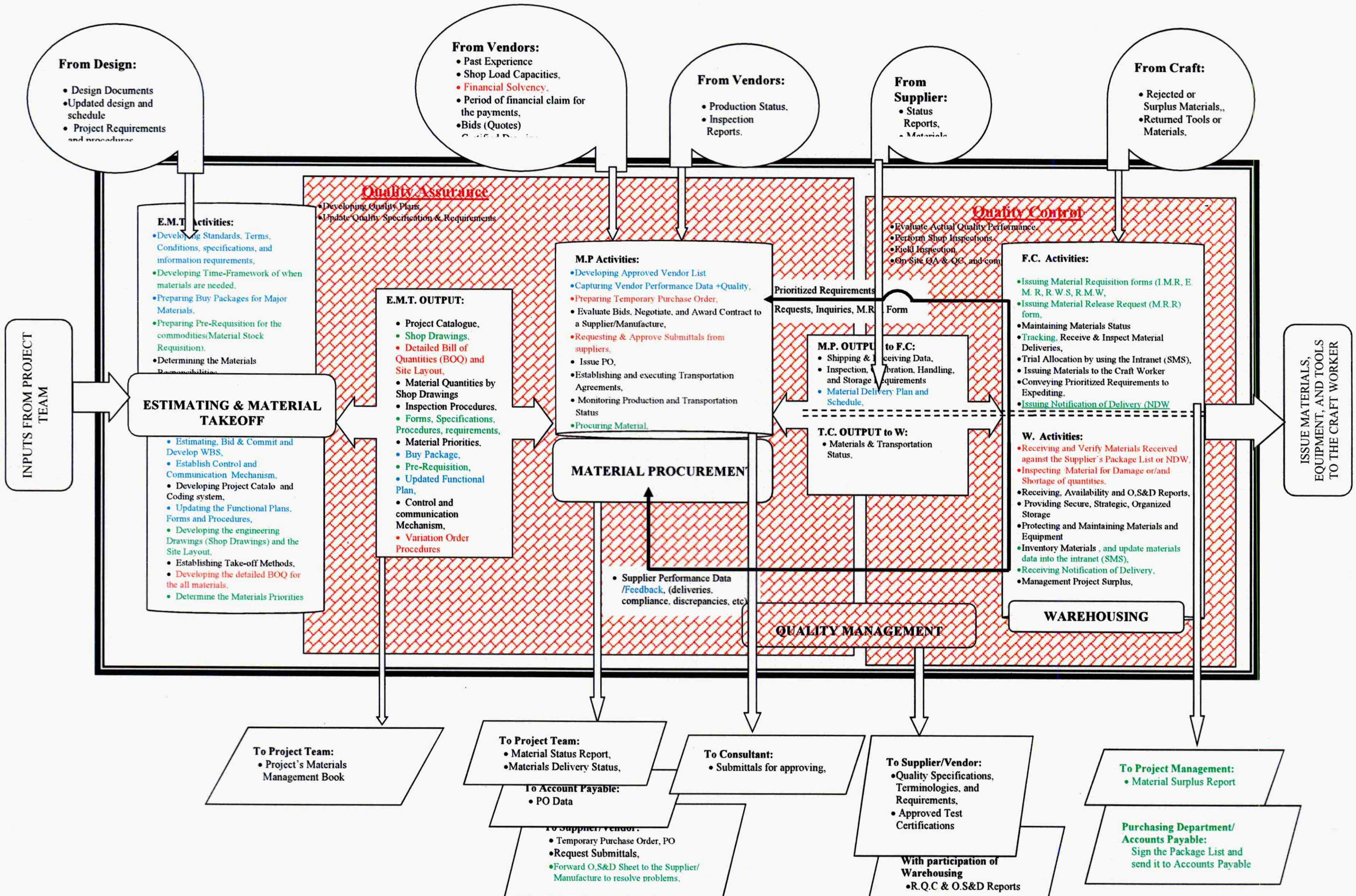


Figure J.7: The practical workflow diagram of the CMM process within Case Study **E**

4.5 Measurement of the CMM Performance:

1- Mechanisms/Approaches Currently in Use for Evaluating CMM Performance;

Case Study E utilises a computerized-integrated system (electronic intranet-SMS), which is to some extent similar to that used by Case D. This made the mechanism for evaluating the performance of the CMM process within this case somewhat similar to that practiced by Case D for obtaining indications on the extent of the effectiveness of CMM performance. Similarly, the main mechanism, which is used for assessing the performance of the CMM process, is built on evaluating the efficiency of using the electronic information system (SMS-intranet), examining the effectiveness of the CMM system in delivering the materials on time with the right quantity and quality, and reducing the level of wastage. However, unlike Case D, practicing this mechanism within Case E employs some qualitative and quantitative methods, as outlined below;

a) Frequently, monitoring and examining the lead-time of order fulfilment; this is undertaken by measuring the time between the date of placing an order and the date of delivering the required material to the construction site. This applies for both the Internal Material Request (I.M.R) forms for internal requests, and the Material Release Request (M.R.R) forms for external requests.

b) Periodically, evaluating the efficiency of implementing the SMS (Electronic-Intranet) through monitoring and examining the information exchange between the participants (the PM, the CSM, main Warehouse, sub-stores on the site) includes,

- Measuring the processing time for receiving and updating the materials to SMS; this is carried out by measuring the difference between the date of stamping the Packing Slip form by the warehouse's personnel and returning a copy to the supplier and the date of updating the materials received into the system (SMS),
- Monitoring the accuracy of the information and data exchanged within the system. This can be conducted through examining the data or information discrepancies related to material delivery, such as, the problems that occur when introducing erroneous or inaccurate data, which produce a mismatch between shipping documents and POs, BOQ, Packing List or others,
- Monitoring periodically the responses of the participants to the information exchanged by the SMS, by examining the flow, accuracy and speed of the movement of documents, procedures and the feedbacks received.

c) Monitoring and examining periodically the delivery dependability through the following considerations;

- Considering the supplier/vendor performance feedbacks, which are sent by the warehouse and field control personnel,
- Following up with the field operation the quality/services of feedbacks and the flexibility in supplying different types of items and equipment in order to meet the changing field operation needs,

- Examining the R.Q.C, O.S&D Reports in order to identify the ability of the CMM system and suppliers in delivering the right type, quantity, and quality of materials at the right time and the right place

d) Measuring the value or number of unused materials or items, before they are coded for return to the main warehouse disposed. This can be conducted by examining the Availability Reports, Materials Status Reports, and Monthly Reports, through the intranet (SMS),

e) Monitoring the level of material wastage by comparing the amount of materials expected to be wasted (Planned) to the actual amount of waste materials.

These procedures above, which form the mechanism that are used by Case E for assessing the performance of the CMM process, can be conducted by the project management team, quality management team or the team of Information Technology (IT).

2- A Set of Measures for Evaluating the Effectiveness of the CMM Performance;

Although there are some quantitative measures used in this case to evaluate the performance of some of the activities and procedures, there is no official or uniform list of measures taken to assess the effectiveness of CMM performance that has been recognised. Nonetheless, a comparison with the proposed list of measures, which has been derived from the literature review, highlights some similar measures or techniques that are practiced separately or non-systemically to follow up the performance of the CMM process as summarized in the tables below;

a) Measures are existent, but they are practiced separately, even if they are for the purpose of monitoring and following up the CMM performance and not for quantitative measurements,

NO	*The Measure's Code*	*Its Attribute*	*Notes*
1	Q2	Quality	Using Notifications of Return/non-conforming Items
2	T6	Timelines	Using the M.D.S Reports
4	C3	Cost	The M.D.S Report, Document related to Material Financial Reports and Statements of Cash flows Reports
5	C5	Cost	For identifying the causes of delay
6	C8	Cost	The reason could be attributed to the saving materials (considering as +/_). Using Electronic Warehouse System (SMS), Material Status Report
8	AV2	Availability	Indicate the warehouse ability to manage its needs & demands
9	F3	Flexibility	Using Material Status, availability report, and Warehouse System

b) Actions/Techniques, which are similar to the proposed measures, aim to evaluate the performance of the same functions that are assessed by the proposed measures, even if they are not from quantitative method,

NO	*The Technique Practiced*	*The Similar Measure/ Attribute*	*Notes*
1	Counting & Listing the line items that received with discrepancy	AC1&AC2/Accuracy	Problem Sheet
2	Periodic inventory inspection	AC3/Accuracy	
3	Measuring the number of performed M.R.Rs	QN1/Quality	Using M.R.Rs
4	Measuring the number of performed POs	QN2/Quality	
5	Measuring the processing time from issuing PO to receiving and updating materials in the warehouse system	T3&T4	POs and Inventory Record
6	measuring the number of the urgent/express deliveries that were done within a specific period of time	C4/Cost	Using M.D.S Report, POs
7	Following up the Construction Reports and listing the equipment that were required for rework for the issues of VOs	Q1/Quality	
8	Measuring the percentage of issued materials to required materials	AV1	Using Releases, Site Receipts, Availability Reports

c) Alternatives that are practiced to monitor/follow up the performance of the CMM process,

NO	*A Measure/Attribute*	*The Alternative*
1	T5/Timelines	Observing the material delivery progress, using the SMs
2	C7/ Cost	Monitoring and recording any warehouse safety incidents
3	F1/Flexibility	Following up the milestone schedule (Time Schedule) to determining overlapping between delivery lead-time and other activities' lead-time and slack time
4	F2/Flexibility	Monitoring & Examining the flexibility in supplying different types of items and equipment in order to meet changing field operation needs, by following VO(s) and RE-PO(s)

d) Some new measures that emerged in this case are;

NO	*The New Measure*	*Attribute*	*Notes*
1	Measuring the ratio of the actual amount of waste materials to the materials that are expected to be waste (Planned waste)	Cost	Monitoring the Wastage Level
3	Measuring the Procurement Processing time from issuing the M.R.R to issue the Temporary-PO	Time	
4	Measuring the order fulfilment processing time from issuing the I.M.R to issue material to the craft	Timeliness	Similar to T7 but processing time not lead-time

e) The rest of the proposed measures do not exist due to one or more of the following reasons;

- The difficulty involved in their calculation; C6, T1
- Their irrelevance to skeleton works, QN3, QN7, QN8, but it could be in finishing works
- Lack of their importance; QN4, C1, C2; where the employees are paid monthly salaries,
- Unused or there is no need; QN6 (EDI technology is unused in this project), QN5 (no field purchase)
- It is not measured in case; T2, T7

4.6 Terminology:

The main contractor in Case E is not a local contractor; rather, it is an international Arab contractor. It has, thus, its own terminologies that are slightly different from their peers within the JCI. Among the terms that are distinguished in this case, are the following:

- ➢ Buy Package: a document that contains a list of the major material needed, specifications of those materials, quantities and time when they are needed, any additional information required for clarification, temporary PO, notes related to items and drawings for the job.
- ➢ Pre-Requisition (Pre-Req): a document containing a list of the miscellaneous materials (commodities) needed, specifications for that material, and quantities along with the time when they are needed, any additional information required for clarification, temporary PO, notes related to items and drawings for the job.
- ➢ Temporary PO: a report that is generated electronically by the computerised system (SMS) and sent to the purchasing department by the PM; it guarantees the purchase, and becomes a PO for purchase material, once contracts/submittals are approved.
- ➢ Material Release Request (M.R.R): a form that is issued by the PM through the SMS electronic intranet (Construction Team) to request materials from the main warehouse for a period of time in advance based on the progress of the work and the schedule of the project.
- ➢ Material Stock Requisition Form (M.S.R): a sketch sheet (hardcopy) that states the quantities (75-80% of the original estimated quantities) and descriptions of materials needed (for commodities),

and sent to the PM, who updates it and converts it electronically to M.R.R. It allows the purchasing Department to shop around, because commodities are not job specific.

- Notification of Delivery to Warehouse (N.D.W): a from that is filled by the PM to notify the warehouse personnel that certain material will be delivered to the warehouse for storage. This form specifies the type and quantity of the material to be delivered, job number, supplier/vendor's name, carrier name, and the holding period for material.
- Over, Short, and Damaged (OS&D): a report lodged by a recipient of a shipment (Warehouse Personnel +Quality Controller), together with a claim, to the carrier of the shipment. It details what items listed in the shipping documents have been received over-shipped, short-shipped, or in an unsatisfactory or damaged condition.
- Surplus is not/over planned materials = waste in skeleton materials (bulk materials),
- Trial allocation: it is an activity of a materials control system (usually within the Field Control Function) comparing the material requirements to requisitions, purchases, and inventory to ensure material availability for construction.

Responsibility Matrix for Materials:

The responsibility matrix below shows the distribution of responsibilities for managing the CMM functions in Case E.

Table J.4: Responsibility Matrix for Managing Materials in the Case Study E

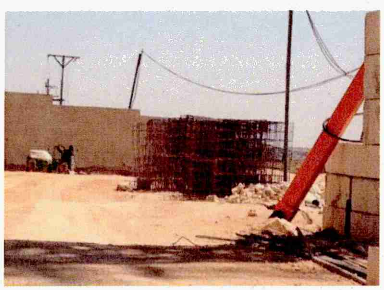
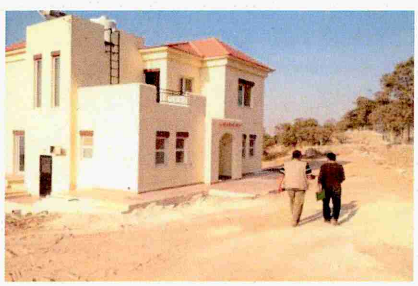
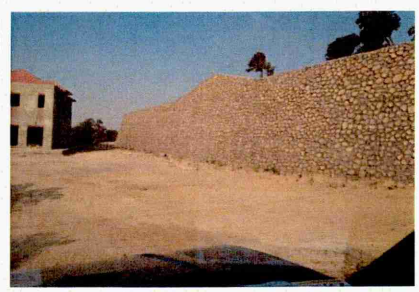
	CLIENT LEVEL		CONTRACTOR LEVEL							
	PROJECT OWNER		CONTRACTOR-HOME OFFICE				CONTRACTOR-FIELD TEAM			
FUNCTION	In- house Consultative office	Site Consultative office	Planning Team	Purchasing Team	Projects Management Team	Warehousing Team	Project Management Team	Construction Site Management Team	Materials Team (Material Officer)	Site-Store Team
Planning	**I,E**				**C**		**E**			
Materials Take-off & Design Interface		**A,C**			**I**		**E**	**C**		
Vendor Inquiry & Evaluation				**I,E**	**A**	**E**	**C**		**C**	
Main Purchasing				**I,E**	**A**	**C**	**E**		**C**	
Field Purchasing										
Expediting & Transportation				**I,E**	**A**	**C**	**E**		**C**	
Field Control					**A**		**I,E**	**E**	**C**	**C**
Warehousing						**I,E**	**A**	**C**	**C**	**E**
Quality Management (QA+QC)	**I**	**C**			**I**	**E**	**C**	**E**	**C**	**E**
		Keys of Actions: **I**=Initiate; **A**=Approve; **E**=Execute/Prepare; **C**=Coordinate;								

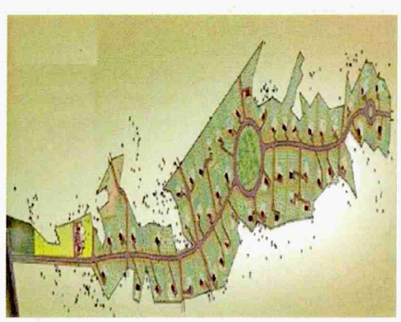
5 CASE F: MODERN RURAL VILLAGE:

5.1 Project Description/Background:

The project is a private real estate investment that aims to establish the first and the most prestigious farmer-houses community in Jordan. It is developed on a total built area o**f 300.000**m^2, and it is located in a picturesque hilly area, near the archaeological site between Jarash and Alzarqa Governorates; it offers a relaxed retreat to its tenants. The project consists of 51 fully serviced farm-villas that are built on four different Andalusian styles of 100 to 250 m^2 built up areas, each on an individual piece of land between 4000-6000 m^2. Each villa is built on a small farm that includes a garden with a pool and it is surrounded by a stone fence. The project also includes a recreational club that has commercial shops, two huge multipurpose halls, indoor and outdoor swimming pools, a restaurant, playgrounds, and a gym. Besides, main and sub asphalt roads, infrastructure works (water, electricity, Lighting...etc.), a variety of facilities and landscape elements (green areas and walkways) in a rural environment style that gives a sense of the spontaneous life and natural variety within the project. The estimated construction cost is about 38,000,000 JD = £35,346,778. The project is at the end stages (91% of building works).






