Global Manufacturing Capability

Modelling and Evaluation

Ratnayake Liyanage Chamli Srimal Pushpakumara

A thesis submitted in partial fulfilment of the requirements of Sheffield Hallam University for the degree of Doctor of Philosophy.

January 1999

Collaborating Organisations:

Avesta Sheffield
British Steel Engineering Steels
Sheffield Forgemasters

Abstract

Desires to gain access to new markets, minimise production cost, take advantage of regional investment incentives and enhance technological development have prompted many companies to study the feasibility of globalising their manufacturing activities. They need evaluation tools which will provide structured and systematic methodologies to study and facilitate global manufacturing decisions. Past work by numerous academics and researchers in comparing the manufacturing competitiveness between different nations provide valuable insight into the advantages and disadvantages of locating manufacturing facilities in different countries. In an operational point of view, however, companies require more specific information about a changing industry and its sub-industries with the view of evaluating their capabilities within the context of global socio-economic and technological trends.

This thesis proposes a conceptual model that will assist companies to measure, compare and project their manufacturing performances when supplying to a particular market using products manufactured in different locations. This Manufacturing Capabilities Model is conceptually represented by a cuboid, the three axis of which relates to manufacturing process, performance and potential respectively. Manufacturing processes and performance measures are organised in a hierarchical matrix under major stages of the production process and four main performance criteria of cost, quality, delivery and flexibility. The relative importance of these four performance criteria to a company varies according to the structure of the industry in a particular region. Potential represents the changes in performance in response to changes in the business environment. The validity of the model is demonstrated based on its implementation on the steel industry.

The Manufacturing Capabilities Model adopts Analytic Hierarchy Process (AHP) technique to evaluate global manufacturing competitiveness. This model enables a company to compare the competitiveness of different production route configurations encompassing different plants in different countries. It analyses the multiple-attribute problems by decomposing them to hierarchies. It provides pairwise comparison of criteria and generates an integrated overall score based on which alternative decisions can be ranked and compared.

Software built on Expert Choice, a software package based on AHP, facilitates the implementation of the model in the steel industry. User interface is provided by Microsoft Excel with Visual Basic for Applications. Several options are available for the users to analyse performance results.

The model validation is supported by a comprehensive questionnaire which facilitates data collection in the steel industry. Two industrial case studies based on the Chinese steel industry are used to validate the overall modelling methodology.

Table of Contents

List of Figures

List of Tables

This thesis is dedicated to my parents, my wife and our son, *HASIRU*.

Acknowledgement

I wish to express my sincere gratitude to my Director of Studies, Professor E K Lo for his guidance, unfailing interest and invaluable advice through the entire duration of this research. The support from my supervisors, Mr. Charles Pickford and Mr. David Eaton is gratefully acknowledged. Valuable advise was given by Mr. Brian Jeremiah also.

I would like to extend my gratitude to the School of Engineering, Avesta Sheffield, British Steel Engineering Steels and Sheffield Forgemasters for sponsoring my study.

Special thanks are due for my colleague, Mr. Zong Dai for his valuable support in the collection of industrial data from China. I also wish to extend my appreciation to Mr. Y B Zhang and Mrs. D M Leng for their kind assistance in translating valuable information published in the Chinese Language.

I am indebted to Dr. S R D Kalingamudali of the Department of Physics, University of Kelaniya, Sri Lanka for paving me the way to pursue higher studies. The encouragement given by Mr. Lalith Munasinghe and the rest of the staff of the Department of Industrial Management, University of Kelaniya is gratefully acknowledged.

The assistance given by all the colleagues during these three years is highly appreciated.

R L C S Pushpakumara

Declaration

I declare that, while registered as a candidate for the University's research degree, I have not been a registered candidate or enrolled student for another award of the University or other academic or professional organisation. I further declare that no material contained in this thesis has been used in any other submission for an academic award.

R L C S Pushpakumara

Chapter 1

Globalisation and Its Impact on Manufacturing Industries

1.1 Introduction

Globalisation of economic activities has, directly or indirectly, affected virtually everyone in the world today. This phenomenon has generated a considerable amount of research interest in recent times in a wide range of related areas. The objective of this chapter is to review the literature on economic globalisation and its implications on the manufacturing industries. It will also survey the strategic options available for and used by these industries to face the challenges of globalisation.

Section 1.2 reviews the globalisation process. The economic globalisation has affected the manufacturing organisations basically in two ways: intensifying pressures for competitiveness and survival, and providing opportunities for expansion into global markets. Different theories are available to explain the factors that make a company *go global*. Various authors have written on strategies available for the companies to embark on globalising their operations. The options available for organising production units in a global manufacturing network are also studied.

Section 1.3 relates the effects of globalisation to three industries, viz. Steel, clothing and machine tool, with the main emphasis on steel industry. Steel industry has undergone major structural changes in the past two decades. The position of developed countries as major steel producers has seriously been challenged by developing nations such as China, South Korea, India and Brazil. Clothing industry is one of the first industries to expand globally, and a vital industry for both developing and developed countries. The structure of the machine tool industry, once dominated by USA, has undergone vast changes in the last few decades with a large percentage of world production coming from emerging nations such as China and South Korea.

Section 1.4 analyses the steel-making process with the view of studying the possibility of organising the production operations globally. Major sub-processes are studied to identify the alternative technologies available.

Section 1.5 provides an overview for the thesis.

1.2 Globalisation

Globalisation is one of the most popular terms found in the recent literature in virtually every discipline. It has become so popular a term today that it is used and misused in a vast array of contexts. According to Porter [Porter 86a], the term *global* has become overused and under-understood. In the business world, the terms *global business*, *global competition*, *global company* and *global strategy* are used ambiguously and misleadingly to describe a number of diverse activities or entities [Hamel 88]. These range from the establishment of manufacturing operations overseas to match the lower labour costs of foreign competitors to restructuring an organisation to consolidate strategic responsibility for a particular business at its headquarters.

Because of the ambiguity in the use of the terms internationalisation and globalisation, it was evident that on many occasions both terms have been used to describe similar scenarios. In contrast to the internationalisation process which involves only the extension of economic activities across national boundaries, the globalisation process involves not only the geographical extension of economic activities, but also the functional integration of such internationally dispersed activities [Dunning 92].

In an operational perspective Shi and Gregory [Shi 94] have defined globalisation as the 'process of moving from an independently managed business serving local markets to networks of businesses serving the businesses' chosen markets in a co-ordinated and optimised way'.

However, by globalisation of operations it does not necessarily mean organising operations to cover all parts of the world. It is concerned with the overall view as to how the networks of operations are configured and co-ordinated in order to achieve the maximum benefit, irrespective of the extent of the geographical area that they would cover.

1.2.1 Economic Globalisation: How It Affects Business Organisations

The process of economic globalisation is a major phenomenon that characterises the last few decades of world history. The integrated economic system that exists today as a result of the evolving of the global economy offers opportunities for aggressive global manufacturers [Schully 93]. A firm should be able to read the changes in the global environment and adapt in time to stay competitive.

Economic globalisation has affected manufacturing firms in two ways. It has intensified competitive pressures on manufacturing firms on one hand. On the other hand it has initiated a move towards creating global markets [Fawcett 92]. Cost was the dominant competitive factor in the early stages of this process. The market dominance of North American, European and Japanese companies was threatened by newly emerging economies, particularly in the Far East, which had the advantage of low cost labour. The threat from the new entrants to the international industrial activities is far from over

[Vos 91]. Potential industrial giants such as former Soviet Union states, China, India and Brazil may enter the fray in an even bigger scale than did their Far Eastern counterparts. The emergence of a global market can partly be attributed to the rapid developments in the communications technology over the years [Verter 92]. These developments in telecommunications technology caused a standardisation in demands of people in different geographical regions. The economic liberalisation of the countries particularly in the Far Fast and Asia also created a new potential market with a high growth rate. These factors offered the companies opportunity to exploit the benefits of economies of scale and economies of scope [Meffert 91].

Bolt [Bolt 88] confirmed the argument that there is no single set of criteria to assess what makes a firm a successful global competitor. That is because of the complexity of the factors involved. However he introduced a broad criteria that is necessary to become, and has been evident in successful global competitors, in the form of ten statements. Paramount of these is the necessity to formulate a sound strategy on an integrated world wide basis. In spite of the awareness created among the manufacturing community about these developments in the macroeconomics situation during the past few decades, the lack of global view has been rated in a recent survey as the number one barrier for the management of international operations [Klassen 94].

Considering the possible negative aspects of this process, however, some critics caution that the economic integration should not be achieved at the cost of social disintegration [Rodrik 97]. They argue that globalisation, if not properly handled, would expose a deep fault line between those who have the skills and mobility to flourish in global markets and those who have not. On the other hand, the economic integration and the resultant interdependencies of economies have made countries and regions in different parts of the world become more vulnerable to the setbacks in economic activities in the other parts of the world. A crisis in one region will affect the others in a chain reaction. A classic example for this phenomenon is the recent financial crisis in the South East Asia, effects of which eventually reached the other parts of the world as well in the form of a global economic meltdown.

