SimLean: a reference framework for embedding simulation in lean projects

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SimLean: A Reference Framework for Embedding Simulation in Lean Projects

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A thesis submitted in partial fulfilment of the requirements of

Sheffield Hallam University

for the degree of Doctor of Philosophy

September 2010

ABSTRACT

The intense global competition in today's market is forcing organisations to looking for good process improvement techniques constantly. Currently lean methodology is one of the most popular programs for process improvement. However, the static lean tools have caused problems in lean implementation.

The main aim of the research work is to develop a reference framework about embedding simulation in lean projects. By embedding simulation method in lean projects, deficiencies of static lean tools such as their inability to assess the effects of variation, to validate effects of proposed changes before implementation, to identify other possible improvements or to capture the interactions between system components (Standridge and Marvel, 2006) might be overcome.

A combination of research methodology approaches is adopted. This includes conducting literature review, observing companies' practices and interviewing experts, and adopting several case studies.

The focal points of the reference framework are designed in the pre-implementation stage of lean projects. Referring to the detailed implementation of the framework, a new modelling environment is proposed. This new environment will use customised VSM templates built in Microsoft Visio software and in Arena simulation system respectively to achieve the quick modelling for lean projects. The proposed modelling environment is validated through five case studies.

The main features of the proposed framework are summarized as systematic, generic and the ability to overcome major challenges. A major contribution of the developed system is its ability to simplify, facilitate and standardize simulation modelling in lean projects. It dramatically reduces building blocks in the model, saves model constructing time and eliminates errors in logic design; the simulation models provides better results than static VSM; meanwhile, the interface between Arena and Visio greatly reduces users' fear for complex simulation modelling environment, and increases the ease of use.

ABREVIATIONS

5S	Sort, Set in order, Shine, Standardize and Sustain
ANOVA	Analysis of Variance
C/O Time	Changeover Time
DES	Discrete Event Simulation
DMAIC	Design-Measure-Analyze-Improve-Control
DOE	Design of Experiments
FIFO	First in First Out
FMEA	Failure Modes and Effects Analysis
JIT	Just In Time
NVA	Non Value Added
PDCA	Plan-Do-Check-Act
PCE	Process Cycle Efficiency
PLT	Production Lead Time
PM	Preventative Maintenance
PnP	Plug and Play
QFD	Quality Function Deployment

SMED	Single Minute Exchange of Dies
SPC	Statistical Process Control and Control Charts
SS	Six Sigma
TPM	Total Productive Maintenance
TPS	Toyota Production System
WIP	Work In Progress
VA/T	Value-Added Time
VOC	Voice of Customer
VSM	Value Stream Mapping

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1 INTRODUCTION

1.1 BACKGROUND

To survive in an ever increasing global and competitive marketplace, organisations are forging strategic alliances to gain a competitive advantage over their rivals. Consequently, it is now recognised that process improvement techniques are very important. Currently, one of the most popular management programs is lean management. Lean methodology originated at Toyota in Japan and has been implemented by many major firms world wide. Lean aims to continuously minimize waste (non-value-added activities) to maximize flow. The driving force behind the development of lean management was the elimination of waste, especially in Japan, a country with few natural resources (Arnheiter and Maleyeff, 2005).

Lean is a necessary but not a sufficient approach to analyzing production system issues (Standridge and Marvel, 2006). Deficiencies in lean methodology have caused problems in implementation of process improvement. Some of these deficiencies are described as following (Standridge and Marvel, 2006):

(1) Variation such as customer demand, machine breakdowns and different production schedules must be addressed in operating systems. While lean methods acknowledge the need for inventory due to variation, no methods are provided for computing how much is needed.

(2) A more thorough analysis of data is required. Since lean procedure only computes average value of quantities, the results might be inaccurate or even misleading.

(3) Component interaction is not considered in lean approach.

(4) No validating methods are included in lean methodology, and without validation approach, the results obtained from static models are doubtful.

(5) What's more, no tools are included in lean method to identify the best solution among several future state alternatives.

To sum up, since lean is a deterministic method and it uses only descriptive value stream maps to model production operations (Standridge and Marvel, 2006), it has limited the development of manufacturing operations, and caused bottlenecks in further improvement.

1.2 MOTIVATION

The highlighted market competitiveness that challenging deficiencies or limitations of lean methodology; has been the major motivating factor for this research. This research is also valuable for further promoting applications of lean.

In order to compensate for the shortcomings of lean methodology, experts in industry as well as academia scholars are looking for solutions. One possible way is to embed simulation in lean projects.

Computer simulation is a technique that imitates the operation of a real-world system as it evolves over time. Process simulation, often used to model production and business processes in both the manufacturing and service sectors, is referred to as discrete event simulation (DES) (El-Haik and Al-Aomar, 2006). This thesis only deals with discrete, dynamic and stochastic simulation models. Such models have collectively been termed as discrete event dynamic models (DEDM) or discrete event simulation (DES) in the literature.

Simulation modelling as an industrial engineering tool for system design and improvement has undergone tremendous development in the past decade. This can be pictured through the growing capabilities of simulation software tools and the application of simulation solutions to a variety of real-world problems in different business arenas (El-Haik and Al-Aomar, 2006). Ferrin, Miller and Muthler (2005) explained that "simulation is complimentary with Lean methodology. Simulation is a well designed capability that brings the statistically robust solution and associated confidence to meet the customers' expectations that a process will deliver at Lean Sigma quality levels." Crosslin (1995) stated that "virtually all of the Fortune 50, a majority of the Fortune 1000 and military planning units of all technologically advanced countries, use simulation rather than subjective notions to make decisions about key manufacturing and logistics process decisions. There are no good reasons why simulation should not be used to aid decisions about key business processes. On the contrary, there are numerous good reasons why simulation should be used for BPR." “Simulation can be considered a worthwhile tool whenever we consider changes where experience tells us that the outcome is in doubt or, that there would be a considerable expense due to failure. Simulation can help you mitigate your risk potential.” (http://leanandagile-mhc.com/Simulate.htm). A number of case studies also show the great success of their combination (Bayle, et al. 2001) (Abbas, et al. 2006) (Adams, et al. 1999) (Wang, et al. 2005) (Bodner and Rouse, 2007) (Huang and Liu, 2005) (Lian and Van, 2007).

However, all the case studies available just make use of simulation in one or several stages of the individual steps of lean methodology, while does not explain systematically how simulation can be embedded into the lean projects, or illustrate how to build a holistic framework or structure to embed simulation into lean projects. The lack of integrity of the reference framework will in turn greatly influent simulation application in lean projects. McClellan (2004) stated that making an accurate simulation model is very difficult because of the tremendous amount of factors in a normal manufacturing system.

While the use of modelling and simulation in manufacturing is steadily gaining acceptance for certain applications (such as capacity planning), there is still a long way to go before it is commonly applied for a multitude of other applications (Rose 2004). Currently, the combination of simulation and lean has not yet been widely adopted by industry, fear of their complexity and effectiveness. Enterprises do not know how much revenue it will cost and what benefits can be brought by their integrity; such uncertainty has increased concerns of the enterprises to adopt lean and simulation.

1.3 RESEARCH AIM AND OBJECTIVES

Research aim is to develop a reference framework which enables embedding of simulation in lean projects.

Research objectives are listed below:

1. Conduct Literature Survey;

2. Develop an integrated framework to capture the interaction between lean and simulation;

3. Establish role of simulation within the above framework;

4. Develop the reference framework to embed simulation;

5. Validate the reference framework.

A software toolkit is proposed, which integrates simulation and lean, and accomplishes being a very comprehensive optimization framework about embedding simulation into Lean projects.

1.4 THESIS STRUCTURE

This research thesis is composed of seven chapters. Chapter one describes research background, motivation, aim and objectives and thesis structure.

Chapter two provides literature review and critical assessment of related work in lean manufacturing and DES (discrete event simulation) methodology, and summarizes the research gap.

Chapter three describes the research methodology adopted for the research study.

Chapter four presents the overall framework of embedding simulation in lean projects. The proposed SimLean framework contains seven stages, which cover the whole project cycle from "qualify need for simulation" to "post implementation".

Chapter five explains the development of a customised simulation environment, which has simplified, facilitated and standardized model building process for lean projects.

Chapter six presents the evaluation process of the proposed system. Through five case studies discussed in Chapter six, the customised simulation environment is validated and its limitations are pointed out.

Chapter seven contains discussions and conclusions of the overall research work. It also highlights the limitations of the research work and recommended future work.

2 LITERATURE REVIEW

In previous chapter the research aim and objectives have been explained. In this chapter, the literature review has been presented and the literary contributions towards lean manufacturing and simulation integration have been provided. The main aim of this chapter is to examine the academic literature review on the subject of lean manufacturing, DES (discrete event simulation) and their combination, in order to discover the research gaps and collect information for research design.

In order to achieve the above aim, this chapter has been structured as follows: Section 2.1 introduces the history and principles of lean manufacturing; Section 2.2 outlines the available tools used in lean manufacturing; VSM (value stream mapping) is described in Section 2.3 because of its unique capability to visualise a whole and complex manufacturing system and represent the materials and information flow within a facility (Rother and Shook, 1999) and (Tapping, et al. 2002); Shortcomings of lean manufacturing tools are stated in Section 2.4; In Section 2.5, simulation applications in lean projects are described; Section 2.6 presents and discusses the critical assessment of the overall literature review; At last, Section 2.7 provides conclusion to the literature review exercise.

2.1 LEAN METHODOLOGY

In the last ten years or so, a new term "lean" has entered our vocabulary. Executives and decision makers, especially in senior management, quality, operations, engineering, and human resources have been hearing of lean in a context other than dieting (Alukal and Manos, 2006).

Lean is a manufacturing or management philosophy that shortens the lead time between a customer order and the shipment of the parts or services ordered through the elimination of all forms of waste. Lean helps firms in the reduction of costs, cycle times, and non-value-added activities, thus resulting in a more competitive, agile, and market-responsive company (Alukal and Manos, 2006).

There are many definitions of lean. For instance, here is one that is used by the Manufacturing Extension Partnership of National Institute of standards and Technology, a part of the U.S. Department of Commerce: "A systematic approach in identifying and eliminating waste (non-value-added activities) through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection." Lean focuses on value-added expenditure of resources from the customers' viewpoint. Another way of putting it would be to give the customers: what they want; when they want it; where they want it; at a competitive price; in the quantities and varieties they want, but always of expected quality (Alukal and Manos, 2006).

A planned, systematic implementation of lean leads to improved quality, better cash flow, increased sales, greater productivity and throughput, improved morale, and higher profits. Once started, lean is a never-ending journey of ever-improving processes, services, and products. Many of the concepts in total quality management and team-based continuous improvement are also common to the implementation of lean strategies (Alukal and Manos, 2006).

2.1.1 BRIEF HISTORY OF LEAN

The concept of lean management can be traced to the Toyota production system (TPS), a manufacturing philosophy pioneered by the Japanese engineers Taiichi Ohno and Shigeo Shingo (Inman, 1999). However, most of the lean concepts are not new. Many of them were being practiced at Ford Motor Company during the 1920s or are familiar to most industrial engineers (Alukal and Manos, 2006). Ohno greatly admired and studied Ford because of his accomplishments and overall reduction of waste at early Ford assembly plants (Hopp and Spearman, 2001). The TPS is also credited with being the birthplace of just-in-time (JIT) production method, a key element of lean production, and for this reason the TPS remains a model of excellence for advocates of lean management (Arnheiter and Maleyeff, 2005).

A few years after World War II, Eiji Toyoda of Japan's Toyota Motor Company visited the American car manufacturers to learn from them and to transplant U.S. automobile production practices to the Toyota plants. With the eventual assistance of Taiichi Ohno and Shigeo Shingo, the Toyota Motor Company introduced and continuously refined a system of manufacturing whose goal was the reduction or elimination of non-value-added tasks (activities for which the customer was not willing to pay). The concepts and techniques that go into this system are now known as Toyota Production System (TPS), and were recently reintroduced and popularized by James Womack's group in the United States under the umbrella of lean manufacturing (Alukal and Manos, 2006).

Lean concepts are applicable beyond the shop floor. Companies have realized great benefit by implementing lean techniques in the office functions of manufacturing firms, as well as in purely service firms such as banks, hospitals, and restaurants. Lean manufacturing in this context is known as lean enterprise (Alukal and Manos, 2006).

2.1.2 BASIC PRINCIPLES OF LEAN

Among the several quality management concepts that have been developed, the lean concept, as in lean manufacturing, lean production, et al. is one of the most wide-spread and successful attempts. Briefly, lean is about controlling the resources in accordance with the customers' needs and to reduce unnecessary waste, including the waste of time (Andersson, et al. 2006).

Lean principles are fundamentally customer value driven, which makes them appropriate for many manufacturing and distribution situations. Five basic principles of lean manufacturing are generally acknowledged (Womack and Jones, 1996) (Curry and McIvor, 2001):

1. Understanding customer value. Only what the customers perceive as value is important.

2. Value stream analysis. Having understood the value for the customers, the next step is to analyse the business processes to determine which ones actually add value. If an action does not add value, it should be modified or eliminated from the process.

3. Flow. Focus on organising a continuous flow through the production or supply chain rather than moving commodities in large batches.

4. Pull. Demand chain management prevents from producing commodities to stock, i.e. customer demand pulls finished products through the system. No work is carried out unless the result of it is required downstream.

5. Perfection. The elimination of non-value-adding elements (waste) is a process of continuous improvement. There is no end to reduce time, cost, space, mistakes, and effort.

Lean is especially important today as a winning strategy. Some key reasons are listed below (Alukal and Manos, 2006):

1) To compete effectively in today's global economy

2) Customer pressure for price reductions

3) Fast-paced technological changes

4) Continued focus by the marketplace on quality, cost, and on-time delivery

5) Quality standards such as TS 16949:2002 and ISO 9001:2000

6) Original equipment manufacturers (OEM) holding on to their core competencies and outsourcing the rest

7) Higher and higher expectations from customers

8) The need for standardized processes so as to consistently get expected results

To compete successfully in today's economy we need to be at least as good as any of our global competitors, if not better. This goes not only for quality, but also for costs and cycle times (lead time, processing time, delivery time, setup time, response time, and so on). Lean emphasizes teamwork, continuous training and learning, production to demand (pull), mass customization and batch-size reduction, cellular flow, quick changeover, total productive maintenance, and so on. Not surprisingly, lean implementation utilizes continuous improvement approaches that are both incremental and breakthrough (Alukal and Manos, 2006).

2.1.3 THE EIGHT WASTES OF LEAN

Waste of resources has direct impact on our costs, quality, and delivery. Conversely, the elimination of wastes results in higher customer satisfaction, profitability, throughput, and efficiency. Excess inventory, unnecessary movement, untapped human potential, unplanned downtime, and suboptimal changeover time are all symptoms of waste (Alukal and Manos, 2006).

Taiichi Ohno, a former executive at Toyota, identified seven categories of waste. Many in the Lean community consider there to be an eighth category -- Underutilized People -- that can have significant importance to the development process. The eight categories of waste are explained as follows (Locher, 2008):

1) Overproduction. In overproduction, organizations product more information or provide greater service than is needed, sooner than is needed either by the next process step or by the end user or customer. The impetus behind overproduction is the impulse to "stay ahead." Although this reasoning is commendable, it creates other problems and other wastes. For example, information is more subject to changes and can even become out-of-date if it is processed too early.

2) Excess Inventory. Excess inventory is more than the absolute minimum required to maintain uninterrupted flow of information or service. People will often "batch" development activities. Most often they do so because they believe that it is more efficient. Sometimes there are real reasons to batch development activities, such as system limitation. The root causes for all

such practices need to be addressed in order to allow for more flexible processing.

3) Defective product or service. This type of waste refers to the discovery and correction of information or a service that has been processed incorrectly or is missing altogether. The correction and clarification of information as it flows through a company can require tremendous effort and cost. To counter this unnecessary expenditure of resources and effort, organizations must address the root causes for the lack of complete and accurate information. Information or service "defects" simply cannot be allowed to continue and become the norm in any company.

4) Over processing (or Non-Value-Added - NVA). NVA occurs when teams expend extra effort beyond what is actually needed by the customer. Extra steps or entire processes within the development process fall into this category, including many of the administrative activities performed in support of the development process. While it may not be possible to eliminate them all, at the very least, the amount of time and effort to perform them can be reduced.

5) Waiting. Information or services can wait for numerous reasons, thereby impeding flow. To reduce the likelihood of this type of waste, organizations must focus on the necessary information itself or on the customer, not on the people performing the work. People can generally keep busy at all times. However, if a customer has to wait beyond an acceptable time frame, customer satisfaction will decline. If, for whatever reason, information must wait, other problems will arise, such as declines in customer service or a rise in quality-related issues.

6) Excess Motion. Although organizations rarely consider this category when looking for ways to trim waste, excess motion by employees in the course of their work can, in fact, be a significant waste category. For example, if employees need to consistently travel to different parts of the building in order to reach necessary supplies, they are likely to be less efficient and less productive than they would be if the supplies were within easy reach.

7) Transportation. Transportation refers to the movement of information or a service, either manually or electronically. Although it requires little physical effort, even the electronic transportation of information can be considered wasteful. This issue with transportation waste is not solely the time required, but the other problems that arise with each transfer. For example, the potentia' for informatior to end up in another queue waiting to be processed increases with each transfer, as does the potential to lose information. Quality tends to decline with each transfer of information.

8) Underutilized People. In this instance, staff members are not using their full skills and abilities. People are often given very limited roles and responsibilities when, in reality, they can assume much more if the process has been designed effectively.

Although most people are now familiar with these waste terms, they may still have difficulty in recognizing them in the development process, and some have contended that the terms do not apply to the development process at all. Regardless of whether an organization develops a product, a process, or a service, these terms are, in fact, all applicable. Going Lean requires that people expand their exiting, sometimes narrow, definitions for these now-common terms (Locher, 2008).

To assist the Lean practitioner in developing "eye for waste," Table 2-1 provides selected examples for each waste category. It is important to note that the eight wastes are fundamentally interrelated and may overlap; in other words, the examples below may fit into more than one category (Alukal and Manos, 2006).

Table 2- 1 Development Waste Examples

Waste Types	Explanations
Overproduction	Completing design elements that are not needed for some time; Including features that the customer does not see as a value (could also be included in nonvalue-added or over processing waste); "Over-engineering".
Waiting	Approvals from superiors; A lack of available capacity; Input from customers; System response time; Completion of other design elements.
Transportation	E-mailing information. Multiple hand-offs; Report distribution; Circulating paperwork for signatures.
Nonvalue-Added Processing (or Over processing)	Re-entering data; Extra copies; Unnecessary or excessive reports or paperwork; Redesigning something that already has been designed (i.e., reinventing the wheel); Most engineering support services.
Excess Inventory	Filled in-boxes (electronic or paper); Batch processing transactions; "Large" design releases; Retaining documents beyond what is required.
Defects (or Correction)	Design errors; Service failures; Engineering change orders due to errors; Not clearly understanding customer needs;

Waste Types	Explanations
	Missing or incomplete information.
Excess Motion	Going to / from printer, fax machine, central filing, and meetings; Travel.
Underutilized People	Limited authority and responsibility for basic tasks; Management "command and control"; Not sufficiently sharing knowledge; Not involving suppliers early in the development process; Not involving manufacturing early in the development process.

2.1.4 LEAN IMPLEMENTATION ROADMAP

Knill (1999) states that five initiatives are necessary for a successful implementation of Lean Manufacturing:

1. Supplier programs;
2. Continuous improvement;
3. Flexibility;
4. Eliminate waste;
5. Zero defects.

LM (Lean Manufacturing) is the umbrella over these concepts, and while many companies often grasp a couple of these concepts, the full potential of a company cannot be reached without implementing all of these initiatives.

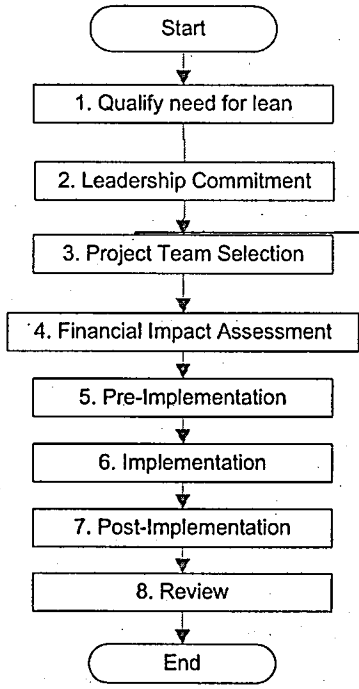


Figure 2- 1 Structure of Lean Manufacturing Implementation

Achanga (2007) proposed a framework for assessing the impacts of implementing lean manufacturing within small-to-medium sized manufacturing firms (SMEs). By assessing the impact of lean implementation, SMEs can make informed decisions on the viability of lean adoption at the conceptual implementation stage. Companies are also able to determine their status in terms of lean manufacturing affordability. Figure 2-1 shows the structure of lean implementation developed by Achanga (2007).

Firstly, qualify need for lean, which means to decide whether or not to use lean methods for the projects. A company can carry out investigations of its current manufacturing issues to identify the issues or problems that its business faces. If results of this phase are not conclusive, the project may be reassessed or abandoned completely.

Secondly, the leadership commitment is essential for the success of the projects. If the company is intending to apply lean for the first time, its requirements for lean consultancy and training may be huge. It needs full support from the leadership to start the project.

Then the project team and time scale need to be decided. If the company cannot find someone who knows the work in the company and understands lean concept at the same time, it may abandon the project completely, or revise it again.

Phase four is the financial impact assessment, which aims to calculate the possible outcomes of the lean project. The assessment result will be referenced by managers to make decisions. If managers are not satisfied with the possible financial gains, the company may abandon the project completely or revise it.

Next step is pre-implementation, where project team members measure the problems in current state as well as design the future state.

At implementation stage, changes should be made according to the plans made in pre-implementation step. Changes to the system are made according to the detailed design of future state.

After implementation process, the project team need to summarize their work, and write up reports and documentations at post-implementation stage.

2.2 LEAN MANUFACTURING TOOLS

The tools and techniques used to introduce, sustain, and improve the lean system are sometimes referred to as the lean building blocks. Many of these building blocks are interconnected and can be implemented in tandem. For example, 5S (workplace organization and standardization), visual controls, point-of-use storage (POUS), standard work, streamlined layout, working in teams, and autonomous maintenance (part of total productive maintenance) can all be constituents of lean tools. The building blocks are introduced as follows: (Alukal and Manos, 2006):

2.2.1 5S

A system for workplace organization and standardization. The five steps that go into this technique all start with the letter S in Japanese (seiri, seiton, seison, seiketsu, and shitsuke). These five terms are loosely translated as sort, set in order, shine, standardize, and sustain. Achanga (2007) stated that the 5S approach is not simply a system for house keeping; but a method for organising, standardising and improving the whole of a manufacturing process. The sole objective of the technique is to ensure total eradication of unwanted items within the working environment of an organisation.

2.2.2 VISUAL CONTROLS

The placement in plain view of all needed information, tools, parts, production activities, and indicators so that everyone involved can understand the status of the system at a glance.

The intent of a visual factory is that the whole workplace is set-up with signs, labels, colour-coded markings, etc. so that anyone unfamiliar with the process can, in a couple of minutes, know what is going on, understand the process, and know what is being done correctly and what is out of place.

A visual factory is made up of visual displays and visual controls. Visual displays and controls help keep things running as efficiently as they were designed to run. Sharing information through visual tools helps keep production running smoothly and safely. Shop floor teams are often involved in devising and implementing these tools through 5S and other improvement activities.

Visual controls describe workplace safety, production throughput, material flow, quality metrics, or other information. Visual controls supply the feedback to an area, much the same way that SPC (statistical process control) can give process feedback to the operator running a particular operation.

A visual display relates information and data to employees in the area. For example, charts show the monthly revenues of the company or a graphic depicting a certain type of quality issue that group members should be aware of.

The efficient design of the production process that results from lean manufacturing application carries with it a set of assumptions. The process will operate as it was designed as long as the assumptions hold true. A factory with expansive visual controls and displays will allow employees to immediately know when one of the assumptions has not held true.

Audio signals in the factory are also very important because they signal malfunctioning equipment, sound warnings before the start of machine operation, or other useful information.

A visual factory allows the people operating the process to stay on target. (http://www.dwassoc.com/visual-controls.php)

2.2.3 STREAMLINED LAYOUT

A layout designed according to optimum operational sequence.

2.2.4 STANDARD WORK

Consistent performance of a task, according to prescribed methods, without waste and focused on human movement (ergonomics).

2.2.5 BATCH-SIZE REDUCTION

The best batch size is one-piece flow, or “makes one and move one”. If one-piece flow is not appropriate, reduce the batch to the smallest size possible.

2.2.6 TEAMS

In the lean environment, the emphasis is on working in teams, whether it is process improvement teams or daily work teams.

2.2.7 QUALITY AT THE SOURCE

This is inspection and process controlled by employees so they are certain that the product or information that is passed on to the next process is of acceptable quality.

2.2.8 POINT-OF-USE STORAGE

Raw materials, parts, information, tooling, work standards, supplies, procedures, and so on, are stored where needed.

2.2.9 QUICK CHANGEOVER

The ability to change tooling and fixtures rapidly (usually in minutes) to enable multiple products in smaller batches can be run on the same equipment.

2.2.10 PULL / KANBAN

A system of cascading production and delivery instructions from downstream to upstream activities in which the upstream supplier does not produce until the downstream customer signals a need (using a kanban system).

2.2.11 CELLULAR / FLOW

Physically linking and arranging manual and machine process steps into the most efficient combination to maximize value-added content while minimizing waste. The aim is single-piece flow.

2.2.12 TOTAL PRODUCTIVE MAINTENANCE (TPM)

A lean equipment maintenance strategy for maximizing overall equipment effectiveness. Achanga (2007) states that Total Productive Maintenance (TPM) is a brainchild of Preventive Maintenance (PM), and works identically to Total Quality Management (TQM). The idea behind TPM is that of having zero tolerance at breakdowns as well as defects. This production technique is very central to the lean manufacturing ethos since it has the attributes of making problems visible so that they are not buried but dealt with right away. TPM also calls for simplicity in the tasks people carry out as well, allowing the workforce enjoyment while carrying out work they are assigned to do. The essence of implementing the lean manufacturing technique of TPM is the provision of a cost effective operation and support of the available manufacturing system.

2.2.13 OTHER TOOLS

Besides these building blocks, there are other concepts or techniques that are equally important in lean: value stream mapping (VSM), just-in-time (JIT) methods, error-proofing (poka-yoke), autonomation (jidoka), change management, root cause analysis and problem solving, Kaizen (continuous improvement) and policy deployment (hoshin planning). Since lean is a never-ending journey, there is always room for continuous improvement.

2.3 VSM (VALUE STREAM MAPPING)

In "Lean Thinking (1996)", James Womack and Daniel Jones identified the three critical management tasks of any business:

1) Problem solving (e.g., product or service design)

2) Information management (e.g., order processing and other transactional activities)

3) Physical transformation (e.g., converting raw materials to finished product)

The authors define a value stream as the set of all specific actions required to bring a specific product or service throughout the critical management tasks. Clearly, there is a strong relationship among the three. For example, a product design that is difficult to build will negatively impact the "physical transformation" value stream. Also, poor information management from the market will negatively impact the "problem solving" value stream. Therefore, in manufacturing, all three tasks ultimately must be addressed.

The original Lean concept of "flow" dates back to around 1910 and is attributed primarily to Henry Ford. Toyota, however, is credited with taking Ford's original flow concepts to the next level, with diversified small lot production. While not specifically using the term “Lean”, Toyota has applied Lean concepts for more than fifty years to its production and product development systems and is widely recognized as the leader in the application of Lean thinking. In 1990, James Womack and Daniel Jones documented the success of the Toyota Production System (TPS) in "The Machine that Changed the World". Womack and Jones went on to demonstrate that it represented a fundamentally different way of thinking about processes, systems, and organizations as a whole when they published "Lean Thinking" in 1996 (Locher, 2008).

But, what is still missing from the literature is a "how-to" book. How can organizations get their arms around an often poorly defined existing development process and redesign it based on the concepts of Lean thinking? To start, they need a reference to guide them through a step-by-step methodology that they can apply, in a real-time, practical way, to their own development processes (Locher, 2008).

Why do we use value stream mapping as the methodology? Value stream mapping is a method of visualizing the flow of a service, a product, or information. It provides a system's view of the flow of work, involving multiple processes, that goes well beyond traditional process mapping techniques. Through the use of symbols or icons, it conveys a great deal of information in a succinct manner. Also it incorporates process and system-related data to further increase the power of the mapping methodology. As such, value stream mapping is the assessment and planning tool of Lean practitioners, and an enabling tool to apply Lean thinking (Locher, 2008).

2.3.1 ADVANTAGES OF VSM

The true power of value stream mapping lies not in visually depicting the current state of a process, but rather in the actions that are taken and the results achieved by doing so. In other words, the power of the process lies in developing achieved "future states" that provide breakthrough results to an organization (Locher, 2008). Rother and Shook (1999) states that value stream mapping (VSM) is an easy technique to visualise a whole and complex manufacturing system, identify wastes and their sources and guide improvement efforts. The core of VSM consists of the definition of an actual state map (ASP) being a graphical representation of both materials and information flow within a facility (Tapping et al. 2002). The capability to track an order throughout the facility and to measure how long it remains in one place is extremely useful, because it allows to uncover the roadblocks in product flow and to understand the `root causes` of waste. Therefore, VSM helps to streamline work process using lean concepts and to evaluate the improvements that are obtainable through lean manufacturing. These objectives are usually formalised in a future state map (FSM), which represents the ideal pull production system to be obtained (Braglia, et al. 2009).

With respect to other mapping techniques, VSM offers several advantages (Braglia, et al. 2009):

1). It shows the linkage between product flow and information flow;

2). It includes information related to production time as well as to inventory levels;

3). It helps to visualise the production process at the plant level, not just at the single process level;

4). It relates the manufacturing process internal to the facility to the whole supply chain;

5). It links products planning and demand forecast both to production scheduling and to flow shop control, using operating parameters such as Takt Time, which determines the production rate at which each processing stage in the manufacturing system should operate;

6). It makes decisions about the flow evident, enabling people to discuss them;

7). It gives managers and employees the same tool and a common language to communicate;

8). It constitutes the basis of a well-structured implementation plan.

2.3.2 PROCESS MAP FOR VSM (Locher, 2008)

As with all tools, there is a recommended process for using value stream mapping (Figure 2-2). The first step in the process -- the "preparation" step -- is critical to conducting an effective value stream mapping event, and to the successful implementation of the envisioned "future state"; the preparation step occurs before the mapping event itself. During the preparation step, the team tasked with the objective of improving the development process is assembled.

Next, this team develops the "current state" -- a visual, agreed upon depiction of how things work today. The team then develops the future state -- their shared vision of a new, lean development process. Finally, there is the "planning and implementation" step.

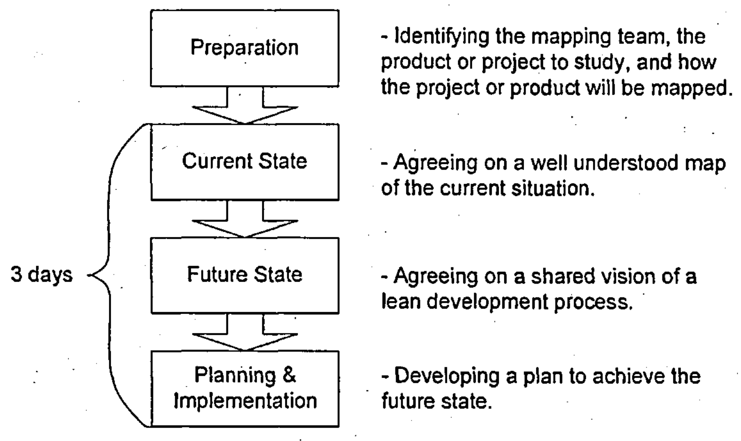


Figure 2- 2 Process Map for VSM

The ultimate goal to value stream mapping is to achieve the future state and to realize the expected benefits. The typical duration of the mapping event is three days, including the development of the current state, the future state, and a detailed implementation plan. Obviously, implementation will occur after the event, over a one - to twelve-month period of time (Locher, 2008).

2.4 SHORTCOMINGS OF LEAN MANUFACTURING TOOLS

Value Stream Mapping (VSM) has become an integrated and essential technique in lean projects; it combines material processing steps with information flow as well as other important related data (Tony Manos, 2006). However, being a static method, VSM has many limitations such as its inability to assess the effects of variation, to validate effects of proposed changes before implementation, to identify other possible improvements or to capture the interactions between system components (Standridge and Marvel, 2006). Braglia, et al. (2009) summarizes the main drawbacks of VSM as follows:

1. It is a paper- and pencil-based technique, thus the accuracy level is limited and the number of versions that can be handled is low;

2. It lacks the spatial structure of the facility layout and how that impacts interoperation material handling delays;

3. It fails to show the impact of inefficient material flows on work in process (WIP), order throughput and operating expenses;

4. It cannot address the complexity of high-variety low-volume type companies, whose value streams are composed of hundreds of industrial parts and products;

5. It can be effectively applied only to linear product systems, as it fails to map value streams characterised by multiple flows merging together;

6. It lacks the capability for a rapid development and evaluation of multiple what-if analyses that are required to prioritise different alternatives;

7. It cannot be applied to engineering processes due to fundamental differences between manufacturing and engineering methods;

8. It is unable to give a real vision of the variability problems concerning the production process analysed.

From literature review we find out that by embedding simulation in VSM, it may be possible to overcome some of these limitations. However, so far there has been no uniform way of modelling VSM. In order to fill in the research gap, a reference framework about embedding simulation in lean projects (especially in VSM tool) is proposed in this thesis.

2.5 SIMULATION APPLICATION IN LEAN PROJECTS

2.5.1 SIMULATION CLACIFICATIONS

Computer simulation models can be classified in several ways (Rubinstein, 1998), (Law and Kelton, 1991), (Banks, et al. 2001) and (Zeigler, et al. 2000):

1. Static versus Dynamic Models: Static models are those that do not evolve over time. In contrast, dynamic models represent the behaviour of systems over time.

2. Deterministic versus Stochastic Models: Models that incorporate at least a single random variable in the representation of the model are termed stochastic models, while models that incorporate non random (deterministic) variables exclusively in their representation are termed deterministic models.