5.2 Organisation Profile:

The project is established by a public shareholding company whose plan focuses on investing in different economic sectors; providing financial, commercial and agricultural services besides the real estate and tourism sectors, through establishing several companies and entities (subsidiaries) owned partially or totally by the main company.

The main contractor of this project is a fully owned subsidiary (sub-company) for the real estate sector within the main holding company. The main activities of this subsidiary are the implementation and management of the entire real estate projects (under the responsibility of the real estate sector) including modern villages, smart and industrial cities. The main contractor, with the participation of the subcontractors of fixing steel and framing woodwork (Shuttering), executes the skeleton works of the project. The process of securing and managing all the building materials is under the main contractor's responsibilities (DARAT, 2014)

5.3 Data Collection Process:

The Senior Construction Manager of the project is one of the key-of-contacts of the data collection process; access to the project data and sites was an easy mission. Also because of that, the project is built on a wide land area that includes various construction sites, nine field tours were conducted within the site visit technique, in order to cover as many as possible of the sub-sites. Those site visits, which were conducted within six weeks, included observing the process of securing and managing the building materials, following up the documentary cycle of requesting materials, and monitoring the process of storing materials in the warehouse, in addition to some discussions with relevant personnel within the organisational level of the main contractor. Moreover, two semi-structured interview-sessions were conducted; one with the Senior Construction Site Manager; it lasted about four hours and concentrated on understanding the management and movement of the building materials within the sites; it also reviewed the mechanism used for monitoring and evaluating the CMM performance. The second interview was an open discussion with the Procurement Manager within the purchasing department, which focused on realising the procedures taken to provide the project with the required materials.

5.4 The Process of CMM Practiced:

1- General Overview and CMM-Related Departments and Responsibilities:

In general, the nature of the project and the circumstances surrounding it can play an essential role in managing the building materials. Therefore, there is no specific, uniform, or written mechanism for managing the building materials within the projects that are implemented by this organisation.

Commonly, the CMM process starts by receiving the drawings and specifications from the owner/general contractor or their representative, and then within the planning and take-off functions, the contractor identifies and estimates the materials needed, the special requirements, and quantities, and submits a bid package to the client/general contractor for the bidding phase. However, in the present case study, the contractor, who carries out this project, is the client-in house, and thus the phase of bidding does not exist; the processes of designing and preparing the executive drawings, planning, identifying and estimating the required materials and equipment are conducted by the consultative subsidiaries.

In Case F, the role of the main construction contractor starts with the re-take-off function. The re-take-off team includes the procurement manager, the PM (within the organisational level of the Contractor), the CSM and his/her team (site engineers, foremen, and the Surveyor within the field level). The team reviews the executive drawings, re-estimates the quantities for the materials needed for each building stage, and generates a 'Material Requisition Schedule' that includes specifying the types of material, quantities needed, the need-dates, and any notes associated with the particular items. Within the material procurement phase, the procurement manager, the PM and the CSM select the local suppliers through request quotations from the suppliers, whom the contractor trusts or has worked with on previous projects, evaluate bids, and award contracts to the selected suppliers. After selecting the suppliers, agreements are made by issuing the temporary POs that becomes POs according to the progression of the work and the need for materials. Within the construction phase, the CSM and his/her team have to, systematically, follow up the status of order material in order to ensure that deliveries to the main warehouse in the construction field are on specified time and in the quantities needed. Although the organisational structural of this company is somewhat complicated, **Figure J.8** below can illustrate the noticeable relevant sections, departments, and personnel that are responsible for the construction materials of this particular project;

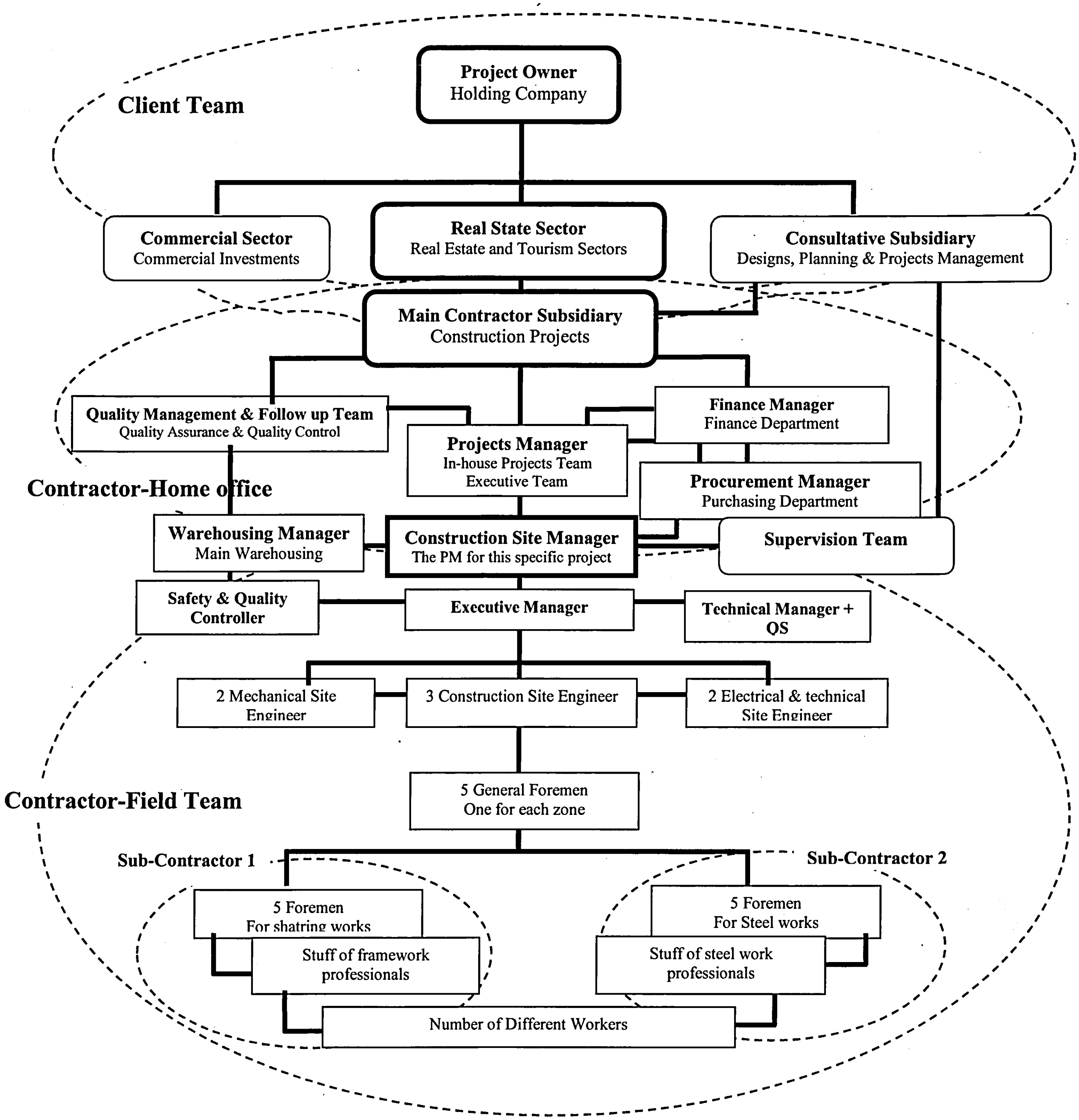


Figure J.8: The Project Team Structure-Related to CMM Process in Case Study F

2- Processing the Request of Building Materials:

As stated above, the nature of the project, the progress of site works and the surrounding circumstances can impose certain approaches and procedures to ensure the success of the materials management process. The construction work of the project aims to establish 51 villas and tens of service buildings spread on 300,000 m^2 land area. This scattering of the building sites in addition to the fact that the project is located in a rural area (away from the material suppliers/vendors) imposed a fundamental set of actions to facilitate the processes of managing and securing the building materials on the site. These are:

(1) Establishing the main warehouse on the site,

(2) Asking the concrete supplier for installing the concrete mixer plant on the site,

(3) Asking the fixing steel subcontractor to create at least five groups to start work on different sub-sites sequentially, and to prepare the whole requirements for shaping the reinforcement steel on the site;

(4) Asking the subcontractor of the framing woodwork to create at least five groups to start work on different sub-sites sequentially and to prepare the whole requirements needed for that,

(5) In order to speed up the process of requesting materials, the documentary cycle and the officials of this process have been reduced. They are left only with CSM, the main foremen and warehouse manager who form the internal cycle of ordering materials.

In Case **F**, a material requisition process within the skeleton stage is not too different from others; it can be summarized in the next proceedings;

a) At the early stage of execution, the CSM and the general foremen generate the Material Release Request (M.R.R) form for the specific part(s) of buildings or for a specific period of time. It includes the type, quantities, and specification of materials, items and the equipment needed, the code or serial number of these materials, items within the BOQ, and the dates needed. This form is sent to the PM, who is within the organisational level, for signing and forwarding to the purchasing/procurement department,

b) Based on the data of the M.R.R form, the purchasing department issues the POs to the suppliers, who have been identified in the earlier re-take-off stage, for delivering the materials and items according to the need within the field operation and the capacity of the warehouse. By phone, the PM confirms and instructs the supplier(s) on the items types, quantities, dates needed, and instructions for delivering.

c) After that, the PM, through sending the N.D.W form, notifies the warehouse personnel and the CSM that required material will be delivered to the warehouse for storage at a certain date or schedule,

d) Once the required materials are delivered to the warehouse, its personnel and the quality controller (sometimes with the participation of the CSM) verify and match the material received with the data included in the N.D.W form, stamp the packing list, and forward a copy of the packaging list along with the O,S&D Report (in case there is any damage material) to the PM, who in turn forwards them to the purchasing department or accounts payable, and forwards a copy to the supplier,

e) Whenever the materials or items are needed at any of the building sites, professionals of each sub-site can ask his/her general foreman, who is in charge of this sub-site to order the required material,

f) The general foreman fills the Material Request from the Warehouse (M.R.W) form, which is signed by the CSM, and then handed to the warehouse personnel to provide the required material to the concerned sub-site(s),

g) Once the required material is received on the site, the general foreman or any of the site staff can sign the received material receipt,

h) A quality controller is a person assigned by the project manager to follow up the quality of the work on the site and materials used, in addition to participating in receiving the material delivered and to prepare the O,S&D reports,

i) The daily used materials can be secured by the field purchases, which are usually conducted by the CSM and the warehouse manager.

The previous actions constitute the general process of requesting the majority of the materials used for the completion of the skeleton works. They are somewhat similar to the previous cases taking into consideration the fact that the construction Site Manager (CSM) is the only one who is responsible for setting up the plan for the movement of materials between and within the sites, while the foremen are responsible for implementing this plan.

3- Functions and Activities that Form the CMM Process in the Case Study:

In view of the fact that the project is an investment of the client and the main contractor and the consultative company are from the client subsidiaries (Client-in house), the majority of the activities are conducted by the consultative subsidiary. Those activities (including the planning activities, some activities of the take-off and design interface function, design process, preparing the executive drawings, and initially identifying and estimating the materials and the needed equipment) are outside the scope of the construction contractor's work. As a result, the functions that form the CMM process and their activities (within the construction contractor company) are distributed as follows;

a) The activities that are employed for developing bid packages for the tendering phase are not needed, as the main contractor of implementing the project has been already selected (the client-in house subsidiaries),

b) There is no noticeable emergence for the function of 'Planning' within the scope of the CMM process that is practiced by the contractor (case study F),

c) The 'Re-Take-off' function is the first function within the CMM process that is located within the scope of the contractor's management (practiced by the contractor). This function is carried out by the re-take-off team including the procurement manager, the PM (within the organisational level of the Contractor), the CSM and his/her team (site engineers, foremen, and Surveyor within the field level); it includes the following activities,

NO	*Activity's Name*	*Situation in the Typical CMM*	*Notes*
1	Reviewing and updating the Executive Drawings & and the Site Layout		
2	Re-estimating the Quantities for the Materials Needed for each Building Stage,		
3	Generating a material requisition schedule	Take-off	*developed from the BOQ and Shop drawings*
4	Establishing Control and Communication Mechanism	Planning & Take-off	
5	Updating Functional Plans, Forms and Procedures	Planning & Purchasing	
6	Developing/updating Time-Framework of when materials are needed	Planning	*Developing Milestone Schedule*
7	Preparing Buy Packages for Major Materials	Planning	*Planning Initial Bulk Buy*
8	Preparing Pre-Requisition for the commodities		
9	Determining the Materials Priorities	New	
10	Developing Daily Used Material List	Planning	
	Establish Forms and Procedures	Purchase	
	Develop Detailed BBQ for all materials	Take off	

d) The function of the 'Vendor Inquiry and Evaluation' is not essential, because the suppliers of the major materials of skeleton works are already selected amongst those whom the contractor trusts or has worked with in the previous projects. Thus, the function activities are distributed within/under the 'Procurement' function and 'Warehousing' Function.

e) The activities of the 'Purchasing' function and 'Expediting and Transportation' function are combined under the function of 'Material Procurement and Transportation', which is performed by the purchasing department and the PM team; it includes the following activities;

NO	*Activity's Name*	*Situation in the Typical CMM*	*Notes*
1	Requesting Quotations from the pre-selected Suppliers,	Purchasing	*Issuing RFQs*
2	Evaluating Bids, Negotiating, and Awarding Contract to a Supplier/Manufacture	Purchasing	
3	Preparing and Issuing Temporary Purchase Order	Purchasing	*Pre-Purchase Order*
4	Prepare and Issuing PO	Purchasing	
5	Establishing and executing Transportation Agreements	Expediting & Transportations, Planning	
6	Monitoring Production and Transportation Status	Expediting & Transportations,	*Overlapped between procurement and field control function*

NO	Activity's Name	Situation in the Typical CMM	Notes
7	Forwarding O,S&D Sheet to the Supplier/Manufacture to resolve problems	Take-off/Field & warehousing	

f) The border between the 'Field Control' and 'Warehousing' functions, is somewhat inconspicuous, and all the actions that are conducted by the warehouse should be with the knowledge of the CSM, however, the activities that distinguish the warehousing function are listed below;

NO	Activity's Name	Situation in the Typical CMM	Notes
1	Receiving and Verifying Materials Received against the Supplier's Package List/NDW		*With participation of Field Control personnel*
2	Inspecting Material for Damage or/and Shortage of quantities		*With participation of the Quality Control Team*
3	Issuing and Receiving, Availability and O,S&D Reports	Warehousing	*With participation of the Quality Control Team*
4	Providing Secure, Strategic, Organised Storage	Warehousing	
5	Protecting and Maintaining Materials and Equipment	Warehousing	
6	Receiving N.D.W form	Feedback	*From the PM*
7	Inventory Materials , and updating materials data into the inventory system	Warehousing	
8	Signing the Package List and send it to Accounts Payable (the PM in organisational Level)	Feedback	
9	Material Project Surplus	Warehousing	*With participation of the PM*
10	Providing Vendor/Supplier Performance Feedback	Feedback	*Vendor Inquiry & Evaluation*

g) Although many activities of 'Field Control' and 'Warehousing' functions overlap, the most recognisable/noticeable activities within the Field Control functions are;

NO	Activity's Name	Situation in the Typical CMM	Notes
1	Issuing Material Request from the Warehouse (M.R.W) form	New	
2	Issuing Material Release Request (M.R.R) form	New	*It could be scheduled in advance*
3	Maintaining Material Status	Field Control	
4	Tracking, Receive & Inspect Material Deliveries	Field Control	*With participation of warehouse personnel*
5	Trial Allocation	Field Control	*With participation of warehouse personnel*
6	Issuing Material to the craft Worker	Field Control	
7	Conveying Prioritised Requirements to Expediting	Field Control	

NO	Activity's Name	Situation in the Typical CMM	Notes
8	Purchasing, Receiving, Issuing, and Tracking the Daily Used Material	Field Control	
9	Issuing Notification of Delivery to warehouse (NDW),		

h) The 'Quality Assurance' activities are essentially conducted within the planning stage by the consultative subsidiary,

i) The 'Quality Control' activities, which could be located in the interface between the 'Material Procurement and Transportation' function (from one side) and the 'Field Control and Warehousing' functions (from the other side), are conducted by the quality controller, who is assigned by the project manager to follow up the quality of the site-work and materials used and to participate in receiving material delivered and preparing O,S&D reports,

j) The 'Field Control' team and the 'Warehousing' personnel participate with the quality controller in performing the Quality Control activities.