1.2.2 Why Companies Globalise Manufacturing Operations

Many authors who attempted to identify the factors that contributed to the globalisation (and internationalisation) of manufacturing have classified them according to several dimensions. One of the notable early contributors is John H Dunning who introduced the eclectic paradigm of international production [Dunning 92]. It suggests that firms will engage in international activities based on three advantages:

- Ownership-specific advantages :

  Possession of intangible assets that give a firm a competitive advantage. E.g. specific properties of the production management, know-how and legally protected rights.

- Internalisation-incentive advantages :

  Ability of the firm to exploit the ownership-specific advantages by itself, without selling or leasing them to other firms. E.g. by vertically integrating processes.

- Location -specific advantages :

  The ability of the firm to exploit its assets overseas, which makes it more profitable for the firm. E.g. markets, resources, production costs and political conditions.

However, it is emphasised that all three of these conditions have to be satisfied for international production to occur.

Fawcett [Fawcet 1993] has identified two different reasons for businesses to embark on global manufacturing operations according to their objectives and has presented them in the form two distinct strategies:

- Factor input strategy

  This strategy aims at enhancing the competitive position of a firm in the home market by taking the advantage of regional comparative advantages in terms of the best mix of factor inputs (low costs and/or high quality).

- Host market strategy

  The aim of this strategy is to enhance the firm's access to foreign markets.

Whatever is the strategy the firm is adopting, according to Dunning's eclectic paradigm, they have to satisfy all three conditions for globalisation to occur. However, the exact factor that gives the advantage in each criteria may differ, and as such different sets of advantage factors could be defined according to the objective the firm expects to achieve through globalisation.

Sheth and Eshghi [Sheth 89] described four major factors that have influenced the globalisation of manufacturing operations : cost competitiveness, competitive markets, government policy and improved manufacturing processes.

As discussed in Section 1.2.1, cost competitiveness and competitive markets are the two major factors that influenced global operations. Newly developing nations such as South Korea and Taiwan which were looking for investment capital and new technologies offered attractive incentives for these companies to locate their manufacturing facilities in their countries. In some cases, locating manufacturing plants in a host country enables a company to circumvent possible market entry barriers.

The other major force encouraging global manufacturing operations is improved manufacturing processes. New technologies have encouraged distributed manufacturing by lowering capacity thresholds for scale economy in operations. The breakthrough advancements in the information technology, transportation and communications also contributed in this respect.

Figure 1.1 summarises the view of [Sheth 89] on the factors that contributed towards global manufacturing operations.

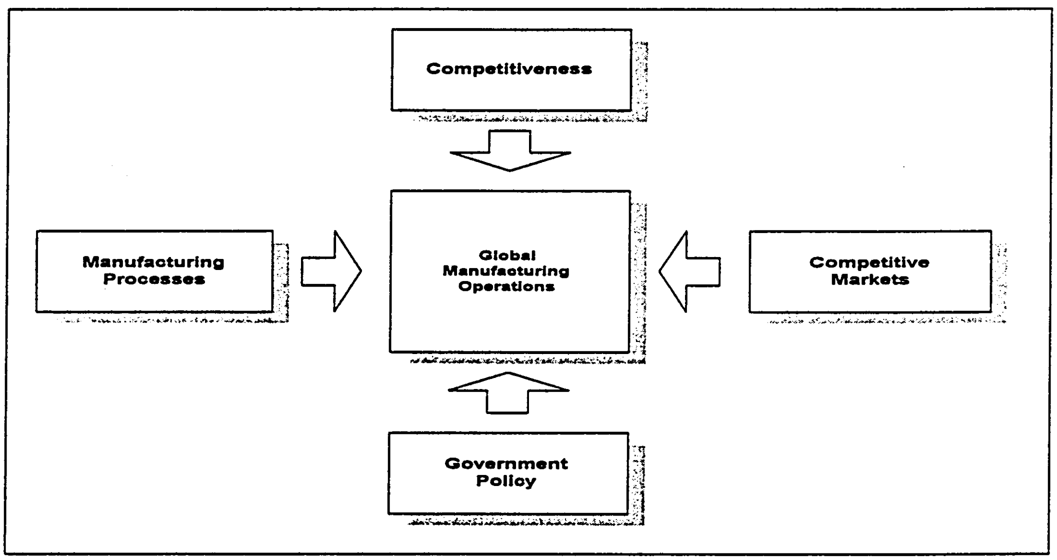


Figure 1.1: Factors contributed towards globalisation of manufacturing operations.
Source: [Sheth 89]

1.2.3 Contingency and Systems Theories in Globalisation

Looking from an academic point of view, Fawcett [Fawcett 92] attempted to describe the manufacturing globalisation process according to the contingency and system theories.

The contingency theory generally discussed in the management literature states that organisations are open systems affected by their environment where managers select appropriate competitive strategies to succeed. Fawcet has used this environment - strategy - performance contingency relationship to describe globalisation of operations. He argued that the competitive pressures brought about by economic globalisation has necessitated that firms develop global manufacturing strategies to maintain or enhance performance. This view is summarised in Figure 1.2.

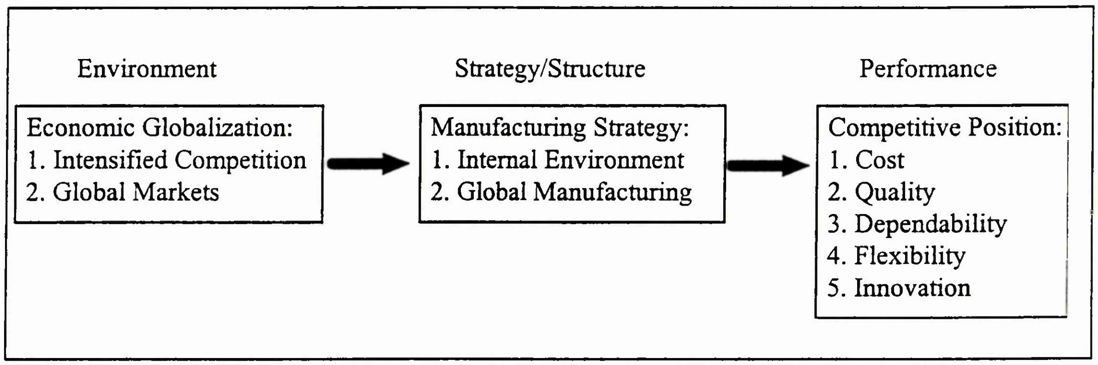


Figure 1.2 : Contingency theory in global manufacturing
Source: [Fawcett 92]

As discussed earlier in Section 1.2.1, the environmental changes brought about by globalisation affect the firms in two ways: intensified competition, and creation of global markets. There are two general approaches adopted by manufacturing firms to enhance manufacturing competitiveness : improvement of internal manufacturing performance by introducing new manufacturing philosophies such as just-in-time (JIT) and total quality management (TQM), and taking advantage of global resources by establishing global manufacturing strategies. The ultimate objective of any strategy should be to improve the competitiveness measured in relation to the competitive priorities selected.

The necessity to optimise the total system rather than optimising the various individual subsystems holds true for global manufacturing as well. One of the main objectives of co-ordinated global manufacturing is to rationalise the production resources in a cost effective manner. In the system's perspective of global manufacturing, therefore, it involves the analysis of many functional relationships across a variety of performance objectives such as cost, quality, delivery and flexibility.

1.2.4 Strategies for Organising Globalised Operations

For most companies, the major question is not whether they need to globalise the operations, but what form this should take and what strategies they should adopt [Meffert 91]. Analysis of recent literature revealed the growing interest in the research community to develop strategies for globalised operations.

The organisation of the production network and selecting the most suitable locations for the manufacturing plants and other facilities are key actions involved in starting global operations. The success of these global networks, to a great extent, depends on two key factors: configuration and co-ordination [Schully 93] [Porter 86b]. Configuration refers to the facility location and resource allocation along the production value chain. In an international context, configuration can range from concentrating an activity in one location to serve the whole world from it to dispersing the activities to perform every activity in each country. International manufacturing networks are integrated, not aggregated [Shi 98]. Co-ordination refers to the strategic linkage and integration of these facilities in order to achieve the objectives of the firm. It can range from high to none. Finding the right configuration and co-ordination, therefore, is one of the most important aspects to be considered in designing these networks.

Dicken [Dicken 92] identified four major ways of organising transnational production units, depending on what strategy a firm adopts for globalisation. Cohen and Lee [Cohen 89] also presented a classification that supports Dicken's rationale.