3. Continuous versus Discrete Models: Models can also be classified in the way the notion of time is handled. In continuous models the state of the model changes continuously with respect to time. Continuous models generally employ a system of differential or difference equations to express a model of a particular system. Examples of continuous models include models of air flow on aircraft wings, models of chemical reactions and system dynamics models, etc. Simulations of these models are performed by solving the differential equations either on an analogue computer or digital computer. On the other hand, discrete models update their state instantaneously at a finite number of discrete points in time. The manner in which the state is transformed is expressed using a logical

state transition function as opposed to mathematical equations. Simulation is performed by employing discrete event simulation software on a digital computer. Discrete event models are usually used in the modelling of queuing network systems such as manufacturing systems, etc.

This thesis deals only with discrete, dynamic and stochastic simulation models. Such models have collectively been termed as discrete event dynamic models (DEDM) or discrete event simulation (DES) in the literature.

2.5.2 DES (DISCRETE EVENT SIMULATION) MODELLING

Banks (1998) stated that process simulation, often used to model production and business processes in both the manufacturing and service sectors, is referred to as discrete event simulation (DES). Discrete event systems are dynamic systems that evolve in time by the occurrence of events at possibly irregular time intervals, since this resembles the nature of the majority of real-world applications. Examples include traffic systems, manufacturing systems, computer communication systems, call centres, bank operations, hospitals, restaurants, production lines, and flow networks. Most of these systems can be modelled in terms of discrete events whose occurrence causes the system to change from one state to another in a stochastic manner.

Law and Kelton (1991) stated that by utilizing computer capabilities in logical programming, random generation, fast computations, and animation, DES modelling is capable of capturing the characteristics of a real-world process and estimating system performance measures at different settings of its design parameters. System modelling with DES includes mimicking the structure, layout, data, logic, and statistics of the real-world system and representing them in a DES model. Figure 2-3 shows the elements of system modelling with DES. Abstracting the real-world system in a DES model can be approached by precise understanding and specification of the details of the five system modelling elements shown in Figure 2-3.

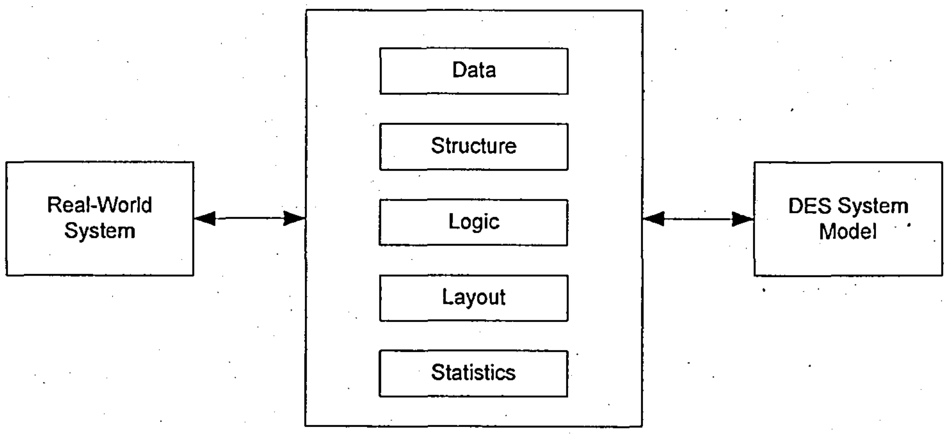


Figure 2- 3 Elements of System Modelling with DES

1). System Data: Real-world systems often involve a tremendous amount of data while functioning. Data collection system (manual or automatic) are often used to collect critical data for various purposes, such as monitoring of operations, process control, and generating management reports. DES models are data-driven; hence, pertinent system data should be collected and used in the model. Model performance and results are highly dependent on the quality and accuracy of such data, based on the commonly used term garbage-in-garbage-out. Table 2-2 presents the data that need to be collected for modelling various simulation elements.

Table 2- 2 Data Collected for Various DES Elements

Element Modelled	Pertinent Simulation Data
Machine	(Load, cycle, unload) time, MTBF, MTTR
Conveyor	Speed, capacity, type, accumulation
Operator	Walk speed, work sequence, walk path

Element Modelled	Pertinent Simulation Data
Buffer	Capacity, discipline, input / output rules
Automated guided vehicle	Speed, acceleration / deceleration, route
Power-and-free system	Speed, dog spacing, chain length
Part / load	Attributes of size, colour, flow, mix

2). System Structure: A system DES model is expected to include the structure of the actual system being simulated. This structure is basically the set of system elements in terms of physical components, pieces of equipment, resources, materials, flow lines, and infrastructure. Elements of a manufacturing system are different from the elements of a business system. Whereas manufacturing systems are modelled using machines, labour, work pieces, conveyors, and so on, business systems are modelled using human staff, customers, information flow, service operations, and transactions. Modelling such elements thoroughly is what makes a model realistic and representative. However, the level of details and specifications of model structural elements depends primarily on the objective and purpose for building the model. Table 2-3 shows examples of structural elements for a plant or a manufacturing system.

Table 2- 3 Examples of Structural Elements in DES

Structural Element Modelled	Model Performance Factor Affected
Conveyor length	Conveyor Capacity
Unit load dimensions	Number of units stacked
Buffer size	Buffer capacity
Length of aisles and walkways	Walking distance and time
Size of automated guided vehicle AGV	Number of AGV carriers
Length of monorail	Carrier travelling time
Dog spacing of power and free system	Power and free throughput
Dimensions of storage units	Storage and retrieval time

3). System Logic: System logic comprises the rules and procedures that govern the behaviour and interaction of various elements in a simulation model. It defined the relationships among model elements and how entities flow within a system. The programming capability of simulation languages is often utilized to implement the system logic designed into the DES model developed. Similarly, real-world systems often involve a set of simple or complex logical designs that control system performance and direct its behaviour. Abstracting relevant logic into a DES model is a critical modelling task. In a typical simulation model, it is often the case that several decision points exist within the model operations, such as splitting and merging points. At these decision points, certain scheduling rules, routing schemes, and operational sequences may need to be built into the DES model to reflect the actual performance of the underlying system. Table 2-4 provides examples of such logical designs.

Table 2- 4 Examples of Model Logical Designs

Model Activity	Logical Design
Parts arriving at loading dock	Sorting and inspection scheme
Requesting components	Model mix rules
Producing an order	Machine scheduling rules
Material handling	Carrier routing rules
Statistical process control	Decision rules
Machining a part	Sequence of operation
Forklift floor operation	Drivers' dispatching rules
Storage and retrieval system (AS / RS)	AS / RS vehicle movement rules

4). System Layout: A system layout is simply the configuration plan for a system's structural elements. The layout specifies where to locate pieces of equipments, aisles, repair units, material-handling systems, storage units, loading and unloading docks, and so on. Similar to system structure, placing and sizing model elements according to the layout specified results in a more representative DES model. Sticking to layout specifications helps capture the flow path of material or entities within the system. When designing new systems or expanding existing ones, the layout often plays an important role in assessing design alternatives. Facility planning is the topic under which the layout of a plant or a facility is designed. Department areas and activity-relationship charts are often used to provide a design for a facility layout. Locations of departments, distances between them, and interdepartmental flow need to be captured in the DES model to provide accurate system representation.

5). System Statistics: System statistics are means of collecting run-time information and data from a system during run time and aggregating them at the end of simulation run time. During run time, such statistics are necessary to control the operation and flow of system activities and elements. At simulation end, these statistics are collected to summarize system performance at various system design and parameter settings. In a system DES model, therefore, statistics are collected and accumulated to provide a summary of results at the end of run time. Such statistics are used to model real-time monitoring gauges and clocks in a real-world system. Because of model flexibility, however, some statistics that are used in the model may not actually be in the real-world system. This is because statistics do not affect model performance. Therefore, we can define statistics that are necessary to system operation and other statistics that may provide useful information during run time and summarize the results at the end of run time. Table 2-5 provides examples of model statistics.

Table 2- 5 Examples of Model Statistics

Model Statistic	Value Measured
Jobs produced per hour	System throughput
Percent of machine busy time	Machine utilization
Number of units in system	Work-in-progress level
Time units spend in system	Manufacturing lead time
Number of defectives	Process quality
Number of machine failures	Maintenance plan
Number of units on a conveyor	Conveyor utilization
Number of units on a buffer	Buffer utilization

2.5.3 STEPS IN A SIMULATION STUDY

Law and Kelton (1991), Banks (1998) Banks, et al. (2001) and El-Haik and Al-Aomar (2006) summarized procedure for conducting simulation studies. Figure 2-4 shows the flowchart of the step-by-step simulation procedure.

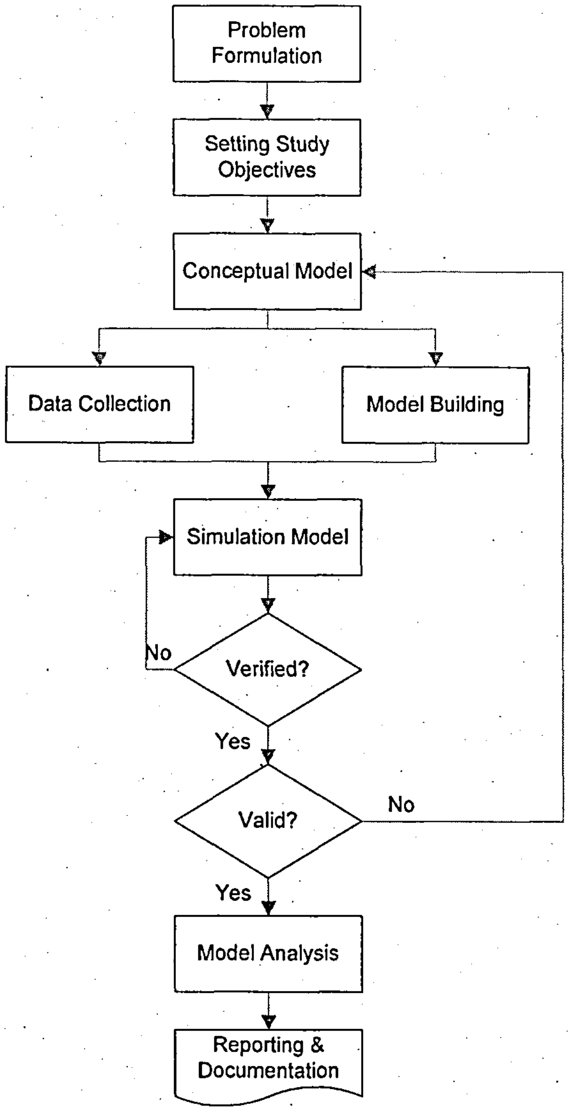


Figure 2- 4 The Simulation Procedure

1). Problem Formulation: The simulation study should start with a concise definition and statement of the underlying problem. The problem statement includes a description of the situation or the system of the study and the problem that needs to be solved. Formulating a design problem includes stating the overall design objective and the constraints on the design process. Similarly, formulating a problem in an existing system includes stating the overall problem-solving objective and the constraints on the solution proposed.

2). Setting Study Objectives: Based on the problem formulation, a set of objectives can be set to the simulation study. Such objectives represent the criteria through which the overall goal of the study is achieved. Study objectives simply indicate questions that should be answered by the simulation study. Examples include determining current-state performance, testing design alternatives, studying the impact of speeding up the mainline conveyor, and optimizing the number of carriers in a material-handling system.

3). Conceptual Modelling: Developing a conceptual model is the process through which the modeller abstracts the structure, functionality, and essential features of a real-world system into a structural and logical representation that is transferable into a simulation model. The model concept can be a simple or a complex graphical representation, such as a block diagram, a flowchart, or a process map that depicts key characteristics of the simulated system, such as inputs, elements, parameters, logic, flow, and outputs. Such a representation should eventually be programmable and transferable into a simulation model using available simulation software tools.

4). Data Collection: Simulation models are data-driven computer programs that receive input data, execute the logic designed, and produce certain outputs. Hence, the data collection step is a key component of any simulation study. Simulation data can, however, be collected in parallel to building a model using the simulation software. This is recommended since data collection may be time consuming in some cases, and building the model structure and designing model logic can be independent of the model data. Default parameters and generic data can be used initially until the system data are collected.

5). Model Building: Data collection and model building often consume the majority of the time required for completion of a simulation project. To reduce such time, the modeller should start building the simulation model while data are being collected. The conceptual model can be used to construct the computer model using assumed data until the data collected become available. The overlap between model building and data collection does not affect the logical sequence of the simulation procedure.

6). Model Verification: Model verification is the quality control check that is applied to the simulation model built. Like any other computer program, the simulation model should perform based on the intended logical design used in building the model. To verify a model, we simply check whether the model is doing what it is supposed to do. Other verification techniques include applying rules of common sense, watching the model animation periodically during run time, examining model outputs, and asking another modeller to review the model and check its behaviour.

7). Model Validation: Model validation is the process of checking the accuracy of the model representation to the real-world system that has been simulated. It is simply about answering the following questions: Does the model behave similarly to the simulated system? Since the model will be used to replace the actual system in experimental design and performance analysis, can we rely on its representation of the actual system? Several techniques are usually followed by modellers to check the validity of the model before using it for such purposes. Examples include checking the data used in the model and comparing them to the actual system data, validating the model logic in terms of flow, sequence, routing, decisions, scheduling, and so on, with regards to the real-world system, and matching the results of the model statistics to those of actual system performance measures.

8). Model Analysis: Having a verified and validated simulation model provides analysts with a great opportunity since it provides a flexible platform on which to run experiments and to apply various types of engineering analyses effectively. Model analysis often includes statistical analysis, experimental design, and optimization search. The objective of such methods is to analyze the performance of the simulation model, compare the performance of proposed design alternatives, and provide the model structure and parameter setting that will lead to the best level of performance.

9). Study Documentation: The final step in a simulation study is to document the study and report its results. Proper documentation is crucial to the success of a simulation study. Documenting the simulation study is the development of a study file that includes the details of each simulation step. Comprehensive documentation of a simulation study comprises three main elements: detailed documentation of the simulation model, the development of an engineering simulation report, and the presentation of simulation results to customers and partners of the simulation project.

Documentation of the simulation model includes both the concept model and the simulation program. Such documentation facilitates making model changes, explaining the data used in the model, debugging code and logic, understanding model behaviour, and interpreting model results.

El-Haik and Al-Aomar (2006) stated that the major deliverable of the simulation study is the development of a simulation report. A simulation report includes the following elements:

(1) The system being simulated

a. Background

b. System description

c. System design

(2) The simulation problem

a. Problem formulation

b. Problem assumptions

c. Study objectives

(3) The simulation model

a. Model structure

b. Model inputs

c. Model assumptions

(4) Simulation results

a. Result summary

b. Results analysis

(5) Study conclusion

a. Study finding

b. Study recommendations

(6) Study supplements

a. Drawings and graphs

b. Input data

c. Output data

d. Experimental design

e. Others

Results presentation often includes a summary of the simulation results (summary of study steps, results and findings, conclusions, and recommendations). The presentation should include running animations, movies, or snapshots of the simulation model in a variety of situations. Such animations help explain the study results and aid the analyst in selling the design proposed, comparing design alternatives, and securing management support through proposed solutions and plans of action.

2.5.4 VSM MODELS WITH STANDARD TEMPLATES

Value Stream Mapping (VSM) has become an integrated and essential technique in lean projects; it combines material processing steps with information flow as well as other important related data (Tony Manos, 2006). However, being a static method, VSM has many limitations such as its inability to assess the effects of variation, to validate effects of proposed changes before implementation, to identify other possible improvements or to capture the interactions between system components (Standridge and Marvel, 2006). All these shortcomings have led to the use of simulation.

Many attempts have been made to embed simulation in lean projects. For instance, Bayle, et al. (2001), Abbas, et al. (2006), Adams, et al. (1999), Wang, et al. (2005), Bodner and Rouse (2007), Huang and Liu (2005), and Lian and Van (2007) gave an overview of embedding simulation in lean projects and used case studies to illustrate how simulation could be used in lean manufacturing.

In recent years, many researchers are trying to combine simulation method with static value stream mapping (VSM). Traditional VSM models are built with standard simulation templates, which are time-consuming and unreliable; since there are no uniform ways of modelling VSM, the reliability of simulation models depends on model builder's experience, and it is very difficult for non-experts to build simulation models of VSM on their own. McClellan (2004) stated that making an accurate simulation model is very difficult because of the tremendous amount of factors that are a part of a normal manufacturing system.

Many papers have used traditional simulation methods -- which means through basic templates offered by simulation software to build VSM models. For instance, Donatelli (2002) tried to integrate value stream mapping (VSM) into discrete event simulation to further the continuous improvement goals of lean manufacturing.

Abdulmaled and Rajgopal (2007) developed a simulation model (using Arena 5) to analyze current and future state of VSM in a steel mill.

However, since they used standard templates to build models, the models were very large and the logic was very complicated. A lot of time was spent on code checking and logic verification aside from model building. The whole process was time-consuming, and the model was complicated and not reusable. It was very difficult for non-experts to build such complex models.

Detty (2000) used SIMAN V language to build simulation models of VSM, which is very difficult for users to understand the program, not to mention change the internal logic of the model.

2.5.5 VSM MODELS WITH CUSTOMISED TEMPLATE

In Arena, simulation models were built by placing modules in a working area of a model window, providing data for these modules, and specifying the flow of entities through modules (Miwa and Takakuwa, 2005). Traditional models are built by using basic templates which contains basic modules offered by simulation software. Customised template is designed and developed on the basis of basic templates, for instance, the customised template proposed here is designed for VSM (value stream mapping) modelling.

Many attempts have been made to design customised template for VSM simulations as well. For example, Lian and Van (2007) developed a VSM-based simulation generator, and described its database structure. However, it requires a lot more data information than the data shown on static VSM. The static VSM can only provide basic information for the model such as entities, locations, setup times and cycle time, more detailed data need to be obtained from ERP database, and some reformatting and data filtering techniques are required as well. The simulation generator requires users to be familiar with ERP database as well as simulation model, which stops non-experts to use it.

Treadwell and Herrmann (2005) developed a kanban module to facilitate simulating pull production model. They stated that modern discrete-event simulation software has many modules to help analysts quickly construct simulation models of manufacturing systems. Moreover, simulation is a very useful tool for designing manufacturing systems. However, pull production control has not been adequately addressed. They discussed various ways to implement pull production control in discrete event simulation (specifically, Arena, by Rockwell Software). A kanban workstation module was modelled as resources. Thus, all of the overhead for tracking kanbans is managed internally, while providing flexible options for entity creation or input from an external source. The analyst needs to include only a single, easily customized module to represent each workstation. Constructing a complete model then requires much less effort than if it were to be constructed from standard Arena components. At this point, the kanban workstation module can model stations with parallel, identical servers but cannot be used for fork or join processes. They claimed that users could save more than half the time to construct a simulation model with their tool. However, to use their tool, users have to be familiar with VSM (value stream mapping) as well as Arena software, and have a deep understanding of resource concept in the simulation model; thus it is not a completely simplified tool for model constructing, and non-expert of simulation may find it very difficult to understand and use.

Lian and Van (2002) designed a template containing four basic modules to simulate VSM models. However, the templates were only designed for pull system, and users still have to use standard templates to build simulation models for push system, which makes the modelling process more complex and confusing. Again, it is not a completely simplified tool for VSM model constructing..

2.5.6 ALTERNATIVE APPROACHES FOR MODELLING LEAN PROJECTS

Apart from simulation models built for VSM (value stream map) as discussed in Section 2.5.5 and Section 2.5.6 in details, there are other solutions to lean problems. For instance, Agbulos and AbouRizk (2003) designed a simulation model for drainage operations maintenance crews. The application of the industrial engineering philosophy of work measurement, lean production theory, and simulation analysis was used to capture current work methods, generate and test alternative methods, and develop new standards. The principles of lean thinking were applied to this model. The daily work (Service Line Roding) activity was broken down to a number of tasks and then further subdivided into work elements. In addition, each element of the work process was designated as either value added (VA) or non-value added (NVA) work step. The current state model is built in a hierarchy that represents different levels of detail for the actiiti. The highest level of the hierarchy represents the work preparation, work steps, work completion and transportation elements. The actual service line rodding is found at the lowest level of the hierarchy (child level). The paper illustrated the improvement in SLR productivity of 10.6% through applying lean theory to current SLR work methods.

Van der Zee and Slomp (2005) developed a simulation game to support the introduction of lean principles in an existing assembly line. The simulation game can be used to demonstrate applicability of a lean control concept at the assembly line and to train workers to make appropriate control decisions within this concept. The user interaction is intrinsic for this gaming model. The model concerns a segment of the assembly line – 5 stations. It allows a single player to make decisions on worker deployment by dragging worker icons to respective stations. As an input for decision making a player may consider shop status, i.e., the distribution of jobs and workers over the line, and several indicators. Alternative scenarios may be chosen by changing the experiment number in the display, and worker and station settings are reflected by setting their labels accordingly. Game runs take about one half hour per scenario. During a run, decisions are recorded for further analysis. After each scenario learning experiences and initiatives towards rule construction are collected by means of a questionnaire.

Khurma, Bacioiu and Pasek (2008) developed simulation models for current and future states of Emergency Departments (ED) in Canadian hospitals. This paper described an effort aimed at improvement of patients' experience over their ED stay. A combination of Lean tools were used to analyze, assess and improve the current situation, such as Cycle Time Analysis, Work Combination

Charts, Cause & Effect Matrix, Fish-bone Diagram, and Affinity Diagram. The outcome helps to understand why the process system is creating long waiting lines and overwhelming delays. In addition, simulation model software was used to convey this information in a visual form and perform comparative analysis. The modified process offers a better-managed, balanced and continuous patient flow through ED. Consequently, a comprehensive and feasible improvement appears that will ultimately enhance the quality of health care services provided by the institution. The paper addressed some of the wastes (Muda) in the front-end ED process, including transportation, over-processing, waiting, motion etc. A future state layout was designed to dramatically reduce the amount of travel the patient has to go through, simplify the whole triage process and reduce travel for the hospital personnel.

Evans and Alexander (2007) discussed the use of multi-criteria models in conjunction with optimization procedures and simulation in order to identify an ideal system state and associated policy. An illustration of a replenishment policy for a distribution system is described. A criterion model is a way of combining all of the outputs from the simulation model so that a ranking of the various alternatives associated with the simulation study can be accomplished. A simulation model was built to represent the distribution system. Several different types of control variables can be input to the model; however, the main type investigated in this cast study, is that whether each branch orders a product line directly from the vendor, or through the distribution centre (DC). Various performance measure values are output by the model, including sales dollars, lost sales, shipping charges, inventory carrying charges, and cost of purchasing stock keeping units (SKU) from the vendor. In order to keep this case study brief in nature, only one product line, consisting of 27 different SKUs, is considered. This gives us an optimization problem involving 19 zero-one decision variables; hence, considering all possible combinations of 19 zeros and ones, there are 2 to the 19^{th} power possible solutions to this problem. Using principles as procedures from the area of multi-objective decision analysis, an appropriate criterion model can be identified which, when used with an optimization procedure and simulation model, will allow for the identification of an ideal system state along with a policy that will lead to that ideal state.

2.6 CRITICAL ASSESSMENT OF LITERATURE SURVEY

From the literature survey, we can see that:

First of all, lean is a very powerful and popular methodology, among which VSM is the assessment and planning tool of Lean practitioners, and an enabling tool to apply Lean thinking (Locher, 2008). It provides a system's view of the flow of work, involving multiple processes, that goes well beyond traditional process mapping techniques.

Secondly, as a static method, lean has many limitations. Particularly for VSM, Standridge and Marvel (2006) and Braglia, et al. (2009) summarized the main drawbacks of VSM such as its inability to assess the effects of variation, to validate effects of proposed changes before implementation, to identify other possible improvements or to capture the interactions between system components. By embedding simulation, it might be possible to overcome some of these limitations.

Thirdly, many papers have discussed building simulation models for VSM. Traditionally, people use standard template to build simulation models for VSM, as demonstrated by Donatelli (2002) and Abdulmaled and Rajgopal (2007); some researchers tried to design customised template for VSM modelling, such as Treadwell and Herrmann (2005) and Lian and Van (2002). However, problems with standard template is that it is time-consuming and logically complicated; and the template proposed by Treadwell and Herrmann (2005) and Lian and Van (2002) has limitations as well.

Fourthly, many attempts have been made to design process models for lean projects, see works of Evans and Alexander (2007), Khurma, Bacioiu and Pasek (2008), Van Der Zee and Slomp (2005), Agbulos and AbouRizk (2003), etc. Agbulos and AbouRizk (2003) designed simulation models with hierarchy for current state and future state of the drainage operations maintenance, and the multiple levels of sub-models have sufficiently represented the complexity of the system. However, the reusability of the models is very low. The developed simulation model can only demonstrate lean improvement for the particular drainage maintenance system, and for another drainage maintenance system, the models become totally useless and meaningless; not to mention other systems which has requirements of lean improvement. Other case studies shown in Section 2.5.6 have the same problem as being so specific to a particular problem in a particular system, while do not provide generic solutions for model constructing in lean projects.

Last but not least, the combination of Lean methodology and Simulation has achieved greater success than merely use Lean method. But currently all the case studies just make use of simulation in one or several stages of the individual steps of lean methodology, while does not explain systematically how simulation can be embedded into the lean projects, or illustrate how to build a holistic framework or structure to embed simulation into lean projects. And lacks of integrity of the reference framework in turn will greatly influent Simulation application in lean projects.

2.7 SUMMARY

In summary, no authors have proposed a completely simplified method of VSM modelling, see works of Lian and Van (2002) and Treadwell and Herrmann (2005). The case studies presented in Section 2.5.6 have provided simulation solution for some particular problems in particular systems; while they do not have generic and holistic influence for building simulation models for lean projects. Since lean methodology is a well developed process improvement approach which contains systematic lean tools, there is a possibility to develop a generic and holistic reference framework which enables easy model building for lean projects. The method proposed in this thesis is a completely simplified method of VSM modelling, it overcomes the limitations mentioned above, and it enables non-expert of simulation build VSM models quickly and accurately.

Considering all problems mentioned above, a reference framework, termed SimLean, is proposed to illustrate how to embed simulation in lean projects step by step. A customised simulation environment is designed for VSM modelling to compensate the drawbacks of static VSM; to simplify and facilitate VSM modelling; and finally to standardize model building process of lean projects.

3 RESEARCH METHODOLOGY

The literature review in last chapter has revealed three research gaps. These gaps have facilitated the development of this research work, which aims to develop a reference framework about embedding simulation in lean projects. Hence, a hybrid research methodology was adopted for the research work. This chapter describes the research methodology designed and used in the overall research investigation.

The remainder of this chapter is structured as follows: Section 3.1 summarizes the research questions based on the research gaps; Section 3.2 provides the design of research methods; Section 3.3 discusses the adopted research methodology; At last, Section 3.4 describes the results obtained from interviews.

3.1 RESEARCH QUESTIONS

The research questions were based on the research gaps identified from literature review in last chapter. A fundamental issue raised from the gap was that companies are not certain of the actual gain and benefit of embedding simulation in lean projects. They also do not know how to use simulation in lean projects. What's more, they fear the simulation technique is too complicated to apply to real manufacturing industry. The above statements have facilitated the creation of the research questions, and the research questions below are designed to guide the focus of this assumption.

1) Is it possible to embed simulation technique within lean projects?

2) What are the main concerns of embedding simulation?

3) How can companies embed simulation in lean projects?

4) Can embedment of simulation help companies overcome some limitations in lean implementation?

5) What is the most suitable delivery medium for the reference framework?

3.2 DESIGN OF RESEARCH METHODS

Once we have stabilized our research questions, we can move from content to method. The connection from content to method is through data. Data includes evidence, information, or empirical materials. The essential idea is first-hand observation and information about (or experience of) the world. Data is a very broad term, and is subdivided into quantitative and qualitative (Punch, 2005).

Quantitative data are in the form of numbers, from either counting, or scaling, or both. Measurement turns data into numbers, and its function is to help us make comparisons. Denzin and Lincoln (1994) defined qualitative data as 'qualitative empirical materials', which includes interview transcripts, recordings and notes, documents and the products and records of material culture, audiovisual materials, and personal experience materials (such as artefacts, journal and diary information, and narratives). The qualitative researcher thus has much wider range of possible empirical materials than the quantitative researcher, and will typically also use multiple data sources in a project.

A comparison of quantitative and qualitative approaches in aspects of characteristic and advantages are presented as follows (Punch, 2005):

- The quantitative approach conceptualizes reality in terms of variables, and relationships between them. It rests on measurement, and therefore pre-structured data, and usually research questions, conceptual frameworks and design as well. Its methods in general are more uni-dimensional and less variable than qualitative methods. It is therefore more easily replicable.

- On the other hand, the qualitative approach deals more with cases. It is sensitive to context and process, to lived experience and to local groundedness, and the researcher tries to get closer to what is being studied. It aims for in-depth and holistic understanding, in order to do justice to the complexity of social life. Samples are usually small, and its sampling is guided by theoretical rather than probabilistic considerations. Its methods are less formalized than those in the quantitative approach. They are also more multidimensional, more diverse and less replicable. It therefore has greater flexibility.

- There are different strengths and advantages to each approach. Quantitative data enable standardized, objective comparisons to be made, and the measurements of quantitative research permit overall descriptions of situations or phenomenon in a systematic and comparable way.

- On the other hand, there are important strengths and advantages to the qualitative approach as well. Qualitative methods are more flexible than quantitative methods. Therefore they can be used in a wider range of situations and for a wider range of purposes. Because of their great flexibility, they are well suited for studying naturally occurring real-life situations. Qualitative methods are the best way we have of getting the insider's perspective, the meanings people attach to things and events.

This means they can be used to study the lived experience of people, including people's meanings and purposes.

Based on the comparisons above, this research decides to adopt qualitative research approach. This decision was made with reference to a number of factors, but most important thing is the matching of research question with method - using quantitative methods for quantitative questions, and qualitative methods for qualitative questions. The main direction of influence is from question to method. The research questions presented in Section 3.2 are more about getting holistic information or finding out the interpretations it has for the people involved; than making standardized and systematic comparison or in accounting for variance.

3.3 THE SELECTED RESEARCH METHODOLOGY

This research project has employed a hybrid research methodology. Specifically, the research methodology adopted techniques such as literature review, interviewing lean practitioners in companies and case studies as shown in Figure 3-1. The selected research methodology is discussed in the following five phases in details:

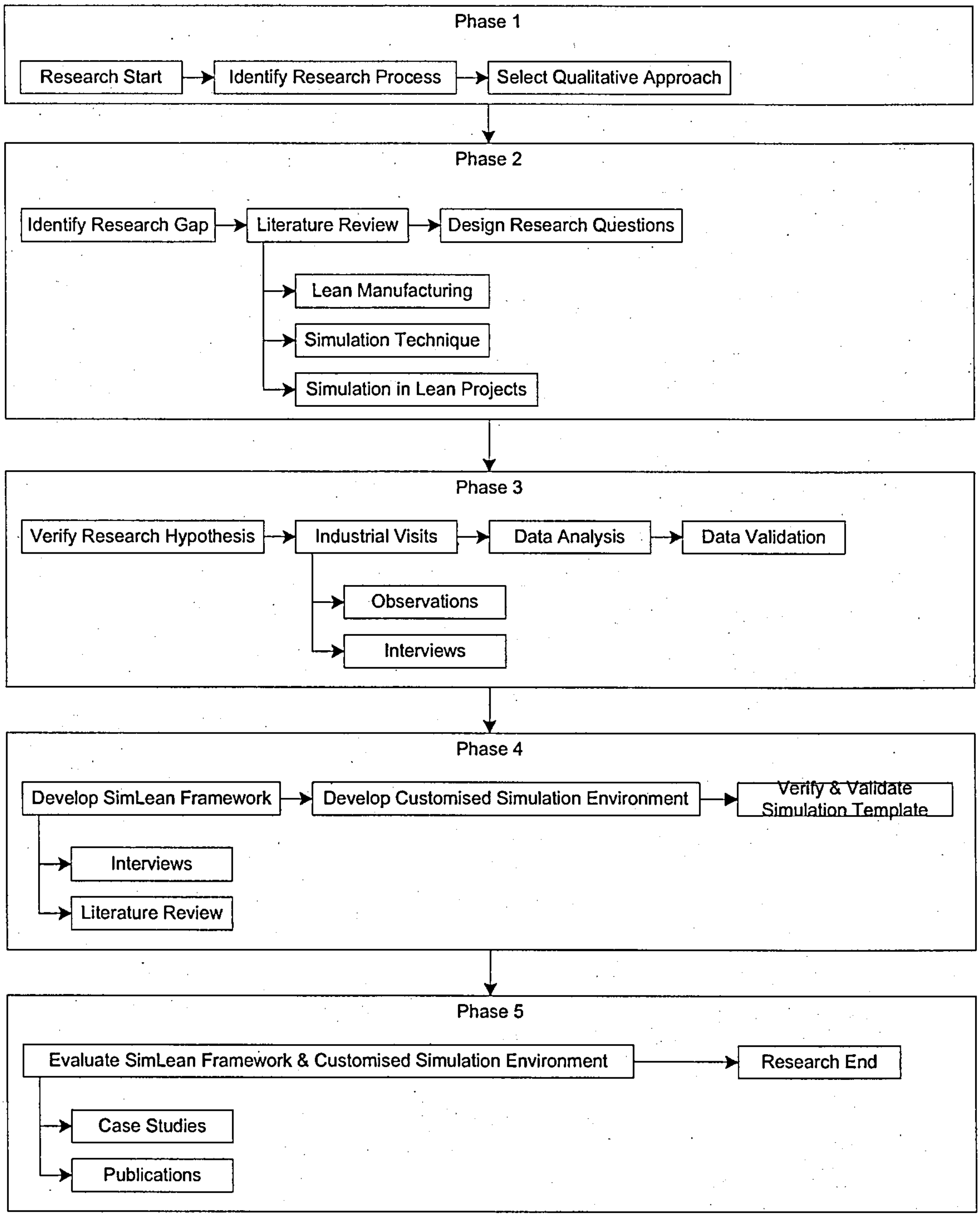


Figure 3- 1 The Selected Research Methodology

(1) Phase 1: Identification of the research process

Phase one of the research process aims to identify the most suitable approach for the whole research work. After examining both quantitative and qualitative research approaches, deeply analyzing their strengths and weaknesses, we have decided to use qualitative research approach. The main reasons are presented in Section 3.3 in details.

(2) Phase 2: Problems definition and literature review

The second phase of the research work aims to identify research gaps through obtaining and analyzing background information on the relevant subject areas. These areas include literatures on lean methodology, simulation technique and simulation applications in lean projects. In addition, the limitations and shortcomings of the case studies were also reviewed. The literature review was conducted at the initial stages of the research investigation, and it revealed the research gaps in knowledge. It is significant to note that, the review did not provide specific information on building a reference framework about embedding simulation in lean projects.

Therefore, there is a need for further research within the existing company that has implemented the lean method previously. The idea behind it is to investigate further, in order to determine the necessity, benefit and simplicity for simulation embedment.