Figure J.9: the functions that form the CMM process in case study F, and the allocation of the activities within these functions

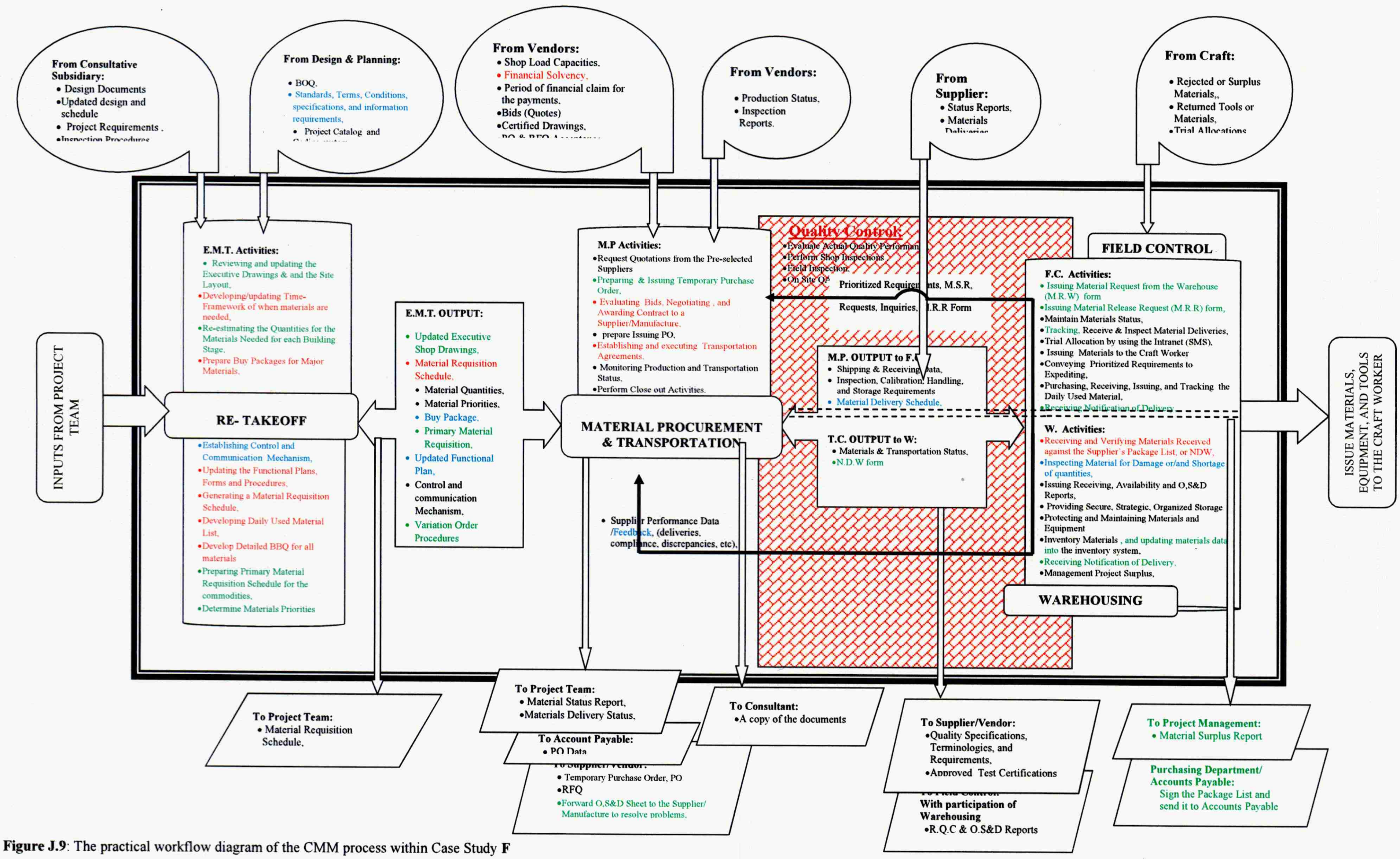


Figure J.9: The practical workflow diagram of the CMM process within Case Study **F**

5.5 The Measurement of the CMM Performance:

1- The Mechanisms/Approaches Currently in Use for Evaluating the CMM Performance;

No specific mechanism or system for measuring the effectiveness of the performance of the CMM process has been found in Case F. However, generally in this case, the basic indication of the extent of the effectiveness of the CMM performance is the ability of the CMM process to meet the project's aims on time within the estimated budget and acceptable quality. Therefore, time, cost, and quality are the most recognised parameters that form the assessment mechanism adopted by Case F. This mechanism is practiced through examining these parameters, qualitatively, in terms of their compatibility with the planned scheme;

a) **Cost:** Monitoring whether the cost of the materials bought is within the estimated cost, through matching the material prices listed in the packaging list with those in the BOQ,
b) **Timelines:** inspecting whether the material is requested, ordered, delivered, and/or received on time through examining the dates of issuing the M.R.W from and the M.R.R form and the dates of receiving the material, and comparing them with dates needed,
c) **Quality:** Ascertain whether the materials received conform to the approved specifications and requirements, through monitoring the O,S& D reports and the rejections of nonconforming items,
d) **Communication:** Monitoring the efficiency of the system of material reporting feedback between the CMM process participants,
e) **Flexibility:** The ability of the CMM system to react to the changes in design or field operation needs, without affecting the estimated cost and the planned time schedule. This is assessed through investigating the Variation Orders (VOs), Field Work reports, the Daily and Monthly Reports.

The PM team within the organisational level of the contractor and the CSM and the quality controller within the contractor's field level accomplish the majority of those techniques.

2- A Set of Measures for the Effectiveness of the CMM Performance;

Despite the fact that the contractor is a client subsidiary and that some CMM activities fall outside the scope of the contractor's work, there was emergence for some measures that are adopted to evaluate the performance of the CMM process. A comparison with the proposed list of measures revealed the following findings;

a) Measures exist but they are practiced separately, even if they are for the purpose of monitoring and following up the CMM performance and not for quantitative measurements.

NO	*The Measure's Code*	*Its Attribute*	*Notes*
1	AC	Accuracy	Using R.Q.C, O.S&D Reports AC1&AC2 combined
2	AC3	Accuracy	Manually & Periodically
3	QN2	Quantity	Using POs

NO	The Measure's Code	Its Attribute	Notes
4	T2	Time	Evaluating Bids, Negotiating, and Awarding Contract to a Supplier (RFQs+POs)
4	C3	Cost	Schedule of the general expenses.
5	C5	Cost	Monitoring the ability of the field control, The daily & monthly reports, Daily labour sheets,
6	C8	Cost	The reason could be attributed to saving materials (considering as +/_). Using Material Returned/Rejection Form, Inventory Record/ Warehouse System, Site Material Status Report, Availability Report
7	AV1	Availability	Using Materials requests (MRS & MRW form), Inventory Record, Site Receipt, Availability Reports

b) Actions/Techniques, which are similar to the proposed measures, aim to evaluate the performance of the same functions that are assessed by the proposed measures, even if not from quantitative perspective.

NO	The Technique Practiced	The Similar Measure/ Attribute	Notes
2	Listing the number and the type of materials that are purchased by the field team,	QN5/Quantity	Daily & Monthly Reports
2	Measuring the processing time of PO to receiving material in the warehouse,	T3&T4	
3	Listing the deliveries that are not made on or before the required delivery date (delayed deliveries)	T6/Timelines	Using the M.D.S Report
5	Listing the number of the urgent/express deliveries that were done within a specific period of time	C4/Cost	POs, M.D.S
6	Counting and recording quantities and types of the materials that were unavailable in the Warehouse when they were requested by Field Control	AV2/Availability	Using Material Availability Report

c) Alternatives that are practiced to monitor/follow up the performance of the CMM process,

NO	***A Measure/Attribute***	***The Alternative***
1	Q1/Quality	Monitoring the Site Work (structure) Reports including the number of installing equipment that required reworking, and the VOs
2	QN1/Quantity	Following up the progressing of M.R.R
3	T5/Timelines	Following-up the Material Delivery Status (M.D.S) Report
4	C7/ Cost	Monitoring the incidents in the warehouse using R.Q.S/O.S&D
5	F1/Flexibility	Monitoring the delivery lead-time with other project functions' lead-times and slack time
7	F3/Flexibility	Examining & Providing a report showing the required demand volume, planned demand, and the volume of the demand that has been already met, using M.S.R and Availability Report.

d) Some new measures that emerged in this case;

NO	***The New Measure***	***Attribute***	***Notes***
1	Measuring and Examining the processing time of the In-door delivery	Timeliness	Using M.R.W and the Material Receipt
2	Measuring the ratio of the actual amount of waste materials to the amount of the materials that are expected to be a waste (Planned waste)	Cost	Monitoring the Wastage Level
3	Counting the number of the inspections that were rejected for the all materials to the total number of inspections	Quality	Material Returned/ Rejection Forms/ Similar to Q2

e) The rest of the proposed measures do not exist due to one or more than one of the following reasons;

- The difficulty involved in their calculation; C6, T1, F2
- Their irrelevance in the skeleton works, QN7, QN8, but it could be the finishing works
- Lack of their importance; QN3, QN4, C1, C2; where employees are paid monthly salaries,
- Unused or there is no need for; 6 QN6 (EDI technology to be used in this project),
- It is not measured in case; T7
- "*F2 is an irrelevant measure, and it could reflect the ability of the supplier or vendor to react to these changes, without affecting the planned cost or operation process, rather than the contractor CMM process*", argued Senior Construction Manager

5.6 Terminology:

There is no new noticeable terminologies that can distinguish Case F. The following terminologies are the most frequently used in documents and forms that are adopted by case study F for managing the processes of requesting and delivering building materials;

- Material Requisition Schedule (M.R.S): a schedule that is generated by the re-take-off team (the PM, the CSM and their team); it is developed from the BOQ, Shop Drawings and re-estimating the major material. It includes specifications of the types of material, quantities needed, dates needed, and any notes associated with particular items.
- Material Request from the Warehouse (M.R.W): a form that is filled by a general foreman for requesting specific materials to a specific construction sub-site. This form should be signed by the CSM, and then be handed to the warehouse personnel to provide the required material.
- A Material Release Request: M.R.R form,
- Notification of Delivery to Warehouse: N.D.W from,
- Over, Short, and Damaged: OS&D report,
- Surplus is not/over planned = waste in skeleton materials (bulk materials),
- Trial allocation,

Responsibility Matrix for Materials:

The distribution of the responsibilities for managing the CMM functions in Case Study **F** can be illustrated through the responsibility matrix below;

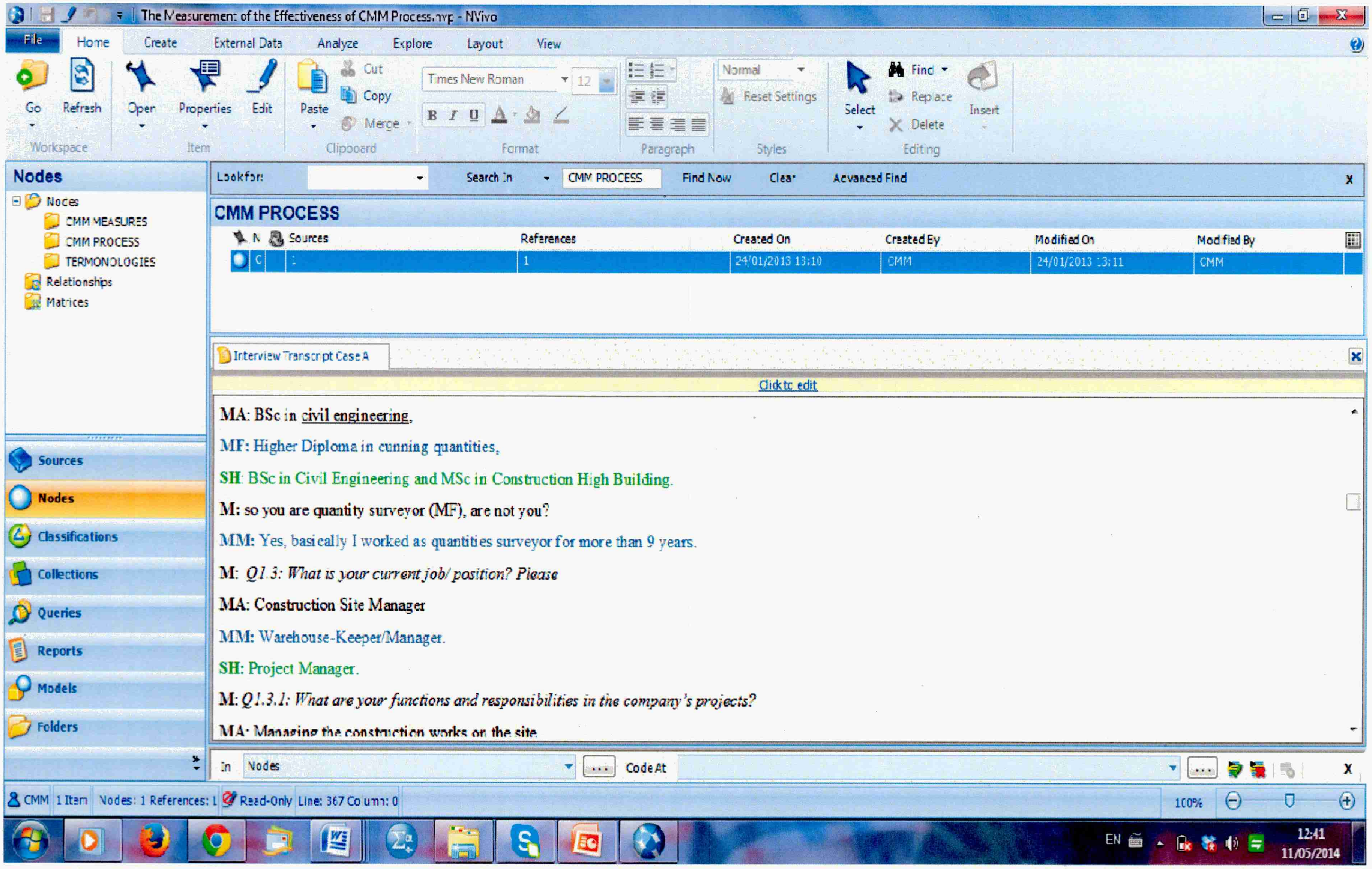
Table J.5: Responsibility Matrix for Managing Materials in the Case Study F

	CLIENT LEVEL		CONTRACTOR LEVEL (Client Subsidiary)						
	PROJECT OWNER		CONTRACTOR-HOME OFFICE			CONTRACTOR-FIELD TEAM			
FUNCTION	Consultative Subsidiary	Supervision Team	Project Management Team	Purchasing Team	Quality Management & Follow up Team	Construction Site Manager	Executive Team	Warehousing Personnel	Quality controller
Planning & Primary take off	I, E		C			C			
Re-Take-off	A		I,E	E		E	C	C	
Material Procurement & Transportation	A		I,E	E		E	C	C	
Field Control		A, C	A	C	C	E	E	C	C
Warehousing			I,A	C	C	E		E	E
Quality Management	I,E	C	C		E			C	E

Keys of Actions: I=Initiate; A=Approve; E=Execute/Prepare; C=Coordinate;

APPENDIX K:

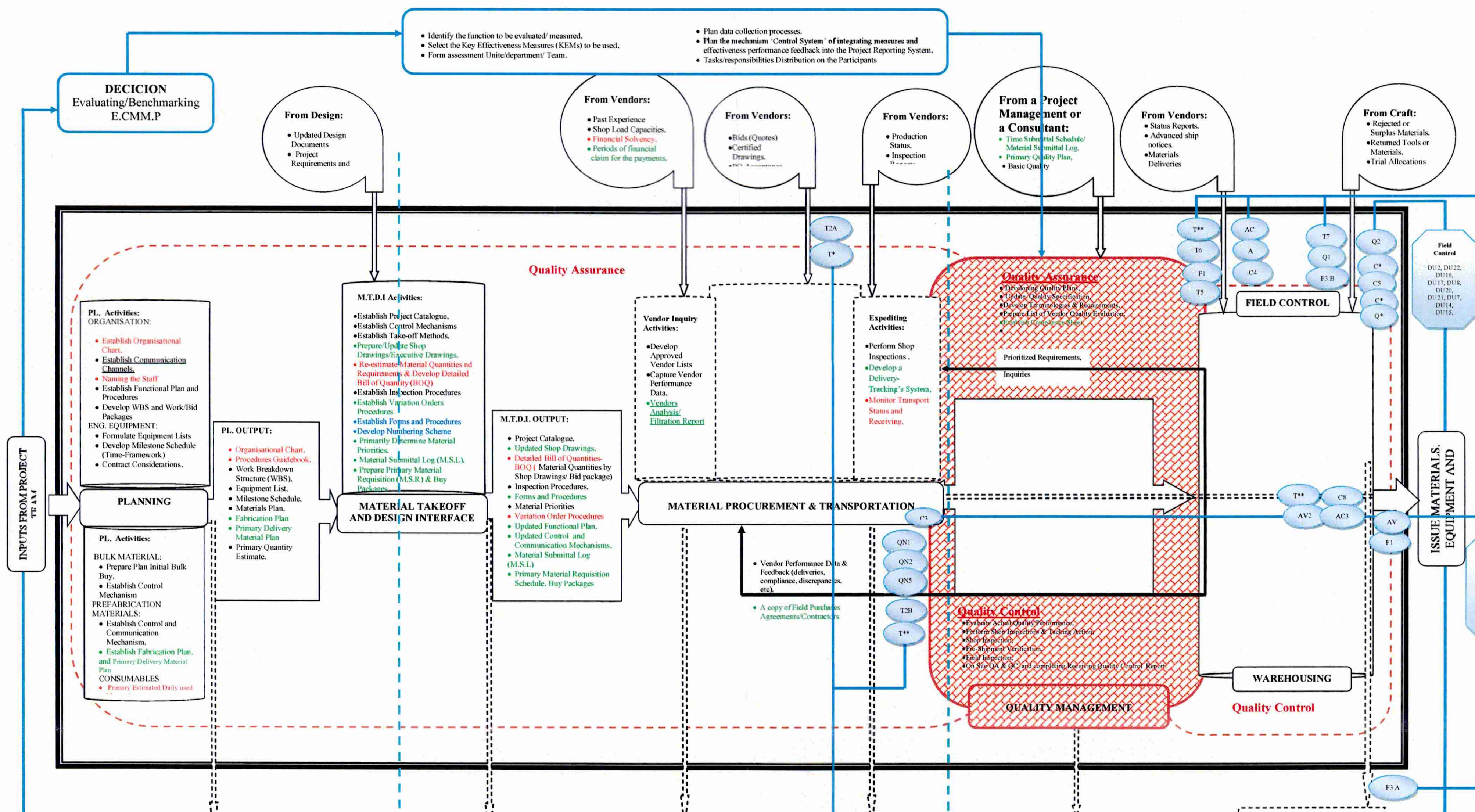
NODE SCREEN DISPLAY (NVIVO)


The Measurement of the Effectiveness of CMM Process.nvp - NVivo
Nodes
CMM MEASURES
CMM PROCESS
TERMONOLOGIES
Relationships
Matrices
Sources
Nodes
Classifications
Collections
Queries
Reports
Models
Folders
CMM PROCESS
Sources
References
Created On
Created By
Modified On
Modified By
1
24/01/2013 13:10
CMM
24/01/2013 13:11
CMM
Interview Transcript Case A
Click to edit
MA: BSc in civil engineering.
MF: Higher Diploma in cunning quantities.
SH: BSc in Civil Engineering and MSc in Construction High Building.
M: so you are quantity surveyor (MF), are not you?
MM: Yes, basically I worked as quantities surveyor for more than 9 years.
M: Q1.3: What is your current job/ position? Please
MA: Construction Site Manager
MM: Warehouse-Keeper/Manager.
SH: Project Manager.
M: Q1.3.1: What are your functions and responsibilities in the company's projects?
MA: Managing the construction works on the site.

Appendix K-1

APPENDIX L:

THE DETAILED E.CMM.P FRAMEWORK


DECICION
Evaluating/Benchmarking
E.CMM.P
• Identify the function to be evaluated/ measured.
• Select the Key Effectiveness Measures (KEMs) to be used.
• Form assessment Unite/department/ Team.
• Plan data collection processes.
• Plan the mechanism 'Control System' of integrating measures and effectiveness performance feedback into the Project Reporting System.
• Tasks/responsibilities Distribution on the Participants
From Design:
• Updated Design Documents
• Project Requirements and
From Vendors:
• Past Experience
• Shop Load Capacities.
• Financial Solvency.
• Periods of financial claim for the payments.
From Vendors:
•Bids (Quotes)
•Certified Drawings.
From Vendors:
• Production Status.
• Inspection
From a Project Management or a Consultant:
• Time Submittal Schedule/ Material Submittal Log.
• Primary Quality Plan.
• Basic Quality
From Vendors:
• Status Reports.
• Advanced ship notices.
•Materials Deliveries
From Craft:
• Rejected or Surplus Materials.
•Returned Tools or Materials.
•Trial Allocations
INPUTS FROM PROJECT TEAM
PL. Activities:
ORGANISATION:
• Establish Organisational Chart.
• Establish Communication Channels.
• Naming the Staff
• Establish Functional Plan and Procedures
• Develop WBS and Work/Bid Packages
ENG. EQUIPMENT:
• Formulate Equipment Lists
• Develop Milestone Schedule (Time-Framework)
• Contract Considerations.
PLANNING
PL. Activities:
BULK MATERIAL:
• Prepare Plan Initial Bulk Buy.
• Establish Control Mechanism
PREFABRICATION MATERIALS:
• Establish Control and Communication Mechanism.
• Establish Fabrication Plan, and Primary Delivery Material Plan
CONSUMABLES
• Primary Estimated Daily used
PL. OUTPUT:
• Organisational Chart.
• Procedures Guidebook.
• Work Breakdown Structure (WBS).
• Equipment List.
• Milestone Schedule.
• Materials Plan.
• Fabrication Plan
• Primary Delivery Material Plan
• Primary Quantity Estimate.
M.T.D.I Activities:
•Establish Project Catalogue.
•Establish Control Mechanisms
•Establish Take-off Methods.
•Prepare/Update Shop Drawings/Executive Drawings.
• Re-estimate Material Quantities nd Requirements & Develop Detailed Bill of Quantity (BOQ)
•Establish Inspection Procedures
•Establish Variation Orders Procedures
•Establish Forms and Procedures
•Develop Numbering Scheme
• Primarily Determine Material Priorities.
• Material Submittal Log (M.S.L).
• Prepare Primary Material Requisition (M.S.R) & Buy Packages
MATERIAL TAKEOFF AND DESIGN INTERFACE
M.T.D.I. OUTPUT:
• Project Catalogue.
• Updated Shop Drawings.
• Detailed Bill of Quantities-BOQ (Material Quantities by Shop Drawings/ Bid package)
• Inspection Procedures.
• Forms and Procedures
• Material Priorities
• Variation Order Procedures
• Updated Functional Plan.
• Updated Control and Communication Mechanisms.
• Material Submittal Log (M.S.L)
• Primary Material Requisition Schedule. Buy Packages
Quality Assurance
Vendor Inquiry Activities:
•Develop Approved Vendor Lists
•Capture Vendor Performance Data.
•Vendors Analysis/ Filtration Report
Expediting Activities:
•Perform Shop Inspections .
•Develop a Delivery-Tracking's System.
•Monitor Transport Status and Receiving.
MATERIAL PROCUREMENT & TRANSPORTATION
• Vendor Performance Data & Feedback (deliveries, compliance, discrepancies, etc).
• A copy of Field Purchases Agreements/Contractors
Quality Assurance
•Developing Quality Plans.
•Update Quality Specification.
•Develop Terminologies & Requirements.
•Prepare List of Vendor Quality Evaluation.
Prioritized Requirements.
Inquiries
Quality Control
•Evaluate Actual Quality Performance.
•Perform Shop Inspections & Taking Action.
•Shop Inspection.
•Pre-Shipment Verification.
•Field Inspection.
•On Site QA & QC and completing Receiving Quality Control Report
QUALITY MANAGEMENT
FIELD CONTROL
WAREHOUSING
Quality Control
ISSUE MATERIALS, EQUIPMENT AND
Field Control
DU2, DU22, DU16, DU17, DU8, DU20, DU21, DU7, DU14, DU15.
T2A
T*
T**
T6
F1
T5
AC
A
C4
T7
Q1
F3 B
Q2
C*
C5
C*
Q*
T**
C8
AV2
AC3
AV
F1
C3
QN1
QN2
QN5
T2B
T**
F3 A

APPENDIX M:

THE ANNUAL CONFERENCE OF THE JORDANIAN CONSTRUCTION CONTRACTORS ASSOCIATION (JCCA)


نقابة مقاولي الانشاءات الاردنيين
JORDANIAN CONSTRUCTION CONTRACTORS ASSOCIATION
JORDANIAN CONSTRUCTION
CONTRACTORS ASSOCIATION


EXIT

Appendix M-1

APPENDIX N:

PUBLICATIONS ABSTRACT

INVESTIGATING AND EVALUATING THE EFFECTIVENESS OF CONSTRUCTION MATERIALS MANAGEMENT PERFORMANCE ON LARGE-SCALE CONCRETE BUILDING PROJECTS IN THE ARAB REGION

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The rapid growth of the construction sector in the Arab region of the Middle East has contributed to the increasing number and types of large-scale projects currently being undertaken. This has consequently resulted in the growth and use of building materials and the identification of effective and efficient material management services to ensure overall construction process performance. The literature reviewed, previous studies investigated, and pilot studies carried out to date, confirm that the effectiveness of the construction materials management (CMM) process and extent to which it meets the needs and expectations of construction operations, has not been adequately defined or measured.

The primary aim of this research project is therefore to establish a set of uniform measures for evaluating the Effectiveness of Construction Materials Management Performance (ECMMP), and to develop a framework for use within large-scale concrete building projects in the Arab Region.

The work adopts a mixed research methodological approach involving both quantitative and qualitative data collection techniques. A case study project was also introduced where site visits and semi-structured interviews were carried out to establish a practical workflow diagram to reflect real-life CMM processes. This also included the identification of a set of measures to be used for evaluating the ECMMP on construction projects.

Based on the data collection and case study materials, a framework was developed to integrate effective measures within the practical workflow diagram of the CMM process, allowing an operational mechanism to communicate and operationalise those uniform measures within the workflow process.

This was followed by a framework validation designed to evaluate the functionality and appropriateness of the developed ECMMP through two techniques of formative and summative evaluations. Based on feedback, comments, and recommendations, refinements to the developed framework were addressed and incorporated prior to proposed implementation and operation.

Keywords: Evaluating; Effectiveness; Performance; Construction Materials Management (CMM Process); and Jordanian Concrete Building Projects

APPENDIX O:

PUBLISHED POSTER

EVALUATING THE PERFORMANCE OF MATERIALS MANAGEMENT PROCESS ON CONCRETE BUILDING PROJECTS IN THE ARAB REGION

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INTRODUCTION

The implementation of new technologies and the changing of existing methods are slow within the construction industry. However, the significant question that can be raised is, "*how the impact of these changes and applications can be evaluated in order to identify the extent of their effectiveness, suitability, and/or the need for more improvement or replacement*". Thus, there is a pressing need for measuring the performance of the Construction Materials Management (CMM) process to provide a basis for the follow-up and for evaluating and analysing the impact of any improvements or process changes on the material management process and the overall construction process performance. The rapid growth of the construction sector in the Arab region, along with other sectors that are based on construction projects has contributed to increasing the number and types of the large-scale projects; thus, it has realized growth in the use of building materials that promotes the identification of the material management services.

AIM

Consequently the primary aim of the research was "to establish a set of uniform measures for evaluating the effectiveness of Construction Materials Management (CMM) performance and to develop a framework for their use within the large-scale concrete building projects in the Arab Region".

OBJECTIVES

To achieve the research's question and aim above following objectives and sub-objectives were formulated;

- To critically review the existing literature on materials management processes and to identify, theoretically, the typical workflow diagram(s) of the material management process in the construction industry. (CMM)
- To identify and assess the material-related measures used within different industries and to establish a proposed set of measures to evaluate the Effectiveness of CMM Performance (E.CMM.P) in the building projects.
- To develop a practical workflow diagram for communicating the integrated functions and activities that form the CMM process within the large-scale concrete building projects in the Arab Construction Industry (A.C.I).
- To explore practical Effectiveness Measures of the CMM (ECMMP) on the Arab building projects
- To develop and validate framework for using the effectiveness measurement of the CMM performance on large-scale concrete building projects in the Arab regions (E.CMM.P Framework)

METHODOLOGY

1 Research Methodology: The work adopts a mixed research methodological approach involving literature review and both quantitative and qualitative data collection techniques.

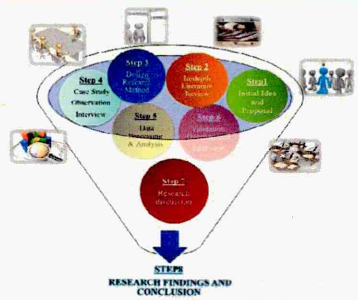


Figure 1: *Diagram outlining the Research Methodology*

2 Data Collection Technique: A case study project was introduced where site visits and semi-structured interviews were carried out to establish a practical workflow diagram to reflect real-life CMM processes. This also included the identification of a set of measures to be used for evaluating the E.CMM.P on construction projects

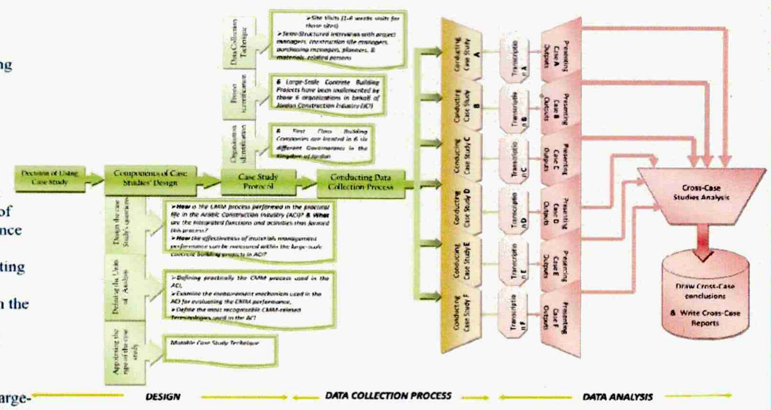


Figure 2: *The Case Study Protocol Framework: Design and analyse of the case studies*

RESULTS

1 Literature Review Findings: The Literature Review process aims to achieve the first and second objectives of the study, and its main findings are;

- Develop, Theoretically, the Typical Workflow Diagram(s) of the Material Management in Construction Industry,
- Develop a Proposed Set of Measures for Evaluate the Effectiveness of Construction Material Management Performance (E.CMM.P) in Building Projects,

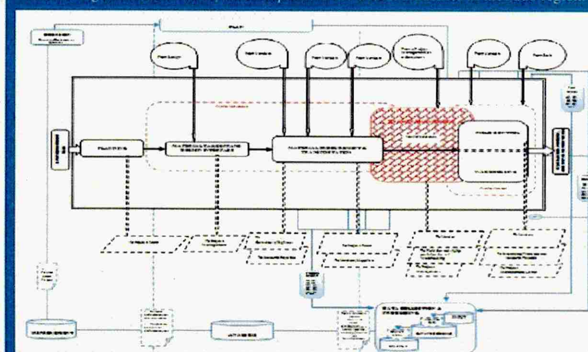
2 Data Collection Findings: The case study approach is designed to accomplish the third and fourth objectives . The main findings of the cross-case studies (Six case studies) analysis are;

- Developing the Practical Workflow Diagram for Communicating the Integrated Functions and Activities that Form the CMM Process within the Large-Scale Concrete Building Projects in Arabic Construction Industry (A.C.I).
- Establishing the Set of Measures that can be practically used for Evaluating the Effectiveness of the Construction Material Management Performance (E.CMM.P) in the Large-scale Concrete Building Projects in the A.C.I.

CONCLUSIONS

Based on the main outputs obtained from the literature review and the case study findings, the Framework of Evaluating the Effectiveness of the Performance of the Construction Materials Management Process (E.CMM.P Framework) was developed.