- **Globally concentrated production**

  All production occurs at a single location and products are exported to world markets. It is the strategy used by Japanese manufacturers initially to reach a global market. However, [Cohen 89] point out that despite having the advantages of economies of scale and economies of scope, higher distribution costs could be a disadvantage.

- **Host-market production**

  Each production unit produces a wide range of products and services for the national market in which it operates, with no cross-border sales. Income levels of the host countries, the structure of demand and consumer tastes, cost related advantages and government barriers to market entry are the criteria to consider in setting-up host market plants. Even though the developments in technology has reduced the necessity to adopt host market production on cost terms, it continues to be popular among firms due to the necessity to be closer to the markets and overcome both tariff and non-tariff barriers to entry into a market.

- **Product-specialisation for a global or regional market**

  Each production unit specialises in producing one product which it supplies for sale throughout a regional market. This strategy has become popular over the last few decades with the development of special economic alliances such as the European Union and NAFTA. Cost-efficiency and quality performance will be the key elements in the successful implementation of this strategy. It provides a close link between manufacturing and marketing , and enhances customer service.

- **Transnational vertical integration**

  Each production unit performs a separate part of the production process. Output from one plant is input to the next. In assembly, each production unit ships its output to the assembly plant in another country. It involves geographical specialisation by process or by semi-finished product. It will facilitate production cost reduction and high degree of quality control. Tighter control procedures are required to co-ordinate production schedules among different plants.

1.2.5 Location of Global Production Units

Facility location is one of the three major decisions to be made in designing any type of manufacturing operation [Dicken 92], irrespective of whether it is local, regional or global (Fig. 1.3).

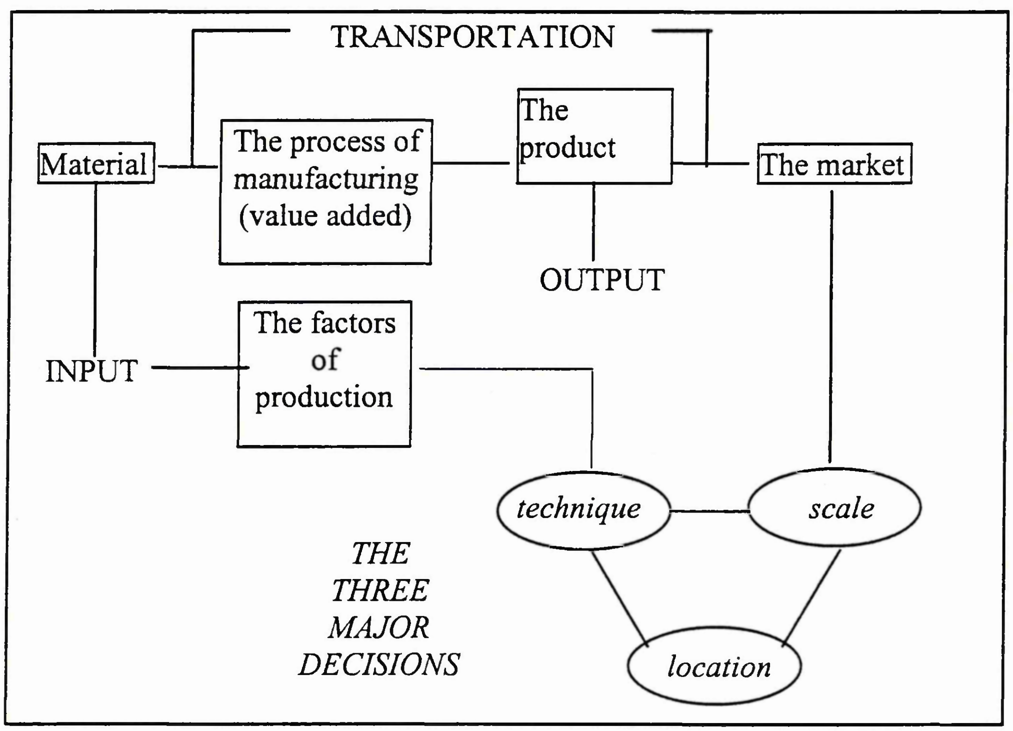


Figure 1.3: The manufacturing operation
Source: [Dicken 92]

In transnational vertical integration strategy, production rationalisation is achieved by way of geographical specialisation by process or by semi-finished product. Production units are linked across national boundaries in a chain-like sequence with the output of one plant being the input of next plant as depicted in Figure 1.4.

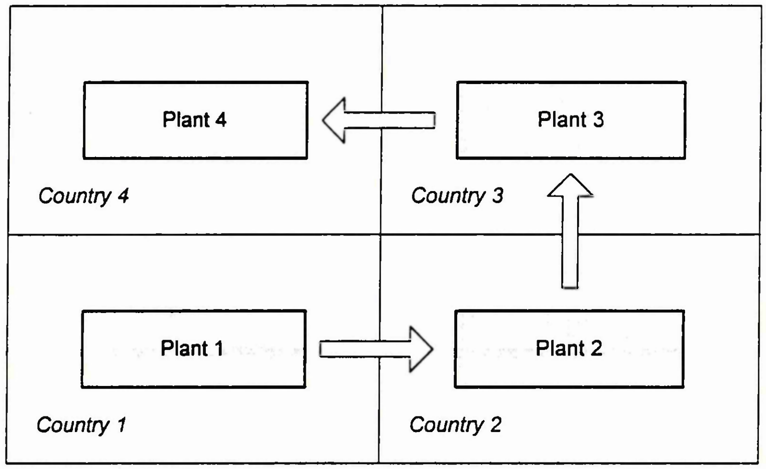


Figure 1.4: Plant locations under transnational vertical integration of production
Source: [Dicken 92]

The technological innovations in production, which have led to a greater degree of standardisation of production processes, have paved way for the segmentation of a number of processes into separate parts. These innovations in production technologies, coupled with parallel developments in transportation, telecommunications and organisational technologies have facilitated the practical implementation of the transnational vertical integration strategy. It allows the companies to locate some production units in different locations to take advantage of geographical variations in production costs at a global scale. Materials, semi-finished products and finished products are transported between geographically dispersed production units. The output of a plant in one country will become the input to a plant of the same firm in another country. The intended market could be in another country or in the home country of the parent firm.

The development of the above type of globally dispersed vertically integrated production strategies, known as *international intra-firm sourcing* has been pioneered by US electronics manufacturers by setting up assembly plants in the Far East and Mexico. Availability of cheap labour at virtually the same productivity levels as in the home countries has been the prime factor for this development. Firms operating such networks used to retain the product design and capital intensive activities in developed countries while transferring labour intensive operations to those countries with low wage rates. This low wage advantage, however, cannot be retained at the same level in the long term. The inflow of overseas investment would stimulate development in these regions. The resultant increases in education levels and the quality of life, in turn, would lead to increases in wage levels, thus reducing the advantages for the overseas firms. As such, this is an ongoing process where firms continue to seek locations with these advantages. The recent surge in moving operations to countries such as Vietnam and Kenya is a good testimony for this process. This is also consistent with Dunning's eclectic paradigm where firms seek to have location-specific advantages when they have ownership-specific and internalisation-specific advantages.

However, Dicken cautions that the selection of location is not a simple decision to make. The mere difference of labour rates in different countries, one of the major reasons for companies to locate plants overseas -specially in the developing countries, is not the only factor to look at. In some instances, the geographical proximity to the home country would be an overriding factor of importance.

It was evident through the analysis of the literature that much emphasis has been placed on the importance of organising the production units in the optimum way to reap the maximum benefits of globalisation. The availability of theories and frameworks for this effect confirms this. However, most of these are of conceptual nature providing little practical tools for the practising manager. A practical framework to evaluate and compare the advantages and disadvantages of setting up the manufacturing network in different possible ways will be of immense use for the companies involved in or contemplating to enter into global manufacturing operations.

This study attempts to address this issue based on the requirements of the steel industry. The applicablity of the solution in other industries is reviwed by extending it to two other industries: clothing and machine tool.

1.3 Globalised Manufacturing

1.3.1 World Steel Production

Steel is one of the most commonly used man made material in the world with a world-wide consumption of about 750 MT per year [Moffat 94]. There had been a steady and continuous growth in world steel production from the end of the second world war until 1974, when the first oil crisis occurred leading to a sharp drop in production. The recovery began only in the late 1970s. Since 1974, a marked cyclical pattern in production could be observed with declines in 1982 and 1992.

The geographical map of steel production has considerably changed in the last two decades. There has been a dramatic increase in the contribution of the developing countries to the world steel industry (Table 1.1). These countries now not only produce over 30% of the world's total steel output, but also compete directly with the industrialised countries for export markets [Hogan 94]. In 1997 China was rated as the world's leading steel producer with 107.9 million tonnes of output [UK Steel 97] ahead of Japan (104.5 million tonnes) and USA (96.7 million tonnes).