This research investigation was directed to a manufacturing company to get the first hand information of the problem domain. What's more, company involvements provided a platform for the data collection of this research investigation. One experienced production manager, one production director and two lean/six sigma consultants who had successfully implemented lean methodology within their premises were selected in the research study.

(3) Phase 3: Research questions verification and interviews

The third phase of the research study aims to verify research questions through collecting data from companies. This was aided by the engagements of production manager, production director and consultants as discussed below.

(i) Initial Contact:

After contacting companies by e-mail and telephone, a formal meeting was arranged between the researcher and four experts (including one production manager, one production director and two lean six sigma consultants).

(ii) Display simulation models:

In order to enable the production manager and director to have a general understanding of simulation, the researcher demonstrated a simulation model of a manufacturing factory, which included internal logic, animation, statistics and a set of variables.

(iii) Observations in a manufacturing company:

In the investigated manufacturing company, the researcher carried out direct observation which lasted about fifteen minutes at each manufacturing process. Real-time information obtained from the observation was recorded as shown in Appendix A. Observations were focused on processing time and error rate.

(iv) Interviews with production manager, director and lean consultant:

After collecting and analyzing data from observation, the researcher conducted some interviews to verify the observation results, as well as to get further information about the research work. Personal interviews were conducted through a set of questions (see Appendix B). The interview lasted for two hours, and all the three experts (including one production manager, one production director and one lean consultant) have at least four years experience of implementing lean concept.

In order to find out their perspectives on lean implementation, the data collection sheets were used and critical information on lean manufacturing projects was obtained. The research designed a number of questions regarding their comprehension of lean manufacturing, the major lean tools they have adopted, the most successful lean projects they have completed and current difficulties or problems in lean implementation. Through the use of prepared questionnaires, the researcher was able to deduce a number of issues.

First of all, by analyzing information provided by the managers, the level of lean implementation in this firm can be easily revealed. Secondly, the study also wanted to find out the difficulties and problems that currently existed in their lean implementation process. This was very important for the retrieval of lean limitations or problems which might be overcome by simulation method. Thirdly, the most commonly used as well as most important tools in their lean operation were discussed. In addition, the collected data from shop floor was also discussed and validated.

(v) Interview with lean six sigma consultant

Another two hour interview was undertaken with a lean six sigma consultant (a black belt). The consultant has two years experience of implementing lean and six sigma project, during which he had utilized modern technology frequently such as statistical analysis software and simulation software. The result of this interview was very helpful to this research investigation as well as to the framework development process.

(4) Phase 4: Development of the SimLean framework

Phase four of the research work aims to develop a reference framework about embedding simulation in lean projects. This phase included two parts. The first part was to develop the framework model; whereas the second part included the development of a customised simulation environment. Both of these activities involved personal interviews and literature survey. After developing the customised simulation environment, verification and validation activities were conducted for each module and the interactions between designed modules were tested.

(5) Phase 5: Evaluation of the SimLean Framework

The final phase of the research work aims to evaluate the proposed SimLean framework through case studies. In order to test the merit and worthiness of the framework and the developed customised simulation environment, five case studies were selected as shown in Chapter six.

3.4 RESULTS FROM INTERVIEWS

Literature review has identified research gaps, as a supplementary process, a number of practitioners were also consulted to assess their views on research gaps identified. This section presents findings from company visits and personal interviews. This section also discusses the major objectives of company investigation and highlights the data collection results.

3.4.1 RESEARCH QUESTIONS VERIFICATION

Chapter one highlighted the effectiveness and popularity of lean methodology, which is very crucial for the improvement of manufacturing performance. This notion is one of the major motivating factors for conducting this research. In order to survive in the intense global marketplace, organisations and companies are adopting various process improvement techniques, such as lean methodology. However, literature review in chapter two revealed that lean method has some limitations, which might be overcome by embedding simulation technique. Unfortunately, literature review does not provide reference framework for simulation embedment.

Hence, there is a need for investigating companies to understand this issue. The major objective of company visits is to explore their lean operations, so as to determine their major difficulties or problems in lean implementation. The industrial investigation also tries to find out the most important and commonly used tools in their lean practices, in order to determine which tool or tools should be assisted by simulation technique. Finally, it is hoped that the results obtained from interviews could help researcher develop the reference framework – SimLean.

The industrial investigation used a list of questions to obtain a meaningful result. The questions asked and their corresponding answers are described below:

1) What type of product is manufactured and what is the volume level?

Production manager: "The major product is frames, the production volume level is large, and the variety of frames which can be manufactured in this company is over 100."

2) How long has this company implemented lean concept?

Lean consultant: “The company has adopted lean manufacturing for about four years until now. “ (The interview time was June, 2008).

3) What is the most successful process improvement during lean applications?

Lean consultant: “The greatest achievement is the reduction of average production error rate from previously 15% four years ago to nowadays less than 3%.”

Production director: “The good result is achieved through continuous improvement. We hold weekly and monthly quality meetings, during which production data are gathered and analyzed. We have adopted lean tools such as employees’ training, work balancing and one-piece flow.”

Production manager:”Through using automation technique and purchasing new machines, we were able to eliminate the error in some processes immediately.”

4) What are the company’s current difficulties or problems in lean implementation?

Production manager: “After ten years’ continuous progress in lean applications, the company has encountered a new difficulty. In order to further improve work performance, we want to apply for bank loans to purchase some new equipment. It is a large investment. However, the productivity of the new equipment varies within a certain range, and the new facility will cause changes to all other processes. Considering the high risk in this investment, I find it difficult to make a decision.”

Lean consultant: “Another problem is the culture in this company. People don't want to change the way they work, and are worried about losing jobs once the company become ‘lean’.”

5) Knowledge about using simulation in lean projects?

Production manager: "When we first started lean project four years ago, we did not have experience to know or to use simulation. But now we know more about lean, and we think simulation is a useful tool in lean project, and we would have got big benefit from using it."

Lean consultant: “We have tried to do simulation on our own system recently, but failed.”

The same questions were asked to the lean and six sigma consultant who has used simulation technique in lean six sigma projects before. He clearly affirmed that simulation technique has a great effect on actual lean and six sigma projects, such as predicting results before implementation, comparing several scenarios by building simulation models and discovering problems in a dynamic system. Furthermore, he believed that simulation technique should be used in pre-implementation stage of lean and six sigma projects, which is consistent with Shapiro's (2002) opinion. Stephen Shapiro stated in "24/7 Innovation, A Blueprint for Surviving and Thriving in an Age of Change" that "Misguided innovation can be costly in time and money and in trust between manager and employee. How can these risks be contained? Many companies find that simulation is the answer. In my experience, the refinement of an idea through computerized simulation is the best route to pre-implementation testing. It allows us to approach, if not achieve, perfection prior to betting the business on it."

6) What are the most commonly used lean tools in your lean projects?

The data was collected using data collection sheet (see Appendix B). Table 3-1 below shows the results provided by two production managers and one lean consultant.

Table 3- 1 Summary Results of Practitioners' Views

Would use simulation	Tools / (Tick) Lean Project	Value stream map (1)	Systems Flow Chart (2)	Spaghetti Chart (3)	F-S Value Stream Map (4)	TAKT Time (5)	Lean Action Item List (6)	Lean Events (7)	5S (8)	Simulation (9)	Others (specify)	Challenges & Difficulties
√	Identify problems	√	√	√		√	√	√	√			Culture
	Train personnel				√			√	√			Culture
√	Rank opportunities for improvement				√		√	√	√			Culture
	Document process		√						√		Standard Operations	Culture
√	Predict impact of improvement				√			√			KPIs	Culture
√	Address random and structural variation						√	√			KPIs	Culture
	Analyze data						√	√			KPIs	Culture
√	Assess the interaction between system components							√				Culture
√	Validate the future state							√				Culture
√	Identify and consider alternatives to the future state							√				Culture
√	Detail dynamic behaviour of production processes		√					√				Culture

The interview questions were designed after conducting literature review. The activities in lean projects as shown in the second column of Table 3-1 were summarized by Standridge and Marvel (2006), where they stated that the deficiencies of lean approach exist in these specific stages or steps. The lean tools shown in row one of Table 3-1 were referenced from Bicheno (2006), Tapping and Shuker (2002), Plenert (2007), Breyfogle (2008), Chase, et al. (2006), Heizer, et al. (2008), Ross (2003), Taylor and Brunt (2001), Santos, et al. (2006), Ortiz (2006), Page (2004), Alukal and Manos (2006), Womack and Jones (2005), Nicholas and Soni(2006), Locher (2008) and Basu (2009). The nine selected lean tools and two other tools mentioned by interviewees are described in details below:

(1) Value Stream Mapping: A waste identification tool that is used to identify lean improvement opportunities based on the non-value-added processes that get identified.

(2) Systems Flow Chart: A mapping tool to detail out the information process to eliminate the non-value-added information flow lines that existed.

(3) Spaghetti Chart: a mapping tool to show the travel time of the materials and/or the people involved in the process.

(4) Future State Value Stream Map: An ideal VSM achievable in the future to help identify a target goal for our improvement effort.

(5) TAKT Time: The time it will take to produce one unit of product in order to meet customer demand.

(6) Lean Action Item List or Lean Newspaper: An action item list of improvements to show the specific areas that are targeted for change.

(7) Lean Events: a team activity designed to eliminate waste and make rapid changes in the workplace.

(8) 5S: The objective is to create an organized, safe, and productive work environment. The 5Ss are:

Sort -- separate the needed from the unneeded items; Set in Order (Straighten) -- physically rearrange the layout; organize the work area; Shine -- clean and remove reasons for contaminants; Standardize -- implement procedures and signalling systems that ensure worker understanding of the process; Sustain -- set up systems to ensure open and complete communication.

(9) Simulation: A means of experimenting with a detailed model of a real system to determine how the system will respond to changes in its structure, environment or underlying assumptions.

Others (1) Standard Operations: Clearly defined activities and standardized step by step procedures for machines and their operators.

Others (2) KPIs: Key performance indicator (KPI) is a measure of performance which is commonly used to help an organization define and evaluate how successful it is, typically in terms of making progress towards its long-term organizational goals.

Table 5-2 shows that apart from "lean events" which has been ticked ten times, VSM (including current VSM and future VSM) is the most commonly used tool in their lean projects (ticked five times); The next commonly used tools are

"Lean Action Item List" and "5S" (ticked four times each); "System Flow Chart" and "KPI" were chosen for three times; The least often used tools are "Spaghetti Chart", "TAKT Time" and "Standard Operations" (one tick each); Finally, last option – "Simulation" was never selected in their lean projects (zero tick). The result of lean tools usage is consistent with their actual operations. This company has weekly meetings to solve quality problems, and it explains the ten ticks in "Lean Events". "VSM" is the second most frequently used lean tool, and the result approves the importance and significance of VSM in lean projects.

7) Which stages do you have difficulties in currently and would like to use simulation technique to make improvements?

The data in column one of Table 3-1 shows that they would like to use simulation in the following stages or activities: "Identify problems", "Rank opportunities for improvement", "Predict impact of improvement", "Address random and structural variation", "Assess the interaction between system components", "Validate the future state", "Identify and consider alternatives to the future state" and "Detail dynamic behaviour of production processes".

Statistical analysis of lean tools selected in each step shows that seven tools were used in "Identify problems" and four tools were chosen to "Rank opportunities for improvement". However, for other six stages ("Predict impact of improvement", "Address random and structural variation", "Assess the interaction between system components", "Validate the future state", "Identify and consider alternatives to the future state" and "Detail dynamic behaviour of production processes") which they would use simulation to assist in, only one to three tools were available to conduct the lean activities.

3.4.2 CONCLUSIONS DRAWN FROM INTERVIEWS

The interview activity was scheduled for no more than two hours. The purpose was to collect as much information as possible from the interviewees. At last, all the information gathered from interviews were analyzed and compared with information obtained from literature review.

The following conclusions were drawn from the interview:

1) A lack of supportive culture has been a big problem during lean implementation in this company; Workers are reluctant to change and are afraid of losing jobs after changes are made. This finding is consistent with Achanga, et al. (2006)'s view from literature survey. They stated that "the creation of a supportive organisational culture is an essential platform for the implementation of lean manufacturing. High-performing companies are those with a culture of sustainable and proactive improvement. Manufacturing, almost more than any other sector, is a global industry; It is highly desirable to have some degree of communication skills, long-term focus and strategic team while intending to implement any new initiative."

2) They have realized the power of simulation technique in general. However, without a clear, step-by-step reference framework, the trial of simulation on their system was a total failure. This finding has further confirmed the importance and urgency of this research work.

3) Interview helped researcher to develop the SimLean framework, particularly in deciding to embed simulation in Pre-implementation stage. Interviews with the experienced lean and six sigma consultant who has used simulation in his projects confirmed the assumption that simulation should be applied before the

lean implementation stage, and the view is consistent with Shapiro's (2002) opinion.

4) The collected data in Table 3-1 showed that one of the most commonly used tools in lean projects is VSM (value stream mapping). Combined with the view of Rother and Shook (1999), who stated that "value stream mapping (VSM) is an easy technique to visualise a whole and complex manufacturing system, identify wastes and their sources and guide improvement efforts", a preliminary notion about designing a customised simulation template based on static VSM was formed.

5) They have no good tools to predict the impact of future state before changes are made. For instance, what is the throughput quantity if a new machine is purchased; what influence will it bring to other processes? Problems like those are difficult for them, and the solutions are not based on scientific statistics but on managers' experience.

6) They lack suitable tools to address variations in operation systems, or to catch the dynamic behaviour of production processes. Data in Table 3-1 shows that besides weekly meetings to discuss the problems and brainstorm solutions, no tool has been used to assess the interaction between system components; only two tools were used to address the variations in system and to detail the dynamic behaviour of production processes.

7) The two stages in lean projects "Identify problems" and "Rank opportunities for improvement" are very important to the company. They have attached great importance to these stages, which can be seen from the number of tools adopted in the two steps. Even though four to seven different tools have been

applied to the above stages, they still want the assistance of simulation technique to further improve the accuracy of the results and outcomes of the two steps.

4 BUILDING THE FRAMEWORK

Literature review in Chapter 2 described a number of lean manufacturing tools, simulation techniques and simulation applications in lean projects, Chapter 3 presented the research methodology adopted by this research study and results gained from company visits and personal interviews. Conclusions from the literature review and company investigations drew a number of research questions. Particularly, it was revealed that existing lean techniques and frameworks do not include holistic and systematic guidance about embedding simulation in lean projects.

To overcome the drawback mentioned above, a reference framework about embedding simulation in lean projects is proposed. This chapter describes the development process of the framework about embedding simulation in lean projects.

4.1 MOTIVATION AND DATA COLLECTION

The motivation for developing a reference framework about embedding simulation in lean projects is to enable enterprises employ simulation technique in their lean operations easily and quickly, especially in pre-implementation stage. Businesses should be able to evaluate their current operations as well as predict their future performance. By embedding simulation method in their lean operations, a company will know the best solution to adopt, choosing from many alternatives; So as to greatly improve the project quality and efficiency, reduce error rates, shorten trial and error time, and save a lot of money.

To achieve this research aim, the researcher tried to find out the difficulties and problems that companies encountered during lean implementation. Oral communications with production manager, production director and lean six sigma consultants, compounded with literature survey provided a lot of information. The information helped the development of the framework. The collected data were analyzed and validated by people in academia as well as in industry to prove its validity and accuracy.

4.2 ANALYSIS OF SIMULATION EMBEDMENT

Simulation embedment in lean projects means to build simulation models for the lean manufacturing processes. First of all, a company or a factory needs to find out the major problems or difficulties in their current system. Traditionally, this is accomplished according to people's experience, or through the use of static lean analysis tools, such as various diagrams and charts. It could work well on some static systems or systems without much variation. However, generally speaking, manufacturing system is a dynamic process, and most problems occur in a continuously changing production. What's more, a system without much variation might not need lean methodology. In a word, static tools can not discover dynamic problems very well, but with the assistance of simulation technique, it becomes possible to discover problems in dynamic productions.

Secondly, what a company or a business cares most is the effect or outcome of the lean transformation. However, the existing lean tools do not have the adequate function to predict results precisely. Without effective tools to predict the results, companies have to make lean implementation through trial and error approach, which costs a lot of workforce, time and money. Fortunately, with the help of simulation method, the effects of different scenarios can be predicted in advance and in details, which could greatly reduce the risk and cost of lean implementation.

4.3 FRAMEWORK DEVELOPMENT

The development of the reference framework about embedding simulation in lean projects included several research processes. Firstly, literature survey was conducted to gather information about current development of lean methodology, simulation approach and their combination status. Data collection sheets and interview questions were designed after literature review process. Secondly, company visits were conducted to collect information such as current difficulties or problems in their lean implementation, and the most frequently used tools in lean activities. The main stages in lean project and the role of simulation in lean projects were analyzed through personal interview with lean six sigma consultants. After that, a reference framework and a customised simulation environment were developed to make the embedment of simulation in lean projects systematically and efficiently.

The proposed framework, termed SimLean, is described below (see Figure 4-1). The SimLean framework is designed based on the assumption that the company is already using lean methodology. There are seven main stages in the framework, which cover the whole project cycle from "Establish need for simulation" to "Post implementation". With the assistance of the simple and generic SimLean framework, managers and model users can easily discover problems in current system and make correct changes to the system based on implementation plan produced in pre-implementation stage.

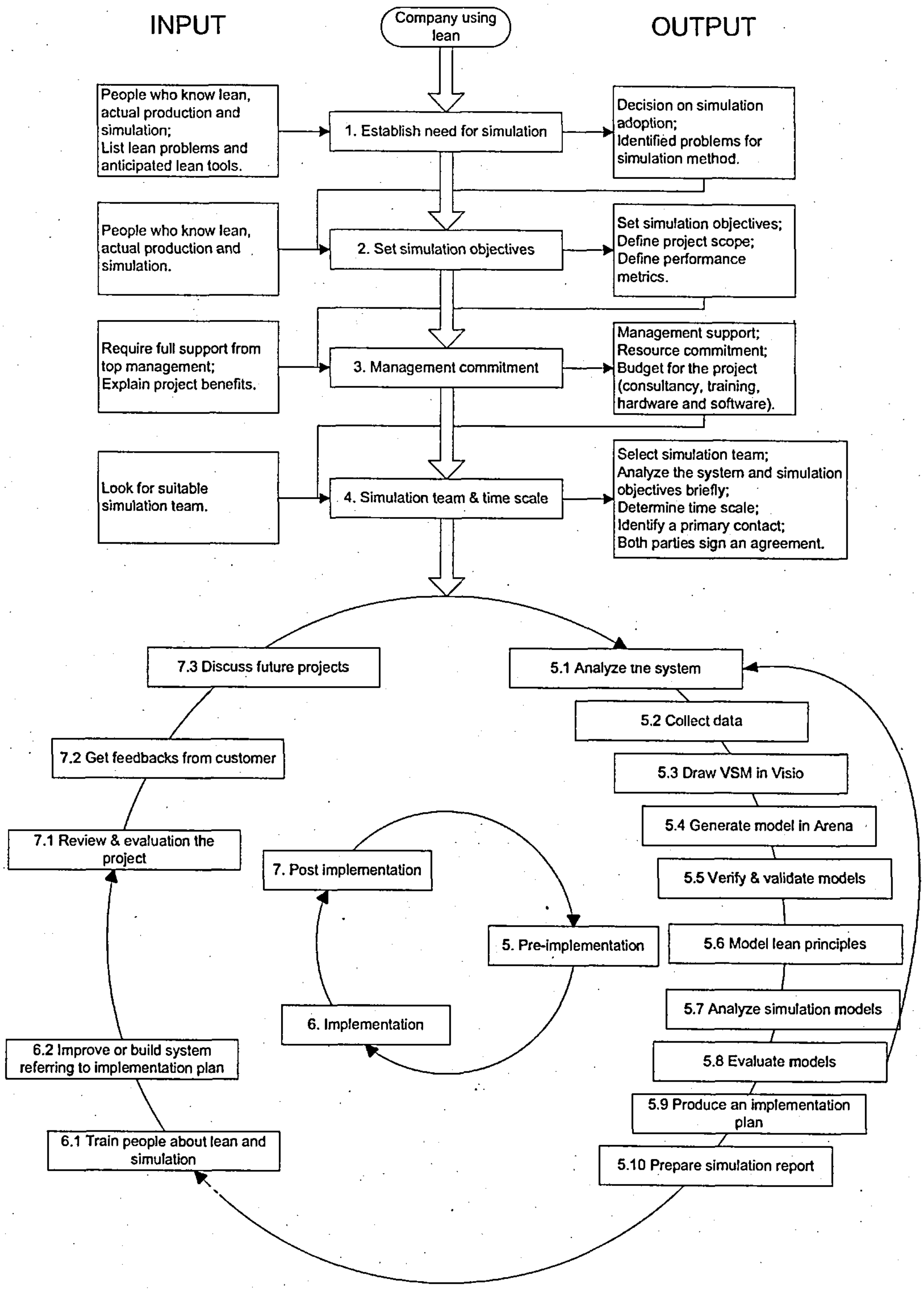


Figure 4- 1 The Proposed SimLean Framework

4.3.1 ESTABILISH NEED FOR SIMULATION

As shown in Figure 4-2, the first stage in SimLean is to establish need for simulation, which means to decide whether or not to use simulation methods for the projects.

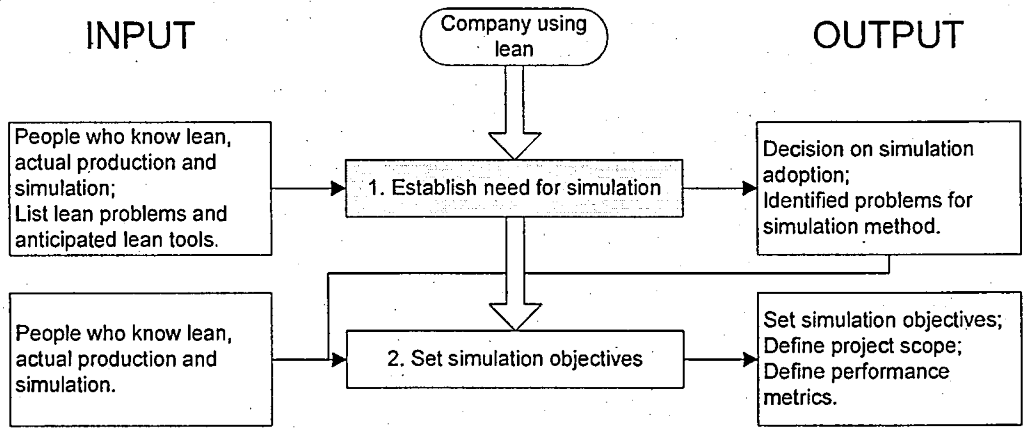


Figure 4- 2 SimLean Stage One

Input elements include a group of people who have knowledge of lean methodology and know the actual production process very well. This group can carry out investigations of its current manufacturing issues in their company to identify the issues or problems that its business faces. Another input element is a list of lean problems the company aims to solve and the anticipated lean tools to be used in the project. Through comparing problems with Table 4-1, the enterprise can quickly figure out simulation suitability in their lean project.

Table 4-1 lists the major lean problems and the simulation applicability for solving them. The scores are determined after conducting literature review. If the lean problems have been solved in case studies, the simulation applicability is set as high; Otherwise, if the lean problems have not been found in literature, the simulation applicability is determined as low. The case studies in Table 4-1 show that simulation technique is suitable for solving complex, dynamic, interactive problems and has an excellent ability in predicting future states as well as testing different scenarios.

Through comparing the existing problems with those listed in Table 4-1, companies can easily find out simulation suitability for their operations, and make decision about simulation adoption in their lean projects. For instance, if output of this investigation shows that they have severe problems such as long lead time, huge inventory, unbalanced work station, et al., they can conclude that simulation technique is the right tool to solve their problems.

Table 4- 1 Simulation Applicability for Lean Problems

LEAN PROBLEMS	SIMULATION APPLICABILITY	CASE STUDIES
Overproduction	High	Duanmu and Taaffe (2007);
Waiting	High	Schroer (2004); Wang, Owen and Mileham (2005); Enns, (2007); Duanmu and Taaffe (2007);
Transportation	High	Wang, Owen and Mileham (2005); Enns, (2007);
Non-value-added processing	High	Enns, (2007); Duanmu and Taaffe (2007);
Excess Inventory	High	Duanmu and Taaffe (2007);
Defects	Low	No
Excess Motion	Low	No
Underutilized people	Low	No
Identify existing problems	High	Schroer (2004);
Rank opportunities for improvement	High	Enns, (2007); Duanmu and Taaffe (2007);
Predict impact of improvement	High	Wang, Owen and Mileham (2005); Bodner and Rouse (2007); Enns, (2007); Duanmu and Taaffe (2007);
Address random and structural variation	High	Standridge and Marvel (2006); Schroer (2004); Bodner and Rouse (2007); Wang, Owen and Mileham (2005);
Assess the interaction between system components	High	Standridge and Marvel (2006); Marvel, Schaub and Weckman (2005); Tan and Platts, (2003); Duanmu and Taaffe (2007);
Validate future state	High	Standridge and Marvel (2006); Marvel, Schaub and Weckman (2005); Bodner and Rouse (2007); Enns, (2007); Duanmu and Taaffe (2007);

LEAN PROBLEMS	SIMULATION APPLICABILITY	CASE STUDIES
Identify alternatives to the future state	High	Standridge and Marvel (2006); Wang, Owen and Mileham (2005); Enns, (2007); Duanmu and Taaffe (2007);
Detail dynamic behaviour of production processes	High	Standridge and Marvel (2006); Marvel, Schaub and Weckman (2005); Duanmu and Taaffe (2007);
Analyze data	High	Standridge and Marvel (2006); Bodner and Rouse (2007); Enns, (2007);
Document process	Low	No
Train personnel	Low	No

4.3.2 SET SIMULATION OBJECTIVES

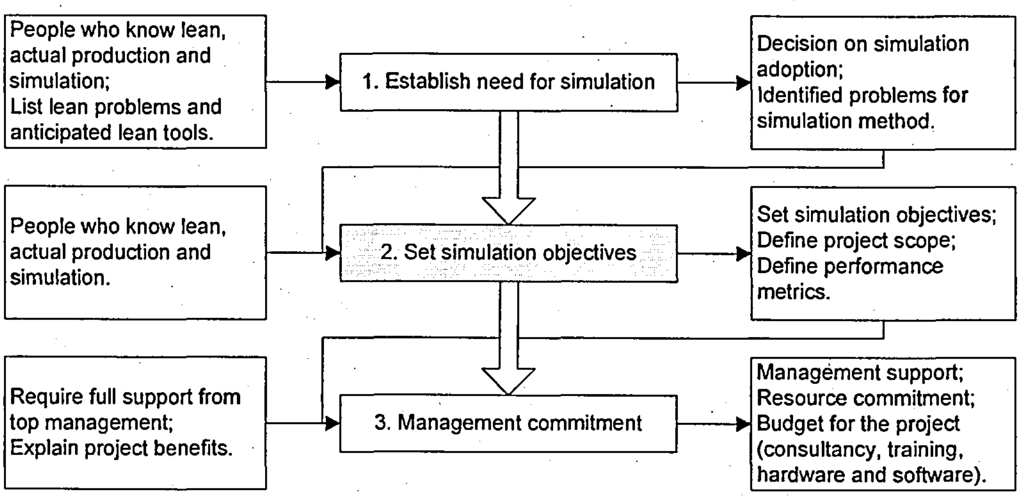


Figure 4- 3 SimLean Stage Two

Figure 4-3 shows the stage two of SimLean framework, which aims to set simulation objectives for the lean projects.

Input elements are a group of people who have knowledge of lean methodology and simulation technology, along with problems identified for simulation method from last stage. This group of people will decide whether or not to adopt simulation technology in their lean projects. Generally speaking, not all lean projects need to employ simulation technique; only for the complex, dynamic systems with many variables, or for predicting results before actual implementations, it requires the use of simulation technique (detailed description can be found in section 2.4, section 2.6 and section 4.2).

The output of this stage is to set simulation objectives for the project. Based on the problem formulation in last stage, a set of objectives can be determined for the simulation study. At the same time, project scope and performance metrics should be defined clearly. Examples include determining current-state performance, testing design alternatives, studying the impact of speeding up the mainline conveyor, and optimizing the number of carriers in a material-handling system.

4.3.3 MANAGEMENT COMMITMENT

Figure 4-4 shows that leadership commitment is essential for the success of projects. For instance, if a company is intending to apply lean for the first time, its requirements for lean consultancy and training may be huge. It needs full support from the leadership to start the project. Achanga, et al. (2006) stated that "leadership and management commitment are the most critical ones in determining the success of a lean project within the SMEs premise. In order to succinctly implement the concept of lean manufacturing successfully within SMEs, the recipient companies should harbour strong leadership traits capable of exhibiting excellent project management styles. Good leadership ultimately fosters effective skills and knowledge enhancement amongst its workforce, improve resource availability, willingness to learn and acquire new ideas and technologies for its corporate competitiveness."

Input elements include strong demand for supporting from top management, explanation of project benefits to the management, and the output elements from stage two.

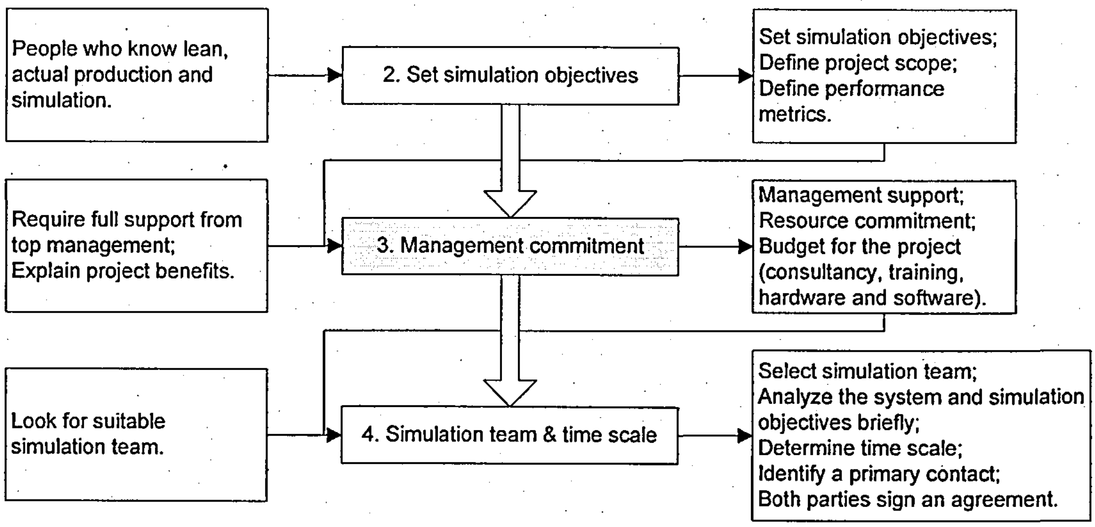


Figure 4- 4 SimLean Stage Three

Output elements of this stage include leadership commitment, and most importantly, enough budget for the project (including consultancy, training, hardware, software and others).

4.3.4 SIMULATION TEAM AND TIME SCALE

After obtaining leadership commitment, the next stage is to find simulation team and determine time scale (Figure 4-5).

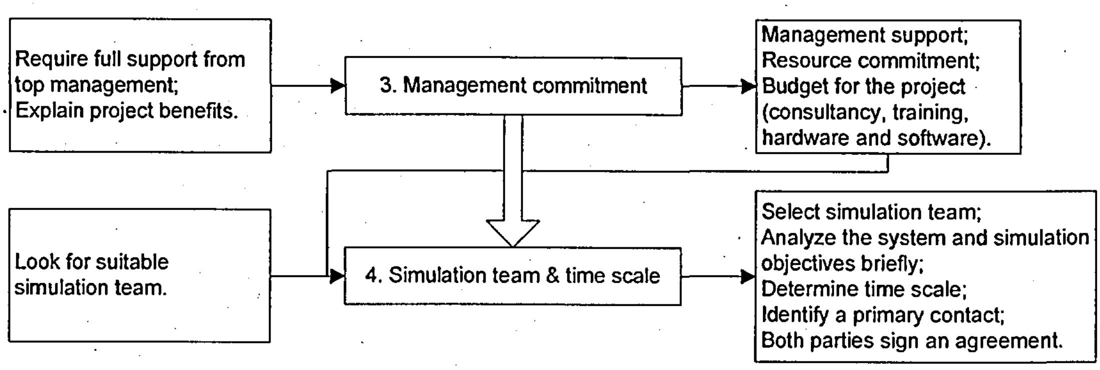


Figure 4- 5 SimLean Stage Four

Input elements are search for suitable simulation teams, and the output elements from stage three. Good simulation teams should have profound knowledge of simulation modelling and plenty experience in industry and lean cases, meanwhile the budget is another factor that influences team selection. Normally three options are available for team selection, which include hiring consulting company, employing some simulation experts or building in-house simulation department. Decisions should be made in consideration of the frequency of simulation adoption, company size and possible budget. Table 4-2 shows the recommendation of team selection principles. For instance, if the company size is small, and its simulation need is low, it might consider hiring some consultants for the simulation projects; On the other hand, if the company scale is big, and its need for simulation is very high, it could think of having its own in-house simulation department.

Table 4- 2 Simulation Team Selection

COMPANY SIZE / SIMULATION NEED	SMALL	MEDIUM	LARGE
LOW*	consultants	consultants	consultants
MEDIUM**	consultants	Experts	Experts or In-house
HIGH***	consultants	Experts	In-house

Low*: Companies only use simulation occasionally to solve particular problems.
Medium**: Companies use simulation frequently.
High***: Companies use simulation regularly or as a general practice in the pre-implementation stage.

After simulation team is determined, the simulation people should analyze the system and simulation objectives briefly, in order to estimate if the mission can be finished within original time scale. To ensure the good communication between company and simulation team, a primary contact in the company who knows production very well should be selected at this stage. At the end of this stage, an agreement should be drafted and signed by both parties.

4.3.5 PRE-IMPLEMENTATION

Next step is pre-implementation; where simulation models are constructed for current state and future state of the system (see Figure 4-6). Detailed descriptions are stated below.

Input elements include output elements from last stage, together with analyzing the system carefully, developing system specification in six elements (see Table 4-3), collecting data in certain format and starting to build simulation models.

Table 4- 3 System Specification in Six Elements (Kelton, et al. 2004)

Elements	Contents
1. Simulation objective	What is to be included in the simulation model? At what level of detail?
2. System description	What are the primary resources of the system? Are process plans or process flow diagrams available? Are there physical, technological, or legal constraints on how the system operates? Are there defined system procedures? How are decisions made?
3. Modelling approach	When will data be available? What form will they be in? How accurate are the data?
4. Animation	What type of animation is required?
5. Input & output	Who will verify and validate the model, and how? What kind of output is required? How many scenarios will be considered? What are the major milestones of the study?
6. Deliverables	What are the deliverables?