This research might be the first attempt to develop a mechanism for monitoring, analysing and evaluating the effectiveness of construction materials management performance in the building construction field, which represents the widest industries in the Arab region.



APPENDIX P:

THE PARTIES, FUNCTIONS, AND ACTIVITIES INVOLVED IN THE CMM PROCESS

THE DEFINITION AND THE ROLES OF THE CMM PARTIES:

1. CLIENTS:

A client is a very important element of any construction project. He/she is the initiator of a construction project, the one who makes the initial decision to procure a construction work and decides the procurement system (Briscoe et al., 2004). To build a construction project, he/she needs to employ a contractor who can be selected either by negotiation (partnering) or competition (tender) (Baldry, 1996). The decision on which a contractor is chosen is heavily based on the client's assessment of the contractor's ability to execute the project within cost, time and quality requirements whether negotiation or competitive tendering is used (Muya, 1999). This demonstrates that a client has a strategic position which may influence the whole project through his decisions on setting up the project and procurement system (Bresnen and Haslam, 1991). His /her level of experience (Bresnen and Haslam, 1991) heavily influences the way in which a client makes a decision. In addition, a client's previous construction experience has also a significant impact on the interaction process between him/herself and construction professionals (e. g. contractor, designer), which in turn may have an impact on the project performance (Gameson, 1996). Due to his position, the clients also are considered to be the most important key factor in the success of supply chain integration (Briscoe et al., 2004).

2. MAIN CONTRACTOR:

The main contractor plays a significant role in the project's success. He is responsible for the completion of the project to a pre-determined time, cost and quality. In construction supply chains, he has a strategic position as a `facilitator' who manages demand from the client/design team and supply from suppliers or subcontractors (Cox, Ireland and Towsend, 2006). The main contractor normally carries out the process of selecting subcontractors and suppliers before the project starts. However, not all subcontractors and suppliers need to undergo selection by a main contractor to obtain contracts. They may be nominated by the client, often with advice from the designer. Some reasons for nominating a subcontractor (Banwell, 1964) in (Muya, 1999), include: the need for specialist techniques from a specialist subcontractor and the need to place order for a specialist work at an earlier time before the main contractor is selected, and a particular quality of work which a specialist subcontractor may offer.

For the contractor, the function of materials management is to: identify materials requirements, define appropriate materials suppliers, manage the ordering process, arrange timely delivery of requisite materials to site and store and dispense those materials on site to locations where they are required. In addition, even though the designer usually selects and specifies materials and components and describes them in the bill of quantities, it is the responsibility of the contractor to evaluate suppliers (those not already nominated), place orders, and receive items on site (Muya, 1999).

3. SUBCONTRACTORS:

Subcontractors play important roles in construction projects. They help the main contractor to carry out specialist works. It is not uncommon for as much as 90% of a construction project to be subcontracted

(Matthews et al., 2000) and consequently that subcontractors may contribute as much as 90% of a main contractor's turnover (Ndekuri, 1998). This exhibits the important position and contribution of subcontractors to the main contractor and the success of the project.

Although the main contractor usually carries out the process of selecting subcontractors (Hatmoko, 2008), due to complexity of construction projects, it is often necessary for the designer to engage the know-how of specialists during the design process, especially when structural steel works, mechanical and electrical installations and lifts are involved (Muya, 1999). Subcontractors' early involvement in a project allows a better understanding of the project itself and helps the overall relationship with the main contractor, which promotes trust and team working between parties (Matthews et al., 1996). It should be noted that good relationships between a main contractor and its subcontractor have been considered as a great strategic asset for both of them (Kale and Arditi, 2001).

4. SUPPLIERS/VENDORS:

In general, suppliers are parties who supply materials to a construction project. Oswald and Burati (1992) define a supplier as "*any enterprise that enters into a contract with a main contractor, a project manager or a client to: supply, manufacture and supply, or to manufacture, supply and erect or install construction materials, products or component the organisation itself supplies*". Perdomo-Rivera (2004) believes that a supplier can include a small local vendor, a producer, a construction materials shop or firm. He also argues that a supplier and a vendor could be used as synonyms. Grifa (2006) is consistent with the concept put forward by Perdomo-Rivera (2004); he confirms that local private vendors and workshops, public building materials vendors and manufactories, and small domestic firms are the key suppliers of construction and building materials that are included in the Libyan Construction and Building Sector (LCBS).

Suppliers/vendors play important roles in a construction supply chain. They supply materials or components for the construction projects in time and at reasonable cost (Venkataraman, 2004), which can reach value as much as 50-60% of the total cost of the project (Stuckhart, 1995). Delivering on time may lead to a shorter cycle time, inventory level reduction and improving service level (Venkataraman, 2004). These justify the importance of managing suppliers along the construction supply chain to obtain good performance of a construction project. In line with this, Bernold and Treseler (1991) and Perdomo-Rivera (2004) argue that the performance of suppliers is related to the success of the materials management system; thus, the selection of vendors is a very significant aspect.

The nomination of suppliers should be conducted during the pre-contract phase to facilitate proper preparation of the bill of quantities (The Aqua Group, 1992). Even then, contractors may still prefer suppliers who they have worked with previously. If the contractor finds the nominated supplier is undesirable, he/she can object, though this rarely happens (Johnston, 1981). The relationship between the contractor and suppliers is crucial for the success of a project and it is vital in determining whether or not a construction company stays in business. If the contractor has a good relationship with the suppliers, better prices and more reliable delivery can be expected.

THE FUNCTIONS THAT FORM THE CMM PROCESS:

1- MATERIALS PLANNING FUNCTION:

Despite the difference in the definition of the conception of planning within the construction materials management context, there is a consensus by many relevant scholars and authors that the function of materials planning is a continuous process that must be undertaken concurrently with engineering, construction and other project plans (Stukhart, 1995; Oswal, 2007; Binti-Kasim, 2008). Although materials planning does not provide detailed programmes and plans, it guides all the subsequent activities and can dramatically influence the project plans. Therefore, materials planning function is considered as the most important of all functions of the construction materials management (CMM) process.

Numerous construction-related institutions, scholars, authors, researchers, and functional professionals have published detailed documents and information that cover the features of the planning function, criteria of materials plans, the key elements of a materials plan and other relevant subjects. The majority of them believe that there may be separate plans for each of the materials management functions, for each project stage, and for each type of building materials (CII, 1988; Stukhart, 1995; Perdomo-Rivera, 2004; Oswal, 2007). Generally, they stress that the function of materials planning should occur at numerous times during the project, involve numerous participants, and have various formats, and the resulting plans must be developed and included within the project's plan. The purpose of a materials planning function is to determine and communicate major objectives to various functions and activities of the CMM process, and this could include various activities under this function. According to Plemmons and Bell (1994), Plemmons (1995), Plemmons and Bell (1995), Al-Darweesh, 1995, Al-Asad (2005) and Al-Alawi, Al-Ghazwi and Al-Saeed (2007), the major and most common activities that form the materials planning function are; defining responsibilities for all project materials and each CMM function, developing staff and training plans, developing a Work Breakdown Structure (WBS) and Work/bid Packages, and establishing communication channels.

As stated earlier, there are three main categories of construction materials: engineered, Bulk and Fabricated, and each of these categories requires a different approach during the planning and execution stages and different planning considerations. Stukhart (1995) addressed in detail the activities that are included within the planning function for each material category; they are briefly introduced as follows;

Planning for Engineered Materials:

The first step in planning for engineered items is the determination of the engineered items required for the project and the formulation of the requirement lists. Owing to that, these items will drive the entire project schedule, it is important that the planning for these items begins during conceptual engineering, although equipment specifications may not be completed until the detailed engineering phase is realized. The development of milestone schedule for engineered equipments is a needed throughout the planning function; it exhibits the development of specifications, approvals by management, preparation of requisition and bidding, preparation of the purchase order, approval to purchase, vendor acknowledgement, and preparation of drawings, approval of drawings, and fabrication. Additionally, contract considerations should be considered within this planning function. Each of the above steps is assigned to one of the major functional organisations, engineering, materials management, project management, owner, and vendor. Engineered items which are frequently referred to as "tagged" are essential for materials control, since each item is identified by its tag number in a bill of materials, a drawing, and/or a purchase order.

Planning of Bulk Materials:

Logically, planning of bulk materials is more complex than that for engineered items, because the quantities required are never exactly identified until the job is over. Many factors can affect bulk materials plan such as, materials availability, transportation, storage facilities, market conditions, and cash flow. This makes the first step within planning bulk materials function which is an estimation of the bulk materials quantities and update requirements. According to the accuracy level and associated man-hour cost, three ways can be used to quantify essentially Bulk materials; estimation, take-off, or calculation. Physical takeoff is the most accurate method; estimated quantities are usually derived from historical data and experience; calculated quantities are a variation of the estimated methods, where the bulk quantities are derived by relationship to some known item of equipment.

Due to a construction stage for many projects can begin before complementing the engineering stage, bulk material items need to be on hand before the total project requirements are known. For this reason, an "initial bulk buy" have to be planned and made from estimated quantities. Depending on the type of material and other factors, the range of the initial buy may be anywhere from 10% to 90% of the base estimation. Therefore, it is essential to establish control mechanism for determining the degree of the control of bulk materials; Materials that are critical or expensive require maximum control, quantity takeoffs, and recording of all issues against the take-off, whereas, materials that are readily available and inexpensive can be controlled by minimum ordering without verification of actual requirements.

Bulk materials are usually identified by a commodity code, which is defined as a code that is a unique identifier for common commodity component. Commodity codes can manifest the component type, size, specification, standard, and various items' information. However, common commodity codes would not necessarily have a unique identification.

Planning of Fabricated Materials:

Generally, fabricated materials plans should consider responsibilities for buying bulk materials to be fabricated, and materials takeoff responsibilities of the fabricator versus Engineer. An extensive fabrication demands an early planning effort to define the specific goals and limitation of the project's prefabrication program. The most visible role for planning fabrication materials is the establishment of control and communication mechanism to direct and manage the elements of the fabrication program including determination of fabrication materials and equipment procurement responsibilities considering scheduling limitations, materials specification, design, and takeoff responsibilities, and location job site versus fabrication sites. Fabricated subassemblies can be identified by individual piece mark codes that display the work item, materials class, piece number, and serial number, this activity is called 'develop tag numbering scheme' (Plemmons, 1995).

McConville (1993) and Plemmons (1995) introduce another type of construction materials; "Consumables" include the items that do not represent a large percentage of the cost of the overall construction procurement effort (cleaning materials, welding materials, small tools, field office supplies, and fuel, lube oil/greases). They suggested to be considered through the function of materials planning by developing quantities estimation and requirements for the consumables.

2- MATERIALS TAKEOFF AND DESIGN INTERFACE FUNCTION:

In general, the International Society of Automation (ISA, 2004) gives a broad definition of a Materials Take off function; "Take *Off (MTO) is the process of analyzing the drawings and determining all the materials required to accomplish the design, and then on its basis, the Bill of Quantities (BOQ) is created*". Al-Juaid (2005), Silver (1988), Al-Draweesh (1999) and Perdomo-Rivera (2004) agree that the take-off can simply be defined as the function of 'identifying' what materials, special requirements and items are needed, and 'calculating' how much, from drawings and specifications.

Although, the materials take-off (MTO) function comes as the second function in this study, some CMM-related researchers considered it as the first step in the bidding phase that starts from the time that a contractor decides to bid and receive the drawings, specifications and design documents from the architect, designer or the owner of the project (Muya, 1999; Perdomo-Rivera, 2004; and Nasir 2008). They also believe that MTO is the basic step to purchasing the actual materials needed to complete the work. However, there is consensus that the function has a great impact on the time and cost associated with the project, and the surplus can be caused by a poorly performed materials take-off.

Rojas (2009) summaries the main objectives of performing the function of materials take-off; these involve: 1) verifying the bid quantities; 2) calculating the accurate quantities for ordering materials and equipment; 3) beginning work sequencing and 4) validating the cost estimate. The achievement of these objectives requires a number of activities that should be undertaken within the MTO function. Many recent studies conducted by Plemmons (1995), Al-Draweesh (1999), UL ASAD, (2005), Al-Juaid (2005), and Rojas (2009) presented the main activities that can form the MTO functions. They believe that setting-up a method for carrying out the take-off function is the first activity that should be conducted, and then applied by determining materials quantities and requirements, establishing coding systems, founding inspection procedures, defining craft preferences, instituting change management procedures, creating control mechanisms, and finally, launching project catalogues. After the takeoff is completed, a consolidated bill of materials is created and entered in a computer system, materials priorities are determined, and control and takeoff procedures are developed (Plemmons, 1995 and Al-Darweesh, 1999).

In line with the report of the Construction Industry Institution (Project Materials Management Primer; 7-2) that was published in 1988, Rojas (2009) views that judgement and experience are required to determine the level of the materials take-off detail. The determination of the level of take-off is influenced by the level of quantity needs to be purchased and the level of control detail that are consistent with the plans for construction work planning. Al-Darweesh (1999) observed that the material take-off function can be executed initially from the plot plans, and then is updated, as more definitive design information becomes available. However, Rojas

(2009) stresses the necessity for comparing the construction take-off to the bid take-off to identify significant differences or discrepancies. It is unlikely that the bid estimate will match exactly the construction take-off. However, most quantities of materials and labours should be within the five percent of the bid amount.

3-VENDOR INQUIRY AND EVALUATION FUNCTION:

Vendors/suppliers have always been an integral part of a construction company's management policy (Ho, Nguyen and Shu, 2007). The performance of vendors/Suppliers is related to the success of the CMM process and it can have a significant influence on the construction company's performance through their contribution to cost reduction, new product design and promoting the constant improvement of quality (Bernold and Treseler, 1991; Monczka et al. 1998; Perdomo-Rivera, 2004; Ho, Nguyen and Shu, 2007). Consequently, the vendor evaluation process is a very important aspect, and a key step for accomplishing the work.

The supplier selection and evaluation processes draw even more concern from scholars and practitioners. Many scholars and researchers have discussed the definition of this function, the activities involved, the criteria that should be considered when selecting and evaluating vendors, and the entity of the function being an independent function or an activity that is involved within one of the main functions of the CMM process. Bell and Stukhart (1986), Plemmons (1995), Plemmons and Bell (1995), Ul-Asad (2005), Al-Alawi et al. (2007), Ho, Nguyen and Shu (2007), Beil (2010), and many others, view 'the vendor inquiry and evaluation' as a independent function whereby companies identify, evaluate and contract with vendors. On the other hand, some scholars and researchers consider vendor inquiry and evaluation as one of the activities that are subsumed under the function of 'purchasing' (CII, 1988; Stukhart, 1995; Al Haddad, 2006 and Patel and Vyas, 2011), or those that are involved within what is called a 'procurement' process (Perdomo-Rivera, 2004 and Nasir, 2008).

There are various methods and criteria for evaluating and selecting vendors. Stukhart (1995, p89) provides a perspective for selecting vendors, which maintains that "*Contractor and owner organisations usually have key vendors/suppliers; these are vendors with whom they transact major purchases, who have certain technical capabilities, or who are leading commodity sources*". Those key vendors frequently become sole sources for key equipment or materials. However, developing a new vendor (not a sole source) and achieving effectiveness in vendor evaluation and selection requires identifying a set of proper and meaningful criteria. It is hard to apply any fixed set of criteria to evaluate and select suppliers (Kannan and Tan, 2002; and Ho, Nguyen and Shu, 2007). Based on examining the studies of the Construction Industry Institution (CII, 1988), Stukhart (1995), Kannan and Tan (2002), Al Haddad (2006), Ho, Nguyen and Shu (2007), one can summarise the key criteria of evaluation and selection vendors; past vendor experience and performance, Financial status, shop load capacities and capability, schedule and quality performance and services, geographic location, and owner preference. On the basis of these criteria, the concerned contractor's department or purchaser can develop an Approved Vendor List (AVL), which is a modification of the key supplier list for specific projects (Dodd et al, 1987; and Stukhart, 1995).

Based on the vendor performance data that is derived from the warehousing and field control function during the execution of the order of the project, a vendor performance evaluation form and checklist can be developed and used for evaluating vendors (see Stukart 1995, p45). Vendor performance ratings (whether from previous projects or in progress project) provide constructive performance feedback to the purchasing, project team and to vendors, which can include vendor performance information regarding quick response time in case of emergency, problem, or special request; the flexibility to respond to unexpected demand changes; and the willingness to change their products and services to meet the purchaser's changing needs (Kannan and Tan, 2002).