Country	1980	1997	% change
China	37.1	107.9	191
Japan	111.4	104.5	-6
United States	101.4	96.7	-5
Russia	n.a	46.9	-
Germany	43.8	45.0	3
South Korea	8.5	42.6	401
Brazil	15.3	26.2	71
Italy	26.5	25.8	-3
Ukraine	n.a.	25.2	-
India	9.5	23.7	149
France	23.2	19.8	-15
United Kingdom	11.2	18.5	65
Taiwan	3.4	16.0	371
Canada	15.9	15.6	-2
Mexico	7.1	14.3	101

n.a = not available

Table 1.1 : 15 major steel producing countries in 1997
(Production in million tonnes)
Source: [UK Steel 97]

The development of the steel industry in China in the last two decades has been phenomenal. An ambitious investment programme with the aim of reaching a production level of 100 million tonnes by the year 2000 has achieved its target well in advance. Their rapid growth can only be compared with that of the Japanese steel industry in the 1960s [Hogan 94]. The other countries with a notable increases in their production are India and Brazil.

Steel industries in the developed world had excess capacity during the second half of the 1970s and early 1980s. In UK , the situation was so acute that the effective capacity was 2.3 times greater than the production, the result of an ambitious investment programme. [Evans 96].

1.3.2 Demand for Steel

The demand for steel in the developed countries has stagnated over the past 20 years [Fitzgerald 95]. At the same time, there has been a tremendous increase in demand in the developing countries, particularly in the Asia Pacific region (Table 1.2).

Region	1980	1997	% change
EU	88[a]	129[b]	46.6
USA	90	113	25.5
Japan	68	82	20.6
South East Asia	30	163[c]	443.3

a=9 countries; b=15 countries; c=China, Taiwan and South Korea only

Table 1.2: Major steel consumers in 1997 (in million tonnes)
Source: [IISI 98]

Still there is immense scope for growth in demand in the developing countries. The rapid growth in infrastructure development taking place in the developing countries has increased the demand for steels, especially for long products. The current economic crisis in Asia has scaled down the development activities in the region leading to a predicted 7.6% drop in steel consumption in 1998. It is expected, however, that this region would regain its momentum and remain as a growth market.

The per capita steel consumption in the developing countries is far below that of developed countries [IISI 98]. For example, per capita steel consumption in China is 82 kg against the European Union average of 230 kg (Table 1.3). World average is 113 kg.

Country	Per capita steel consumption (kg)
South Korea	832
Japan	673
Germany	498
USA	428
Brazil	91
China	82
India	29

Table 1.3: Per capita steel consumption in selected countries
Source: [Worldsteel 98]

Even though the steel production is on the rise in newly developing countries such as China, that consists mainly of low value, construction-grade steels. These countries are depending on imports for high quality steels, an opportunity for developed countries.

1.3.3 Opportunities for Globalisation of Steel-making

Fitzgerald [Fitzgerald 96] identified internal triggers that are essential and external triggers that are supportive for the globalisation of a steel companies operations. As in any industry, internal triggers include the will to globalise, management vision, a sound strategy and the ability to implement. External triggers are mostly specific to the present economic environment of the steel industry. These include:

- the emergence of minimills with low capital costs and greater mobility
- the over-capacity in certain regions
- privatisation
- globalisation of customers, for e.g. automobile industry
- availability of finance for private sector projects.

The lack of growth in demand for steel and the over-capacity of plants caused steel-making companies in the developed countries to look for alternative avenues. The massive demand in the developing countries is, therefore, a good opportunity for these companies to explore. Despite there being major trade flows of steel across national borders, there are no true multinational companies in the steel industry unlike in other industries [Moffat 94]. One major reason for this is the nationalistic nature of the industry, which is seen by the governments as strategic and prestigious. Until recently, the steel industry has been a major source of employment for governments.

Steel is an expensive product to ship in relation to its value: sea freight costs at 10% of the cost of steel. There is a large incentive to develop steel-making capacity in regions where demand is growing [Moffat 94]. Cheap labour is not the determining factor for the steel makers to locate their facilities abroad today. It is a combination of factors such as the availability of raw materials, cost of energy and transport costs [Fitzgerald 96].

1.3.4 Clothing Industry

Textiles and clothing are the first manufacturing industries to expand globally, with operations geographically dispersed across both developing and developed countries [Dicken 92]. Being an important industry for both developing and developed countries, Western Europe and Asia dominate world clothing exports today (Fig. 1.5). Developing countries have become major clothing producers, mainly because of their low cost labour advantages. Western Europe and North America are the main clothing importers.

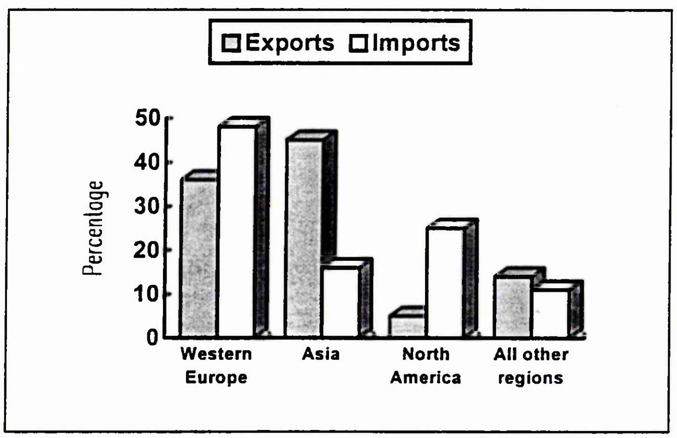


Fig. 1.5: Regional shares of world clothing trade
Source: [Dicken 92]

Demand for clothing depends largely on the level and distribution of personal income. It leads to the demand patterns being determined by the affluent countries. In contrast to other industries, clothing is a major industry that is present in a significant scale in many developing countries. Developed country firms, however, drive globalisation of the industry. Stable demand, the lesser degree of opportunities for automation and the heavily labour intensive nature of the industry has led the firms in developed countries to shift the production to countries with low labour costs. While transferring labour intensive operations to the developing countries, key processes such as design have been kept in-house by these firms.

In a given region also there are regular shifts in theatres of production due to regional variations in labour costs. At the beginning of the globalisation of the industry, low labour cost production centred in Far Eastern countries such as South Korea, Taiwan and Hong Kong. When the labour costs in these countries started to rise due to development, production shifted first to countries such as Malaysia and Indonesia, and later to countries such as Sri Lanka and China. Presently there is a trend to move into countries such as Vietnam and Laos, which have much lower labour costs. However, the Multi-Fibre Arrangement that controls the trade flows in the clothing industry by assigning developing countries specific quota for export would be phased out by Year 2004. This would result in developing countries having to be more competitive to retain their market shares.

1.3.5 Machine Tool Industry

Machine tool industry is another major industry that has undergone major changes in the market structure in the last few decades. Western developed countries, led by USA held a major share in the world machine tool production until late 1970s. The first major change in this position was brought about by Japan, who ranked fourth in the world in 1975, captured the world lead in 1982 [Young 91]. Among the Western European countries, the market share of UK has eroded considerably while Germany has been able to maintain its position. The newly industrialising nations such as South Korea and Taiwan are now threatening to change this picture with their low cost advantages. The production volumes of the top ten machine tool producing countries in 1996 are listed in Table 1.4.

Country	Production ($ millions)
Japan	9,199.9
Germany	7808.1
United States	4914.6
Italy	3,757.3
Switzerland	2,119.3
Taiwan	1,800.6
China	1,790.0
United Kingdom	1,283.7
South Korea	1,190.9
France	889.4

Table 1.4 : World machine tool production - 1996

Newly industrialising nations such as China, Taiwan and South Korea account for a major share of the world machine tool production today. There had been a tremendous growth in the industry in these countries in the last two decades. With their low cost labour advantage, countries such as China are entering the export markets of developed countries. However, there is a need for the development of quality of these machines, especially with regard to precision. China is still a major importer of high end machine tools and the demand is expected to grow further with the development of other industries such as the automobiles industry.

1.4 Steel-making

If the complete value chain in steel-making is considered, it should start with the upstream activities of mining of coal, iron-ore and limestone. These three are the basic and widely used raw materials in making hot iron, a major input for some steel-making furnaces. However, this study concentrates only on the steel-making component of this process. That is from the melting of to the making of final mill products (Fig. 1.5).