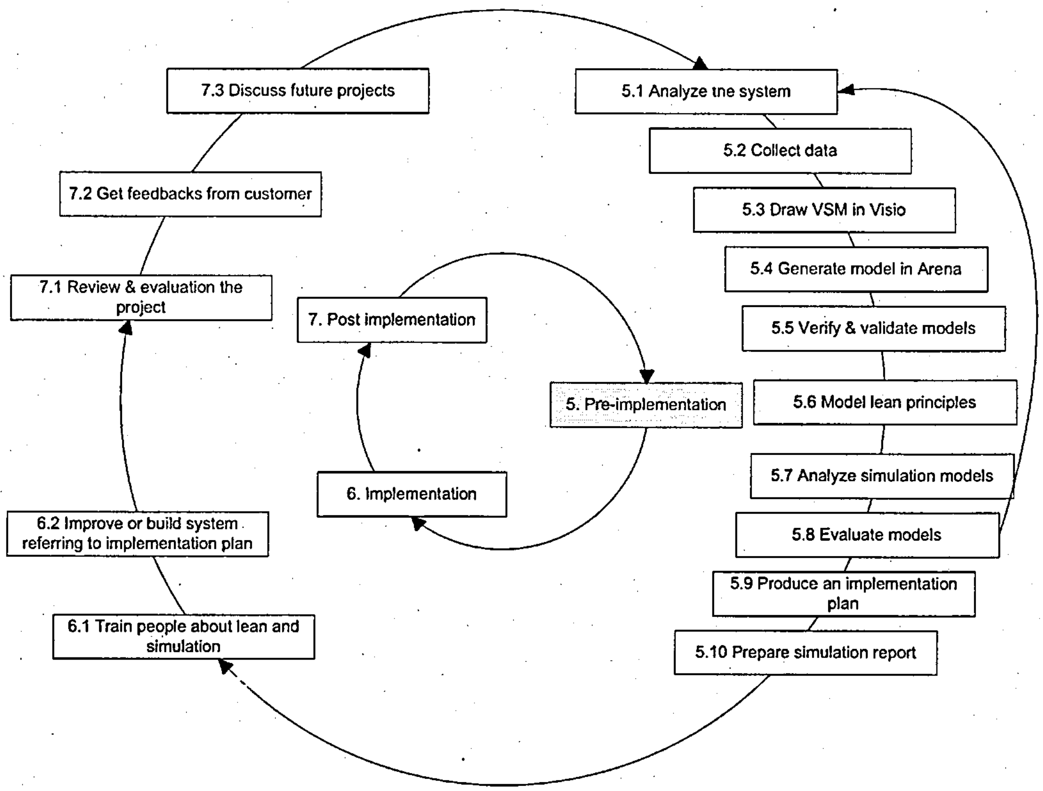


Figure 4- 6 SimLean Stage Five

Output elements include delivering models on time, asking client to install simulation software on their PCs and preparing simulation reports and documentations. Since the most time-consuming and laborious work – simulation model building takes place at this stage, a detailed and step-by-step guidance or roadmap is designed as shown in Figure 4-7.

Simulation modelling process accomplished at pre-implementation stage can be divided into three steps, which are current state modelling, future state modelling and results presenting. The flowchart is shown in Figure 4-7.

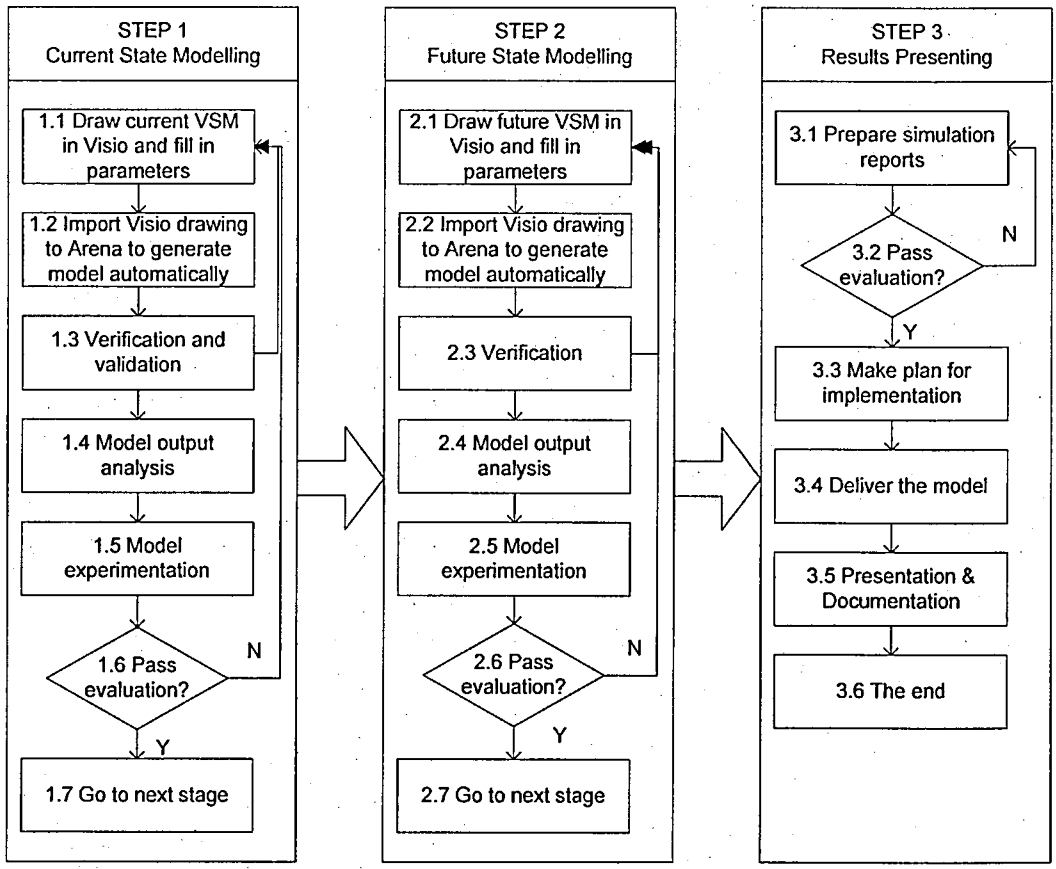


Figure 4- 7 Simulation Modelling at Pre-implementation Stage

(i) Step one

Step one begins with drawing current VSM in Visio software and fill in parameters for each module. In order to simplify and facilitate model building process for VSM, an interface in Visio – termed VisVSM template is designed and described in Chapter five. Here users can draw VSM in Visio with customised VisVSM template which contains parameters for each module in correspondence with SimVSM template in Arena software, details are explained in Chapter five.

After the current VSM is drawn with VisVSM template in Visio, users can export the Visio drawing to Arena via "Simulation -> Simulation drawing" menu in VisVSM template. A mapping file from Arena software to Visio software has been pre-defined to enable the auto-generation of simulation models with the exported VSM drawings (see Appendix E).

Thirdly, it comes to verification and validation process. If the model logic has problems, it can be discovered by verification process. If the output result doesn't match real system, it means the model is not valid, and the modeller has to go back to the concept design step again, which is to draw the static VSM in Visio environment.

After verification and validation step, we can make the output analysis of simulation models. Since simulation technique is good at solving complex, stochastic problems in dynamic systems, it provides better results than static lean tools, such as VSM. The case studies in Chapter six provide detailed descriptions of models' output analysis.

Then we can use optimisation tools to carry out model experimentation. Arena software provide OptQuest package to search for the optimal parameter set for the model; OutputAnalyser (another package in Arena software) to compare different scenarios for current state models. With reference to the results of OutputAnalyser, we can pick up the best one or two scenarios of the current state model, and run models for a long term, e.g. one year to check if variation is within limit.

Step seven is evaluation process. If the customer is happy with the current state model, the project goes to next step; otherwise, be prepared to redo the whole work from step 1.1 "Draw current VSM in Visio".

(ii) Step two

After current state modelling comes to end, we start step two – future state modelling. The procedure is almost the same, what differs from step one is that "Draw current VSM" is replaced with "Draw future VSM" and "validation" process is removed because there is no actual system to be compared with.

(iii) Results presenting

After current model and future model are well developed according to customer requirements, it is time to present results and deliver models.

Simulation report should include outputs of current state model and future state model. However, modellers should be prepared to make some changes to the report; for instance, the customer might want the results in comparison format, and shown in 3D-bar chart; Or the customer might not be interested in those technical specifications, especially for top management, they only care about actual savings on money and cost, in that case, to convert technical specifications to economical numbers, some mathematical calculation might be required.

If simulation report passes the evaluation, modellers can make plan for implementation together with lean experts in the company, with reference to future state model.

After implementation plan is made, the next thing is to disseminate the model within time scale and ask client to install simulation software on their PCs. In the end of the project, the final presentation and documentation should be provided by the simulation team.

4.3.6 IMPLEMENTATION

At implementation stage, changes should be made according to the implementation plans made in pre-implementation stage.

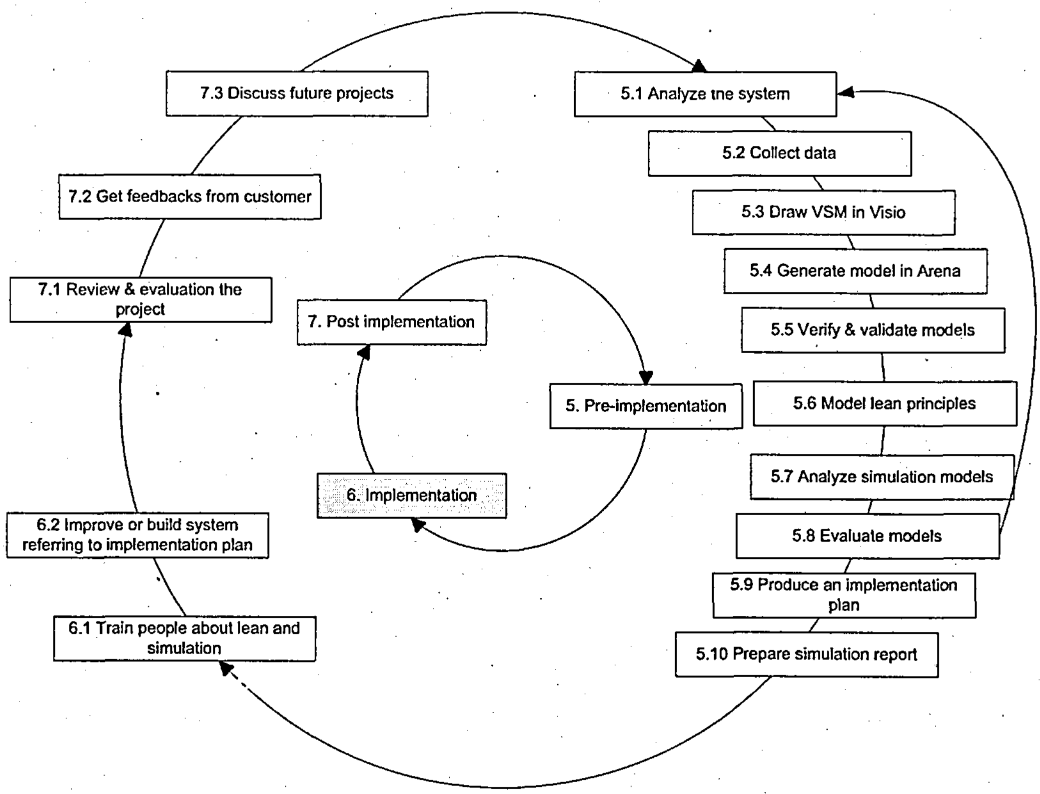


Figure 4- 8 SimLean Stage Six

Input elements are people training and output elements from pre-implementation stage. Production managers should be trained about using simulation models to predict outcomes of their lean project, meanwhile understand simulation report precisely.

Simulation model acts like a reference to managers at this stage (see Figure 4-8). Changes to the system are made according to the implementation plan produced in last stage and the simulation model of future state; since several future scenarios can be analyzed with OptQuest and OutputAnalyzer, managers can clearly see the results of different implementation plans. It also helps to make the culture change and persuade employees to prepare for the changes. Meanwhile, managers can compare real situation with simulation results and make some adjustment to the model when necessary.

4.3.7 POST IMPLEMENTATION

Post implementation stage is all about project review and future project discussion (see Figure 4-9). The simulation team should ask for feedbacks from the customer, and if the customer is satisfied with the simulation work in lean project, he is more likely to discuss future simulation projects.

The discussion should include the contents from Stage one-"Establish need for simulation" to Stage four-"Simulation team and time scale" as explained in previous sections. After the four stages are completed, the project goes to "Pre-implementation" again; hence the SimLean framework forms a loop.

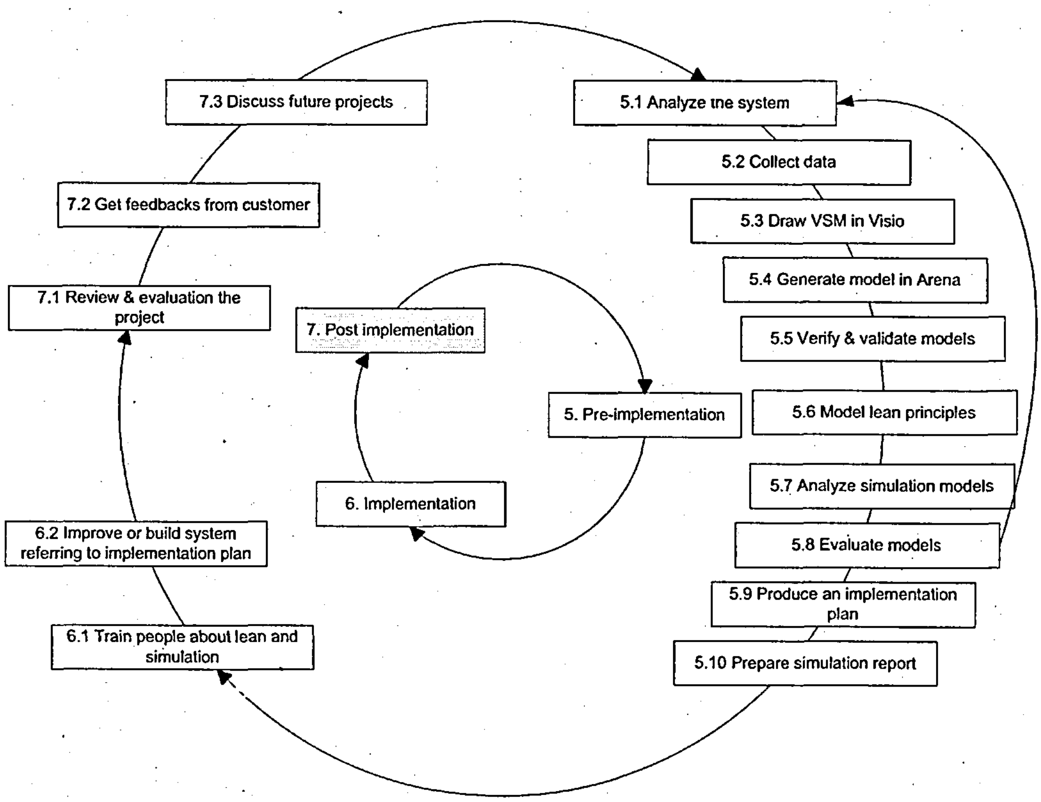


Figure 4- 9 SimLean Stage Seven

4.4 FEATURES OF THE SIMLEAN FRAMEWORK

4.4.1 SYSTEMATIC

SimLean framework contains seven stages, which cover the whole lean project cycle from "qualify need for simulation" to "post implementation", and the structure is clear, coherent and comprehensive.

First of all, distinctions between the seven stages are very clear, each stage has highly summarized the central theme of the stage, and there is no functional overlap or cross. Therefore, the structure of SimLean framework is very clear, which makes it easy to understand and implement.

Secondly, not only does the division of the seven stages have clear significance, but also it is arranged in execution time sequence, which makes it time continuous. For instance, stage one – "Qualify need for lean" is the basis and foundation of all the other stages, and stage two – "Set simulation objectives" can not be conducted until the completion of stage one. Similarly, stage three "Leadership commitment" can not begin until stage two finishes. Stage seven "Post implementation" is the last step in project execution, where review and evaluation about the results achieved after the whole implementation are made and future projects are discussed. As a result, the time continuity of SimLean framework has greatly enhanced its practical feasibility.

Thirdly, SimLean framework includes all the essential elements in "INPUT" and "OUTPUT" sections of each stage. Input elements are people or activities required at the beginning of each stage; and output elements are results achieved in the end of each stage. The detailed items summarized in "INPUT" and "OUTPUT" sections provide a good reference for the actual implementation.

To sum up, SimLean is a systematic reference framework with clear, coherent and comprehensive structure.

4.4.2 GENERIC AND HOLISTIC

SimLean framework has wide applicability. No matter the size of the company is small or large; the type of the main products is food or steel; lean experience of the company is entry level or repeat user; the area of simulation application is within the entire business or just on a specific area; complexity level of the process is low or high; and company strategy of implementation is a quick project or a durable project, SimLean can serve as a suitable reference framework for the company. Therefore, SimLean is a generic and holistic framework for embedding simulation in lean projects.

4.4.3 OVERCOME MAJOR CHALLENGES

SimLean framework has simplified, facilitated and standardized simulation embedding process in lean projects, which has not been achieved before.

McClellan (2004) stated that making an accurate simulation model is very difficult because of the tremendous amount of factors in a normal manufacturing system. From literature review and company interviews, the author has found out that among the dozens of lean tools, VSM (value stream mapping) is an easy technique to visualise a whole and complex manufacturing system, identify wastes and their sources and guide improvement efforts (Rother and Shook, 1999).

Hence, the researcher tried to combine VSM method with simulation technique to simplify model building process for lean projects. Then another problem was found out that there was no uniform way of modelling VSM, and the reliability of simulation models depends on modeller's experience.

In order to solve problems mentioned above, a customised simulation environment (including SimVSM template in Arena and VisVSM template in Visio) is proposed in Chapter five. SimVSM is a customised simulation template for VSM modelling, which contains eleven modules corresponding with VSM icons, integrates up to 23 blocks in logic design of each module. Instead of dragging up to 23 blocks to accomplish some task, users only need to drag one module out from SimVSM template to achieve the same function. VisVSM is an interface in Visio software, which is designed to provide ease of building simulation models for non-expert users. Therefore, the proposed SimVSM template has simplified, facilitated VSM model building process, and provided a type of standard way to embed simulation technique in lean projects.

5 CUSTOMISED SIMULATION ENVIRONMENT

5.1 INTRODUCTION

In previous chapter, the development of a reference framework for embedding simulation technology in lean manufacturing was conducted. Last chapter also presented that stage five in SimLean framework – Pre-implementation is the most time-consuming and laborious stage, where simulation model building takes place. In order to simplify, facilitate and standardize modelling process, a customised simulation environment is proposed in this chapter.

Hence, Chapter five aims to develop a customised simulation environment for implementing the SimLean framework presented in Chapter four.

In order to achieve the above aim, this chapter has been structured as following. An overview of Arena template developer system is outlined and discussed in Section 5.2; Section 5.3 presents the development process of the customised simulation environment; Section 5.4 explains the determination process of VSM modules for simulation template in Arena developer system; Section 5.5 describes the detailed design of template modules which were focused on single product, single supplier, single customer and non-paralleled processes; after conducting further review of VSM, it was found out that in order to deal with complex situations, multiple products, multiple suppliers, multiple customers and paralleled processes need to be included in the SimVSM template, and Section 5.6 describes the necessary changes to the model logic; Section 5.7 demonstrats the development of Visio interface – VisVSM template; Verification and validation of each individual module in the proposed system is presented in Section 5.8; and finally the summary of this chapter is shown in Section 5.9.

5.2 OVERVIEW OF ARENA TEMPLATE DEVELOPER

The customised simulation environment described in this chapter was developed with the aid of Arena template developer system.

Arena provides a fully integrated environment for building, graphically animating, verifying, and analyzing simulation models. It does so by the creation of reusable modelling components called modules that are collected into libraries, or templates. A module definition is created by working with five windows: dialog design, logic, switch, user view, and panel icon. A template window in Figure 5-1 shows these five windows. The five buttons used to open module definition windows (from the toolbar shown in Figure 5-1) are arranged in the order that we find we most often work when initially building a new module; i.e., first defining the dialog design and logic, then switches to control turning on and off module options, and finally the user view and panel icon graphics (Rockwell Automation, 2005).

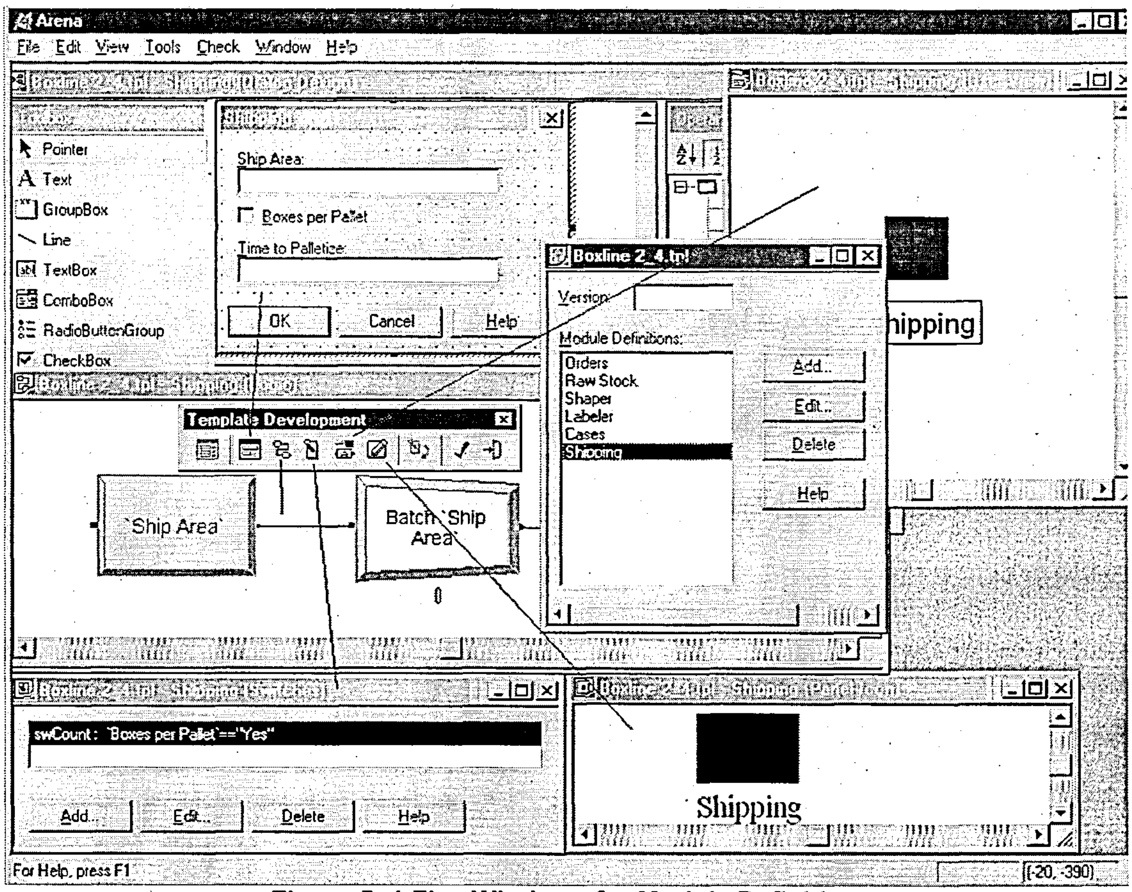


Figure 5- 1 Five Windows for Module Definition

To use a module in an Arena model, a panel containing the module is attached to the Project Bar. This panel displays all of the modules that may be selected for placement in the model. To build a model, you select a module from the panel and place it in the model window. The graphics associated with the module, referred to as its user view, are added to the model window (Rockwell Automation, 2005).

5.3 THE SYSTEM DEVELOPMENT PROCESS

The system development process went through three stages. First stage aims to determine template modules; since VSM is a commonly used tool without a uniform standard, the selection of VSM icons was based on some knowledge elicitation technique, see Section 5.4 for detailed descriptions. Second stage of the development process is to design the template modules; including dialog design, logic design, switch edit, user's view design, panel icon design which are discussed in Section 5.5. Further review of VSM indicated some changes to the module logic which is described in Section 5.6. Interface design in Visio environment is presented in Section 5.7. Stage four is the verification and validation of the developed system as discussed in Section 5.8.

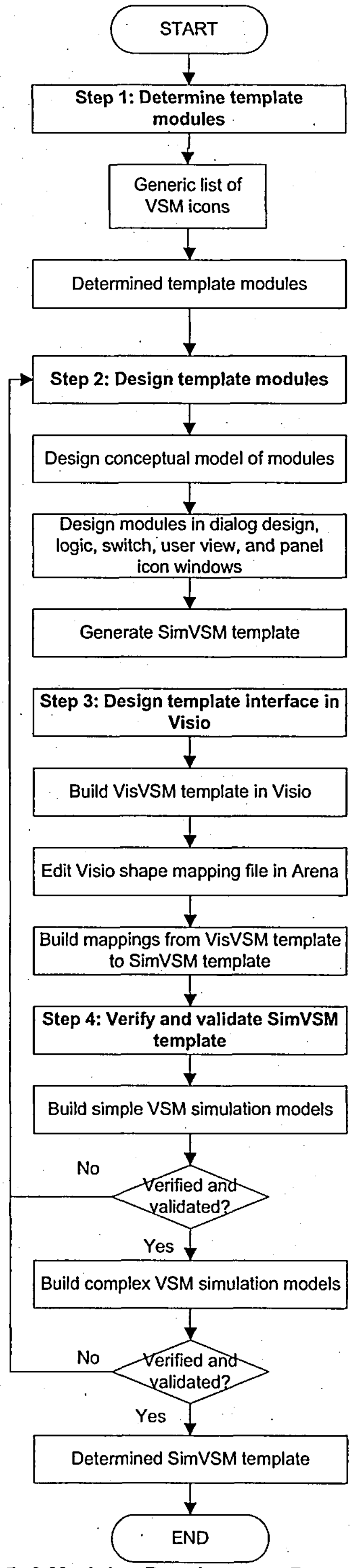


Figure 5- 2 Modules Development Process

5.4 DETERMINE TEMPLATE MODULES

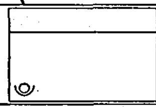
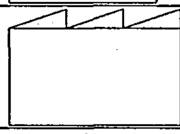
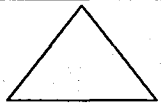
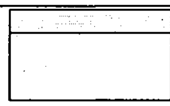
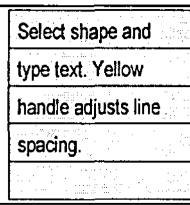
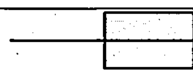
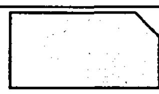
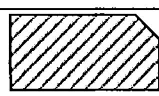
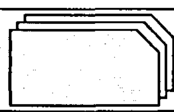
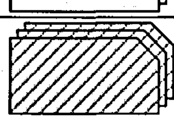
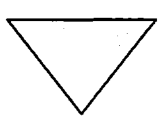
Stage one of the system development process aims to analyze the functions of static VSM icons so as to determine template modules in Arena software. In terms of selecting VSM icons, it is important to note that even though there is no standard set of VSM icons generally acknowledged, the most important and fundamental icons are accepted and shown in almost any lean books and papers.

In order to determine the suitable modules for simulation template, firstly literature review was used to collect the function of each VSM icon. In order to reduce confusions at this point, a set of VSM icons drafted by Visio 2007 was selected as the prototype for this research. The descriptions of each VSM icon were summarized by Rother and Shook (1999) and McClellan (2004) as displayed in Table 5-1. Secondly, the researcher adopted concept sorting to get a deeper understanding of VSM icons. After that, a few confusions came out and the researcher discussed these problems with supervisor, who provided great help to solve the problems and to determine the final version of VSM modules. At last, eleven modules were selected for the customised simulation template SimVSM. Table 5-2 lists the modules' names and the selected VSM icons in each module.

Because of the difference between static VSM method and dynamic simulation technique, some VSM icons were not included in simulation environment, which were displayed in Table 5-3.

Table 5- 1 Static VSM Icons in Visio 2007

Modules	Icons (Visio 2007)	Descriptions

Modules	Icons (Visio 2007)	Descriptions
Process		One process box equals an area of flow. All processes should be labelled.
Customer / Supplier		Used to show customers, suppliers, and outside manufacturing processes.
Inventory		Count and time should be noted.
Shipment Truck		Note frequency of shipments.
Production Control		Used for departments, such as Production Control.
Data Table		Used to record information concerning a manufacturing process, department, customer, etc.
Timeline Segment		It helps us separate the value added cycle time (taken from data boxes) from the non-value added time (days' or hours' supply info).
Timeline Total		It is used to sum up all the "value-add" cycle times and "inventory" time and note them at the end of the timeline.
Production Kanban		The "one-per-container" kanban. Card or device that tells a process how many of what can be produced and gives permission to do so.
Withdrawal Kanban		Card or device that instructs the material handler to get and transfer parts (i.e. from a supermarket to the consuming process).
Batch Kanban		Production kanbans arriving in batches.
Batch Withdrawal Kanban		Withdrawal kanbans arriving in batches.
Signal Kanban		The "one-per-batch" kanban. Signals when a reorder point is reached and another batch needs to be produced. Used where supplying process much produce in batches because changeovers are required.

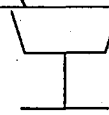
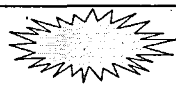
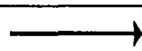
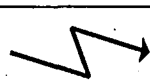
Modules	Icons (Visio 2007)	Descriptions
Kanban Post		Place where kanban is collected and held for conveyance.
Supermarket		A controlled inventory of parts that is used to schedule production at an upstream process.
Safety / Buffer Stock		"Buffer" or "Safety Stock" must be noted.
FIFO Lane		Indicated a device to limit quantity and ensure FIFO flow of material between processes. Maximum quantity should be noted.
Kaizen Burst		Highlights improvement needs at specific processes that are critical to achieving the value stream vision. Can be used to plan kaizen workshops.
Physical Pull		Pull of materials, usually from a supermarket.
Sequenced Pull Ball		Gives instruction to immediately produce a predetermined type and quantity, typically one unit. A pull system for subassembly processes without using a supermarket.
Load Levelling	OXOX	A production scheduling technique used in lean manufacturing to set production to meet customer demand.
Push Arrow		Material that is produced and moved forward before the next process needs it, usually based on a schedule.
Pull Arrow		Pull materials from upstream process or supermarket.
Manual Information		For example: production schedule or shipping schedule.
Electronic Information		For example: via electronic data interchange.

Table 5- 2 Determined Modules for SimVSM Template

Modules	Contained VSM icons
Supplier	Supplier

Modules	Contained VSM icons
Truck	Shipment truck
Customer	Customer, withdrawal kanban, batch withdrawal kanban
ProcessVSM	Production control, data box, withdrawal kanban, batch withdrawal kanban
Inventory	Inventory
Supermarket	Supermarket, production kanban, batch production kanban, signal kanban, kanban post, physical pull arrow
Safety stock	Buffer / safety stock
Kaizen	Kaizen burst
Sequenced pull ball	Sequenced pull ball
FIFO	FIFO
Load levelling	Load levelling

Table 5- 3 Unselected VSM Icons

VSM icons	Unselected reasons
Timeline segment	Simulation report provides better statistical analysis about lead time
Timeline total	Simulation report provides better statistical analysis about lead time
Push arrow	Simulation models use auto-connect arrows for linking two modules
Pull arrow	Simulation models use auto-connect arrows for linking two modules
Manual information	All schedules in simulation models are preset, no manual info.
Electronic information	All schedules in simulation models are preset.

5.5 DESIGN TEMPLATE MODULES

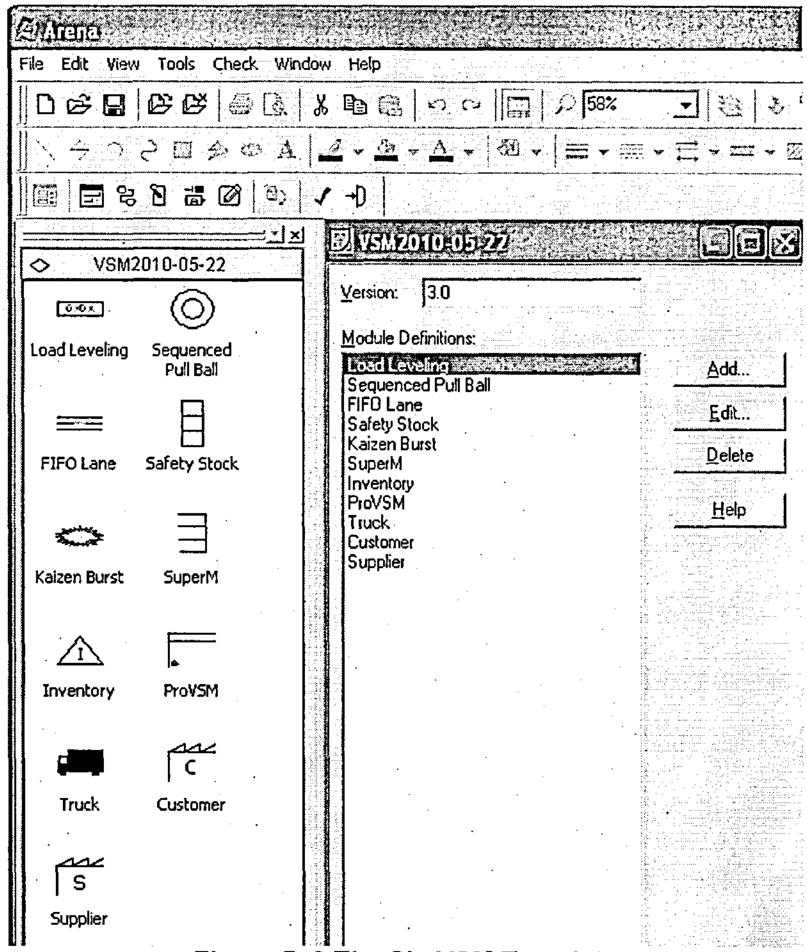


Figure 5- 3 The SimVSM Template

In order to simplify, standardize and facilitate model building process in Pre-implementation stage of SimLean framework, a customised simulation environment with eleven modules is proposed with the adoption of VSM (value stream mapping) icons in Arena software (see Figure 5-3). Seven modules with logic design are included in SimVSM simulation template for push and pull states of VSM (see Table 5-4).