From the AVL and other information, which are converted to the purchasing department as an output of the vendor inquiry and evaluation function, requests for quotation are issued and bids received within the purchasing function.

4-PURCHASING FUNCTION:

'Buying', 'Purchasing' and 'Procurement' are frequently used interchangeably and give the same meaning when they are translated to some languages like the Arabic language (Stukhart, 1995; Wright, 2013; Wilkinson, 2014). However, to understand the definition of purchasing, differences in meaning need to be clarified. Stukhart (1995, p82) presented an overview of the differences between the meanings of these three terminologies; purchasing is "the act of (and functional responsibility for) procuring materials, supplies, and services" (Aljian, 1973). This implies securing these materials at the right quantity, quality, and from the right source at the right time and price. Purchasing involves much more than buying; it embraces planning, organising, controlling and executing the buying function. However, it "*is just one of the three stages of procurement, and it consists of approaching the market, evaluating offers, and establishing a contract*" (Wright, 2013, p5). The term 'procurement" covers the requirements, purchasing, expediting, quality assurance, and contract administration. In the literature, the term 'Procurement' implies the process of deciding what, when and how much to purchase (Glossary of Defense Acquisition Acronyms & Terms, 2011), and the process of ensuring that what is required is received on time and according to the specified quantity and quality, including engineering, transportation, receiving, incoming inspection, and salvage (Burt, 1984; Stukhart, 1995; Wilkinson, 2014). However, Perdomo-Rivera (2004) notes that the common denominator between the term 'Purchasing' and 'Procurement' is that both of them deal with the acquisition of materials to be used in the operations, and the primary function of both is to get the materials at the lowest cost possible, while keeping in mind quality requirements.

Within this context, the majority of the literature review studies have derived the definition of purchasing from the one that was provided by the Construction Industry Institution (CII, 1988, p7); "*The purchasing function is central to materials management. Purchasing has the responsibility and the authority to commit project funds for materials, equipment, and services*", and it involves obtaining the right material, in the right quantities with the right delivery from the right source and at the right price (CII, 1988; Dobler, Burt and Lee, 1990; Arnold, 1991; McConville, 1993; Al-Haddad, 2006, Oswal, 2007; Hatmoko, 2008; and Nasir, 2008).

The term purchasing function encompasses a wide range of activities. These activities are different from one project to another depending on the type of materials, the type of project, the size of project, the type of contract, and other factors (Perdomo-Rivera, 2004). However, according to many relevant researchers and studies, the most common activities that form the typical purchasing function in a typical construction project can include establishing forms and procedures, developing standard terms and conditions of the purchase order, vendor evaluation, issuing requests for quotations, evaluating bids, negotiation, awarding contracts, preparing, executing and managing purchase orders, and executing close out activities (CII, 1988; CII, no date; McConville, 1993; Plemmons and Bell, 1994; Plemmons, 1995; Stukhart, 1995; Al-Darweesh, 1999; Al Haddad, 2006; Oswal, 2007, Binti Kasim, 2008).

Several methods of contracting are available to the purchasing organization, depending on the commodity or service required. Although other forms of agreement are used in varying degrees (e.g. blanked orders), 'Purchasing Orders' are the most common form of contract utilized on projects. Under any form, the contract must encourage the on time delivery and completion of the work (Al Haddad, 2006). The development of the contract form and procedures of purchasing is the first activity that should be conducted to perform the purchasing materials function (McConville, 1993).

According to Construction Industry Institution, the Publication 7-2, 1988, "Standard" or "General" terms and conditions of the order or contract generally address various commercial aspects of the transaction, the respective rights, duties, and obligations of the contracting parties. Thus, developing standard terms and conditions is an essential activity of the purchasing function since special terms and conditions must be incorporated into the body of the purchase order or contract, and items such as schedule, QA/QC requirements, test information, data submittals, drawing approvals, expediting, and terms of payment are typical of the information which must be also clearly specified (CII, 1988 and Al-Haddad, 2006).

Based on the specifications and approval and certified drawings, the purchasing department issues a 'Request of Quotation (RFQ)' to invite the perspective vendors/suppliers. From the drawings, a purchaser (e.g. the purchasing department within a main contractor) can obtain information about the location of materials, equipment, fixtures, details and overall dimensions, interrelation of materials, equipment and space, sizes of equipment, identification of materials at is locations, and other alternatives (Al-Haddad, 2006). From the specifications, a purchaser can obtain the type and quality of materials, equipment and fixtures, quality of workmanship, methods of fabrication, installation, erecting, test and code requirements, unit, options and alternatives (Ahuja, and Dozzi 1994). After the vendors have completed and returned the quotations to the purchasing department, the bids/quotations are analysed for price, compliance to specifications, terms and conditions, delivery and payment terms (Oswal, 2007), and they must be evaluated for commercial and technical requirements (McConville, 1993).

The purchasing department is responsible for price negotiation and obtaining the best price from the vendors. Based on the approved bids (quotes), approved and certified drawings and other additional information, the purchasing department prepares and issues the 'Purchasing Orders (PO)' to formalize a purchase transaction with vendor (s). The PO should contain statements concerning quantity, description, and price of the goods or services ordered; agreed terms as to payment, discounts, date of performance, and transportation; and all other agreements pertinent to the purchase and its execution by the vendor (Stukhart, 1995). A copy of PO(s) is sent to the vendor(s); copies are also sent to other departments such as the accounting and the project team. It is the responsibility of the purchasing department to administrate the purchase orders including ensuring that the vendors deliver the items ordered and find out, early enough, so that corrective actions can be taken, in case there is any doubt that the delivery dates can be met (Oswal, 2007). It is also in charge for executing close out activities, including surplus, disposal, addressing claims, records storage, and final reports (McConville, 1993 and Al-Darweesh, 1999).

The activities above may be accomplished by the home office, the field, or a combination of both depending on the size and scope of the project (CII, 1998). Al-Darweesh (1999) and Nasir (2008) argue that the identification of purchasing responsibilities is the most important action in the purchasing function; this implies defining the purchase responsibilities of the home office and field office. The home office of the main contractor, or in some cases the owner, must maintain planning, procedural, and policy direction over the field operations in order to ensure consistent purchasing practices, and to allow close corporate control taking advantage of possible savings through its buyer specialization, considerations of various job requirements for informed pricing, and access to better sources. On-site purchasing is necessary in remote places when waiting for home office purchasing will delay the progress of the project (Ahuja, 1980; Al-Darweesh, 1999). The field/site office role should be clearly defined within the purchasing function (Nasir, 2008).

5- EXPEDITING AND TRANSPORTATION FUNCTION:

In the previous section, the purchasing function was defined as embodying activities necessary to acquire materials from the right source, at the right price and time, and according to the right quantity and quality. In order to achieve these objectives, there are two fundamental functions that could be performed on almost every project; expediting and quality assurance (Stukhart, 1995 and Oswal, 2007). Frederick, (1991) found out that 28% of the craft-workers time was idle or non-productive due to the unavailability of materials and tools at the time and place of need (reported in Al-Darweesh, (1999). This gives an indication that expediting is an essential part of the integrated project materials management process. It is a "*one control system necessary to assure timely materials and equipments arrival to achieve project completion on schedule*" (Perdomo-Rivera, 2004, p7).

According to Harrison (1985), McConville (1993), Stukhart (1995), Perdomo-Rivera (2004), and Oswal (2007), the main goal of expediting on construction projects is to ensure that the appropriate materials and equipment are delivered to the construction job site in a timely manner that is consistent with the terms of the PO and the project's schedules and requirements. They believe that the expediting function involves continuous monitoring of all steps in the procurement cycle, and continuous review of the performance of vendors and subcontractors to assure reliable, economic, and on-schedule delivery. Harrison (1985) summarised the goals of expediting that encompass: obtaining formal commitments from the vendors as to the delivery dates, monitoring the vendor/supplier's progress, eliminating or minimizing delays, clarifying with the vendors any delivery instructions, reporting to the users and managers the status of orders, determining restraints on production and shipment and eliminating them; and taking other remedial actions where possible to ensure prompt deliveries.

The size of order, its urgency, and project requirements decide the need for expedition, the degree and type of expedition, and the mode of transport. An essential factor for comprehending the role of the expediting function is a clear understanding of the role and importance of the purchase order (PO) document. It is therefore important that the PO be drafted to include: clear definitions of all the requirements and obligations expected from the supplier/vendor; clear and measurable requirements with respect to the vendor's performance; and adequate terms to support and facilitate the effective exercise of the expediting effort (Construction Industry Institution, CII, 1988; Stukart, 1995; Oswal 2007).

Once a PO or a contract has been awarded, it is vital to the success of the construction project that the expediting plan be established (McConville, 1993). This plan helps to ensure that the promised delivery date is maintained, and that it should be integrated into the overall project plan and schedule. This requires that a project scheduler work closely with the materials and the engineering team to draw up the required dates.

Several types of expediting methods are used in the construction industry; they have been found in many relevant literatures; for instance those of McConville (1993), Stukhort (1995), Al-Haddad (2006), among others. They found out that the most frequently used expediting methods can be classified into three types depending on the level of intensity or magnitude and price. In fact, all those reviews used the classification of the Construction Industry Institution (1988) to describe the expediting methods. Along the lines of those reviews, three expediting methods are described below using the definitions that are adopted by CII 1988.

Status Report Expediting: it is the least intense type of expediting and the less stringent compared to the other two types. Periodic (Weekly or Monthly) telephone contact is maintained with the vendor to determine the status or progress of an order, and the information is reported to the project manager in some systematic format. This type of expediting provides basic information to the project, and although it is inexpensive, it does little to prevent or overcome delays or problems with an order. The vast majority of the construction projects utilize this method.

Reactive or Corrective Expediting: it is more intense than the simple status reporting, but it is initiated only in response to some event or action. The vendor contact may be made in response to a problem of delayed or late delivery. This level of expediting requires some consultations along with visits to the vendor (shop inspection) to check those materials that are evidently problems. This method is usually adopted by the contractors in the Second and Third World countries, which are typically less concerned with achieving strict schedule and use expediting only when a problem or delivery delay has occurred or is about to occur (McConville, 1993).

Proactive or Preventative Expediting: it is the most intense, comprehensive, and aggressive type of expediting. Here, the expediting group performs a contact with the vendor, sub-vendor, and subcontractor as soon as the PO is issued and continues throughout the life of the order. On a small project, this activity might be performed by the project manager. The expeditor will review all elements of the order to ensure that the vendor understands the various submittal, testing, and delivery requirements. The expeditor will seek to gain thorough understanding of the vendor's engineering, purchasing, and manufacturing operations as they relate to the particular order. The expeditor (expediting staff) visits the vendors' fabrication shop to monitor and audit the manufacturing and fabrication processes, and also to monitor the production and transportation status. This enables the expeditor to monitor all elements of the vendor's performance with the intent of anticipating and resolving problems before they seriously impact the project. The expeditor should coordinate and inform the various project team members (warehousing staff, field control team, etc.) of any critical inspection requirements, current delivery status and date through preparing and submitting Material and Transportation Status Reports.

Expediting can actually be achieved at the home office, the site, or the vendor's shop, and thus, the more critical expediting requires close coordination between all the participants; the vendor, expeditor, and the construction project team. Accordingly, establishing expediting reporting and communication mechanisms is an essential activity of expediting function. Since the schedule (and, in some cases, prioritized requirements) ultimately directs the expediter's workload and efforts and since materials (or production) status has a major effect on the schedule, there must be two-way communication between expediting effort and the engineering and construction functions (Stukhart, 1995).

In much of the relevant literature, the activities of transportation are usually associated with the expediting function, although the transportation agreements might be developed and identified through the purchasing function or the planning function in some cases. On smaller projects, the activity of transportation could be performed by the site manager or planner/scheduler (McConville, 1993). However, on large-scale projects, expediting staff is responsible for executing transportation agreements. The expeditor is responsible for transporting and moving materials and equipment from the vendors or the place of fabrication to the construction project location according to the transportation/delivery schedule that is built on the *field construction need dates*.

6-WAREHOUSING FUNCTION:

According to Perdomo-Rivera (2004), there are two options to store materials in the building projects; on-site storage and off-site storage. The option of on-site storage includes storage in trucks, storage at work areas or storage at the lay-down areas. The alternative options associated with off-site storage include warehouse, rented space, and subcontractor's yard. They believed that the decision of choosing the proper option is associated with many parameters: storage cost, storage location, storage capacity, security, theft, loss, and damage. The decision can also associate with the parameters under the schedule category including progress of work, productivity, uncertainty in schedule, work to be done, when to use material, planned verses actual (i.e. extra, changes), order to install or order to store (Perdomo-Rivera, 2004). In any case, the contractor needs to consider whether the materials will be bought for installing or warehousing in the early stages of the project planning.

McConville (1993) suggests that storing the materials and equipment close to the final installation location is important. Perdomo-Rivera (2004), however, argues that delivering materials directly to the jobsite for installing purposes may not be feasible in many instances such as the case when critical specialty items are ordered early and are not going to be installed immediately, if a material is used for pre-fabrication, or when storage area at the jobsite is unavailable. In this case, the materials are delivered to the contractor's warehouse, whether it is a site warehouse (site-store) or the contractor's main warehouse (off-site), a subcontractor's storage area for temporary storage, or a pre-fabrication shop facility to assemble components prior to delivery and installation. Apart from the method used, storing the materials and items at the warehouse prior to moving them to the jobsite increases the indirect costs due to re-handling and using physical warehouse facilities (Perdomo-Rivera, 2004)

Within the early stage of the CMM process, it is essential to develop plans for warehouse facilities, including material and storage requirements, personnel procedures, bonded warehousing requirements, inventory control, and just-in-time materials programs (McConville, 1993), for providing secure, strategic, organized storage (Plemmons, 1995). Once materials, items and equipment are delivered, the warehouse personnel verify the material received against the Purchase Orders (POs), Advanced Ship Notices (ASNs), Notification of Delivery to Warehouse (NDW) forms, or other documents, and stamp the packing slip for acknowledgment that the material was received. If there over, short or/and damaged material, it should be noted on the packing slip, and the purchase department and project management team should be notified trough the Receiving Reports that include the Over, Short, and Damaged (OS&D) status, availability, etc. For payment purposes, a copy of the packing slip and receiving report is sent to the financial department (accounts payable). Besides, the vendor is notified for OS&D materials, and POs for shortages that can also be prepared and sent to the vendor. During the construction process, one of the most important activities for the warehousing function is to protect and maintain materials and equipment over all the construction stages.

Once the construction phase is completed, the contractor (usually by the warehouse staff) has to manage any surplus material. However, the decision of what to do with the surplus material depends on many factors such as the availability of a warehouse and storage space, the actual need for materials in the existing project, expected need for the materials in future projects, and inventory holding cost (Perdomo-Rivera, 2004). Perdomo-Rivera (2004, p113), thus, notes that "*the contractor needs to decide between sending the surplus to the vendor (a penalty cost might be incurred for speciality items), selling the materials to other contractors or sending the material to the warehouse*". He added that the decision, which is usually taken by the contractor's organisational level personnel, depends heavily on the tradeoffs between cost savings from making materials readily available versus holding costs. On the other hand, WRAP (2007) consider the decision of what to do with the surplus material is a shared responsibility between all parties of the CMM process, from the client to the main contractor and down to sub-contractor.

Stukhart (1995) believes that good materials inventory management should be the objective of the warehouse function. He summarised the objectives of construction materials inventory into three main points: 1) to meet the needs of the construction user, 2) to do so in an efficient way, and 3) to do so in a cost-effective way. There are several essentials that should be considered by warehousing for managing inventory: keeping records to tell what is on hand, maintaining physical protection and security, knowing the exact location and nomenclature and controlling inventory cost. To achieve these essentials, Stukhart (1995) provides four main requirements; the first requirement is usually achieved by recording receipts, issues and adjustments through physical counting; the second by various physical protection measurements; the third by using skilled people who can identify and classify items; the last is the most difficult and it requires cooperation between materials management and accounting. In fact, in large-scale construction projects, materials records should be automated.

7-FIELD CONTROL FUNCTION:

Among all materials functions, field activities are the most visible and they have the greatest immediate impact on construction (Stukhart, 1995). This implies that the field must be integrated with project materials control. According to Muya (1999), in large construction companies and large-scale construction projects, the home office usually performs the activities of the selection of suppliers, ordering of materials and payment of accounts for materials, while all the activities are performed when materials are received to final installation into the building; they are left to the field control function/team.