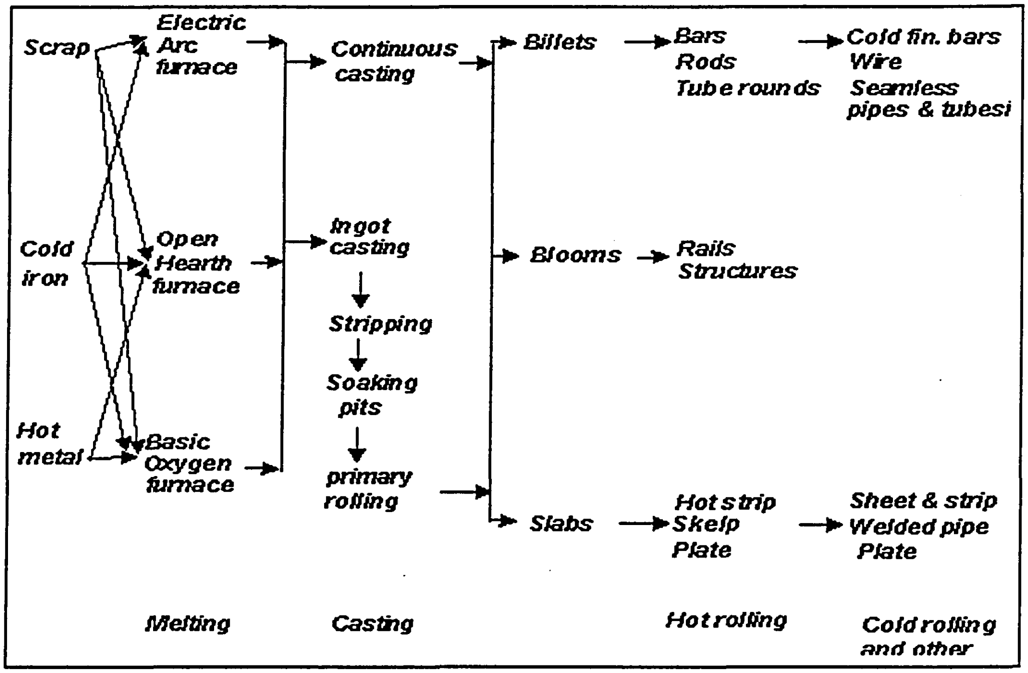


Fig. 1.6: The steel-making process

1.4.1 Melting

Currently there are three types of technologies used for steel melting: Basic Oxygen Furnace (BOF), Electric Arc Furnace (EAF) and the Open Hearth Furnace (OHF). On a world-wide basis, the current usage of the OHF is less than 6.8 % compared with 60.3% of BOF and 32.9 % of EAF [ISSB 97]. It is considered that OHF technology is becoming increasingly obsolete and will be phased out by the turn of the century. The use of Electric Arc Furnace is expected to increase further. Consequently, this study focuses on steel-making using the Basic Oxygen and Electric Arc processes.

- Basic Oxygen Furnace

This commonly used furnace is capable of producing large volumes of high quality steels with relatively low operating cost compared to other techniques. However, these furnaces require high capital investments compared to EAF. The metallic charge for the conventional BOF mainly consists of molten pig iron , which is the output of the blast furnace, and scrap. This metallic charge is refined into steel by blowing high-purity oxygen under high pressure [Ginzburg 89]. Plants employing the blast furnace - BOF steel-making route are termed integrated mills.

- Electric Arc Furnace

The EAF furnace is increasingly becoming popular as the new generation steel-making method because of its intrinsic robustness [Swinden 80]. The minimills, which contain EAFs are steadily gaining popularity over integrated mills. The product range possible to be made in EAFs is increasing due to developments in technology. This has resulted in expanding the usage of EAFs to the traditional BOF product domain as well. Its eco-friendly nature is another plus factor. The metallic charge for EAFs mainly consists of steel scrap and granulated iron and other cold charges.

1.4.2 Casting

There are two basic types of casting used in the steel-making: Ingot casting and continuous casting. Continuous casting is gaining popularity over ingot casting because of its advantages in improving yield and reducing energy consumption [Irving 93].

- Ingot casting

This traditional casting method is losing popularity world-wide mainly because of its energy inefficient nature. Cast ingots are hot rolled to semi-finished or finished products by passing through the slabbing, roughing and finishing processes. These intermediate steps consume a considerable amount of energy, mainly for reheating the ingots or slabs to the desired temperature for rolling, and produce more waste.

- Continuous casting

Introduced in the 1920s, continuous casting has gained immense popularity over ingot casting in the last few decades because of its excellent quality, productivity and flexibility. It has replaced ingot casting as the widely used casting method in the steel industry, accounting for 76.4 % of the world steel production in 1996 [ISSB 97]. It is gaining popularity in the developing countries as well with China's continuous casting ratio growing from 8 % in 1980 to 47.1 % in 1996.

1.4.3 Rolling

The type of rolling process used after the casting of steel depends on the type of the product manufactured. In the broadest possible terms, steel products can be classified as long products and flat products. Different types of rolling mills are used to produce long product according to the shape and the size of the final product. For example, heavy sections are rolled in heavy section mills while light sections and bars are rolled in bar/section mills.

Flat products go through a sequence of rolling processes until the desired thickness and product properties are achieved. These rolling processes up to the production of cold rolled strip/coil are examined here as this study mainly concentrates on flat products.

- Hot rolling

A semi-finished product may undergo several hot rolling processes depending on the shape and properties of the final product [Ginzburg 89]. These include slabbing, roughing and finishing. Only ingots require slabbing. The main processes involved are discussed briefly below.

- Slabbing

Steel ingots are rolled into slabs at the slabbing mills. Preheating of ingots is necessary prior to the slabbing. Continuously cast steel does not require slabbing.

- Roughing

Roughing mill converts the preheated slab into a transfer bar.

- Finishing

Finishing mill converts the transfer bar or continuously cast thin slab into strip. Shear, located in front of the finishing mill, cut both the head and tail ends of the transfer bar prior to their entry into the mill.

With the development of new technologies in continuous casting, there is scope for the elimination of some of the intermediate processes as shown in Figure 1.6. However, those new technologies are still gaining popularity and most of the processes described above are still widely in use.

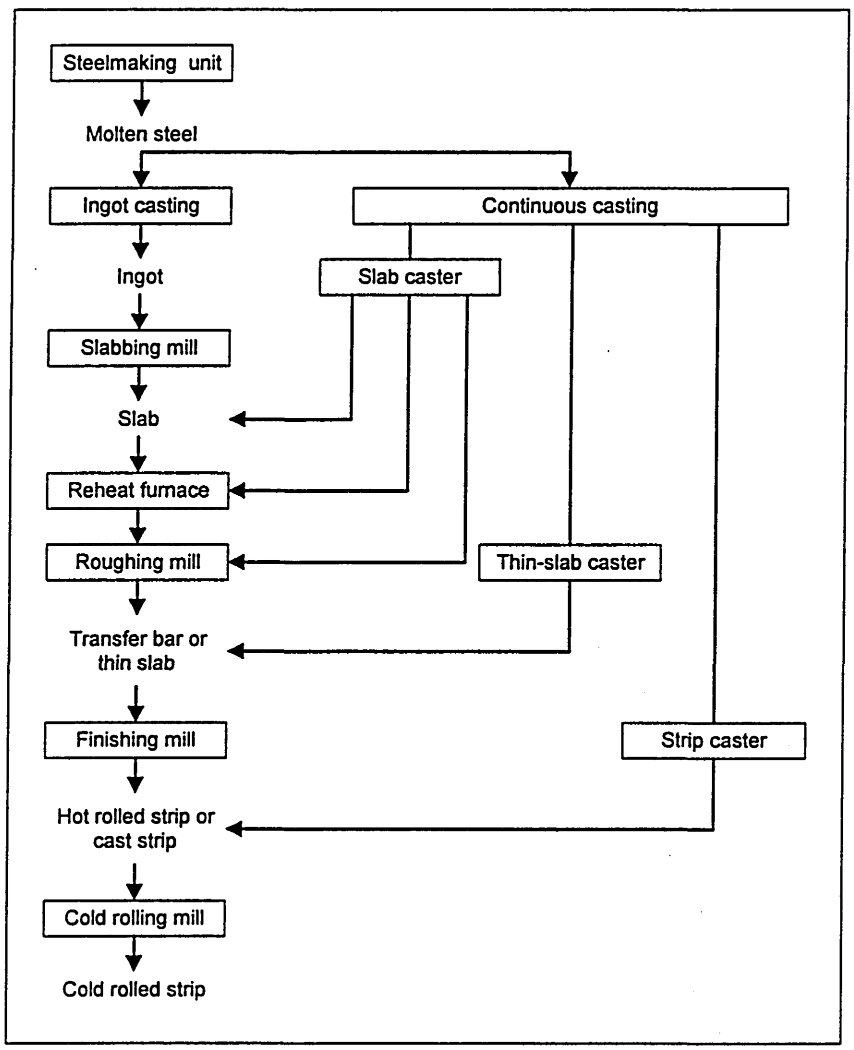


Fig. 1.7: New developments in casting leading to reductions in rolling
Adapted from: [Materials 90]

- Cold rolling and customising

Cold rolled strip or coil products are manufactured in a cold rolling mill using a repeated sequence of annealing, pickling and rolling operations. Hot rolled strip/coil is used as input for this process. Special processes such as bright annealing are applied to meet specific requirements.