Table 5- 4 Block Number of Modules in SimVSM Template

Module Name	No. of blocks used in logic design
Supplier	4

Module Name	No. of blocks used in logic design
Customer	10
Truck	3
Safety stock	4
ProcessVSM	23
Inventory	12
Supermarket	17

From Table 5-4, we can see that the customised simulation environment – SimVSM template has packaged 4 to 23 blocks in different modules, thus dramatically reduces block numbers used in model construction, and greatly saves model building time and eliminate logic errors in simulation models.

5.5.1 SUPPLIER MODULE

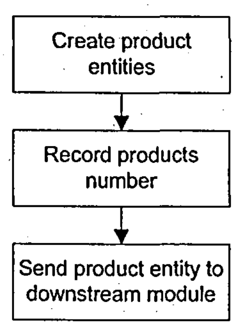


Figure 5- 4 Logic Concept of Supplier Module

The supplier module is used to create product entities in the model. Users can define supplier name, entity type, supply quantity, supply interval and time unit. After product entities are created, the logic will record the total product number and send product entities to downstream module via “next label” (see Figure 5-4).

5.5.2 CUSTOMER MODULE

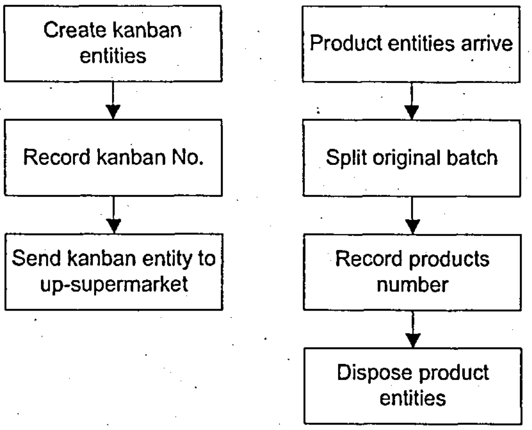


Figure 5- 5 Logic Concept of Customer Module

The customer module has two functions. In push system, it receives product entities from upstream module, split the original batch, record the total product number, and at last dispose all product entities. In pull state, besides the functions applied in push state, it has other tasks – create kanban entities, assign withdrawal kanban tag to the kanban entities, and send those wkanban entities to upstream supermarket (see Figure 5-5).

5.5.3 TRUCK MODULE

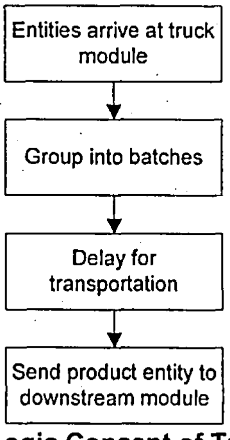


Figure 5- 6 Logic Concept of Truck Module

Truck module is designed to transport raw materials from suppliers to downstream manufacturers, or ship products to customers. Product entities arriving at truck module are grouped into batches, delayed for a certain time for transportation, and sent to downstream module in the end. Users can set up parameters such as truck name, transport time and truck batch size (see Figure 5-6).

5.5.4 SAFETY STOCK MODULE

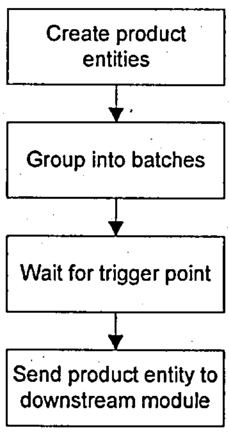


Figure 5- 7 Logic Concept of Safety Stock Module

Safety stock module is designed to protect downstream operations from being starved due to currently out-of-control process variances. Product entities are created and grouped into batches, waiting for the trigger point or signal from downstream module; when the trigger point is reached, pre-defined amount of product entities are sent to downstream module immediately via “next label”. Module parameters include stock name, stock quantity, next process name, product batch and trigger point (see Figure 5-7).

5.5.5 PROCESSVSM MODULE

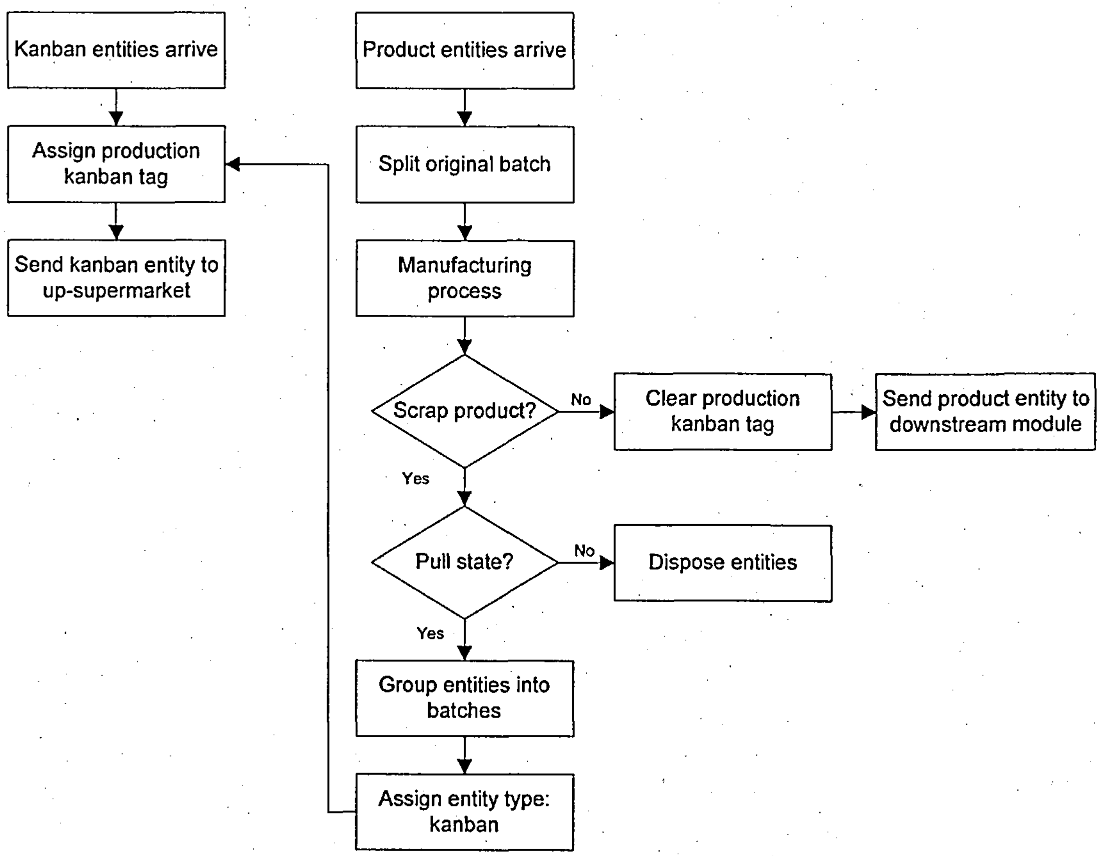


Figure 5- 8 Logic Concept of ProcessVSM Module

There are two parts of ProcessVSM logic design. One part is focused on processing products, while the other part is responsible for dealing with kanban signals. For instance, in push state, after the product entities arriving at this module, the original batch is split, and each product entity goes through manufacturing process, as shown in Figure 5-8. If the product is qualified, the entity goes to downstream module via "next label" link; otherwise if the product is scrapped somehow, it couldn't go to the next module and the entity will be disposed immediately.

If the system is in pull state, the ProcessVSM module will receive kanban entities from downstream supermarket module, then assign production kanban tag to kanban entities, and send those kanban entities to upstream supermarket module to ask for more raw materials. Meanwhile, the scraped products will be grouped into product batches permanently, assigned kanban attribute, and these newly created kanban entities will be sent to upstream supermarket.

There are ten parameters to set up in this module: process name, product batch, capacity, variations, scrap rate (0-1), cycle time (sec), changeover time, uptime (1-100), upstream supermarket, and system type (push or pull).

5.5.6 INVENTORY MODULE

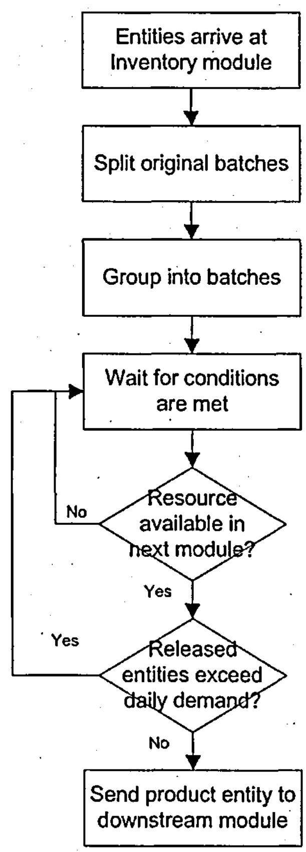


Figure 5- 9 Logic Concept of Inventory Module

The inventory module is used in push system. When product entities arrive at inventory module, the original batches will be split into individual entities, then grouped into "product batches", and wait for two conditions to be met. If the resource is available in downstream process, meanwhile the released entities have not exceeded the daily demand, it will send product entities to downstream module, otherwise the products will keep waiting. There are six parameters to fill in: inventory name, inventory quantity, next process, entity type, product batch and daily demand (see Figure 5-9).

5.5.7 SUPERMARKET MODULE

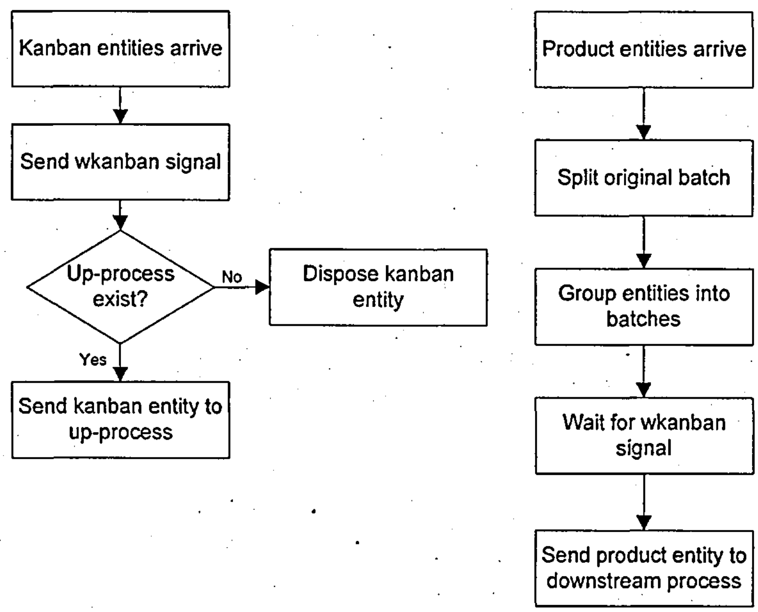


Figure 5- 10 Logic Concept of Supermarket Module

Supermarket module is used in pull system. The logic design includes two parts: kanban logic and product logic. The left part shown in Figure 5-10 is the kanban logic. When kanban entities arrive at Supermarket module, a decide block is used to determine whether or not the upstream process exists; If so, the kanban entities are sent to upstream process, if not, the kanban entities are disposed.

The product logic is shown on the right side of Figure 5-10. Firstly, product entities arrive at supermarket module, after that, the original batch is split into individual product entity, then entities are grouped into batches and waits for withdrawal kanban signal, and after receiving the withdrawal kanban signal, the individual entities are sent to downstream process via "next label" link.

Six operands are designed in this module, which include store quantity, supermarket name, upstream process, product batch, entity type and daily demand.

5.6 TEMPLATE MODIFICATION

Further review of VSM indicated that in complex situations, multiple products, multiple suppliers, multiple customers and paralleled processes need to be included in the template. This section describes the modifications made to four modules in SimVSM template.

The modified modules are customer, inventory, supermarket and ProcessVSM. Table 5-5 lists the block number in the modified four modules. The new dialog design of ProcessVSM module, Inventory module and Supermarket module are shown in Appendix C.

Table 5- 5 Block Number of Modified Modules in SimVSM Template

Module Name	No. of blocks used in logic design
Customer	10
ProcessVSM	38
Inventory	23
Supermarket	39

From Table 5-5, we can see that except Customer module, the other three modified modules contain more blocks than the original version (as shown in

Table 5-4). The changes in logic design of the four modules are presented as follows.

5.6.1 CUSTOMER MODULE MODIFICATION

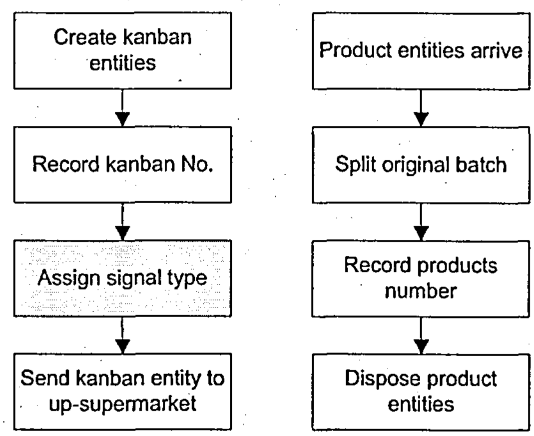


Figure 5- 11 Logic Concept of Modified Customer Module

The change to the customer module is in Kanban logic section as shown in Figure 5-11. In the original version, only one product can be manufactured in the system, thus the kanban entity has only one mission – to send signal to the upstream supermarket. However, in the modified system, up to three products can be processed in the system at the same time, which requires the customer module to distinguish the product type on the kanban entity; therefore an attribute of signal type has been assigned to the kanban entity.

5.6.2 INVENTORY MODULE MODIFICATION

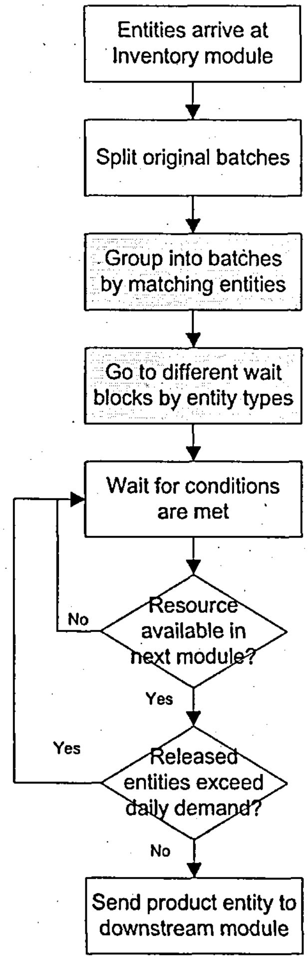


Figure 5- 12 Logic Concept of Modified Inventory Module

Modifications to the inventory module include two parts. First part is "group into batches"; to deal with multiple products in one inventory module, the logic has to batch the products of the same entity type. Secondly, considering that different products might go to different process modules, they should be placed in different wait blocks in the inventory module, and the following decide modules, scan modules and exit points have to be separated for different products as well (see Figure 5-12).

There are six new parameters to fill in on the module dialog: entity type2, next process2, inventory quantity2, entity type3, next process3 and inventory quantity3.

5.6.3 SUPERMARKET MODULE MODIFICATION

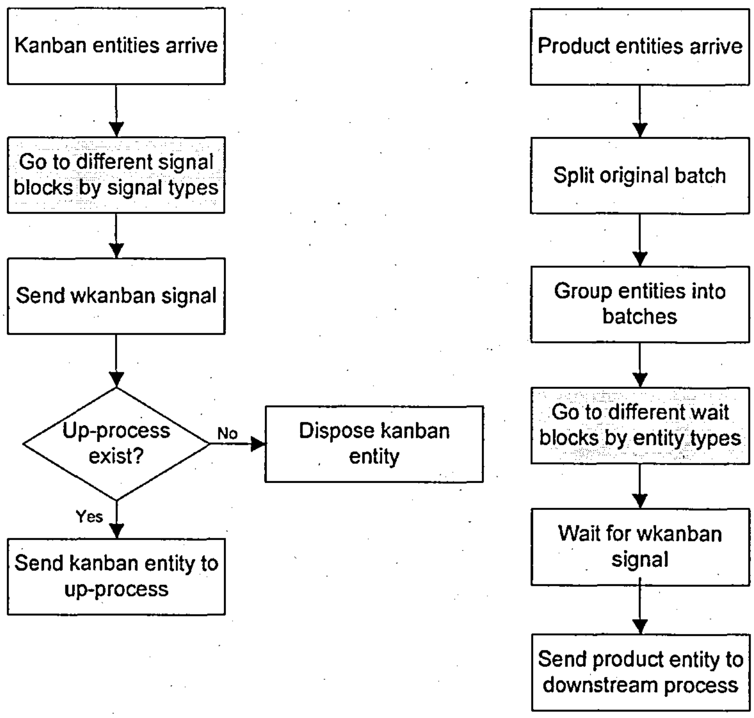


Figure 5- 13 Logic Concept of Modified Supermarket Module

The logic design of Supermarket module contains two parts: kanban logic and product logic (Figure 5-13). Both parts need modifications. For kanban logic section, after kanban entities arrive there, a decide module will send them to different signal blocks according to their attribute – signal type. After passing the signal blocks, the following decide blocks and route blocks have both been multiplied to suit the multi-product / multi-process requirement. In the product logic section, after been batched by entity types, the products are sent to different wait blocks according to their signal types. After that, the products are sent to different downstream processes via different exit points.

Six operands are added to this module, which include entity type2, upstream process2, store quantity2, entity type3, upstream process3 and store quantity3.

5.6.4 PROCESSVSM MODULE MODIFICATION

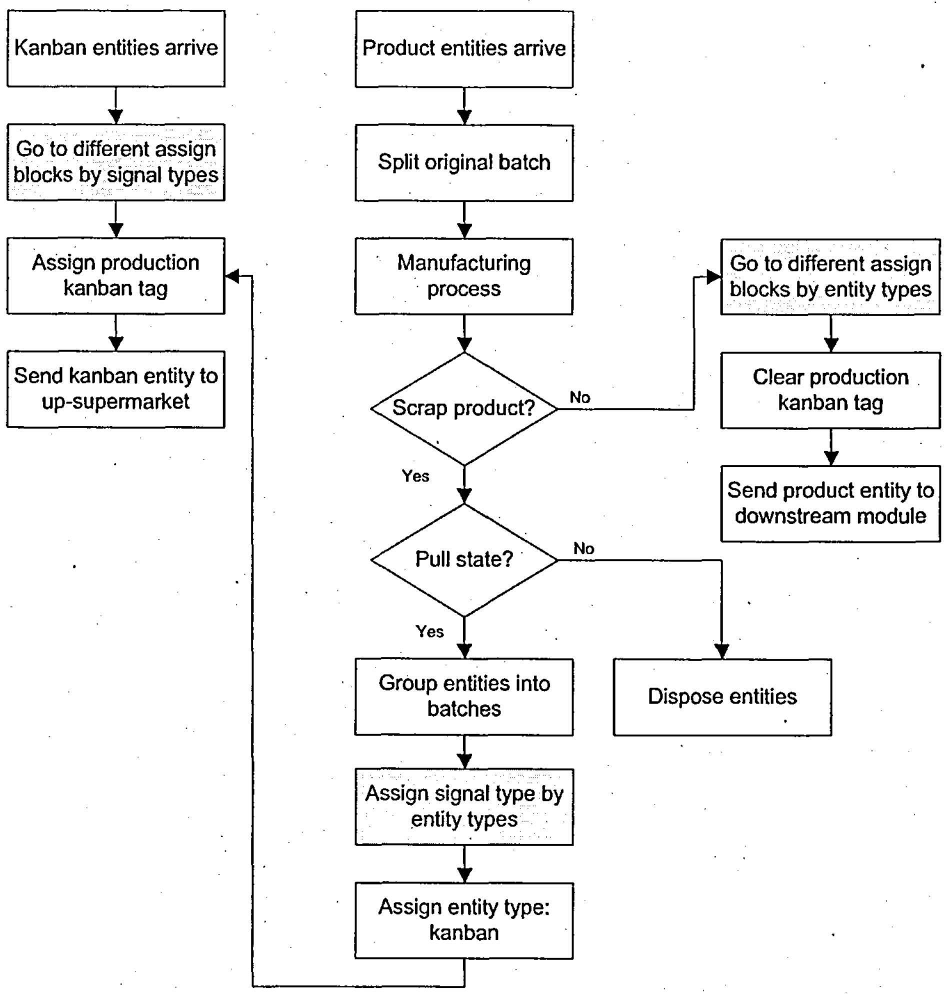


Figure 5- 14 Logic Concept of Modified ProcessVSM Module

There are three modifications to the ProcessVSM logic design (see Figure 5-14). One part is in the kanban logic section. After kanban entities arrive in the module, they are sent to different assign blocks by their "signal type" attribute, then they will go to different assign blocks to assign production kanban tag, after that, they are transported to different process modules via different route blocks. Part two of the modifications lie in product processing logic. If the products are not scraped, a decide block will decide where to send them referring to the entity types; after that, different assign blocks and exit points are designed for different product entities. The last part of the change is in the scraped products logic; in pull state, the scraped products are not disposed directly, instead they are grouped into batches and assigned attribute – signal type according to their original entity types; then the entity type is changed to kanban and these kanban entities are sent to assign blocks in the kanban logic section.

There are four new parameters added up to this module: entity type2, upstream supermarket2, entity type3 and upstream supermarket3.

5.7 TEMPLATE INTERFACE IN VISIO

In previous section, a customised simulation template for VSM modelling – SimVSM was developed. It has achieved the task of simplifying, facilitating and standardizing modelling process in lean projects. In order to further increase the ease of operation of the SimVSM template, an interface in Visio is proposed and described in this section.

Section 5.7 has been structured as follows: Section 5.7.1 presents an overview of Arena interface to Visio applications; Section 5.7.2 illustrates the structure of process simulator; Section 5.7.3 explains the development of VisVSM template; and Section 5.7.4 describes the editing of mapping file which links SimVSM template and VisVSM template.

5.7.1 ARENA INTERFACE TO VISIO APPLICATIONS (ROCKWELL AUTOMATION, 2005)

Arena supports the importing of Visio Drawing files. Rockwell Software, Inc. is a Visio Business Partner and has worked closely with Visio Corporation to provide an integrated, high quality, flexible interface to the industry-leading Visio application.

This interface features include:

- Support for conversion of any Visio shape (including custom shapes) to any Arena module (including custom modules).
- Support for copying any shape custom property data to any module operand value.
- Convert Hierarchical Visio Drawings to Hierarchical Arena models.
- A Visio Process Simulator for linking directly to Arena's Basic Process panel.

Software Architecture is shown in Figure 5-15:

The Visio Link is launched via the Import Visio Drawing item on Arena's File menu. After you select the Visio drawing to be imported, the Visio Link creates a new Arena model file containing modules and drawing objects (lines, boxes, etc.) that correspond to the objects in the Visio drawing. To decide what modules should be placed in the model, the Visio Link looks in the active map file, which lists a set of Visio shapes and the target modules that should be used in Arena.

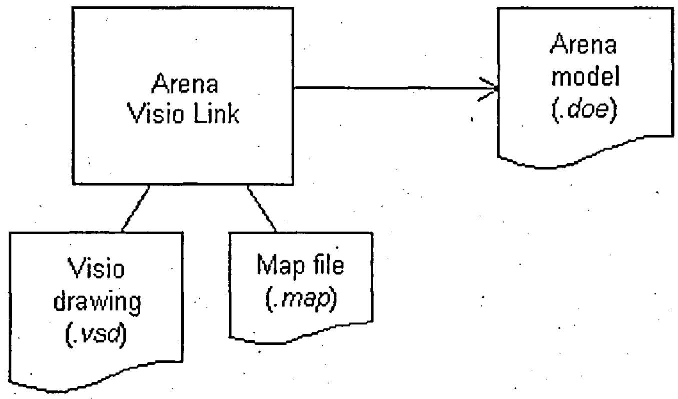


Figure 5- 15 Arena Software Architecture

5.7.2 PROCESS SIMULATOR INTRODUCTION (ROCKWELL AUTOMATION, 2005)

Arena software includes a Visio Process Simulator. This simulator consists of a custom Visio stencil and template that map directly to simulation constructs in Arena's Basic Process panel. If you have Arena Basic Edition or are primarily developing models in the Basic Process panel, the Visio Process Simulator provides an easy way to flowchart a process in Visio and import the drawing into Arena.

The Visio Process Simulator includes a custom Visio stencil and template (Process Simulation.vss and Process Simulation.vst) that allow you to map and define business processes in Visio drawing files, then easily export these drawings to Rockwell Software's Arena software for dynamic simulation. Rockwell Software, Inc. has worked closely with Visio Corporation (now Microsoft) to provide an integrated, high-quality, interface to the industry-leading Visio application.

The Visio Process Simulator requires Visio Professional version 2002 or 2003. Before opening the stencil, it is necessary to have an administrator on the machine to set the Visio macro security options to Low so that macros will be enabled.

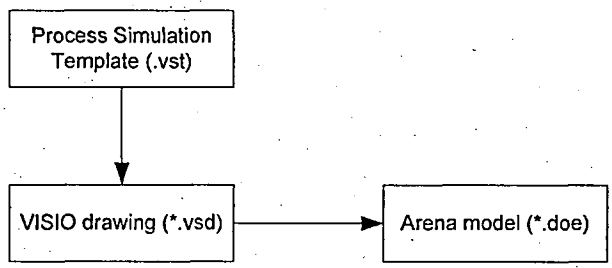


Figure 5- 16 Process Simulation Approach

Figure 5-16 shows the process simulation approach using Process Simulation Template. The detailed descriptions are illustrated below:

1). Flowchart your process and data in Visio using the Process Simulation stencil and template.

2). Export your drawing to the Arena simulation system by clicking "Simulation Drawing" off of the "Simulation" menu in Visio.

3) Analyze the performance of the process via dynamic animation. Watch the drawing come "alive". Enhance the model using Arena's graphical flow charting tools (similar to Visio).

5.7.3 VISVSM TEMPLATE DEVELOPMENT

Process simulator provides great convenience in model construction via Visio interface. However, to create a customised VisVSM template in Visio, we can not use Process Simulator directly, instead, some changes have to be made to the Simulator. Figure 5-17 shows the development process of VisVSM template.

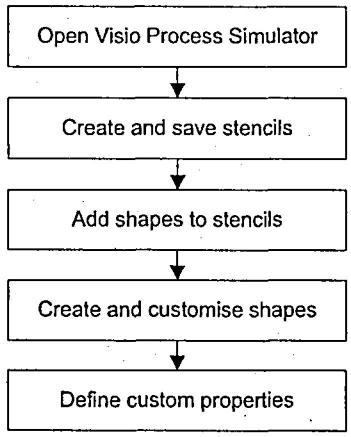


Figure 5- 17 VisVSM Template Development

Firstly, open Process Simulation.vst defined in the Visio Process Simulator which customised a "SIMULATION" menu in VISIO to enable the exporting of VISIO drawing to Arena immediately.

Secondly, create and save the VisVSM stencil. Since VSM stencil has been defined in VISIO 2007 professional version, here we just modify the existing VSM stencil to the VisVSM stencil. The steps are described as following: Instead of clicking Open immediately, click the drop-down arrow on the Open button and choose Copy from the drop-down menu. Visio opens a copy of the stencil in the Shapes window using a default name, such as Stencil1. The icon in the stencil title bar includes an asterisk, indicating that the stencil is editable. To save the new stencil, right-click the stencil's title bar and choose Save from the shortcut menu. In the Save As dialog box, type VisVSM for the stencil and then click Save.

Thirdly, add shapes to the VisVSM stencil. Since the SimVSM template in Arena has organized all VSM icons into eleven modules, correspondingly the VisVSM stencil needs only eleven masters in it, so we need to delete the unwanted thirteen icons and then add a new master named Supplier. Right-click inside the VisVSM stencil window and choose New Master. In the New Master dialog box, specify the master name as Supplier, edit graphics and change the icon image.

Step four is to create and customise shapes. After finishing step three, eleven shapes are created in the VisVSM stencil. However, some modifications still need to be made, such as renaming the master, modifying master graphics and changing the icon image.

Last but not least, edit the custom properties in each shape. In order to store data in shapes of the VisVSM stencil, you must first create custom properties and then associate them with the masters or shapes. In Visio 2007 environment, when editing the master shape, right-click the current shape, select data -> shape data -> define shape data now, and define new properties for each shape by specifying options, as shows in Table 5-6 (Biafore, 2004).

Table 5- 6 Custom Property Options

OPTION	DESCRIPTION
Label	Consisting of alphanumeric characters and underscore characters, the label is the name of the custom property and appears next to the field in which you enter the property value.
Type	The data type for the property, including String, Number, Fixed List, Variable List, Boolean, Currency, Date, and Duration.
Language	Specifies the language to correctly format the date and time when you create a Date property. For example, English (U.S.) uses mm/dd/yy, whereas English (U.K.) uses dd/mm/yy.
Calendar	Specifies whether to use the Arabic Hijri (Islamic), Hebrew Lunar (Jewish), Saka Era (Hindu), or Western (Gregorian) calendar to convert a date entered in a Date property.
Format	The format for the data type. The options available depend on the type and Calendar options selected. You can select from lists of

OPTION	DESCRIPTION
	predefined formats when you define data types such as String, Number, Fixed List, Variable Lit, Currency, Boolean, Date, and Duration. To specify fixed lists or variable lists, type each item in the list separated by semicolons. For example, you can create a colour list by entering red;white;blue. If you create a fixed list, you can only select one of the entries on the list. With variable lists, you can enter another value, such as green.
Value	Specifies the initial value for the property. For existing properties, this box shows the current value. Omit this value if you want the property to be blank initially.
Prompt	Specifies text that appears when you select the property in the Custom Properties dialog box or pause the pointer over the custom property label in the Custom Properties window. You can use the prompt to see a description of the property or instructions on its use.
Properties	Displays the existing custom properties for a shape. When you select a property in the list and modify it, Visio applies the changes you make to its definition immediately.
New	Creates a new custom property.
Delete	Deletes the custom property selected in the Properties list.

According to the descriptions listed in Table 5-6, custom properties are defined for the eleven masters in VisVSM stencil, and the details are presented in Appendix D.

5.7.4 MAPPING FILE EDITTING

When Arena creates a new model from a Visio drawing, it uses the active map file to decide which Arena module to place for each Visio shape. A map file is simply a list of Visio shapes and Arena modules, along with a detailed mapping from one to the other, including the mapping of Visio shape custom properties to Arena module operand values.

The default map file used by Arena is called Arena Basic.map. This pre-defined map file links Visio shapes in the Process Simulation stencil (provided by Rockwell Software) to Arena modules in the Basic Process template. Thus, you can use the Process Simulation stencil to map and define business processes in Visio drawing files, and then easily export these drawings to Rockwell Software's Arena software for dynamic simulation.

In addition to the Arena Basic map file, you can create other map files to serve as blueprints for the transfer of shapes and data from other Visio stencils (e.g., the Basic Flowchart stencil). To do this, go to Tools/Options/VisioOptions in Arena. Leave the File Name prompt for the Visio Shape Mapping File blank and click the Edit button (see Figure 5-18). This action will load the Shape Map Editor where you can create a new mapping. When done, save this new map file with a different name, then close the Shape Map Editor. Make sure that your new map file is shown on Arena's Tools/Options/VisioOptions page in order for the map file to be used the next time you import a Visio drawing. The actual mapping file for this customised simulation environment is shown in Appendix E.

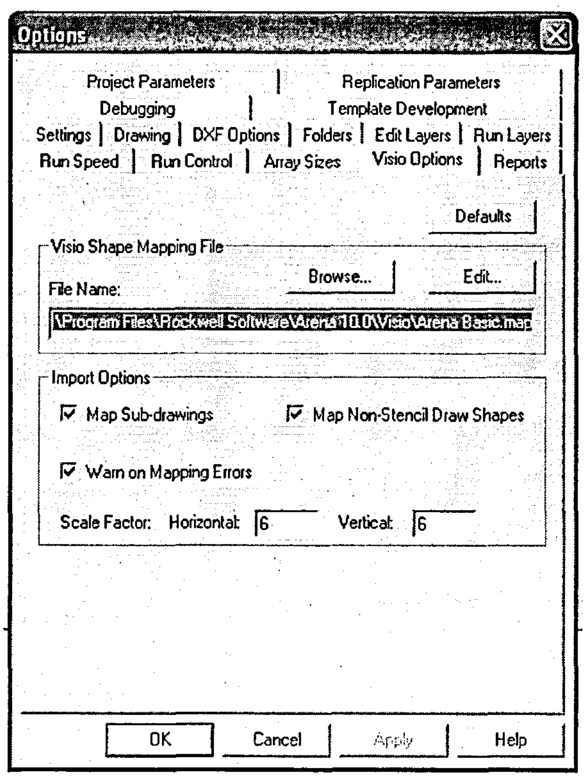


Figure 5- 18 Visio Shape Mapping File

5.8 VERIFY AND VALIDATE SIMVSM TEMPLATE

In order to verify and validate each module in SimVSM template, simulation models have been built with each individual module from SimVSM template together with the modules from Basic template. Since the modules in Basic template have already been verified and validated by Rockwell Software, the verification and validation of each module from SimVSM template can be achieved through constructing models with the verified modules in Basic template. For instance, to test the Supplier module in SimVSM template, the researcher has built a simple VSM simulation model with Supplier module from SimVSM template and other modules from Basic template, then analyze the results; after that, the researcher tries to build some complex VSM models with Supplier module from SimVSM template to further verify and validate it.

It is worth mentioning that verifying and validating small modules doesn't mean that the whole model is verified and validated; to verify and validate the whole model logic requires more laborious experimentations, such as to construct big models with all required modules from the customised simulation template.

After this step, all the 11 modules in SimVSM template have been verified and validated.

5.9 SUMMARY

A description has been made on the development of a customised simulation environment for embedding simulation technique into lean projects. The developed system consists of a customised simulation template for VSM modelling in Arena software and an interface of the developed SimVSM template in Visio software. The system provides a fast and accurate modelling of VSM that is in common use of lean projects. Moreover, the interface in Visio software as described in Section 5.7 is perceived as a useful tool to simplify and facilitate VSM modelling. The verification and validation of each individual module in SimVSM template is shown in Section 5.8. Therefore, this chapter has demonstrated the accomplishment of research objective number four as stated in Section 1.3; developing the reference framework to embed simulation in lean projects. The research objective contributes to the accomplishment of the research questions presented in Section 3.1 which presumes that developing a reference framework about embedding simulation in lean projects would motivate companies' adoption of simulation technique.