As mentioned earlier, the activities of purchasing materials may be accomplished by a combination of the home office and the field. There is considerable variation in the materials and equipment procured at the home office versus those in the field; however, a construction industry survey has demonstrated that 45% of all bulk materials and 4% of the engineered materials are field purchased (Stukhart, 1995). Based on this fact, Stukhart (1995) divides the materials at the construction site into two major categories;

1. Home office procured materials that are controlled and handled at the site. These are primarily equipment and fabricated materials, plus the initial bulk materials buys.
2. Field-Purchased materials; a major part of bulk materials plus consumables (lumber, nails, gravel, welding wire, etc), shorts, parts, tools, and construction equipment

Ideally, the specific materials to be purchased in the field should be identified at the early stage of the project materials planning. Personnel who carry out the field control function must be trained; they must be knowledgeable and able to requesting and executing field procurement (including; purchase, receive, issue and track tools/consumables) for at least those items and materials that are planned to be purchased in the field like those listed in (2) above (Construction Industry Institution, 1988; and Stukhart, 1995).

On many building projects, especially the large-scale projects, many activities for the physical control of materials at the jobsite such as, expediting, maintaining materials status, receiving and inspecting material deliveries, and issuing materials to the craft-worker, are a responsibility shared among the field control staff and the warehouse personnel (Kirby, 1995; Stukhart, 1995; Muya, 1999). In accordance with the SS Consulting Services (2013) reports the 'Trial Allocation' is an important activity of the field control function. The activity is based on comparing the material requirements to the requisitions, purchases, and inventory to ensure material availability for construction and this is carried out through examining the material status that includes quantities in the inventory, quantities currently on reservation, quantities issued to date, and quantities outstanding on existing purchase orders and their applicable delivery dates. This activity allows the field control team to plan work activities based on accurate material information, and to identify and convey the prioritized requirements to expediting (Plemmons, 1995).

8-QUALITY MANAGEMENT FUNCTION:

There is a consensus on the part of the vast majority of CMM-related scholars, researchers and functional professionals that the management of construction quality has always been a major concern to owners and contractors and the end users of projects or facilities, because they realize that the quality of construction materials, products, equipment and installation have an effect on the project schedule, ultimate cost, and performance of the constructed facility. Construction Industry Institution (1988), McConville (1993), Stukart (1995), and Legacy Site Services (2011) believe that the quality management process of construction materials is the sum of quality assurance and quality control activities. It is important to fully understand the terms of quality, quality assurance, and quality control. There are various definitions for these terms. The definitions below are the most common definitions that have been adopted and provided by several researchers and authors such as, Crosby (1979), Juran (1989), McConville (1993), Stukhart (1995), Al-Delma General Contracting LLC (2010), Legacy Site Services (2011), and TeamGrowth (2013);

Quality: it refers to conformance to established requirements. Construction materials and equipment can be considered of good quality when they fully conform to the established norms of specifying architecture or engineer, specifications and/or drawings.

Quality Assurance: it refers to planned or systematic actions necessary to ensure product conformance to requirements (Stukhart, 1995). Over the last 40 or so years, quality assurance, which is often abbreviated as QA, has been the owner's solution to ensuring that the contractors, vendors and sub-vendors have conformed to procedures that were established prior to the fabrication and manufacturing process (McConville, 1993). QA has traditionally been a mean for a contractor to demonstrate to an owner that proper procedures would be followed. This includes a set of proactive activities; the development and implementation of plans to ensure conformance to requirements, verification that all participants in the fabrication and inspection program follow established and specified procedures (CII, 1988),updating the quality specification, developing terminologies and requirements and preparing a list of vendor quality evaluation. As QA aims to prevent arising defects when the product is being developed, everyone on the team involved in developing the product is responsible for quality assurance (TeamGrowth, 2013) though the contractor usually assigns someone on its staff to perform the same role as the owner's inspector.

Quality control: it is the actual set of methods, such as testing, measuring, and inspection, necessary to verify conformance to the requirements (Stukhart, 1995). Team Growth (2013) reports that the aim of quality control is to identify (and correct) defects in the finished product; therefore, it is a reactive process. Juran (1989) states that quality control, which is often abbreviated as QC, consists of three main steps; 1) evaluating actual quality performance through ensuring that the installation of materials, and equipment is performed in compliance with the particular specifications, drawings, and installation procedures, (McConville, 1993); 2) comparing actual performance to quality goals, using actual testing, inspection, and documentation for materials and methods used in the installation process (McConville, 1993); 3) taking action regarding the differences. Stukhart (1995) argues that on site quality control usually consists of field inspection and disposition of conforming and nonconforming materials at the receiving stage, but it is not substitute for the vendor/supplier quality; "Once a product leaves the door of a supplier, it becomes very expensive to make corrections" (Ibid, p119). Therefore, activities such as, performing shop inspection, pre-shipment verification, and tracking action, are also essential activities within QC, and they should be built into the supplier's operations. In order to ensure that all materials are received and inspected and that they are in compliance with the specifications and POs, the receiving personnel, who could be placed within the warehousing function, should work in close coordination with the site QA/QC. Due to the preparation of Over, the Short, and Damaged (O,S&D) report is a job shared among the receiving personnel (at Warehousing), site receiving staff (at Field Control), and QA/QC personnel (Quality Management), site receiving has the responsibility to notify and coordinate with the QA/QC personnel when shipments are received. Since, the failure to prepare O, S&D reports and poor coordination with the site inspection will directly affect the availability of quality of materials for installation (Stukhart, 1995, p163).

With regard to the unit, person or department, who is usually responsible of conducting QA and QC functions, is still the subject of controversy. The Construction Industry Institution (CII), based on a survey that was carried out by it, found out that large contractors have QA/QC departments, which are separate from engineering or construction, are usually responsible for performing the QA/QC activities and report directly to some senior managers (Matthews and Burati, 1989). This, in fact, is contrary to what was reported by Legacy Site Services, (2011) and TeamGrowth (2013) that Quality Management (QM) function is usually the responsibility of a specific team of QA/QC or a combination of both warehousing and field control, whereby the home office and other participants can also be involved in the function. This argument came to support the perspective that was provided by Stukhart (1995, p173), who believes that "*The field frequently feels that the home office bows out of the picture once it has issued the purchase order, when in fact the home office may still be struggling with the receiving quantities*" (Stukhart, 1995, p173).

APPENDIX Q:

DESCRIPTIONS OF THE PROPOSED EFFECTIVENESS MEASURES OF THE CMM PERFORMANCE

1- MEASURES COMMUNICATED ACCURACY ATTRIBUTE:

Name: Material Receipt Problems, Code: AC1

Measure:

AC1 reports the data discrepancies associated with a material delivery that if not detected and corrected would cause inaccuracies in the project materials management database. AC1 is the percentage of line items received without discrepancy. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{Line items received without discrepancy}}{\text{(Line items recieved with discrepancy+Line items received without discrepancy}}\right] \times 100$$

Description:

Material receipt problems occur when shipping documents or materials do not agree in specific areas with the purchase order or receiving report. The action of clarifying or correcting one error associated with an individual PO line item constitutes one discrepancy. Discrepancies may be identified on bills of lading, packing lists, POs, Advance Shipment Notices (ASNs), and other materials documentation.

Measure Location:

At the interface between the Vendor and the Warehouse function.

Name: Material Receipt Problems – Internal, Code: AC2

Measure:

AC2 reports the accuracy of internally generated material related data as determined at the point of receipt. AC2 is the percentage of line items received without internal discrepancy. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{Line items received without internal discrepancy}}{\text{(Line items recieved with internal discrepancy+Line items received without internal discrepancy}}\right] \times 100$$

Description:

The Problems associated with materials receipt processing may influence the materials management database system by introducing erroneous or inaccurate data. Examples of discrepancies with internal origins may include 1) materials correctly purchased and delivered to the site without a PO number, 2) the commodity code on the PO is not in the materials catalogue, and 3) the PO is not available to receive the materials against. Internal sources of the problems may be segregated by location, home office, and field.

Measure Location:

At the interface between Vendor and the Warehouse function.

Name: Warehouse Inventory Accuracy, Code: AC3

Measure:

AC3 measures process quality by reporting the accuracy of the information associated with the warehouse function. The AC3 is, essentially, calculated by carrying out a statistical analysis comparing the physical counts versus the system counts. AC3 is the ratio of the number of items that are found accurate to the number of random items to be counted (items that are used to form the random sample). This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{Number of items found accurate}}{(\text{Number of random items to be counted})}\right] \times 100$$

Description:

This measure is determined by comparing through a statistical sampling the data in the materials database with the physical assets in the warehouse and controlled laydown areas. The inventory results indicate the accuracy of the materials management database system when compared with the physical asset count. Any difference between the inventory records and the actual physical counts constitutes a discrepancy.

Measure Location:

It is located within the Warehouse function.

2- MEASURES COMMUNICATED QUALITY ATTRIBUTE:

Name: Installing Equipment Rework, Code: Q1

Measure:

Q1 can be reported as a percentage of the total number of installing equipments identified as requiring rework (field modification) to the total number of installing equipments. Q1 may be reported as a cumulative and/or periodic measure. To provide the effectiveness ratio of Q1, the total number of installing equipments identified as requiring rework is divided by the total number of the installing equipment, multiplied by 100. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{Total number of installing Equipements required rework (rejected by engineer)}}{\text{Total number of installed equipements}}\right] \times 100$$

Description:

Q1 reports materials related process quality as a specific evaluation of design and supplier (fabrication) performance. Installing Equipment constitutes major and critical elements of some construction projects and the rework may significantly impact construction productivity. The root cause of IER may relate to any number of sources such as, design and fabrication accuracy, owner/contractor changes (i.e. modifications), untimely deliveries/schedule acceleration, and non-compliance with specification. In the case of owner or contractor changes, evaluating IER provides feedback on the impact of earlier decisions. Target levels of IER may be selected during the planning process as a project success factor

Measure Location:

At the interface of Construction with the Field Control function.

Name: Jobsite Rejections of Tagged Equipment, Code: Q2

Measure:

Q2 represents the percentage of all rejections of tagged equipment. A rejection occurs when 'Construction' notifies the 'Field Control Function' of the return of the item, because the construction group considered it unfit in its current form. Q2 is calculated by dividing the total number of the rejected tagged equipment to the total number of the issued tagged equipments, multiplied by 100. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{Total number of items of tagged equipment rejected}}{\text{Total number of items of tagged equipments issued}}\right] \times 100$$

Description:

The ability of the design and materials management processes to provide tagged equipment in accordance with the requirements is critical to maintaining efficient construction operations. The measure accounts for the situation where the materials management process functions correctly to provide an item that cannot be used in its current form or configuration.

Measure Location:

At the interface between the Construction Operations and the Field Control function.

3- MEASURES COMMUNICATED QUANTITY ATTRIBUTE:

Name: Home Office Requisition Ratio, Code: QN1

Measure:

QN1 reports the percentage of requisitions for quotations (RFQ) performed by the home office compared to the total number of request for quotations (RFQs) during a period of time. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{Number of requisitions for quotations (RFQ)performed by the home office}}{\text{(Total number of request for quotations (RFQs)during a period of time}}\right] \times 100$$

Description:

The QN1 ratio serves as an indicator of the degree of economizing transaction activities by performing RFQs (Requisitions for Quotations) in the home office. For this measure, a requisition submitted in an actionable format is considered the source of a RFQ. The purpose of a requisition is to initiate the flow of activities to purchase and receive specified materials.

Measure Location:

At the interface of Purchasing function with the Vendor.

Name: Home Office Purchase Order, Code: QN2

Measure:

QN2 reports the percentage of purchase orders (POs) performed by the home office compared to the total number of POs transactions during a period of time. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{Number of purchase orders (POs) performed by the home office}}{\text{(Total number ofpurchase orders (POs)transactions during a period of time}}\right] \times 100$$

Description:

The NQ2 ratio indicates the proportion of POs transmitted from the home office; it serves as an indicator of PO activity performed by the home office.

Measure Location:

At the interface of the Purchasing function with the Vendor

Name: Average Line Items Per Release, Code: QN3

Measure:

QN3 is the ratio of the average line items per release and the planned number of line items per release. The measure might be reported in a ratio format to communicate average and planned values. This can be interpreted mathematically in effectiveness format as;

$$[\frac{\text{(The Average Number of Line Items per Release)}}{\text{The Planned number of line items per release}}] \times 100$$

Description:

The NQ3 measure provides a general indication of the throughput for a given amount of effort to generate a release. The objective would be to maximize the line items per release. This measure could report actual versus planned releases in a periodic or cumulative format.

Measure Location:

At the interface of the Purchasing function with the Vendor

Name: Commitment – Home Office, Code: QN4

Measure:

QN4 reports the percentage of the value of materials and tagged equipment committed by the home office compared to the total commitment value during a specified time period. This can be interpreted mathematically in effectiveness format as;

$$[\frac{\text{The value of materials and tagged equipment committed by the home office}}{\text{(Total comitment value during a specified time period)}}] \times 100$$

Description:

This is a companion measure to Commitment - Field (QN5)

Measure Location:

At the interface of the Purchasing function with the Vendor

Name: Commitment – Field, Code: QN5

Measure:

QN5 reports the percentage of the value of materials and tagged equipment committed by the field compared to the total commitment value during a specified time period. This can be interpreted mathematically in effectiveness format as;

$$[\frac{\text{The value of materials and tagged equipment committed by the field}}{\text{(Total comitment value during a specified time period)}}] \times 100$$

Description:

This is a companion measure to Commitment – Home Office (QN4)

Measure Location:

At the interface of the Purchasing function with the Vendor.

Name: Electronic Data Interchange (EDI) Purchases, Code: QN6

Measure:

QN6 is the percentage of purchases made using electronic data interchange (EDI) applications to the total value of purchases. This can be interpreted mathematically in effectiveness format as;

$$[\frac{\text{The value of purchases made using electronic data interchange (EDI)applications}}{\text{(Total value of purchases)}}] \times 100$$

Description:

Electronic data interchange (EDI) is a technology that permits the transfer of documents, which include purchase orders, requests for quotations, invoices, shipping notifications, materials lists, and payment transfers among others, from one computer application to another. The contribution of EDI is important to the materials management strategy. The total value of purchases is used to monitor the utilization of EDI computer-to-computer linkages. Changes in the measure should reflect paper reduction, clerical time savings and purchase order cycle time reductions. 'Electronic Data Interchange (EDI) is the transfer of data between different companies using networks, such as the internet or intranet. As more and more companies get connected to the internet, EDI is becoming increasingly important as an easy mechanism for companies to buy, sell, and trade information'.

Measure Location:

At the interface of the Purchasing function with the Vendor.

Name: Sole Source Purchases, Code: QN7

Measure:

QN7 is the ratio of materials purchased via sole source to the total amount of purchases for a specified period of time. This can be interpreted mathematically in effectiveness format as;

$$[\frac{\text{The amount of materials purchased via sole source}}{\text{(Total amount of purchases for a specified period of time)}}] \times 100$$

Description:

Sole source transactions would include purchases from key vendors who have negotiated override agreements. Sole source can be defined as "a *non-competitive purchase or procurement process accomplished after soliciting and negotiating with only one source, i.e., specific products or services are available from only one source. Research indicates that competitively bidding these purchases will result in savings*". (Cornell University, 2012).

Measure Location:

At the interface of the Purchasing function with the Vendor.

Name: Minority Suppliers, Code: QN8

Measure:

QN8 is the percentage of total commitments for materials purchased via minority suppliers. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{Total commitments for materials purchased via minority suppliers}}{(\text{Total commitments for purchased materials})}\right] \times 100$$

Description:

For the purpose of defining the term, minority suppliers will encompass small, disadvantaged, minority, and women owned enterprises. 'Minority suppliers with whom the company develops a business relationship are strongly encouraged to develop a broad customer base to ensure an orderly growth and business environment'. This measure allows monitoring of periodic and cumulative percentages to achieve strategic business objectives.

Measure Location:

At the interface of the Purchasing function with the Vendor.