1.5 Thesis Overview

The aim of this thesis is to present a structured methodology for companies engaged in global manufacturing operations to evaluate their manufacturing capabilities.

Chapter 2 reviews the literature on competitiveness and performance measurement. Different models available on building competitiveness are studied with emphasis on their relevance to global manufacturing strategies. Performance measures are reviewed as a means of evaluating competitiveness.

Chapter 3 introduces a conceptual model termed as Manufacturing Capabilities Model that can be used to measure, compare and project manufacturing performances of a company when it supplies to a particular market using products manufactured in different locations. This chapter presents the model framework and elaborates on model parameters.

Chapter 4 presents the capability evaluation technique. The selected technique, Analytic Hierarchy Process (AHP) is studied in detail to assess the appropriateness of the technique in relation to the requirements of the Manufacturing Capabilities Model. Evaluation methodology is demonstrated using an example.

Chapter 5 describes the implementation of the model based on the requirements of the steel industry. It identifies the performance measures specific to the steel-making process and introduces the questionnaire designed for data collection. The software developed for model implementation is presented with appropriate examples.

Chapter 6 validates the model based on two case studies related to the steel industry. Case 1 measures and compares the manufacturing capabilities of three steel-melting plants in China. Case 2 demonstrates the comparison of two alternative production routes.

Chapter 7 presents the final conclusions and identifies further avenues for related research.

1.6 Summary

The effects of economic globalisation has been felt by virtually every section of the world today. As far as manufacturing organisations are concerned, globalisation has intensified competitive pressures. It has created a global market with wide ranging opportunities for the firms positioned to take on the challenge. The exact reason for globalisation may differ from firm to firm. However, past research work into this phenomenon has resulted in assigning them to general frameworks or theories. One notable such theory is Eclectic Paradigm of International Production which suggests that firms would seek to engage in international activities based on ownership specific, internalisation specific and location specific advantages. Once a company has decided on globalising activities, the next major step is to find the best strategy for organising these activities. Several classifications of strategies by different researchers are available in this respect. The approach intended to follow in this study is similar to transnational vertical integration under which each production unit performs a separate part of the production process. Output of one unit would be the input to the next unit in the process, which could be performed in another country.

Like many other industries, steel industry also faces the challenges of globalisation. Competitive pressures are on the steel producers in developed countries when those in developing countries start to produce a different range products to meet both domestic and overseas market needs. Yet, there is a huge market potential in those countries. This is an opportunity for the steel makers in the developed nations to explore.
Steel is a product that is expensive to ship compared to its value. Therefore locating manufacturing facilities close to the markets could be profitable. Clothing and Machine Tool are two other industries with a global potential. Structures of both industries have been changed over the last few decades. Developing countries have become major producers as well as exporters.

The analysis of the steel-making process leads to the conclusion that it can be segmented to distinct production stages which can be performed in different locations. Manufacturing operations of steel can thus be globalised to take advantages of market and locational factors in the developing regions as well as the excess capacities of developed countries.

Chapter 2

Evaluation of Global Manufacturing Capabilities

2.1 Introduction

Whatever the way production is organised, in terms of competitiveness a firm should be at least on par with competitors to survive in the global market. Different firms assign different priorities for elements of competitiveness such as cost, quality, dependability and flexibility. This, in turn, depends on the strategy of the firm concerned.

Section 2.2 assesses the importance of manufacturing function within the context of the corporate strategy as a means of building and sustaining competitiveness. Competitiveness is an issue of paramount importance to be considered in globalised operations. Priorities given to the competitive factors vary from country to country and market to market. This section reviews different models available for building competitiveness within a company.

Section 2.3 discusses how the competitiveness and the actual performance of a company can be evaluated in the global market. During the last two decades, performance measures used by businesses organisations have undergone major changes in response to the changes in the competitive environment. This section reviews the nature and extent of the changes taken place in performance measurement. The characteristics of new performance measures are analysed in detail and several performance measurement systems are investigated.

Finally, several studies that have been conducted on the subject of global capabilities are reviewed in Section 2.4 to identify the necessary directions for a new study. It has been felt that companies either engaged in or planning to enter into globalised operations need specific information related to their performance. This section introduces a framework that can be used to address this need.

2.2 Manufacturing Capabilities

2.2.1 Manufacturing as a Part of The Corporate Strategy

Section 1.2.4 provided an insight into the strategies adopted by firms in globalising their operations. These strategies could be adopted at the corporate level or business level, depending on the size and the structure of the firm. According to the traditional hierarchical planning structure, functional strategies such as the manufacturing strategy and the marketing strategy are driven by corporate and business strategies. With the intensification of global competition, the importance of manufacturing function came to the forefront not only as a competitive weapon, but also as a means of survival of firms. The decline in US industrial competitive strength can partly be attributed to their neglect of the manufacturing function [Fine 85]. Therefore, it warrants studying the manufacturing strategy in detail to understand as to how it can be used to create or enhance competitiveness.

Over the years, this phenomenon has generated a growing interest in the area of manufacturing strategy both in the business and research communities [Minor 94]. Research in this area has evolved considerably since the pioneering work of Wickham Skinner [Leong 90]. Skinner's [Skinner 69] seminal article in the Harvard Business Review brought the manufacturing strategy to the forefront as a means of sustaining the competitiveness of local industry against the threat of foreign competition. Although the majority of the studies in this field are of conceptual nature, there has been a considerable increase in the number of empirical studies during the past decade.

Studies on the subject have focused on both the process of developing the manufacturing strategy as well as its content [Voss 95].

2.2.2 Process and Content Theories

Swamidass and Newell [Swamidass 90] have referred to the content of manufacturing strategy as the 'distinctive competencies of manufacturing function employed in the pursuit of competitive advantage'. Distinctive competencies are those attributes that distinguishes a firm's efforts from its competitors [Zahra 93]. The resource based approach to manufacturing strategy emphasises the need to build organisational resources as a means of obtaining distinctive competencies which, in turn, lead to competitive advantage. High uniqueness or low substitutability of a resource will enhance its competence.

However, in the literature, content is generally referred to as the dimensions of the manufacturing strategy, such as cost, quality, delivery and dependability [Noble 95]. Leong et. al. [Leong 90] presented the most important elements of content in the form of two broad categories : (1) competitive priorities based on corporate or business strategy; and (2) relevant decision areas ranging from facility design to performance measurement (Fig. 2.1).

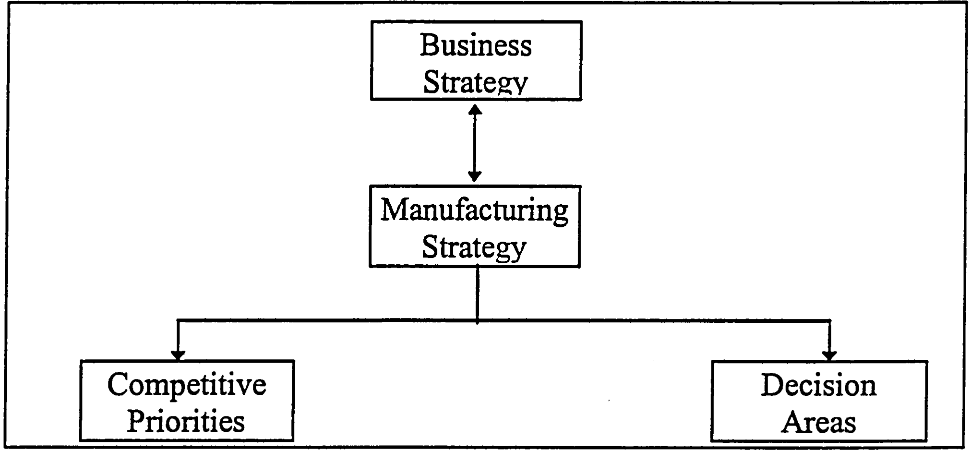


Fig. 2.1 : The content of manufacturing strategy
Source: [Leong 90]

Manufacturing strategy process refers to the development and implementation of the strategy based on the requirements of the corporate strategy. This is basically a top-down view of manufacturing strategy which consists of three major elements : (1) establishment of key tasks, (2) alignment of the policies and actions of the manufacturing infrastructure with the tasks, and (3) involvement of manufacturing managers in the strategic decision process [Swamidass 87]. However, this view can be further augmented by introducing feed back loops to make it an interactive process. Leong et. al. [Leong 90] have presented a comprehensive process model incorporating the views of most writers on the subject (Fig. 2.2).