6 EVALUATION OF THE REFERENCE FRAMEWORK

In this chapter, a description of the evaluation of the SimLean and the developed customised simulation environment is conducted. The essence of evaluation stems from the fact that, research work must be tested for worthiness or merit. Since stage one to stage four of SimLean framework has been validated by best practices from elsewhere, the focus of the evaluation work lies in the customised simulation environment. Murphy and Perera (2001) identified a list of best practices to guide the implementation of simulation from their studies on how simulation has successfully been used in U.S. companies. They suggested that UK companies should follow these best practices in order to encourage the use of simulation more openly. What's more, Mclean and Leong (2001) also agreed that some best practices (e.g. standardising building blocks and data interfaces in model developing process) can reduce project costs and time which finally increase the accessibility to the use of simulation.

The reminder of the chapter is structured as follows. Section 6.1 explains how the case studies are designed for the evaluation of the developed system. In Sections 6.2 to 6.6, details of the evaluation process including key measurements, simulation scene and results analysis are presented and discussed. These sections also highlight the number of blocks saved through the use of the customised simulation environment, which infers a lot of time saving at the same time. The key observations derived from the evaluation exercises are summarised in Section 6.7.

6.1 DESIGN OF CASE STUDIES

To evaluate the developed system's usability, and its effectiveness in assisting the embedment of simulation technique in lean manufacturing, a number of case studies were employed to test the validity of the customised simulation environment. Five case studies were performed at different levels in this process. The details are listed as following:

Level 1: Case study one is a push system of single product, single supplier, nonparallel process, and single customer;

Level 2: Case study two is a pull system of single product, single supplier, nonparallel process, and single customer;

Level 3: Case study three is a push system of single-product, multi-suppliers, nonparallel process, and single-customer;

Level 4: Case study four is a push system of multi-products, multi-suppliers, paralleled processes and multi-customers;

Level 5: Case study five is a pull system of multi-products, multi-suppliers, parallel processes and multi-customers.

The definitions of our key measurements are given as follows:

- Production Lead Time (PLT)
- Value Added Time (VA/T)
- Process Cycle Efficiency (PCE)
- Resource utilisation

Through experimentation with the five case studies, simulation results were obtained under different conditions and compared with static VSM.

6.2 CASE STUDY ONE

6.2.1 VSM DESCRIPTION

Case study one is a push system which contains single product, single supplier, nonparallel process, and single customer. Static VSM describes PB&J manufacturing which produces sandwiches (Pereira, 2008), and the manufacturing processes consist of material purchasing from supplier, Peanut Butter Application, Jelly Application, Packaging process and finally shipping to Customer (as shown in Figure 6-1). We use this case study to demonstrate the easiness of building a simulation model of VSM with the customised simulation template.

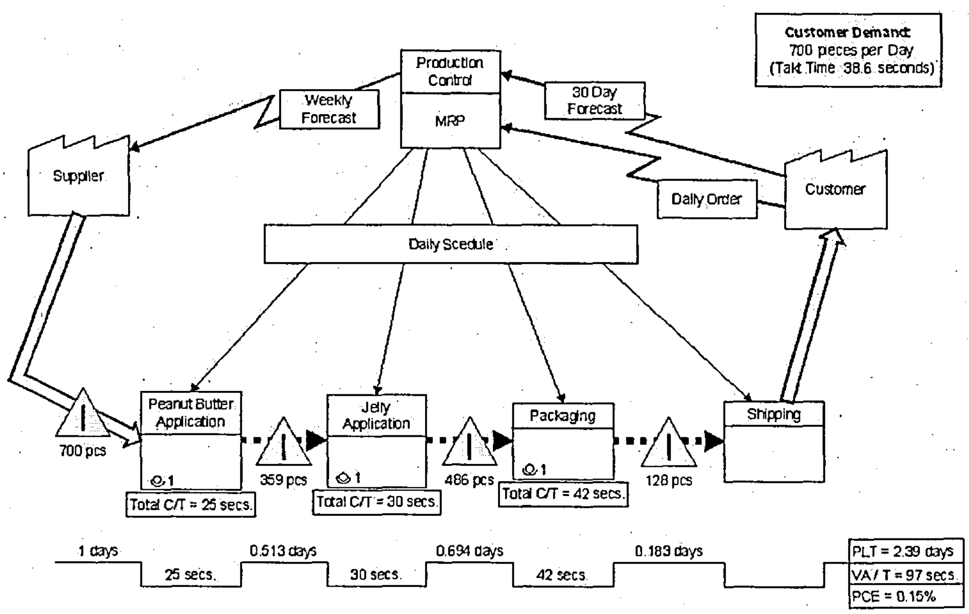


Figure 6- 1 Static VSM of Case Study 1

Production data of PB&J is listed below:

- Daily demand: 700 pieces
- Hours per shift: 8
- Break minutes per shift: 30
- Shifts per day: 1
- Days per week: 5

6.2.2 THE SIMULATION SCENE

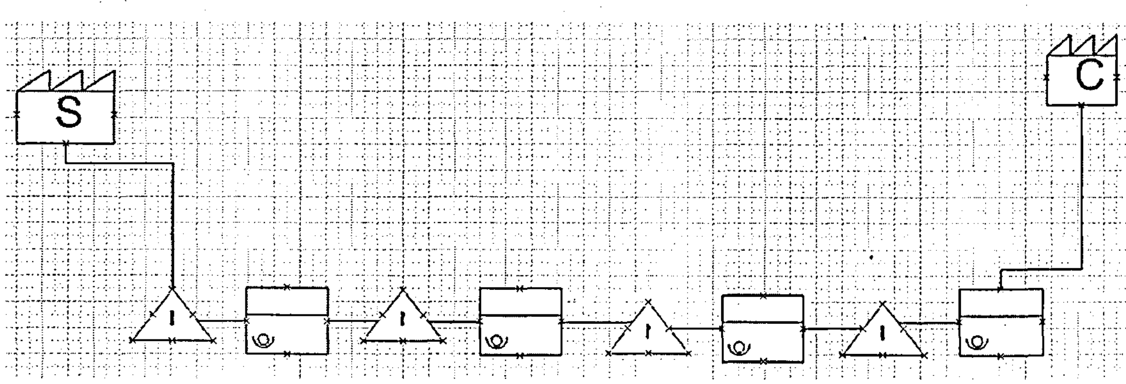
As shown in Figure 6-2, one supplier module, four inventory modules, four processVSM modules and one customer module have been used to simulate case study one. The picture above in Figure 6-2 is the Visio drawing of case study one; and the one below is the simulation model generated from Visio drawing. Three scenarios have been designed as following:

Scenario A: scrap rate = 0; variation = 0; run time = 22 days;

Scenario B: scrap rate = 5%; variation = 5 sec; run time = 22 days;

Scenario C: scrap rate = 0: variation = 0: run time = 252 days.

Results obtained from the above three scenarios are compared with static VSM as presented in Table 6-1.



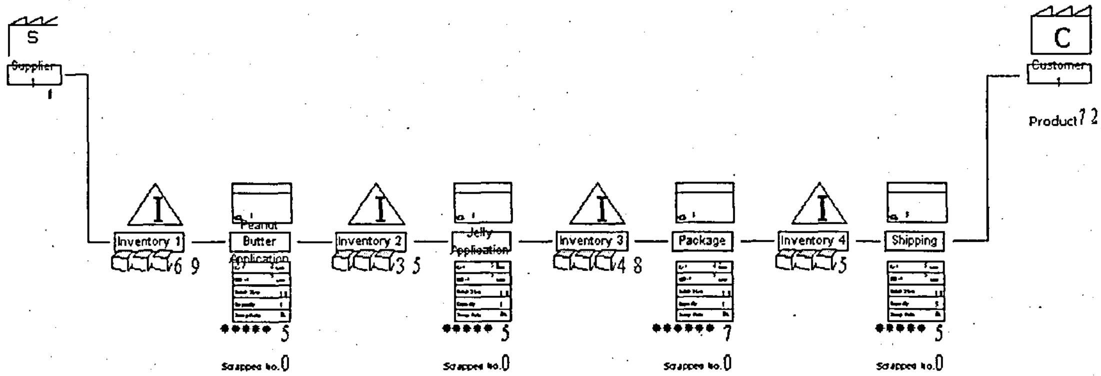


Figure 6- 2 Simulation Scene of Case Study 1

Table 6- 1 Data Comparison of Case Study 1

	VA/T (Sec)	PLT (Hrs)	PCE (%)	RESOURCE UTILIZATION	INVENTORY 1	INVENTORY 2	INVENTORY 3	INVENTORY 4
STATIC VSM	97	19.12	0.15	N/A	700	359	486	128
SCENARIO A	0, 99, 102	0, 21.88, 29.16	0.13	Peanut 60%, Jelly 73%, Package100%	900	390	726	1
SCENARIO B	0, 97, 121	0, 13.84, 24.36	0.20	61%, 71%, 98%	900	109	280	1
SCENARIO C	0, 107, 107	0, 42.03, 66.66	0.07	60%, 73%, 100%	900	390	2364	1

The output data of scenario A and B shown in Table 6-1 is the values of 1 replication, 8-hours per day, and 22 days per replication (assuming 22 working days per month). The result of scenario C is the values of 1 replication, 8-hours per day, and 252 days per replication (assuming 252 working days per year).

6.2.3 RESULTS AND FINDINGS

The crucial purpose of developing a customised simulation environment is to shorten modelling time as well as to eliminate logic errors in model constructing process. With reference to Table 5-5 and Section 6.2.2, we can see that the model of case study one has used 154 blocks which have been packaged into 10 modules, and the adoption of the SimVSM template has save 144 blocks, the saving rate is over 93%.

Through the data comparison of static VSM and simulation results as shown in Table 6-1, we can see that simulation provides more comprehensive data, and helps discover more problems in the system. For instance, resource utilization in scenario A, B and C all indicate that packaging process is a bottleneck of the system; the extremely high quantity of inventory 3 in scenario C also indicate that the downstream process has slowed down the whole process which blocks so many products; the difference between scenario C and the other two also indicates that the system is not stable, which leads to the diversity of short-term data and long-term data.

6.3 CASE STUDY TWO

6.3.1 VSM DESCRIPTION

Case study two is a pull system which contains single product, single supplier, single process, and single customer. Static VSM describes the "future state" of PB&J manufacturing (see Figure 6-3) which contains supermarket and kanban. It is based on the logic that nothing will be produced until it is needed. The U-shaped flow line is a combination of Peanut Butter Application, Jelly Application and Packaging operations. The supplier ships raw material to the supermarket every two days, and customer requires a product every 38.6 seconds. Production data of PB&J is listed below:

- Daily demand: 700 pieces
- Hours per shift: 8
- Break minutes per shift: 30
- Shifts per day: 1
- Days per week: 5
- Takt Time: 38.6 sec

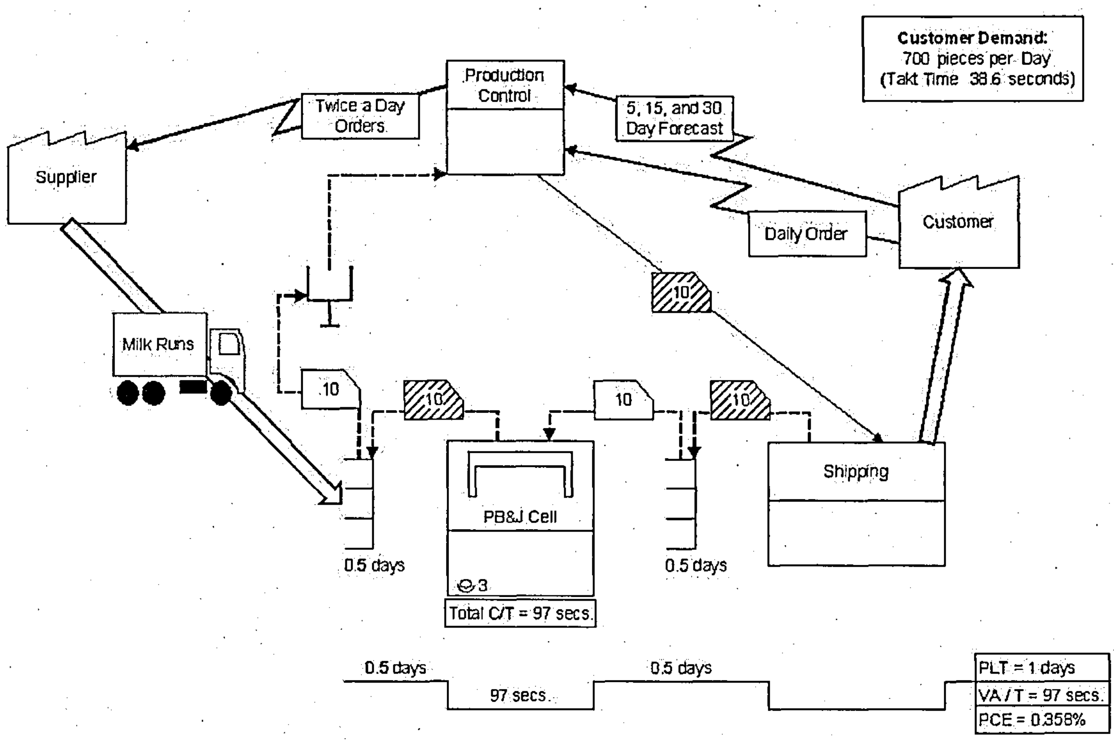


Figure 6- 3 Static VSM of Case Study 2

6.3.2 THE SIMULATION SCENE

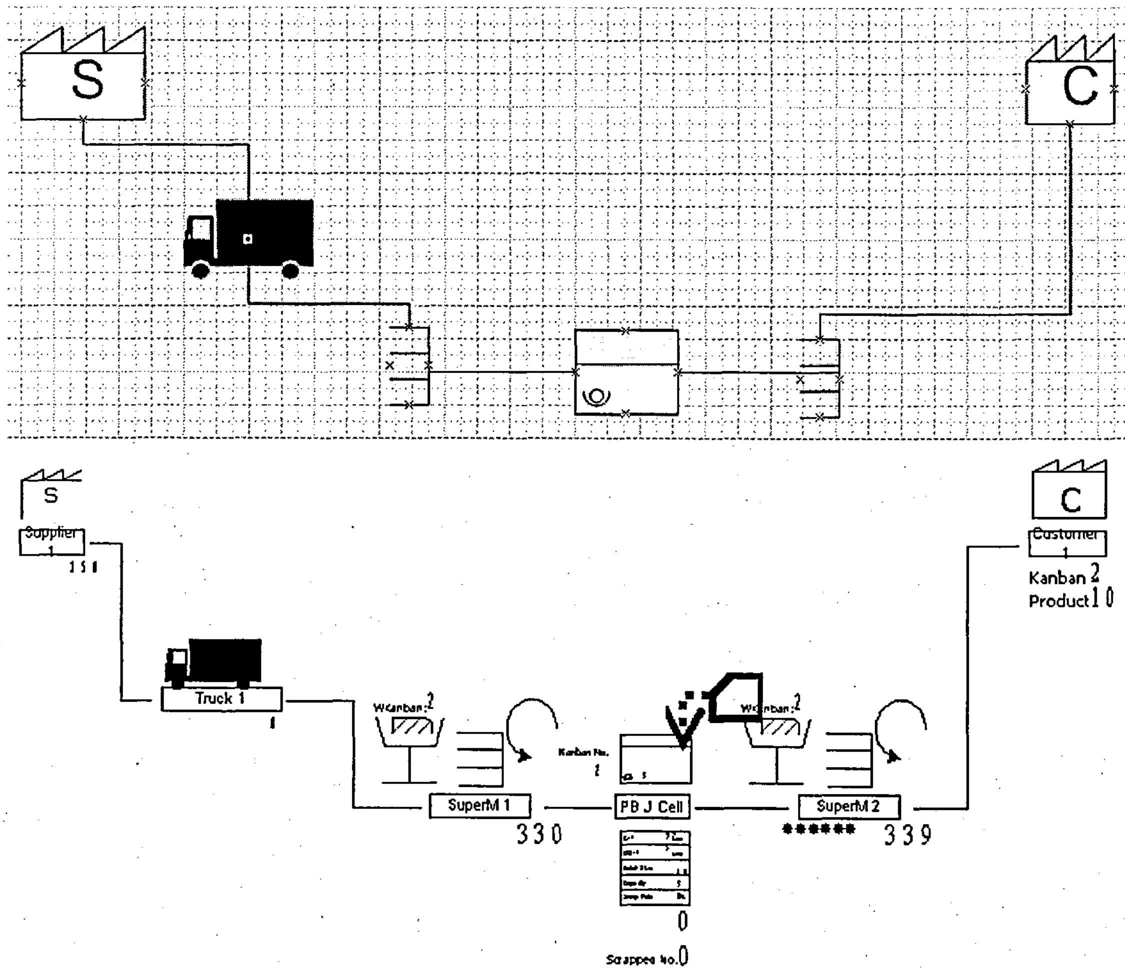


Figure 6- 4 Simulation Scene of Case Study 2

As shown in Figure 6-4, one supplier module, one truck module, two supermarket modules, one processVSM module and one customer module have been used to simulate case study two. The picture above in Figure 6-4 is the Visio drawing of case study two; and the one below is the simulation model generated from Visio drawing. Three scenarios have been designed as following:

Scenario A: scrap rate = 0; variation = 0; run time = 22 days;

Scenario B: scrap rate = 5%; variation = 5 sec; run time = 22 days;

Scenario C: scrap rate = 0: variation = 0: run time = 252 days.

Results obtained from the above three scenarios are compared with static VSM as presented in Table 6-2.

Table 6- 2 Data Comparison of Case Study 2

	VA/T (Sec)	PLT (Hrs)	PCE (%)	RESOURCE UTILIZATION	SUPERMARKET 1	SUPERMARKET 2
STATIC VSM	97	8	0.358	N/A	350	350
SCENARIO A	0, 95, 97	0, 9.44, 21.28	0.279	80%	242	307
SCENARIO B	0, 94, 102	0, 8.33, 20.21	0.316	80%	185	120
SCENARIO C	0, 97, 97	0, 7.85, 21.28	0.343	79%	173	34

The output data of scenario A and B shown in Table 6-2 is the values of 1 replication, 8-hours per day, and 22 days per replication (assuming 22 working days per month). The result of scenario C is the values of 1 replication, 8-hours per day, and 252 days per replication (assuming 252 working days per year).

6.3.3 RESULTS AND FINDINGS

Firstly, we can calculate the efficiency of template adoption. With reference to Table 5-5 and Section 6.3.2, we can see that the model of case study two has used 74 blocks which have been packaged into 6 modules, and the adoption of the SimVSM template has save 68 blocks, the saving rate of building blocks is over 91%.

Through the data comparison of static VSM and simulation results as shown in Table 6-2, we can see that simulation data do not have big difference, which indicate that case study two is almost a stable system. The resource utilization of 80% means that no bottleneck exists in the system. The only difference in the quantity of supermarket 2 in the three scenarios is caused by the customer demand during break times, which has resulted in a temporary shortage of replenishment for supermarket 2. The stocks decline in supermarket 1 and supermarket 2 in scenario C compared with data in scenario A indicate that the customer demand rate is a little faster than the system's actual production rate.

6.4 CASE STUDY THREE

6.4.1 VSM DESCRIPTION

Case study three is a push system which contains single product, multiple supplier, single process, and single customer. Static VSM describes aluminium extrusion process (http://www.leanmanufacture.net/vsm.aspx). The manufacturing processes (as shown in Figure 6-5) consist of material purchasing from two suppliers, reheating furnace, extraction mill, oven, roll corrector, cleaning, edging and finally shipping to Customer. We use the case study to demonstrate the VSM modelling of multi-suppliers. Production data of aluminium extrusion process is listed below:

- Daily demand: 9 pieces
- Hours per shift: 8
- Break minutes per shift: 30
- Shifts per day: 3
- Days per week: 5

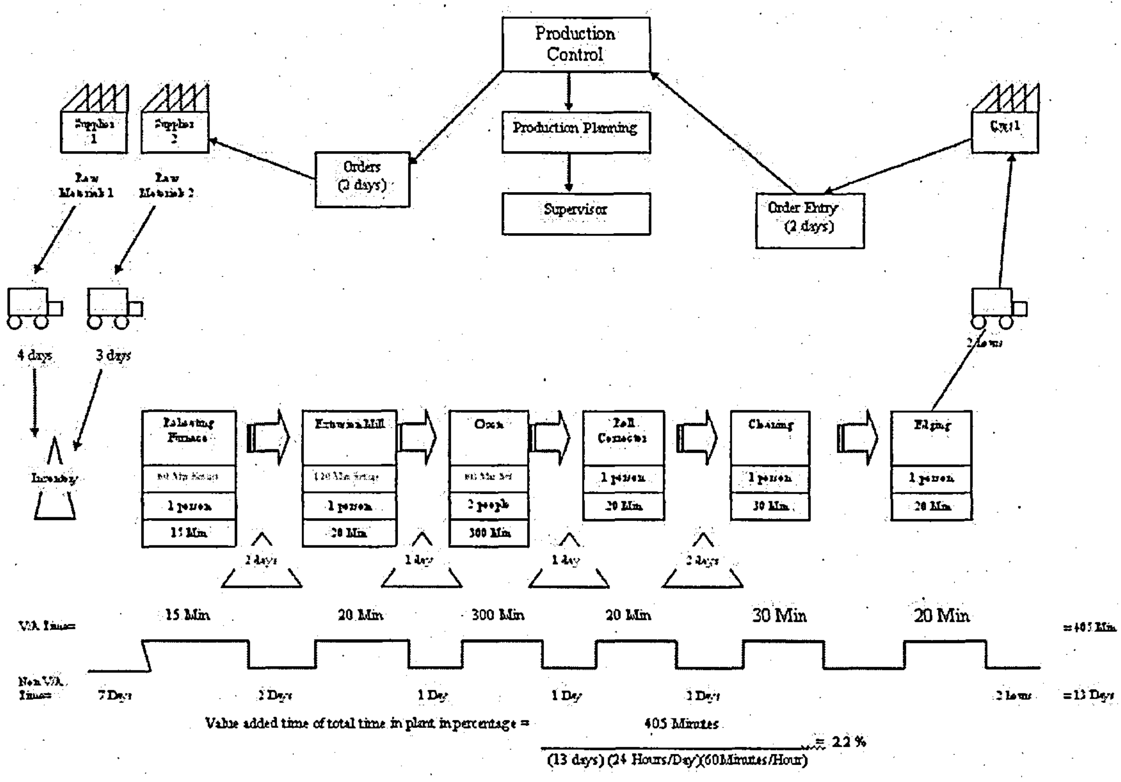


Figure 6- 5 Static VSM of Case Study 3

6.4.2 THE SIMULATION SCENE

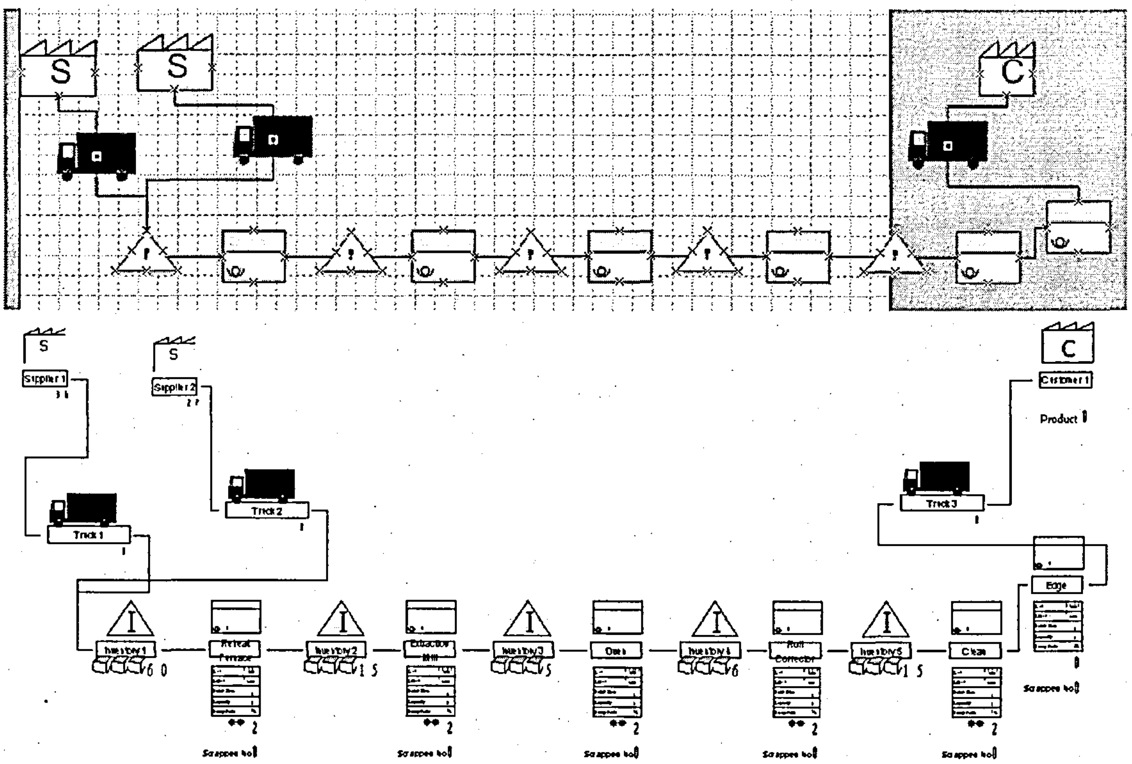


Figure 6- 6 Simulation Scene of Case Study 3

As shown in Figure 6-6, two supplier modules, three truck modules, five inventory modules, six processVSM modules and one customer module have been used to simulate case study three. The picture above in Figure 6-6 is the Visio drawing of case study three; and the one below is the simulation model generated from Visio drawing. Three scenarios have been designed as following:

Scenario A: scrap rate = 0; variation = 0; run time = 22 days;

Scenario B: scrap rate = 5%; variation = 1 min; run time = 22 days;

Scenario C: scrap rate = 0: variation = 0: run time = 252 days.

Results obtained from the above three scenarios are compared with static VSM as presented in Table 6-3.

Table 6- 3 Data Comparison of Case Study 3

	VA/T (Min)	PLT (Hrs)	PCE (%)	RESOURCE UTILIZATION	INVENTORY 1	INVENTORY 2	INVENTORY 3	INVENTORY 4	INVENTORY 5
STATIC VSM	405	312	2.2	N/A	63	18	9	9	18
SCENARIO A	0, 348, 405	248	2.3	Reheat 8%, Extraction 11%, Oven 83%, Roll 11%, Clean 17%, Edge 11%	51	18	10	5	18
SCENARIO B	14, 312, 407	227	2.3	8%, 11%, 82%, 11%, 17%, 11%	51	12	5	5	12
SCENARIO C	50, 400, 405	700	0.95	8%, 11%, 83%, 11%, 17%, 11%	216	18	10	5	18

The output data of scenario A and B shown in Table 6-3 is the values of 1 replication, 24-hours per day, and 22 days per replication (assuming 22 working days per month). The result of scenario C is the values of 1 replication, 24-hours per day, and 252 days per replication (assuming 252 working days per year).

6.4.3 RESULTS AND FINDINGS

With reference to Table 5-5 and Section 6.4.2, we can see that the model of case study 3 has used 225 blocks which have been packaged into 17 modules, and the adoption of the SimVSM template has save 208 blocks, the saving rate is over 92%.

The data comparison of static VSM and simulation results in Table 6-3 indicates that this is a non-balanced system. The resource utilization in three scenarios shows that even though no bottlenecks exist in current system, the work load is not balanced at all; workers in Oven process is much busier than all other departments. From comparison of lead time and inventory 1 data between scenario A and scenario C, we can see that some bottleneck has slowed down the whole process, which results in the accumulation of products in inventory 1 as time goes by.

6.5 CASE STUDY FOUR

6.5.1 VSM DESCRIPTION

Case study four is a push system which contains multiple products, multiple suppliers, paralleled processes, and multiple customers. Static VSM describes complex manufacturing process (http://operationsresources.com/id3.html). The manufacturing processes (as shown in Figure 6-7) consist of material purchasing from three suppliers, fabric cutting, sewing, upholstery, final assy, frame assy, foam assy, foam cutting and finally shipping to two customers separately. We use the case study to demonstrate the VSM modelling of multi-products, multi-suppliers, paralleled processes and multi-customers in a push system. Production data of case study four is listed below:

- Daily demand of product D: 100 pieces
- Daily demand of product T: 100 pieces
- Hours per shift: 8
- Break minutes per shift: 30
- Shifts per day: 1
- Days per week: 5

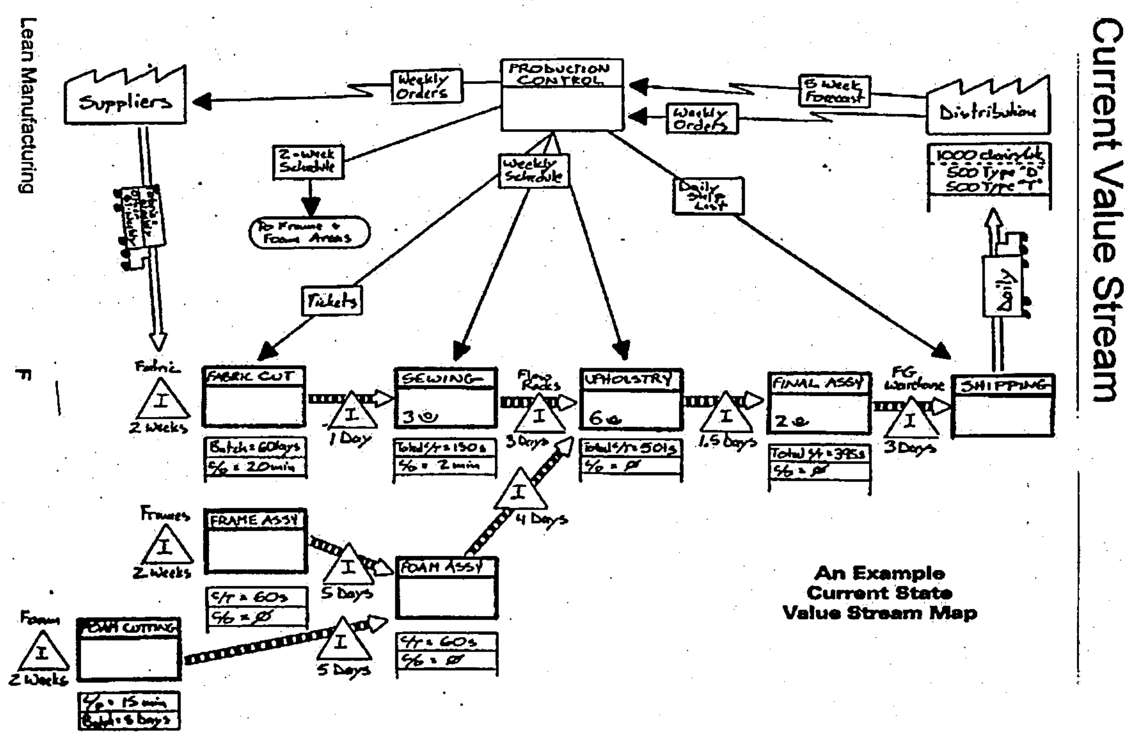


Figure 6- 7 Static VSM of Case Study 4

6.5.2 THE SIMULATION SCENE

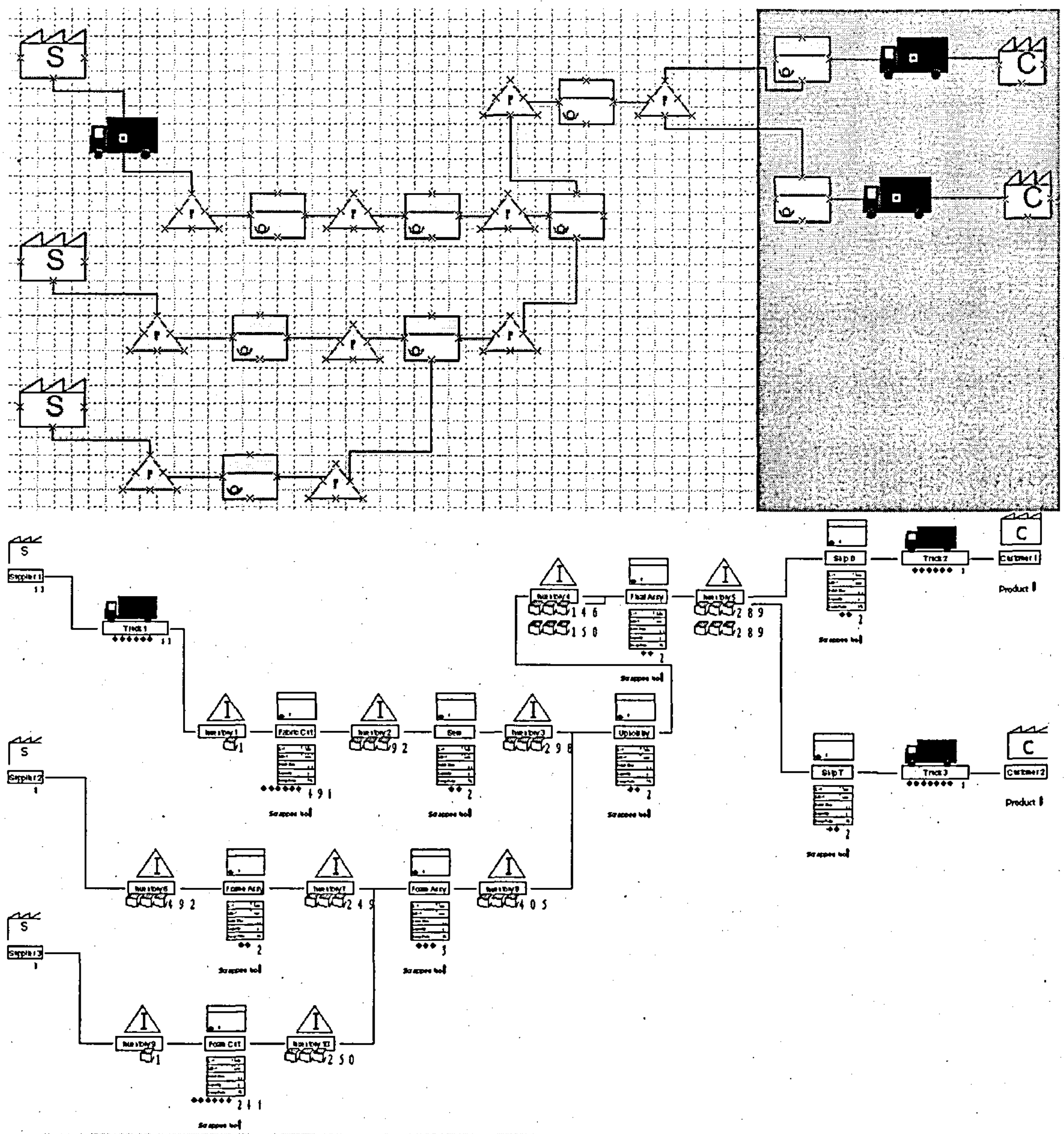


Figure 6- 8 Simulation Scene of Case Study 4

As shown in Figure 6-8, three supplier modules, three truck modules, ten inventory modules, nine processVSM modules and two customer modules have been used to simulate case study four. The picture above in Figure 6-8 is the Visio drawing of case study four; and the one below is the simulation model generated from Visio drawing. Three scenarios have been designed as following:

Scenario A: scrap rate = 0; variation = 0; run time = 22 days;

Scenario B: scrap rate = 5%; variation = 5 sec; run time = 22 days;

Scenario C: scrap rate = 0: variation = 0: run time = 126 days.