4- MEASURES COMMUNICATED TIMELINESS ATTRIBUTE:

Name: Procurement Lead Time, Code: T1

Measure:

T1 is the project ratio of the average procurement lead time in days and the planned procurement lead time. It uses a ratio format to report average actual and planned values. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{(\text{The Average Actual Procurement Lead-time (days)})}{\text{The Planned Procurement Lead-Time (days)}}\right] \times 100$$

Description:

Average procurement lead time is the average duration bounded by the transmission of the request for quotation (RFQ) until the receipt (signed) acceptance of the purchase order from the vendor. The duration may be composed of multiple commodity groups which have been aggregated to provide the average values. The duration encompasses the RFQ, bid evaluation, negotiation and award, and issuance of the PO. The duration reflects the completeness of the RFQ information, the need for additional negotiation, delays, the efficiency of bid evaluation, the mechanism of issuing the PO, and receiving the acceptance copy.

Measure Location:

At the interface between the Vendor and the Purchasing function.

Name: Bid/Evaluate/Commit Lead Time, Code: T2

Measure:

T2 is the average duration reported in days to bid, evaluate, and commit (BEC) to the purchase of materials. It uses a ratio format to report/communicate the average duration and planned duration. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{(The Average B,E,C Lead-time)}}{\text{The Planned B,E,C Lead-Time}}\right] \times 100$$

Description:

The measure is bounded by the receipt of the vendor's response to the RFQ until the issuance of the PO. While it may include some degree of negotiation and clarification, the measure focuses on the sequence of activities within the control of the Purchasing Function. The average BEC durations may be segregated by materials grouping (piping, steel, controls, etc.) or by discipline (civil, electrical, mechanical, etc.) or by process.

Measure Location:

Measures are taken in two locations; the first measure 'T2a' is at the interface of the Vendor with the Purchasing function, and the second measure 'T2b' is taken at the interface of the Purchasing Function with the Vendor.

Name: Purchase Orders (PO) to Material Receipt Duration, Code: T3

Measure:

T3 is the average duration from the issuance of the PO until the receipt data of material(s). It uses a ratio format to communicate the average duration and the planned duration. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{(The Average Duration of the Issuance of PO-to-Material receipt duration)}}{\text{The Planned Duration of the Issuance of PO-to-Material receipt duration}}\right] \times 100$$

Description:

Average duration is calculated based on each PO line item. Therefore, the average duration of the measure is the sum of the issuance—to— receipt duration divided by the total number of receipts;

Average = $\sum$ Issuance-to-receipt duration/ Total Number of Receipts

Measure Location:

The first measure location T3a is at the interface of the Purchasing function with the Vendors, and the second location T3b is at the interface of the Vendor with the Warehouse function.

Name: Material Receiving Processing Time, Code: T4

Measure:

T4 reports the percentage of materials received by the warehouse that is processed within two time periods, 'same day', and by 'next day'. T4 can be expressed mathematically in effectiveness format as;

$$[\frac{\text{(The Average amount of material received by the warehousein the same day)}}{\text{The Average amount of materials received by the warehouse in next day}}] \times 100$$

Description:

The processing time starts when a shipping document is time/date stamped by the warehouse receiving activity, and a copy is returned to the transport carrier. The processing time ends when the material is updated to a received status within the materials management system. The processing time encompasses a number of activities. These activities may include but not be limited to: receiving the delivery, inspecting the paperwork and the materials, determining the over, short, and damage (OS&D) status, resolving spot overages and shortages; documenting damaged goods, adjusting the quantities by PO supplement, and updating the material status. The chronological determination of same day or next day is midnight (0000 hours). This measure may be used in conjunction with the overtime cost and work-hours of craft labour assigned to the warehouse.

Measure Location:

Within the Warehouse and the Field Control functions.

Name: Commodity Vendor Timeliness, Code: T5

Measure:

T5 is the ratio of vendor deliveries that were delivered on time in regards to the 'promised delivery date' and the 'actual delivery date'. 'On Time Delivery' should be defined in an organisation or a project; e.g., it could be established that materials received within two days are considered on time, while materials received after that are considered late deliveries. Calculating 'T5' requires determining the number of on time deliveries and the total number of deliveries during a specified period of time. T5 can be expressed mathematically in effectiveness format as;

$$[\frac{\text{Number of on time promised delivers}}{\text{Total number of delivers (during a specified period of time)}}] \times 100$$

Description:

The chronological determination of same day or next day is midnight (0000 hours). This measure reports the percentage of on time deliveries, but may also represent several subcategories, for example, one to three days late and three or more days late.

Measure Location:

At the interface of the Vendors with Warehouse function.

Name: Commodity Timeliness, Code: T6

Measure:

T6 is the percentage of deliveries made on or before the 'actual delivery date' when compared to the 'required delivery date'. Calculating 'T6' requires determining the number of deliveries made on time or before the required delivery date and the total number of deliveries during a specified period of time. T6 can be expressed mathematically in effectiveness format as;

$$\left[\frac{\text{Number of deliveres made on time or befor the required delivery date}}{\text{Total number of delivers (during a specified period of time)}}\right] \times 100$$

Description:

The chronological determination of the same day or next day is midnight (0000 hours). T6 is reported as the percentage on time, but may represent two or more subcategories, for example 'one to three days late' and 'three or more days late'.

Measure Location:

At the interface of the Vendors with Warehouse function.

Name: Materials Withdraw Request (MWR) Lead-time, Code: T7

Measure:

T7 measures the lead time allowed for the issuance or delivery of materials by reporting time; it is the difference between MWR date and the need or requested delivery date. The measure is reported as a ratio of the average MWR lead-time and the planned MWR lead-time. The MWR date is the date an authorization is issued to the warehouse to withdraw specific materials from inventory. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{(The Average MWR Led−Time)}}{\text{The Planned MWR Lead−Time}}\right] \times 100$$

Description:

The action of requesting a withdrawal of materials initiates a series of actions within the Warehouse and Field Control Functions. Too short of a lead-time could generate inefficiencies that may not be directly related. For example, quick responses to MWRs could interrupt normal warehouse operations and result in increased overtime and loss-time accidents. The results of which may not be clearly definable until the next report cycle. The chronological determination of the same day or next day is midnight (0000 hours). Normally, the materials are staged (made ready for pickup or delivery) for the issue of the particular work planned. The lead time indicates the ability of construction operations to request material as the work package start date approaches, and, thereby, minimize the amount of time craft-workers wait for materials. Accountability is maintained as the withdrawals are issued to individuals in the warehouse or delivered to project material drop sites. The total number of MWRs may be segregated into two/three categories; the first category is 'same day', or MWR date issuance. This category normally reflects the percentage of quick responses or emergency situations where the warehouse function issues materials outside the normal staging procedures. The second category refers to MWR date plus two days 'MWR+2'. Two days are provided to allow the warehouse function to receive the MWR, schedule the withdrawal of materials and stage the materials from inventory, and issue them. Two days normally allows for performing these activities without incurring overtime or additional costs.

Measure Location:

At the interface of Construction with Warehouse function.

5- MEASURES COMMUNICATED COST ATTRIBUTE:

Name: Average Man-hour/ Work-hour per Material Take-off (MTO), Code: C1

Measure:

C1 reports the average number of work-hours required to generate a material takeoff (MTO) for a single drawing sheet. The measure is reported as a ratio of the average number of work-hours and the planned number of work-hours. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{(The Average number of workhours per MTO)}}{\text{Planned number of workhours per MTO}}\right] \times 100$$

The average is determined by dividing the total number of identified MTO man-hours by the total number of MTOs produced during the time period.

$$\text{Average number} = \frac{\text{Total number of identified MTO manhours}}{\text{Total Number of MTOs (Sheets) produced during time period}}$$

Description:

The measure does not differentiate between manual and computer assisted MTOs, but it should include the effort associated with manually checking the final results. For example, a ratio for manually generated MTOs could be (2.2/3), whereas the ratio for computer-assisted MTOs could be (0.2/0.4).

Measure Location:

Within the Material Takeoff and Design Interface function.

Name: Average Man-hour/ Work-hour per Purchase Order (PO), Code: C2

Measure:

C2 reports the average number of man-hours required to generate a purchase order (PO) during the time period. The measure is reported as a ratio of the average number of work-hours and the planned number of work-hours to generate a PO. C2 can be expressed mathematically in effectiveness format as;

$$\left[\frac{\text{(The Average number of manhours per PO)}}{\text{Planned number of manhours per PO}}\right] \times 100$$

Description:

The generation of a purchase order is associated with a series of activities or tasks deemed necessary by management and the contract requirements. Therefore, each PO represents certain amount of work-hours.

Measure Location:

Within the Purchasing function

Name: Freight Cost Per cent, Code: C3

Measure:

C3 reports the percentage of freight costs as a percentage of material expenditures. C3 can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{Total Fright Cost}}{\text{The material expenditures for the time period}}\right] \times 100$$

Description:

The total freight cost is divided by materials expenditures for the time period. The results may be combined and reported as a cumulative or a six-week rolling average to compare more readily with industry average.

Measure Location:

Within the Expediting and Transportation function.

Name: Express Deliveries Percent, Code: C4

Measure:

C4 reports the percentage of express deliveries made to the project warehouse by dividing the number of express deliveries and the total number of deliveries for a specified time period. C4 can be represented mathematically in effectiveness format as;

$$\left[\frac{\text{Number of express deliveries}}{\text{Total number of deliveries for a specific time}}\right] \times 100$$

Description:

Express deliveries are those deliveries where a premium price is normally paid for a quick response type transport of materials or equipment. This measure reflects the ability to plan and utilize standard modes of transportation and delivery.

Measure Location:

Between the Vendor and the Warehouse function.

Name: Construction Time Lost, Code: C5

Measure:

C5 is the percentage of construction time lost due to the impact of materials, as estimated by construction supervisors. To calculate C5, it is essential to determine the total amount of materials-caused lost and the total amount of construction time. Mathematically, this can be expressed as;

$$\left[\frac{\text{Construction Time Lost due to the impact of materials}}{\text{Construction Time}}\right] \times 100$$

Description:

C5 reflects the direct impact of the materials management process upon construction operations. The percentage of time lost due to materials is usually reported and collected using daily labour sheets, the equipment sheets. Feedback to the Field Control function is recommended on a weekly basis.

Measure Location:

Between Construction Operations and the Field Control function.

Name: Payment Discounts, Code: C6

Measure:

C6 reports the percentage of payment discounts correctly taken within the discount period. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{Payment discounts correctly taken within the discount period}}{\text{normal payments within the period}}\right] \times 100$$

Description:

No differentiation is made for the length of the discount period. In other words, a discount period remains a discount period whether it refers to electronic funds transfer (EFT) or letter of credit held by a financial institution. The measure indicates the missed discount opportunities and it may have specific application in an electronic environment where the billing and payment information is entered and transmitted electronically. The measure also reports work process improvements in terms of reducing the payment cycle.

Measure Location:

Within the Purchasing function.

Name: Warehouse Safety Incident, Code: C7

Measure:

C7 reports the incident rate associated with warehouse function. C7 can be expressed mathematically in effectiveness format as;

$$\left[\frac{\text{Number of warehouse lost-time incidents}}{\text{Total number of icidents for the project}}\right] \times 100$$

Description:

The measure reports the percentage of warehouse lost-time incidents compared to the total number of incidents for the project.

Measure Location:

Within the Warehouse function.

Name: Total Surplus, Code: C8

Measure:

C8 reports the percentage value of unused materials in relation to the total purchase cost of materials. Mathematically, this can be expressed as;

$$\left[\frac{\text{Value of unused materials}}{\text{Total Value of purchased materials (Total purchase cost of materials)}}\right] \times 100$$

Description:

The value of unused materials is determined before being coded for return (restocking) or disposition by third parties or facility operations and maintenance.

Measure Location:

Within the Warehouse and Field Control functions.

6- MEASURES COMMUNICATED AVAILABILITY ATTRIBUTE:

Name: Material Availability, Code: AV1

Measure:

AV1 is calculated through dividing the total number of material line items issued by the total number of material line items requested. This mathematically means;

$$\left[\frac{\text{Total number of material line items issued}}{\text{Total number of material line items requested}}\right] \times 100$$

Description:

AV1 represents the ability of the materials management process to issue or deliver properly scheduled and communicated material requirements to construction operations prior to what is commonly recognized as the activity early start date (ESD) or the field need date (FND). This measure is commonly associated with those materials and equipment items with need dates that have been established and updated on a regular basis.

Measure Location:

At the interface of the Warehouse function with Construction Operation

Name: Stock-out Analysis, Code: AV2

Measure:

AV2 is the ratio of the total number of line items that a warehouse is unable to issue to the craft-workers divided by the total number of line items requested. This can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\text{Total number of material line items that a warehouse is unable to issue}}{\text{Total number of material line items requested}}\right] \times 100$$

Description:

This measure reflects the shortage of the materials when required and it is commonly associated with bulk material items; it may be used as an aggregate measure for a number of stock-out situations. These causes may be identified as the stock-out situation occurs and used to calculate percentages for each subgroup. These sub groups support initial actions related to root cause analysis. The categories are:

Ahead of schedule: Construction operations have asked for the material items before the established request date,

MIN/MAX low: Vendor or warehouse procedures were unable to forecast or maintain an adequate quality of material items,

Inventory: Inventory problems resulted in a stock-out situation,

Not short: Warehouse personnel were unable to locate the requested material,

Take-off error: Materials management process was unable to respond to late engineering changes,

Field takeoff: Field take-off quantities were less than the design documents or field conditions indicate,

Already issued: Requested materials have previously been issued to construction operations, and

Other: Non-specified causes.

Measure Location:
Within the Warehouse function.

6- MEASURES COMMUNICATED FLEXIBILITY ATTRIBUTE:

Name: Delivery Flexibility, Code: F1

Measure:
Delivery flexibility can be expressed as the percentage of slack time by which the delivery time can be reduced. Delivery flexibility can also be measured as the proportion of excess slack across all jobs (j). F1 can be interpreted mathematically in effectiveness format as;

$$\left[\frac{\sum_{j=1}^{J}(\text{Latest time period during which the delivery can be made}) - (\text{Earliest time period during which the delivery can be made})}{(\text{Latest time period during whicrh the delivery can be made} - \text{Current time period})}\right] \times 100$$

J could be a material line item or a job in the system.
Latest time period during which the delivery can be made = the due date period

Description:
This is the ability to move planned delivery dates forward. This ability allows the supply chains and/or materials management to accommodate rush orders and special order. An example of high delivery flexibility is just in time, when suppliers deliver the products to the customer at the right quantity, place, and time. (Sanchez and Perez, 2005)

Measure Location:
The first measure location F1a is at the interface of the Vendor with the Warehouse Function, while the second location F1b is at the interface of Warehouse Function with Construction Operations

Name: Changes Flexibility, Code: F2

Measure:
F2 evaluates the ability of the construction materials management system to react to any changes without influencing the cost of field construction phase. The proposed measure can be calculated by dividing the average value of material items required for rework due to the unexpected changes to the planned value of original needed material items;

$$\left[\frac{(\text{Average value of material items required for rework to the unexpected changes})}{\text{Planned value of original needed material items}}\right] \times 100$$

This can be for a specified job or period of time.

Description:

Monitoring F2 may evaluate the ability of the design and materials management processes to react to design changes without impacting construction operations. The root cause of these changes could be;

- Design and fabrication accuracy,
- Owner/contractor changes (i.e. modifications),
- Shipping constraints, or schedule acceleration,
- Untimely deliveries/ schedule acceleration,
- Materials not in right place when needed/ shipping constraint,
- Materials or equipment not tailored to project request.

It can be evident that there is a similarity with the measure of Quality attribute Q1 'Field Activity Rework'. In the case of owner or contractor changes, evaluating F2 provides feedback on the impact of earlier decisions.

Measure Location:

At the interface of construction with the Field Control function

Name: Volume Flexibility, Code: F3

Measure:

The volume flexibility measure, F3, measures the proportion of demand that can be met by the materials management system. This proposed measure depends on dividing the average of demand volume that can be met by the materials management system to the total planned demand volume or the required demand volume;

$$\left[\frac{\text{(The average of Demand volume that can be met by the materials management system)}}{\text{Total Planned Demand volume/ or The Required Demand volume)}}\right] \times 100$$

Demand volume could be units (number of units)

Description:

Volume flexibility is likely to be an important response to uncertainty in highly cyclical industries, (Sanchez and Perez, 2005). Volume flexibility is the ability to adjust capacity to meet changes in customer quantities (Duclos, Vokurka and Lummus, 2003). For manufacturing systems, the development of volume flexibility measures has generally considered the costs associated with volume changes.

Measure Location:

The first measure location F3a is at the interface of the Purchasing Function with Vendor. The second location F3b is at the interface of Warehouse Function with Construction Operations.