2.2.3 A More Comprehensive View

Leong and Ward [Leong 94] pointed out that this traditional planning-oriented view of manufacturing strategy widely suggested in the literature is too narrow. They argue that manufacturing strategy should be viewed in a much broader perspective as a platform for improving the management of manufacturing companies. A multifaceted view of manufacturing strategy has been put forward by them as a more comprehensive

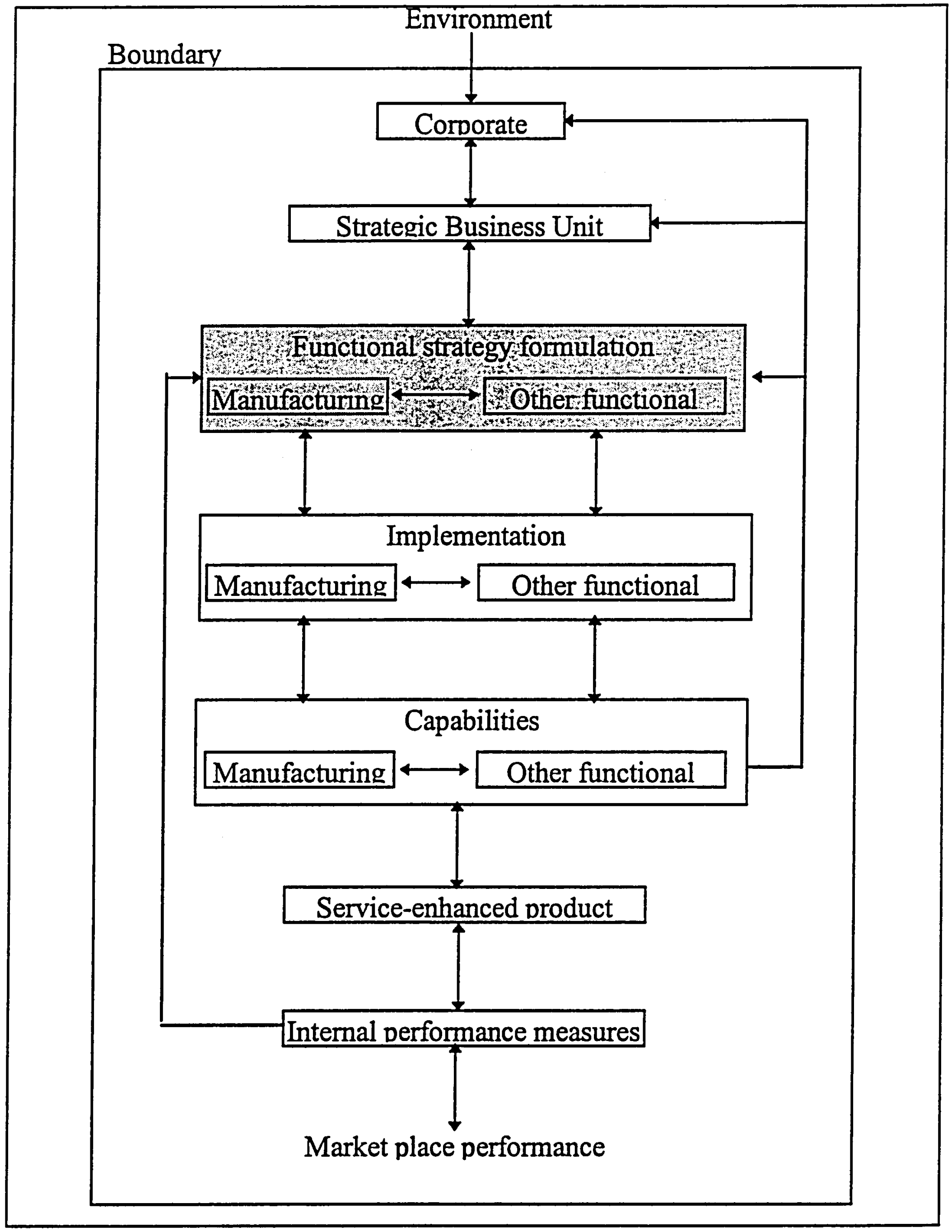


Fig. 2.2 : The process of manufacturing strategy
Source :[Leong 90]

alternative to the traditional view. They have identified six different views or snapshots of manufacturing strategy which reflect the complete picture when considered together. The six distinct views they suggest are Planning, Proactiveness, Patterns of actions, Portfolio of manufacturing capabilities, Programmes of improvement and Performance measures (i.e. 6 Ps). Each P on its own allows only a limited view of the strategy and hence could be misleading if considered in isolation. The integration of these 6 as shown in Figure 2.3, they have suggested, would depict a clear picture of the manufacturing strategy. Planning, proactiveness and performance measurement represent the process of the manufacturing strategy while programmes of improvement, portfolio of manufacturing capabilities and pattern of actions represent the content.

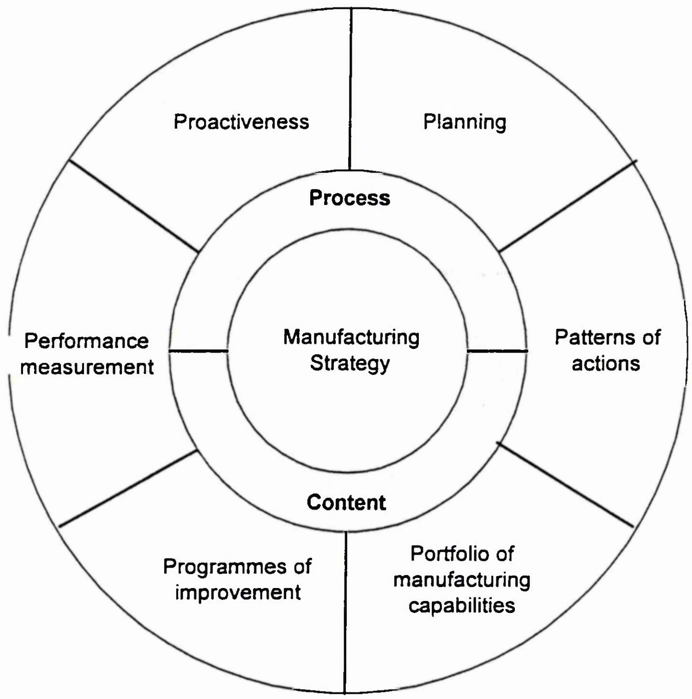


Fig. 2.3: The multifaceted view of manufacturing strategy
Source: [Leong 94]

The analysis of all the above definitions and frameworks of manufacturing strategy led to the identification of one factor common to all: importance placed on manufacturing capabilities. Irrespective of the way a company defines its manufacturing strategy, what is important for it to stay competitive is to perform better than, or at least on par with, its competitors. Manufacturing competitiveness is measured in terms of the ability of a company to perform in accordance with its corporate competitive priorities. Buckley [Buckley 88] pointed out that, for a satisfactory evaluation, these measures of competitiveness should include qualitative measures such as costs, prices and profitability, as well as qualitative measures such as quality.

2.2.4 Competitive Priorities

Leong et. al. [Leong 90] have defined competitive priorities as a consistent set of goals for manufacturing. Nobel [Nobel 95] has opted to use the term 'manufacturing capabilities' to denote the same and points out that the term 'manufacturing priorities' is derived from the necessity to prioritise these capabilities.

Cost, quality, dependability and flexibility are the four most commonly cited competitive priorities in the available literature [Voss 98]. In addition to these several other dimensions such as innovation and service have been suggested by different authors. However, these classifications can differ according to the user's definition of individual factors. Table 2.1 summarises the dimensions suggested by various authors.

Author(s)	Competitive Priorities
Partovi [Partovi 92]	cost, quality, delivery, flexibility
Vokurka and Davis [Vokurka 96]	quality, delivery (dependability), flexibility, cost efficiency
Ferdows and De Meyer [Ferdows 90]	quality, dependability (production system), flexibility, cost efficiency
Swamidass and Newell [Swamidass 87]	cost, quality, flexibility, dependability (production system)
Kim and Arnold [Kim 92]	price (cost), flexibility, quality, delivery, services
Nakane [1986][1]	quality, dependability (delivery), cost, flexibility
Leong and Ward [Leong 94]	cost, quality, delivery performance, flexibility, innovativeness
White [White 96]	quality, speed, dependability (production system), flexibility, cost
Noble [Noble 95]	quality, dependability (production system), delivery, cost, flexibility, innovation
Hall and Nakane [1990][1]	quality, dependability (delivery), cost, flexibility, company-developed culture, innovation

Table 2.1: Classifications of competitive priorities

[1] In Noble [1997]

In an international perspective, it is evident that, at a given time, manufacturers in different countries are placing varying prominence to these manufacturing capabilities. Based on empirical data collected through the Manufacturing Futures Surveys, Ferdows et. al. [Ferdows 89] have concluded that North American and European manufacturers are placing the number one prominence on quality where as their Japanese counterparts are focusing on cost. The interpretation for this is that the Japanese have now shifted their focus to cost after achieving a high degree of quality and maintaining it all the time. Using empirical data they have confirmed the notion that Japanese manufacturers are building these capabilities in a predetermined sequence : First quality, then delivery reliability, production costs next and finally the production flexibility. This demonstrates the dynamic nature of developing these manufacturing capabilities.