Results obtained from the above three scenarios are compared with static VSM as presented in Table 6-4.

Table 6- 4 Data Comparison of Case Study 4

	VA/T (Sec)	PLT (Hrs)	PCE (%)	RESOURCE UTILIZATION	INV1	INV2	INV3	INV4	INV5	INV6	INV7	INV8	INV9	INV 10
STATIC VSM	D1146, T1116	N/A	N/A	N/A	D1000	D100	D300	D150, T150	D300, T300	T500	T250	T400	T500	T250
SCENARIO A	D(0, 664, 1156), T(0, 607, 966)	D84, T84	D0.22, T0.20	Fabric out56%, Sew17%, Upholstry57%, Final assy69%, Frame assy16%, Foam assy37%, Foam cut32%	D309	D1137	D319	D699, T703	D285, T281	T294	T190	T1452	T91	T356
SCENARIO B	D(5, 600, 1168), T(5, 497, 1060)	D78, T71	D0.21, T0.19	56%, 17%, 57%, 69%, 16%, 35%, 32%	D309	D1043	D267	D653, T648	D258, T259	T294	T151	T1303	T91	T310
SCENARIO C	D(10, 1070, 1156), T(10, 966, 1066)	D400, T425	D0.07, T0.06	39%, 17%, 57%, 69%, 12%, 24%, 19%	D123	D1398	D319	D3247, T3251	D285, T281	T138	T37	T2097	T4	T117

The output data of scenario A and B shown in Table 6-4 is the values of 1 replication, 8-hours per day, and 22 days per replication (assuming 22 working days per month). The result of scenario C is the values of 1 replication, 8-hours per day, and 126 days per replication (assuming 126 working days per half-year).

6.5.3 RESULTS AND FINDINGS

With reference to Table 5-5, Table 5-6 and Section 6.5.2, we can see that the model of case study four has used 613 blocks which have been packaged into 27 modules, and the adoption of the SimVSM template has save 586 blocks, the saving rate is over 95%.

From resource utilization statistic of three scenarios as shown in Table 6-4, it is indicated that employees have not reached their full capacities; meanwhile the work flow is not balanced between different processes. High stock quantity in inventory 2, inventory 4 and inventory 8 suggests that the processes after them has slowed down the whole manufacturing process.

6.6 CASE STUDY FIVE

6.6.1 VSM DESCRIPTION

Case study five is a pull system which contains multiple products, multiple suppliers, paralleled processes, and multiple customers. Figure 6-9 depicts a future state value stream map that includes kaizen starbursts for environmental improvement opportunities as well as changes to establish a "pull" system to control inventory levels and to improve production flow (http://epa.gov/lean/toolkit/ch3.htm). Static VSM describes that the "future state" of the manufacturing company (see Figure 6-9) contains supermarket and kanban. Supplier1 and supplier2 ships raw materials every two weeks to the supermarket, the materials go through milling, welding, painting, assembly and inspection four processes, and finally are transported to customer A and customer B separately. Production data of case study five is listed below:

- Daily demand of product A: 40 pieces
- Daily demand of product B: 40 pieces
- Hours per shift: 8
- Break minutes per shift: 30
- Shifts per day: 3
- Days per week: 5
- Takt Time of Customer A: 0.57 hrs
- Takt Time of Customer B: 0.57 hrs

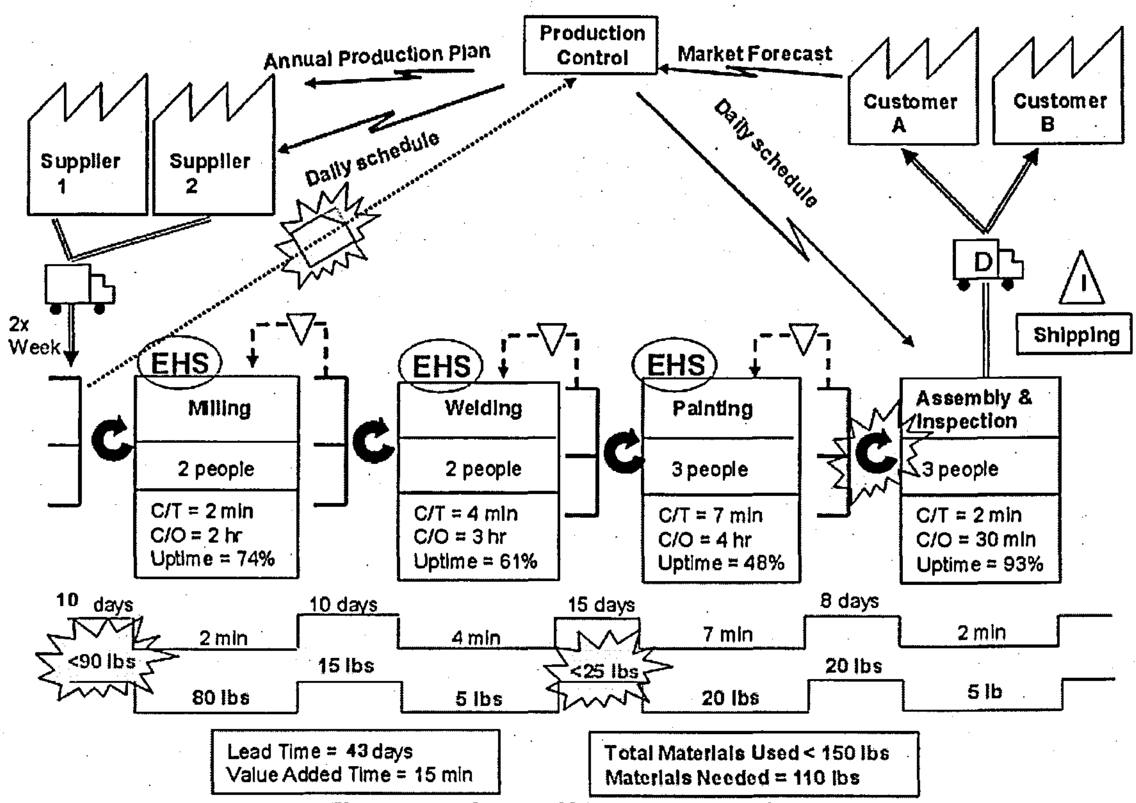


Figure 6- 9 Static VSM of Case Study 5

6.6.2 THE SIMULATION SCENE

As shown in Figure 6-10, two supplier modules, four truck modules, five supermarket modules, four processVSM modules and two customer modules have been used to simulate case study five. The picture above in Figure 6-9 is the Visio drawing of case study five; and the one below is the simulation model generated from Visio drawing. Three scenarios have been designed as following:

Scenario A: scrap rate = 0; variation = 0; run time = 22 days;

Scenario B: scrap rate = 5%; variation = 1 min; run time = 22 days;

Scenario C: scrap rate = 0: variation = 0: run time = 252 days.

Results obtained from the above three scenarios are compared with static VSM as presented in Table 6-5.

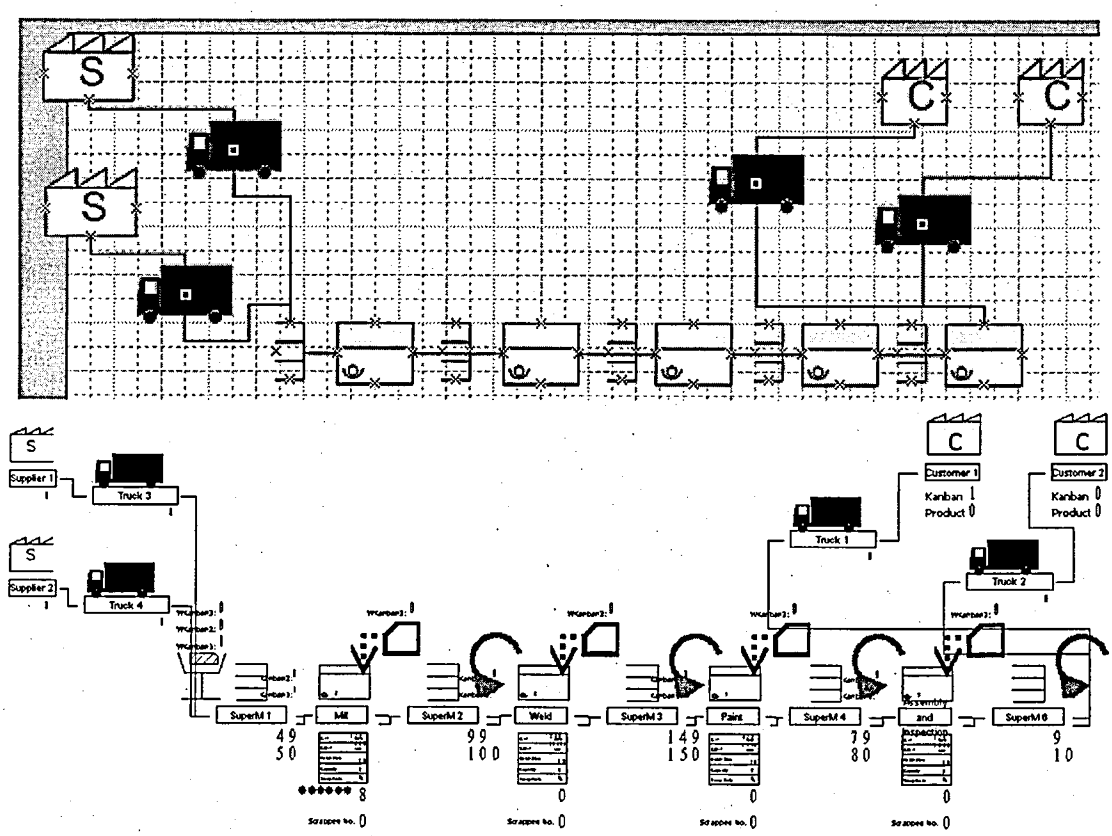


Figure 6- 10 Simulation Scene of Case Study 5

Table 6- 5 Data Comparison of Case Study 5

	VA/T (Min)	PLT (Hrs)	PCE (%)	RESOURCE UTILIZATION	SUPERM 1	SUPERM 2	SUPERM 3	SUPERM 4	SUPERM 5
STATIC VSM	A15, B15	A1032, B1032	A0.02, B0.02	N/A	A400, B400	A400, B400	A600, B600	A320, B320	A40, B40
SCENARIO A	A(0, 6, 9), B(0, 6, 9)	A(0, 264, 528), B(0, 264, 528)	A0.04, B0.04	Mill 6%, Weld 12%, Paint 14%, Assembly 4%	A589, B589	A400, B400	A600, B600	A320, B320	A40, B40
SCENARIO B	A(0, 6, 15), B(0, 7, 14)	A(0, 264, 528), B(0, 264, 528)	A0.04, B0.04	7%, 14%, 15%, 4%	A489, B477	A400, B400	A600, B600	A320, B320	A40, B40
SCENARIO C	A(0, 14, 15), B(0, 14, 15)	A(0, 907, 1229), B(0, 907, 1229)	A0.03, B0.03	6%, 12%, 14%, 4%	A348, B348	A386, B386	A600, B600	A320, B320	A40, B40

The output data of scenario A and B shown in Table 6-5 is the values of 1 replication, 24-hours per day, and 22 days per replication (assuming 22 working days per month). The result of scenario C is the values of 1 replication, 24-hours per day, and 252 days per replication (assuming 252 working days per year).

6.6.3 RESULTS AND FINDINGS

With reference to Table 5-5, Table 5-6 and Section 6.6.2, we can see that the model of case study five has used 217 blocks which have been packaged into 17 modules, and the adoption of the SimVSM template has save 200 blocks, the saving rate is over 92%.

Simulation results in Table 6-5 shows that this is a stable system, based on the small difference between scenario A (short-term data) and scenario C (long-term data). Resource utilization indicates that staffs are not fully used, and work load is not well balanced. However, because of the characteristic of pull system and the adoption of supermarket, the un-balanced work force does not influence the manufacturing process.

6.7 KEY OBSERVATIONS

The most obvious advantage of the customised simulation environment for VSM modelling is that through adopting the template as described in Chapter five and Chapter six, users can save large amount of building blocks as well as modelling time. Rockwell Automation (2005) stated that the customised simulation template can use the terminology that is appropriate for the industry to minimize the abstraction needed for a modeller to translate a system into the simulation software tool. The experimentation with five case studies illustrates that up to 91% blocks can be saved during model constructing process, which indicates that at least 91% modelling time can be saved as well (as shown in Table 6-6).

More importantly, the customised simulation template has provided the ease of model constructing. The interface presented to a modeller can be customized to be very familiar (both in terms of graphical animation and the terminology used in module dialogs); and parts, processes, etc., in the target application environments can be represented accurately (Rockwell Automation, 2005), which has greatly increased the ease of use to non-expert users.

Table 6- 6 Block Savings of Five Case Studies

CASE	BLOCKS	MODULES	BLOCK SAVING
1	154	10	93%
2	74	6	91%
3	225	17	92%
4	613	27	95%
5	217	17	92%

What's more, the adoption of customised template can improve the accuracy of simulation models. Since the model logic in the template is already verified (as presented in Chapter five), it provides better accuracy and fewer mistakes. The model complexity increases, the likelihood of making errors increases as well. Chwif, Barretto and Paul (2000) stated that it is intuitive that a simple model is easier to code, validate and analyze; thus in general complexity will increase the time to perform a simulation study (including conceptualization, implementation and analysis). Building a reusable template or module decreases the likelihood that you might make a mistake in reusing the original model representation, encourages you to reuse what you have learned, and makes it much easier for you to share with others the modelling approach you have developed (Rockwell Automation, 2005).

Besides the three advantages mentioned above, other advantages of simulation include its ability to answer "what if" questions, deal with complex situations, as well as produce more accurate results than static VSM.

Firstly, dynamic VSM is more accurate than static VSM. Take inventory module for an example, the static VSM gives one value of the inventory quantity while simulation result provides three values – minimum, average and maximum. In the manufacturing companies, it is very important to evaluate the inventory quantity precisely to arrange the suitable storage space, and the simulation approach satisfies this demand.

Secondly, simulation model can predict the long-term production data, by setting up the model run-time in Arena software. For instance, in case study 3, the output data of 20 days running time is very different from the output data of 200 days running time, and result shows that the long-term production data is very different from the shot-term data in the organization.

Thirdly, simulation model can demonstrate systems with multiple parameters in the VSM. Even though static VSM has setup many parameters in the process module, such as cycle time, variations, changeover time, scrap rate, uptime, etc., it does not take all these factors into account when calculating the VA/T and lead time. However, simulation model shows its power in dealing with multiple parameters at the same time. The output data in simulation report contains the influence of all the pre-defined operands, therefore the simulation result is more accurate and realistic.

What's more, simulation models can deal with very complex VSM. For some VSM that contains more than one product or has parallel suppliers, customers, inventories, processes or supermarkets, it is very difficult or even impossible to calculate the VA/T, lead time and PCE correctly on a piece of paper; However, through adopting simulation technique, the problem is solved easily. As long as the VSM model can be constructed, meanwhile the parameters are filled in properly; the automatically generated simulation report gives all the key statistics after running the model, which provides users with all the key measurements of the complex system.

Last but not least, in Arena simulation environment, *OptQuest* software can be used to do the parameter optimization task. For example in case study one – a simple push system, if we change batch size in a range of [1, 10], change workers' capacity from 1 to 3, with the limit of 5 workers in total, after optimization, we get minimum lead time under the premier parameter set: the Lead Time reduced from 2.14 Days to 0.51 Days, PCE increased from 0.15% to 0.64%, and no bottlenecks in the system. In case study two – a simple pull system, if we change batch size in a range of [1, 10], change workers' capacity from 2 to 5, change inventory amount in supermarket 1 and supermarket 2 in a range of [10, 700], the optimal parameters illustrate that when batch size is reduces to one, with workers' capacity of four, inventory amount of ten in each supermarket, lead time can be reduced from 0.91 Days to 0.43 Days, PCE therefore increases from 0.36% to 0.78% and operators' utilization decreases from 81% to 59%.

7 CONCLUSIONS AND FUTURE WORK

The literature review presented in Chapter two and the analysis of interview results discussed in Chapter three provided some research gaps, which facilitated the development of the SimLean framework and the customised simulation environment (including an Arena template SimVSM and a Visio stencil VisVSM) as presented in Chapter four and Chapter five respectively. What's more, to test the usability and the effectiveness of the proposed simulation environment, the evaluation process was performed through five case studies as illustrated in Chapter six. In this chapter, all the research findings are explained and discussed against the research aim and objectives in Section 7. 1; Discussions about contributions to knowledge are presented in Section 7.2; Research limitations are explained in Section 7.3 and recommended future work is shown in Section 7.4.

7.1 RESEARCH OBJECTIVES AND ACHIEVEMENTS

In Chapter one it was stated that the research aim of this study was to develop a reference framework which enables embedment of simulation in lean projects. In order to achieve the above aim, a set of research objectives were determined as listed below:

1. Conduct Literature Survey; 2. Develop an integrated framework to capture the interaction between lean and simulation; 3. Establish role of simulation within the above framework; 4. Develop the reference framework to embed simulation; 5. Validate the reference framework.

7.1.1 ACHIEVEMENTS OF THE RESEARCH OBJECTIVES

The first research objective is to conduct literature survey to identify research gaps. To achieve this goal, the research study analyzed the published works within lean manufacturing and simulation technique, and summarized the critical assessment of literature review as presented in Chapter two. The literature review also identified shortcomings of lean manufacturing tools and clarified that simulation technique might be able to overcome these limitations.

A number of different lean manufacturing tools were introduced in the identification process of research gaps. This idea stemmed from the fact that the currently available lean tools are not sufficient in solving dynamic and complex problems in manufacturing systems, or precisely predicting future state of lean projects before the actual implementation takes place. These findings have been supported by several authors who state that simulation is complimentary with lean methodology (Standridge and Marvel, 2006), (Bragliz, et al. 2009), (El-Haik and Al-Aomar, 2006), (Ferrin, Miller and Muthler, 2005), (Crosslin, 1995), (Bayle, et al. 2001), (Abbas, et al. 2006), (Adams, et al. 2999), (Wang, et al. 2005), (Bodner and Rouse, 2007), (Huang and Liu, 2005) and (Lian and Van, 2007).

Moreover, the literature review summarized several frameworks in the domain of lean implementation, VSM (value stream mapping) process map and simulation procedure. However, no framework about embedding simulation technique in lean projects has been proposed before. This scenario therefore suggests that many lean practitioners are in great need of a holistic reference framework which is capable of assisting them in embedding simulation technique in lean projects.

The second objective is to develop an integrated framework to capture the interaction between lean and simulation. This task required the accomplishment of literature survey and several interviews with lean practitioners as a supplementary process. A reference framework named SimLean is proposed and explained in details in Chapter four.

The main role of simulation within the above SimLean framework has been identified and established in pre-implementation stage of lean projects. A customised simulation environment is developed to simplify, facilitate and standardize simulation embedment in lean projects as described in Chapter five and six repectively.

The evaluation of the customised simulation environment – SimVSM template is accomplished through five case studies which contain different structure and states of VSM (value stream map), as presented in Chapter six.

7.1.2 DEVELOPPING SIMLEAN FRAMEWORK

The research has identified a guidance road map for simulation integration in lean projects. The developed SimLean framework comprises of seven stages, which are "Qualify need for lean", "Set simulation objectives", "Leadership commitment", "Simulation team and time scale", "Pre implementation", "Implementation" and "Post implementation". Moreover, the framework is conceptualised in a customised simulation environment which is designed on the basis of static VSM (value stream mapping) icons and generates simulation models in Arena DES simulation software from VSM drawings in Visio software.

7.1.3 EVALUATION OF THE CUSTOMISED SIMULATION ENVIRONMENT

This research has validated the developed customised simulation environment including VSM template in Visio software and SimVSM template in Arena software. Detailed discussions of the evaluation process are presented in Chapter six. Evaluation process includes drawing VSM in Visio software and exporting to Arena software, then running the automatically generated model to see the results. Parameters' optimisation is presented as well. The five case studies have proven the efficiency, accuracy and usability of the developed SimLean framework and its conceptualised simulation environment.

Moreover, the VSM icons adopted by the developed system (including Supplier, Customer, Truck, Process, Data box, Inventory, Supermarket, Production kanban, Withdrawal kanban, Kanban post, Physical pull arrow, Kaizen burst, etc.), provide logical and rapid modelling of lean projects. Furthermore, limitations of the customised simulation environment were also observed, which enabled the researcher to make recommendations for future work. The detailed discussions about the developed framework and the functionality of the proposed system are shown in Chapter four, Chapter five and Chapter six respectively.

7.2 CONTRIBUTION TO KNOWLEDGE

The research study has made a number of contributions to knowledge. To sum up, the novelty of the research can be categorised into two main themes: the research findings in terms of data and results; and the capability of the developed SimLean framework which aims to guide the embedment of simulation technique into lean projects.

7.2.1 NOVELTY IN RESEARCH FINDINGS

In terms of research findings, the research has provided an understanding of how to embed simulation technique into lean projects systematically. A customised simulation environment is proposed to facilitate, simplify and standardize modelling process in lean projects. The results were obtained through conducting literature review and interviewing lean practitioners. A further contribution to knowledge is the simulation applicability for various lean problems (as shown in Table 4-1). Then, the suggestion for simulation team selection is described in Section 4.3.3 in details.

7.2.2 NOVELTY IN CAPABILITY OF SIMLEAN FRAMEWORK

The research work has proposed a novel framework about embedding simulation in lean projects. Moreover, the emphasis of the framework is on building simulation models at pre-implementation stage of the lean project, so as to aid lean practitioners to validate the future state before actual implementation and reduce the risk of making huge mistakes in the end. The capability of the SimLean framework is described as follows:

- It enables companies to establish their simulation needs easily, by comparing their existing problems with problems summarized in Table 4-1.
- It enables a company to predict the outcome of implementing lean manufacturing within its business precisely at an early stage.

- Organisations are able to identify the best implementation plan for their business, since the framework conducts model analysis and scenarios comparison when designing the future state.
- Companies can evaluate their strengths and weaknesses in manufacturing process based on the models of current state.
- The framework can also be used as a reference business tool for embedding simulation in lean projects.

7.2.3 NOVELTY IN CAPABILITY OF THE PROPOSED SYSTEM

The developed SimLean framework is conceptualised in a customised simulation environment, which has been described in Chapter five and Chapter six. The capability of the proposed customised simulation environment is described as follows:

- It saves a lot of building blocks as well as model constructing time through the use of the proposed system (as shown in Table 6-6).
- The customised simulation environment provides the ease of model constructing with the familiar dialog design and Visio interface.
- The adoption of the customise template improves the accuracy of simulation models, since each module in the SimVSM template has been verified and validated as presented in Section 5.8.
- Dynamic VSM constructed with the proposed system provides better result than static VSM as discussed in Chapter six.

7.2.4 SOLUTIONS TO THE IDENTIFIED RESEARCH GAPS

Through literature review and personal interviews presented in Chapter two and Chapter three, a number of research gaps were discovered as listed below.

- Not clear about the best fit for simulation embedment in lean projects. Do companies need simulation wholesome or piecemeal in their lean projects?
- Companies are unaware of the procedure of simulation integration in lean projects.
- There is lack of structured framework to aid enterprises in determining simulation suitability at the conceptual stage.
- Few reasons explaining why organizations have not adopted simulation technique in their lean projects whole-heartedly.
- There are no available models capable of predicting lean effects through dynamic simulation quickly and accurately to potential users.

The research study has provided some solutions to the above research gaps by developing a reference framework about embedding simulation technique into lean projects. Furthermore, as a building block in SimLean framework, a customised simulation environment was developed and validated as described in Chapter five and Chapter six.

7.2.5 ACCOMPLISHMENT OF THE RESEARCH QUESTIONS

Chapter three described a number of research questions, and the answers are listed below.

1) Is it possible to embed simulation technique within lean projects? 2) What are the main concerns of embedding simulation? 3) How can companies embed simulation in lean projects? 4) Can embedment of simulation help companies overcome some limitations in lean implementation? 5) What is the most suitable delivery medium for the reference framework?

The answer to the first question is yes. The research has proven the possibility through the development of SimLean framework which aims to guide simulation integration in lean projects, as discussed in Chapter four.

The answers to question two and three can also be found in Chapter four of the thesis. The main concerns about embedding simulation include: whether or not simulation is applicable to solve the problem; Is simulation capable of overcoming the limitations of required lean tools; Select the suitable simulation team (in-house simulation team, simulation experts, external consultants, etc.); Determine the budget range; and select the most suitable delivery medium for building simulation models. The proposed SimLean framework provides a "how-to" guide for companies to adopt simulation technique in their lean projects.

Question four and five have been achieved through the development and deployment of a customised simulation environment, which can facilitate, simplify and standardize modelling process in lean projects as discussed in Chapter five and six respectively.

7.3 RESEARCH LIMITATIONS

The SimLean framework aims to guide lean users to adopt simulation technique in their projects. Additionally, the developed framework was conceptualised through the use of a customised simulation environment. What's more, the proposed simulation environment was tested and validated through five cases as presented in Chapter six. Thus, the main strengths of this research are listed as follows.

- A unique framework about embedding simulation in lean projects whose structure is systematic and generic and it overcomes major challenges as discussed in Section 4.4.
- The proposed customised simulation environment has simplified, facilitated and standardized simulation embedding process in lean projects, which is a novelty achievement in this research.
- The benefits of the designed simulation environment include dramatically saving model building time; eliminating the possible serious errors caused by incorrect model logic design or unsynchronised parameter modification; reducing threshold for users by designing the interface in Visio software, as discussed in Chapter five and Chapter six respectively.
- The SimLean framework can be used as a guidance roadmap by companies integrating simulation technique in their lean projects; or referenced by simulation teams and consultants as an outline in processing lean projects.

On the other hand, the research work has some limitations as well. For instance, the research project conducted two interview activities which involved only four interviewees. However, the small sample of interviewees is quite acceptable for this case, because the aim of the interviews is to get in-depth and holistic understanding in order to do justice to the complexity of social life (Punch, 2005); and the four selected interviewees hold standard basis to provide expert opinions in the lean projects.

Firstly, all the interviewees have plenty experience in conducting lean projects (see Section 3.4 for details). Secondly, all of them have delivered very successful lean projects in the last few years, which make their opinion very valuable since this whole research is based on the assumption that the company is already implementing lean methodology. Last but not least, the three interviewees in the manufacturing company have developed an interest in simulation technique and the lean six sigma consultant has used simulation in his lean projects before, which is a good match for this research subject. Hence, the adopted two interviews are sufficient for this research project.

Another limitation of the research work is that the proposed framework and developed system can not solve all the problems in lean projects. Even though simulation technique is a powerful tool in dealing with variant, dynamic and complex system, there are some problems that are not suitable for simulation technique to solve. For instance, 5S (sort, set in order, shine, standardize and sustain), visual control (set up the whole workplace with signs, labels, markings, etc.) and teams (an emphasis on team working in process improvement and daily work) are all basic and very important lean tools that can not be replaced by simulation technique.

7.4 FUTURE RESEARCH WORK

After conducting research about embedding simulation technique in lean projects, it is found out that a couple of other researchers are dealing with the same problem as presented in Section 2.5 in literature review. However, none of those research work or products are designed within a systematic framework as have been develop in this thesis. Thus in the future work, the researcher suggests that the comparison between the SimLean framework and other researchers' work can be conducted for future work. The author also suggests that future research investigation can be concentrated on simulation applications in six sigma projects, and finally a reference framework about embedding simulation technique in lean and six sigma projects could be proposed.

In conclusion, the research study has achieved the main aim and research objectives of developing a reference framework about embedding simulation technique in lean projects. Moreover, this thesis has conducted the following activities:

- The thesis has presented a review of lean manufacturing, DES (discrete event simulation) modelling and simulation applications in lean projects.
- The literature survey has identified a number of research gaps. Significantly, it has generated a need for further research work in the area of simulation embedment in lean projects.
- The research has proposed a systemic solution to the identified gaps. In particular, the research has developed a reference framework SimLean to assist simulation integration in lean projects and used a customised simulation environment to achieve fast modelling for lean projects.
- The user-friendly interface in Visio is designed to provide ease of understanding and interpretation for potential users.

- The thesis highlights that the SimLean framework has the features of being systematic and generic, and is capable of overcoming major challenges in simulation embedment.

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APPENDIX A: DATA COLLECTION SHEET

Date __________

Sheet No. __________

Company Name _________

Process Time __________

Error Rate __________

No. of Operators __________

No. of Shift per day __________

Summary of discussion with people in the vicinity

____

____

APPENDIX B: DATA COLLECTION SHEET FOR INTERVIEW

Tools / (Tick) Lean Project	Value stream map (1)	Systems Flow Chart (2)	Spaghetti Chart (3)	F-S Value Stream Map (4)	TAKT Time (5)	Lean Action Item List (6)	Lean Events (7)	5S (8)	Simulation (9)	Others (specify)	Challenges & Difficulties
Identify problems											
Train personnel											
Rank opportunities for improvement											
Document process											
Predict impact of improvement											
Address random and structural variation											
Analyze data											
Assess the interaction between system components											
Validate the future state											
Identify and consider alternatives to the future state											
Detail dynamic behaviour of production processes											

(1) Value Stream Mapping: A waste identification tool that is used to identify Lean improvement opportunities based on the non-value-added processes that get identified.

(2) Systems Flow Chart: A mapping tool to detail out the information process to eliminate the non-value-added information flow lines that existed.

(3) Spaghetti Chart: a mapping tool to show the travel time of the materials and/or the people involved in the process.

(4) Future State Value Stream Map: An ideal VSM achievable in the future to help identify a target goal for our improvement effort.

(5) TAKT Time: The time it will take to produce one unit of product in order to meet customer demand.

(6) Lean Action Item List or Lean Newspaper: An action item list of improvements to show the specific areas that are targeted for change.

(7) Lean Events: a team activity designed to eliminate waste and make rapid changes in the workplace.

(8) 5S: The objective is to create an organized, safe, and productive work environment. The 5Ss are:

Sort -- separate the needed from the unneeded items.

Set in Order (Straighten) -- physically rearrange the layout; organize the work area.

Shine -- clean and remove reasons for contaminants.

Standardize -- implement procedures and signalling systems that ensure worker understanding of the process.

Sustain -- set up systems to ensure open and complete communication.

(9) Simulation: A means of experimenting with a detailed model of a real system to determine how the system will respond to changes in its structure, environment or underlying assumptions.

Simulation is a means of experimenting with a detailed model of a real system to determine how the system will respond to changes in its structure, environment or underlying assumptions. In short, a simulation model can help people to see the effects before a big implementation. Do you think simulation can be used in Lean projects? Comment.

Contact Phone

Address

E-mail

Thanks for your help!

APPENDIX C: DIALOG DESIGN OF SIMVSM TEMPLATE

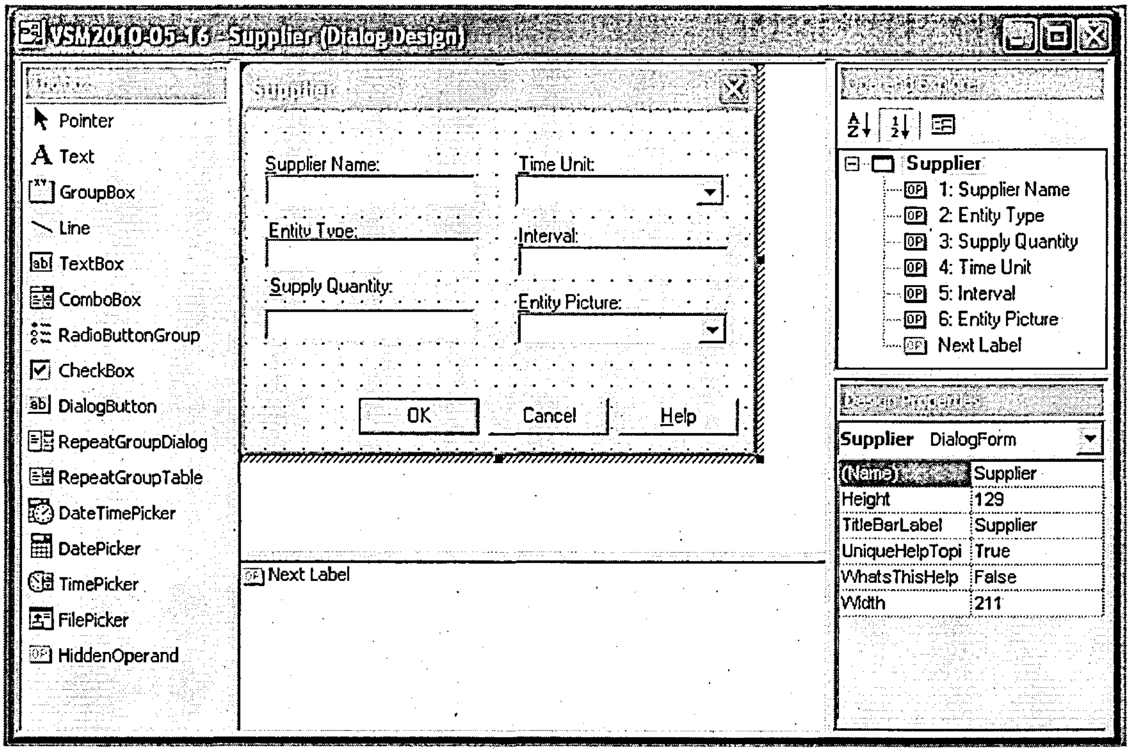

Figure c.1 Dialog design of supplier module

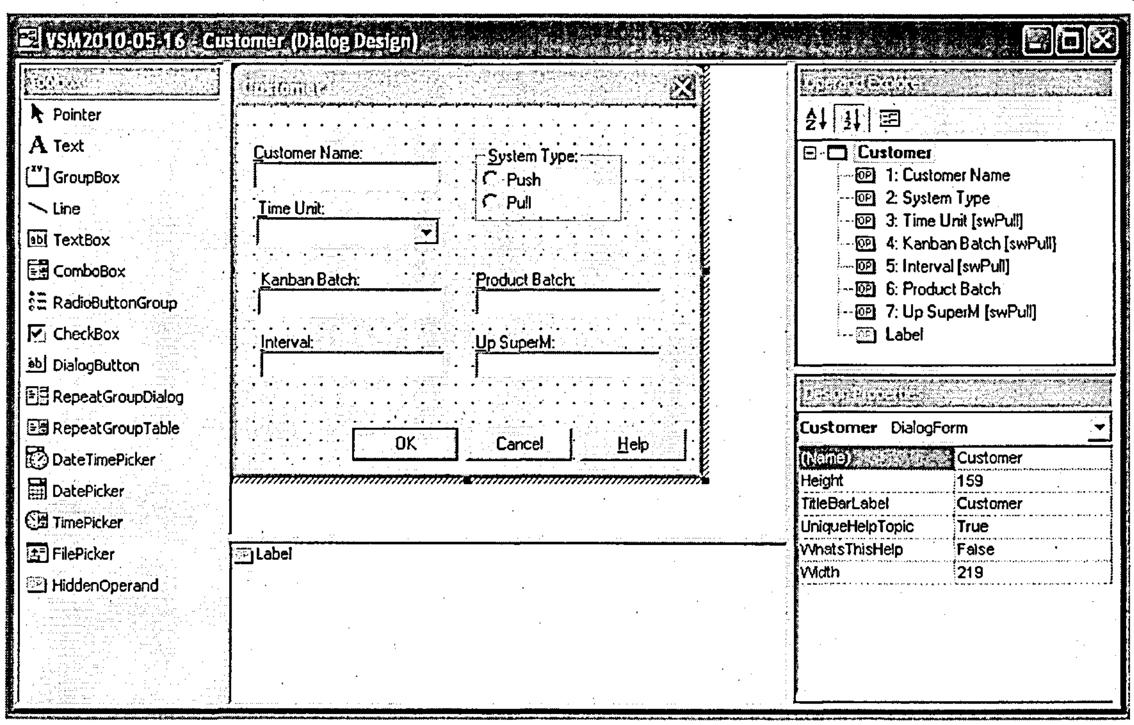

Figure c.2 Dialog design of customer module

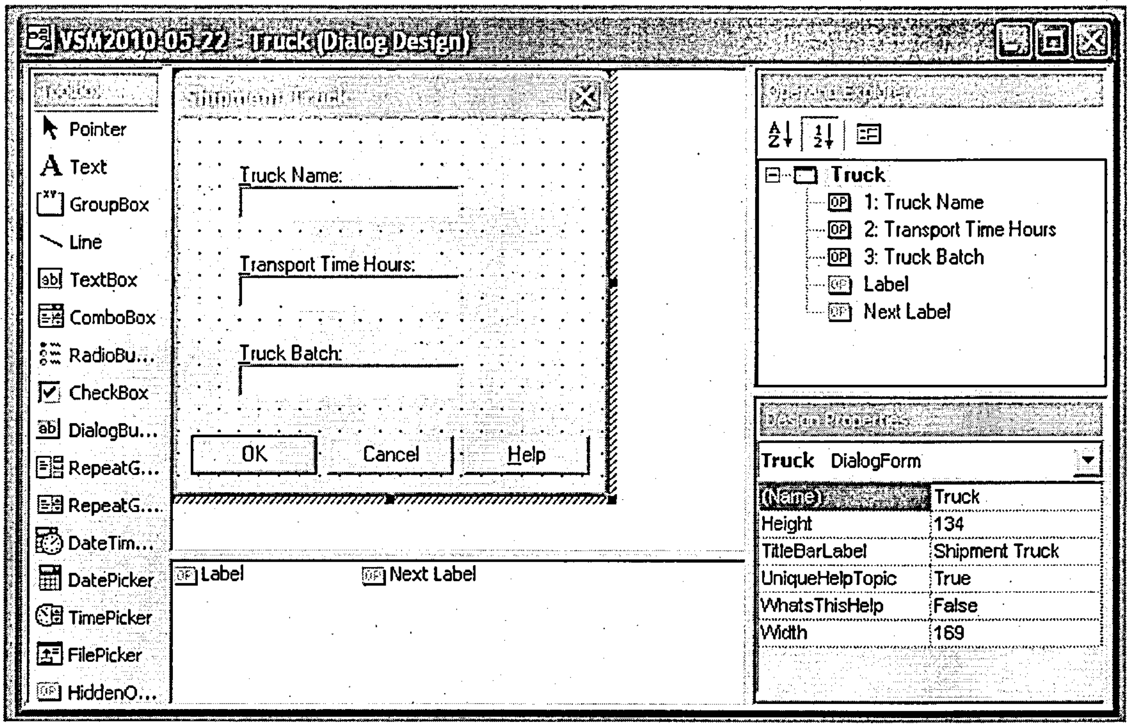

Figure c.3 Dialog design of truck module

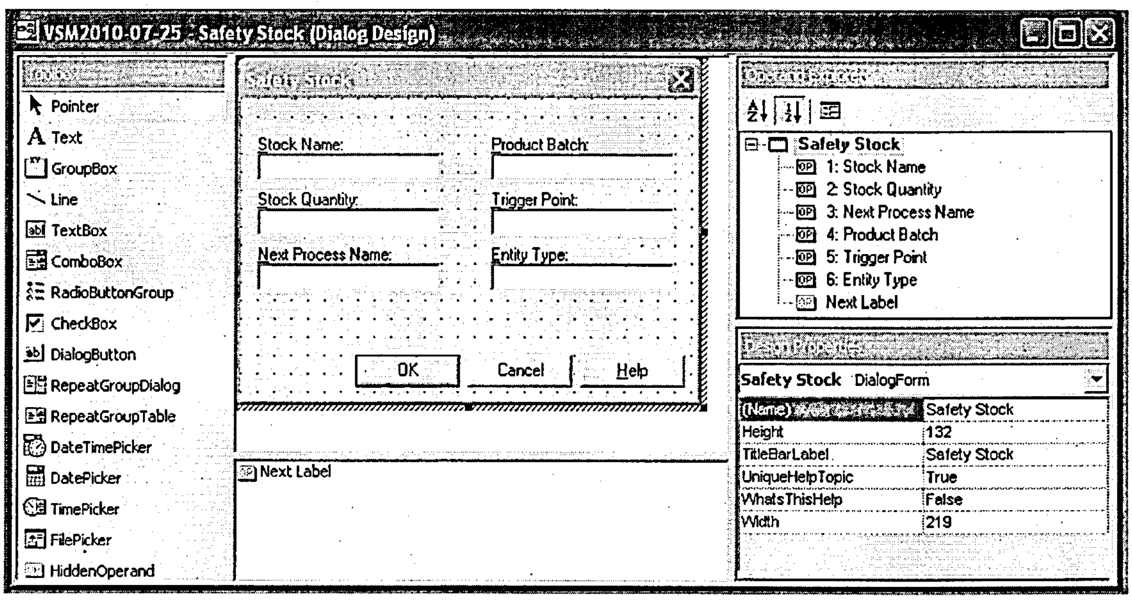

Figure c.4 Dialog design of safety stock module

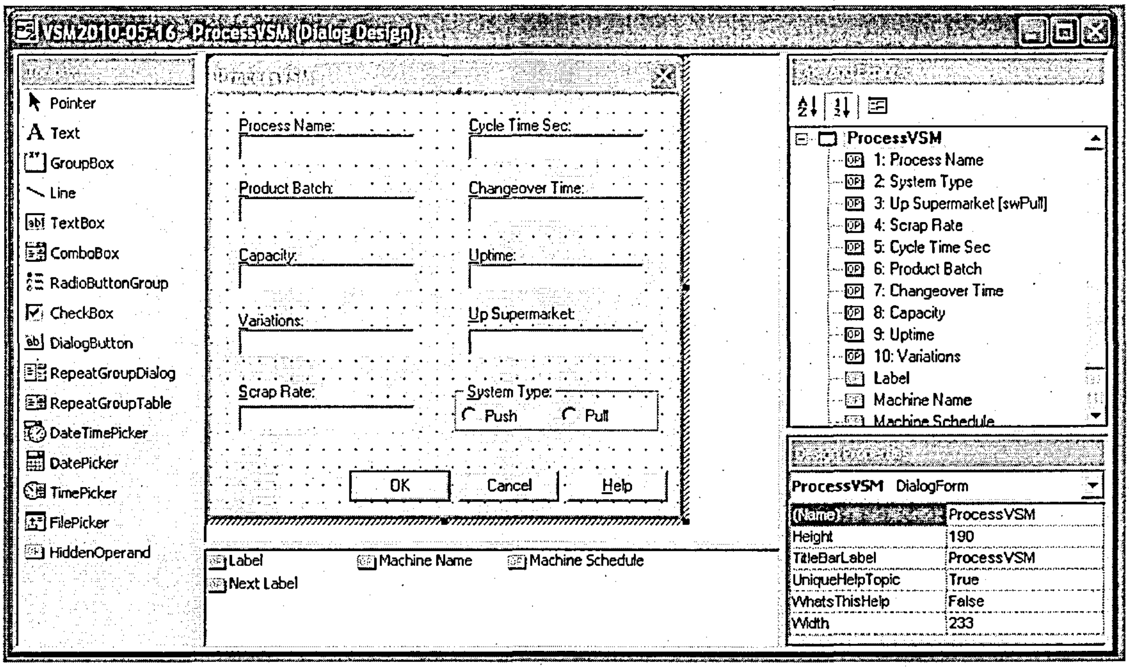

Figure c.5 Dialog design of ProcessVSM module

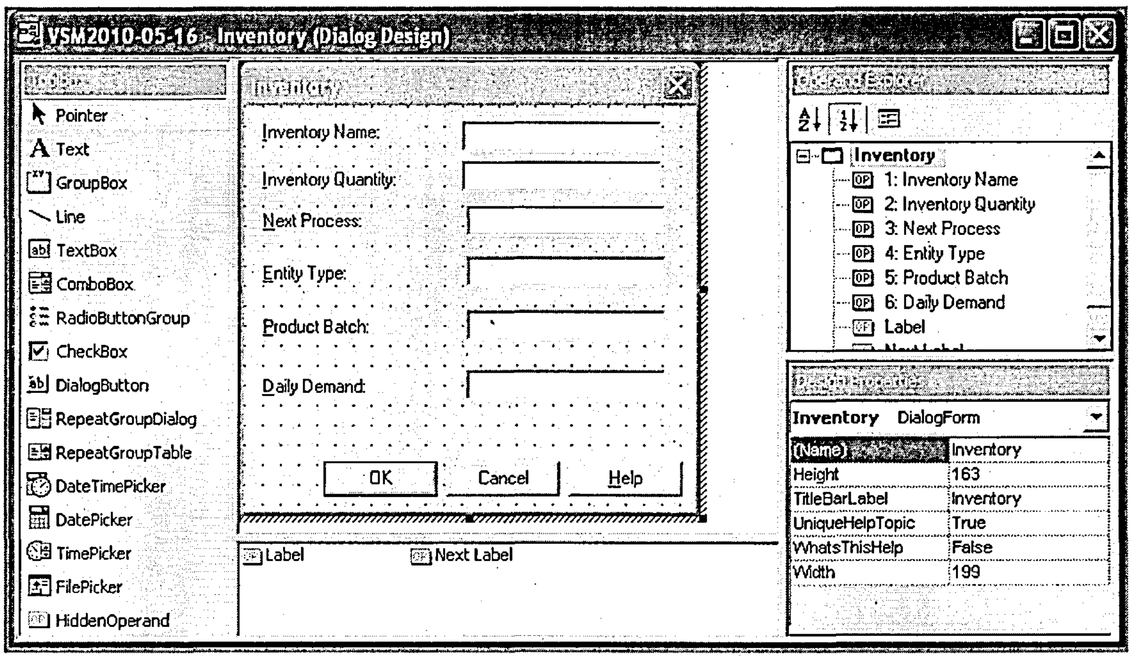

Figure c.6 Dialog design of Inventory module

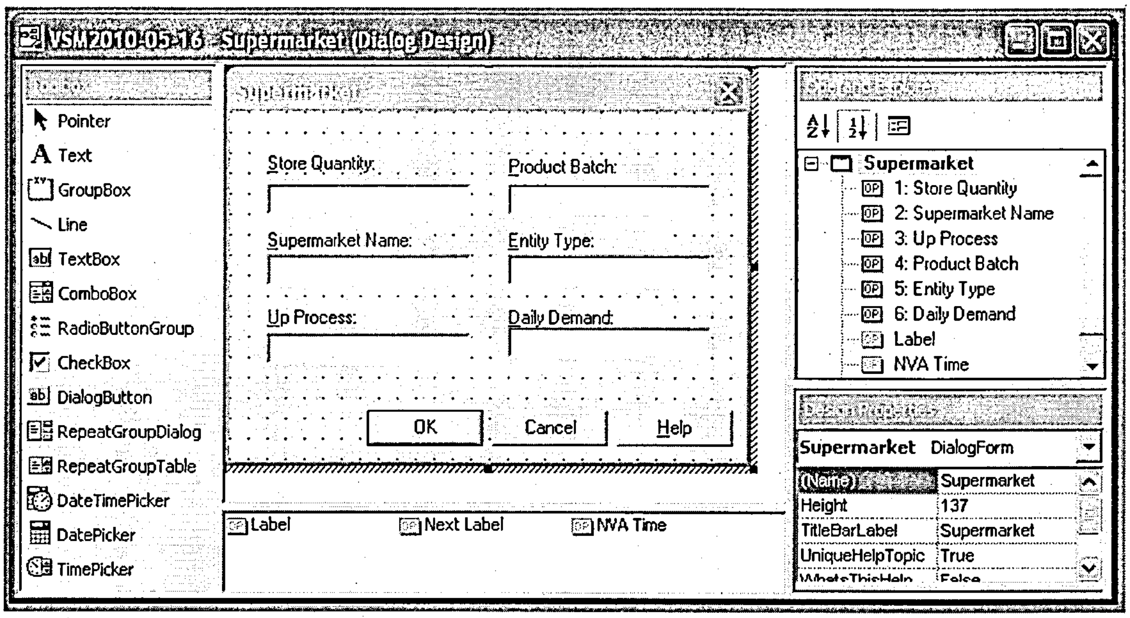

Figure c.7 Dialog design of Supermarket module

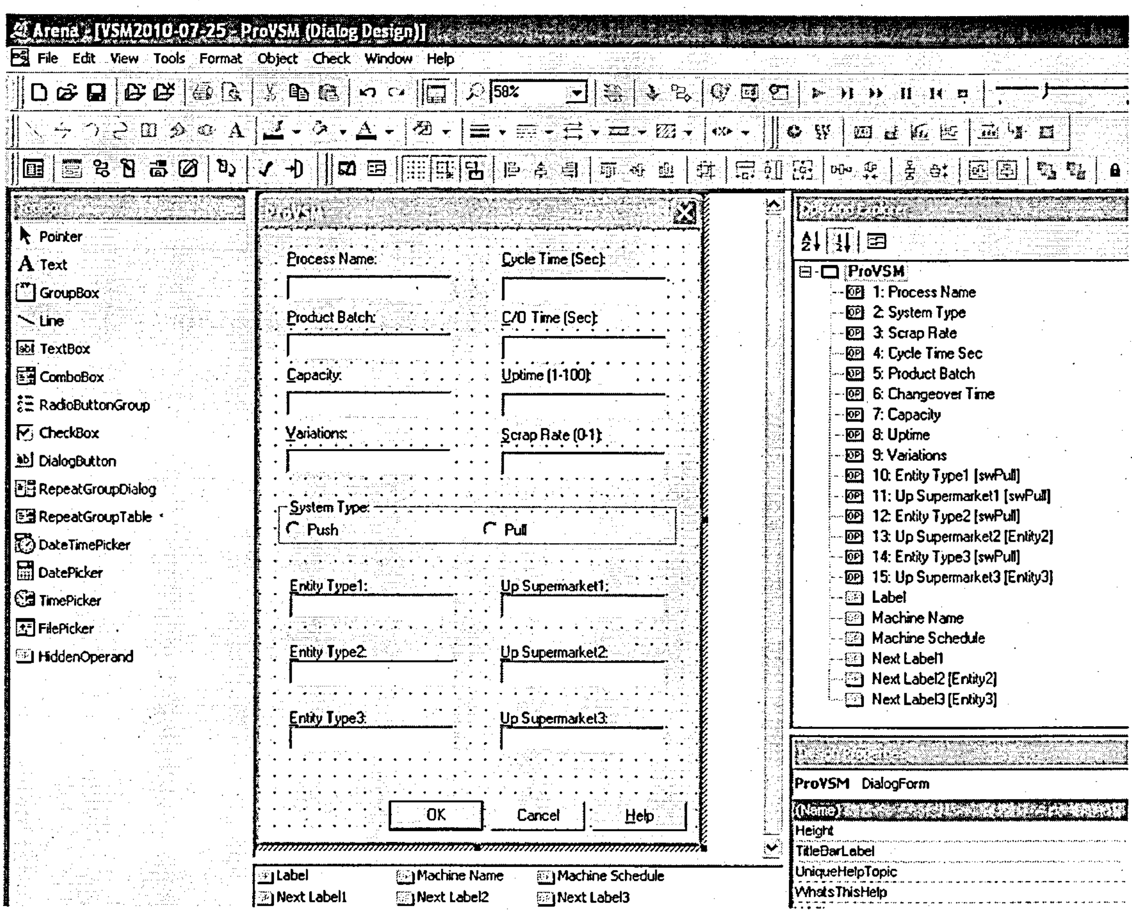

Figure c.8 Dialog design of modified ProVSM module

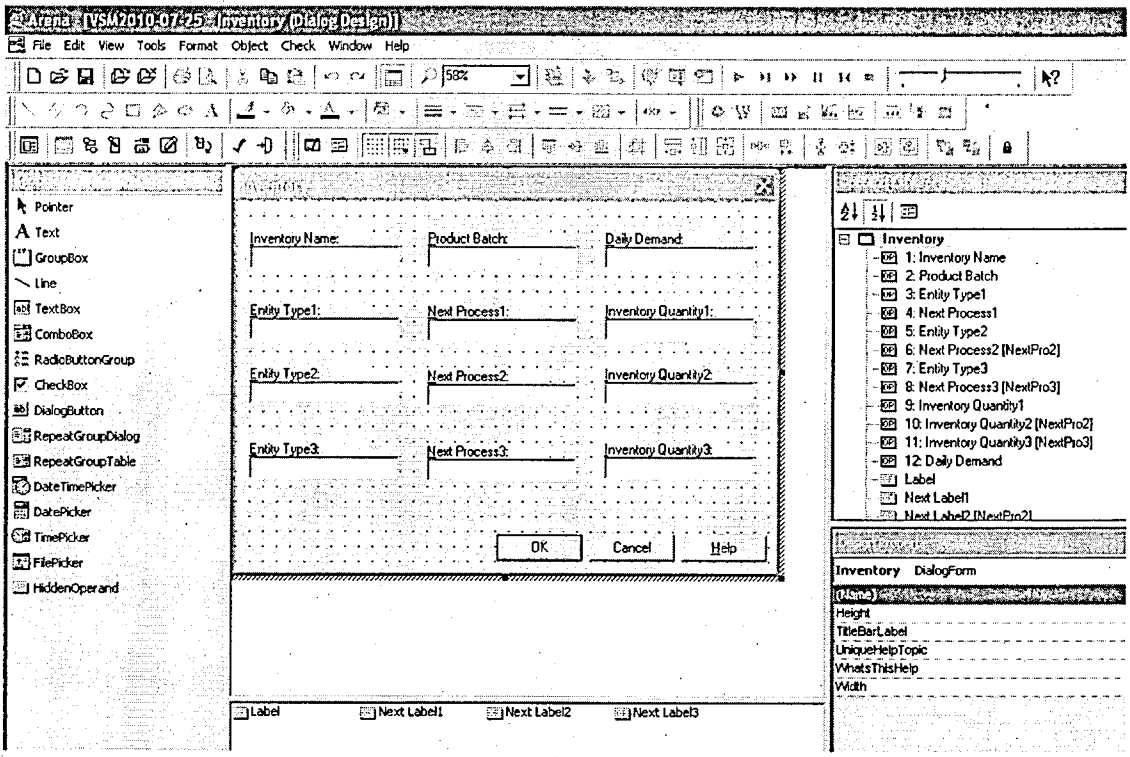

Figure c.9 Dialog design of modified Inventory module

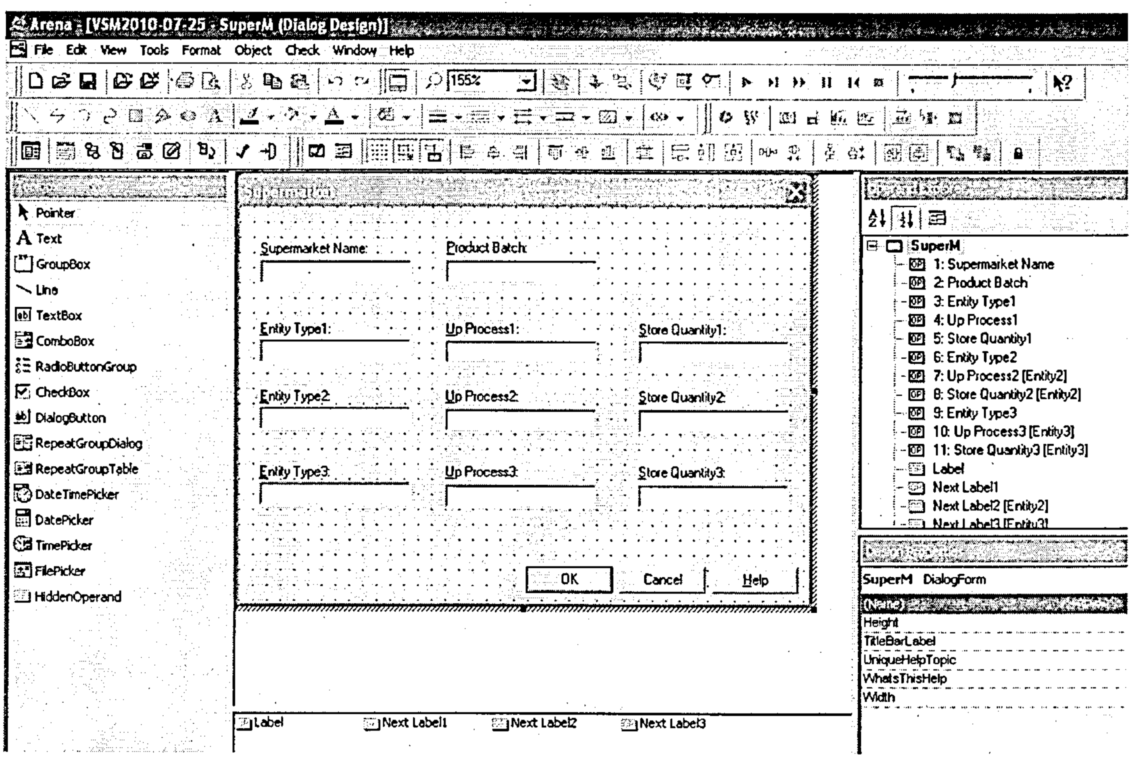

Figure c.10 Dialog design of modified Supermarket module

APPENDIX D: VISVSM TEMPLATE PARAMETERS

SUPPLIER MASTER

Table D.1 Properties of supplier master

LABEL	NAME	TYPE	VALUE	LANGUAGE	CALENDAR
SupplierName	SupplierName	String	Supplier1	English	Western
EntityType	EntityType	String	Entity1	English	Western
SupplyQuantity	SupplyQuantity	String	500	English	Western
TimeUnit	TimeUnit	String	Days	English	Western
Interval	Interval	String	1	English	Western

CUSTOMER MASTER

Table D.2 Properties of customer master

LABEL	NAME	TYPE	VALUE	LANGUAGE	CALENDAR
CustomerName	CustomerName	String	Customer1	English	Western
TimeUnit	TimeUnit	String	Days	English	Western
KanbanBatch	KanbanBatch	String	1	English	Western
Interval	Interval	String	1	English	Western
SystemType	SystemType	String	Push	English	Western
ProductBatch	ProductBatch	String	10	English	Western
UpSuperM	UpSuperM	String	SuperM2	English	Western

TRUCK MASTER

Table D.3 Properties of truck master

LABEL	NAME	TYPE	VALUE	LANGUAGE	CALENDAR
TruckName	TruckName	String	Truck1	English	Western
TransTimeHrs	TransTimeHrs	String	1	English	Western
TruckBatch	TruckBatch	String	500	English	Western

PROVSM MASTER

Table D.4 Properties of provsm master

LABEL	NAME	TYPE	VALUE	LANGUAGE	CALENDAR
ProcessName	ProcessName	String	ProVSM1	English	Western
ProductBatch	ProductBatch	String	10	English	Western
Capacity	Capacity	String	3	English	Western
Variations	Variations	String	5	English	Western
ScrapRate	ScrapRate	String	0.02	English	Western
CycleTime	CycleTime	String	40	English	Western
C/OTime	C/OTime	String	10	English	Western
Uptime	Uptime	String	100	English	Western
UpSuperM	UpSuperM	String	SuperM1	English	Western
SystemType	SystemType	String	Push	English	Western

INVENTORY MASTER

Table D.5 Properties of inventory master

LABEL	NAME	TYPE	VALUE	LANGUAGE	CALENDAR
InventoryName	InventoryName	String	Inventory 1	English	Western
InventoryQuantiy	InventoryQuantity	String	300	English	Western
NextProcess	NextProcess	String	ProVSM 1	English	Western
EntityType	EntityType	String	Entity1	English	Western
ProductBatch	ProductBatch	String	10	English	Western
DailyDemand	DailyDemand	String	600	English	Western

SUPERMARKET MASTER

Table D.6 Properties of supermarket master

LABEL	NAME	TYPE	VALUE	LANGUAGE	CALENDAR

LABEL	NAME	TYPE	VALUE	LANGUAGE	CALENDAR
SuperMName	SuperMName	String	SuperM1	English	Western
StoreQuantity	StoreQuantity	String	350	English	Western
UpProcess	UpProcess	String	ProVSM1	English	Western
ProductBatch	ProductBatch	String	10	English	Western
EntityType	EntityType	String	Entity1	English	Western
DailyDemand	DailyDemand	String	600	English	Western

KAIZEN BURST MASTER

Table D.7 Properties of kaizen burst master

LABEL	NAME	TYPE	VALUE	LANGUAGE	CALENDAR
KaizenName	KaizenName	String	Kaizen1	English	Western

SAFETY STOCK MASTER

Table D.8 Properties of safety stock master

LABEL	NAME	TYPE	VALUE	LANGUAGE	CALENDAR
StockName	StockName	String	Stock1	English	Western
EntityType	EntityType	String	Entity1	English	Western
StockQuantity	StockQuantity	String	500	English	Western
TrigerPoint	TrigerPoint	String	20	English	Western
NextModule	NextModule	String	SuperM1	English	Western

FIFO LANE MASTER

Table D.9 Properties of FIFO lane master

LABEL	NAME	TYPE	VALUE	LANGUAGE	CALENDAR
FIFOName	FIFOName	String	FIFO1	English	Western

SEQUENCED PULL BALL MASTER

Table D.10 Properties of sequenced pull ball master

LABEL	NAME	TYPE	VALUE	LANGUAGE	CALENDAR
SPBallName	SPBallName	String	SPBall1	English	Western

LOAD LEVELLING MASTER

Table D.11 Properties of load levelling master

LABEL	NAME	TYPE	VALUE	LANGUAGE	CALENDAR
LevelName	LevelName	String	Level1	English	Western

APPENDIX E: MAPPING FILE CONTENT

STENCIL	SHAPE	PROPERTY		TEMPLATE	MODULE	OPERAND
VisVSM	Customer			SimVSM	Customer	
VisVSM	Customer	Customer Name		SimVSM	Customer	Customer Name
VisVSM	Customer	EntityType		SimVSM	Customer	Entity Type
VisVSM	Customer	Interval		SimVSM	Customer	Interval
VisVSM	Customer	KanbanBatch		SimVSM	Customer	Kanban Batch
VisVSM	Customer	SystemType		SimVSM	Customer	System Type
VisVSM	Customer	TimeUnit		SimVSM	Customer	Time Unit
VisVSM	Customer	UpSuperM		SimVSM	Customer	Up SuperM
VisVSM	Inventory			SimVSM	Inventory	
VisVSM	Inventory	DailyDemand		SimVSM	Inventory	Daily Demand
VisVSM	Inventory	EntityType1		SimVSM	Inventory	Entity Type1
VisVSM	Inventory	EntityType2		SimVSM	Inventory	Entity Type2
VisVSM	Inventory	EntityType3		SimVSM	Inventory	Entity Type3
VisVSM	Inventory	Inventory Name		SimVSM	Inventory	Inventory Name
VisVSM	Inventory	Inventory Quantity1		SimVSM	Inventory	Inventory Quantity1
VisVSM	Inventory	Inventory Quantity2		SimVSM	Inventory	Inventory Quantity2

STENCIL	SHAPE	PROPERTY		TEMPLATE	MODULE	OPERAND
VisVSM	Inventory	Inventory Quantity3		SimVSM	Inventory	Inventory Quantity3
VisVSM	Inventory	Next Process1		SimVSM	Inventory	Next Process1
VisVSM	Inventory	Next Process2		SimVSM	Inventory	Next Process2
VisVSM	Inventory	Next Process3		SimVSM	Inventory	Next Process3
VisVSM	Inventory	ProductBatch		SimVSM	Inventory	Product Batch
VisVSM	Kaizen Burst			SimVSM	Kaizen Burst	
VisVSM	Kaizen Burst	KaizenName		SimVSM	Kaizen Burst	Kaizen Name
VisVSM	Load Leveling			SimVSM	Load Leveling	
VisVSM	Load Leveling	ModuleName		SimVSM	Load Leveling	Module Name
VisVSM	ProcessVSM			SimVSM	ProVSM	
VisVSM	ProcessVSM	Capacity		SimVSM	ProVSM	Capacity
VisVSM	ProcessVSM	Changeover Time		SimVSM	ProVSM	Changeover Time
VisVSM	ProcessVSM	CycleTime Sec		SimVSM	ProVSM	Cycle Time Sec
VisVSM	ProcessVSM	EntityType1		SimVSM	ProVSM	Entity Type1
VisVSM	ProcessVSM	EntityType2		SimVSM	ProVSM	Entity Type2
VisVSM	ProcessVSM	EntityType3		SimVSM	ProVSM	Entity Type3

STENCIL	SHAPE	PROPERTY		TEMPLATE	MODULE	OPERAND
VisVSM	ProcessVSM	Process Name		SimVSM	ProVSM	Process Name
VisVSM	ProcessVSM	Product Batch		SimVSM	ProVSM	Product Batch
VisVSM	ProcessVSM	ScrapRate		SimVSM	ProVSM	Scrap Rate
VisVSM	ProcessVSM	SystemType		SimVSM	ProVSM	System Type
VisVSM	ProcessVSM	UpSupermarket1		SimVSM	ProVSM	Up Supermarket 1
VisVSM	ProcessVSM	UpSupermarket2		SimVSM	ProVSM	Up Supermarket 2
VisVSM	ProcessVSM	UpSupermarket3		SimVSM	ProVSM	Up Supermarket 3
VisVSM	ProcessVSM	Uptime		SimVSM	ProVSM	Uptime
VisVSM	ProcessVSM	Variations		SimVSM	ProVSM	Variations
VisVSM	Safety / Buffer stock			SimVSM	Safety Stock	
VisVSM	Safety / Buffer stock	EntityType		SimVSM	Safety Stock	Entity Type
VisVSM	Safety / Buffer stock	NextProcess		SimVSM	Safety Stock	Next Process
VisVSM	Safety / Buffer stock	ProductBatch		SimVSM	Safety Stock	Product Batch
VisVSM	Safety /	StockName		SimVSM	Safety	Stock Name

STENCIL	SHAPE	PROPERTY		TEMPLATE	MODULE	OPERAND
	Buffer stock				Stock	
VisVSM	Safety / Buffer stock	StockQuanti ty		SimVSM	Safety Stock	Stock Quantity
VisVSM	Safety / Buffer stock	TriggerPoint		SimVSM	Safety Stock	Trigger Point
VisVSM	Sequenc ed Pull Ball			SimVSM	Sequenc ed Pull Ball	
VisVSM	Sequenc ed Pull Ball	PullBallNam e		SimVSM	Sequenc ed Pull Ball	Pull Ball Name
VisVSM	Shipment truck			SimVSM	Truck	
VisVSM	Shipment truck	TransportTi me Hours		SimVSM	Truck	Transport Time Hours
VisVSM	Shipment truck	TruckBatch		SimVSM	Truck	Truck Batch
VisVSM	Shipment truck	TruckName		SimVSM	Truck	Truck Name
VisVSM	Superma rket			SimVSM	SuperM	
VisVSM	Superma rket	EntityType1		SimVSM	SuperM	Entity Type1
VisVSM	Superma rket	EntityType2		SimVSM	SuperM	Entity Type2
VisVSM	Superma rket	EntityType3		SimVSM	SuperM	Entity Type3
VisVSM	Superma rket	ProductBatc h		SimVSM	SuperM	Product Batch
VisVSM	Superma	StoreQuantit		SimVSM	SuperM	Store

STENCIL	SHAPE	PROPERTY		TEMPLATE	MODULE	OPERAND
	rket	y1				Quantity1
VisVSM	Supermarket	StoreQuantity2		SimVSM	SuperM	Store Quantity2
VisVSM	Supermarket	StoreQuantity3		SimVSM	SuperM	Store Quantity3
VisVSM	Supermarket	Supermarket Name		SimVSM	SuperM	Supermarket Name
VisVSM	Supermarket	UpProcess1		SimVSM	SuperM	Up Process1
VisVSM	Supermarket	UpProcess2		SimVSM	SuperM	Up Process2
VisVSM	Supermarket	UpProcess3		SimVSM	SuperM	Up Process3
VisVSM	Supplier			SimVSM	Supplier	
VisVSM	Supplier	EntityType		SimVSM	Supplier	Entity Type
VisVSM	Supplier	Interval		SimVSM	Supplier	Interval
VisVSM	Supplier	SupplierName		SimVSM	Supplier	Supplier Name
VisVSM	Supplier	SupplyQuantity		SimVSM	Supplier	Supply Quantity
VisVSM	Supplier	TimeUnit		SimVSM	Supplier	Time Unit