At the firm level, there are two distinct models as to how manufacturing capabilities should be built in order to build and sustain competitiveness: The trade-off model and the cumulative 'sand cone' model.

2.2.5 The Trade-off Model

The trade-off model suggests that, unless there is slack in the system, a manufacturing facility cannot be expected to perform well in all manufacturing capabilities simultaneously, and thus some of them must be traded for others [Noble 95]. Popular examples of trade-offs are cost versus quality, and short delivery lead times versus low inventory investments. The origins of this notion can be traced back to the 'focused factory' concept introduced by Skinner [Skinner 74] that would emphasise only one capability, or at most few compatible ones [White 96]. The trade-off model addresses a short time frame and is a reactive, rather than pro-active approach to manufacturing competitiveness [Noble 95]. Figure 2.4 displays the trade-off model.

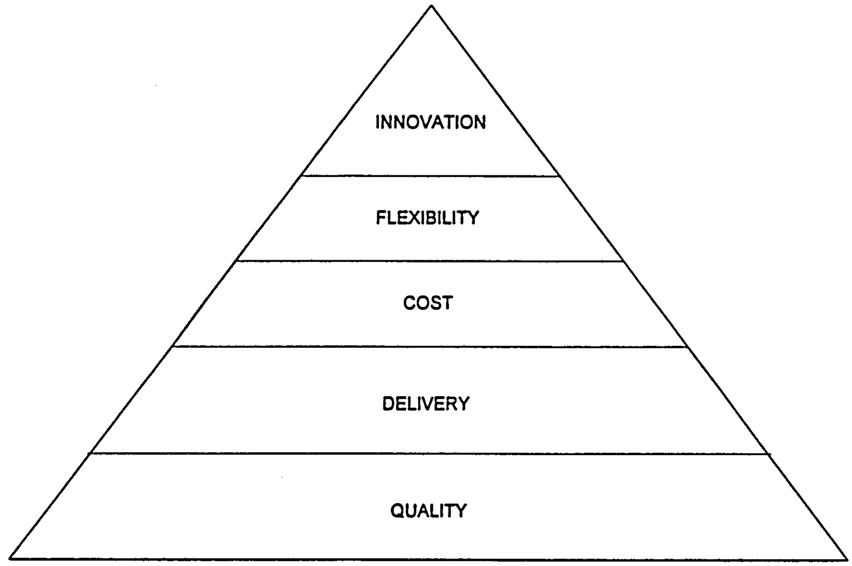


Fig. 2.4 : The trade-off model
Source : Noble [1995]

2.2.6 The Cumulative 'Sand Cone' Model

One of the major arguments of the critics of the trade-off model is that a capability must not be developed at the expense of another. The cumulative model, introduced by Ferdows and De Meyer [Ferdows 90], suggests that capabilities should be built one upon the other in a cumulative fashion in a pre-defined order [Noble 97]. Questioning the universal validity of the trade-off model Ferdows and De Meyer argued that there is evidence to suggest that many companies that are engaged in quality improvement programmes have reduced the costs also simultaneously. Quoting from literature, they have written that:

> *...improvements in cost efficiency and quality performance in manufacturing are not necessarily mutually exclusive, but better cost efficiency can, in fact, be a consequence of investment in quality improvement programmes. Interestingly enough, this does not seem to work in reverse - i.e. increasing cost efficiency does not seem to improve quality. [Ferdows 90, p 169]*

The sequence that the authors have suggested to build capabilities was: first, quality, then dependability, speed (flexibility) and finally, cost efficiency. It is important to note that efforts in one capability does not cease to operate once the firm steps into the next capability. This, they have depicted as analogous to building a sand cone with different layers and hence this model is also known as the sand cone model. According to them , sand stands-in for managerial efforts. First, sand is poured to build the solid foundation of quality improvement. Then, by pouring more sand, a taller sand cone of all four capabilities is made whilst enlarging the quality base and each three subsequent capabilities (Fig. 2.5). The authors have further argued that this model is dynamic, focusing on continuous changes in performance .

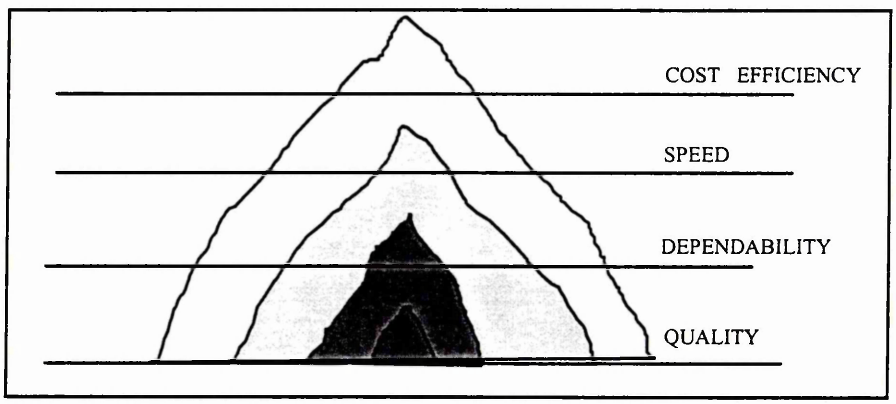


Fig. 2.5 : The cumulative sandcone model
Source: [Ferdows 90]

Nobel [Nobel 95] statistically tested an extended version of the cumulative model by comparing and contrasting manufacturing strategies of companies in several countries. She has used multidimensional variables instead of single item variables to capture the complexity of competitive priorities.

There is another school of thought that has built on the trade-off model where prioritisation of manufacturing capabilities in support of corporate strategy is advocated [Hayes 84]. According to this theory, manufacturing capabilities are prioritised according to their order of importance to the corporate strategy, whilst recognising assumed manufacturing trade-offs.

The notion of qualifying criteria and order-winning criteria suggested by Hill [Hill 89] can be viewed as a derivative of this prioritisation view. This theory suggests that manufacturing must at least meet the qualifying criteria to enter or stay in the market, and even more effort is needed to win orders. Corbett and Wassenhove [Corbett 93] describe this as a minimal threshold to be sustainable in business. A firm may not survive, let alone win orders, if it does not achieve the minimum expected performance in one competitive dimension while having excellent performance in few other dimensions.

Both the trade-off model and the cumulative model have provided valuable insight as to how the companies should develop manufacturing capabilities. The main argument of the opponents of the trade-off model is that while there are instances where it does apply, it cannot be applied under all contingencies. Whilst the cumulative model also advocates the development of multiple capabilities simultaneously, it is questionable whether the sequence suggested therein holds true for all the industries, and specially for all countries. Based on the above, the view advocated in this study is that the manufacturing capabilities should be prioritised according to the requirements of the market.

Whatever are the competitive priorities a company adopts and whatever the way it is going to achieve them, it is important to have a methodology to keep track of the progress. That is because of the fundamental fact that the success of a company depends basically on how it performs compared to the competitors. Performance measurement is the major tool to achieve this.

2.3 Performance Measurement

2.3.1 Performance Measures

The relationship between strategy and performance measures has been emphasised by most of the authors who have contributed to the subject: performance measures should be congruent with or emanate from the firm's competitive strategy [Keegan 89; Eccles 91; White 96; Neely 94]. The linkage between business unit actions and strategic plans can be provided by performance measures by way of feed back loops. It is argued that if performance measures are not changed keeping in line with the changes in the strategies, the obsolete measures would hamper the achievement of new company objectives.

The literature on performance measures has had two main phases [Ghalayini 96]. The first phase which began in the late 1880s and went through 1980s emphasised financial measures such as return on investment, productivity and profit per unit production. These traditional performance measures were primarily based on management accounting systems. Maskell [Maskell 89] criticises traditional cost and management accounting as being 'irrelevant, complex, costly to maintain and misleading'. Furthermore, it has been observed that most financial reports present the results of past performance and do not account for other intangible and qualitative information which may be essential in today's global market [Gregory 93]. They are not only obsolete: they can be harmful as well [Eccles 91].

The next phase, responding to the changes in the world market, apart from cost, focuses on other areas such as quality, flexibility and reliability of delivery. The necessity to extend the traditional measures with new measures is a view expressed in most of the recent literature on the subject. The opponents of traditional accounting methods argue that those financial measures report the results of past actions so that there is hardly any time to take corrective action if necessary. In other words, those measures are reactive rather than proactive and are not of much use in a very competitive business environment. A new set of performance measures which overcome the limitations of traditional financial measures have been introduced as a result [Kaplan 83][Gregory 93] [Tayles 94]. Notable characteristics of these new measures are that they are mostly non-financial, related to the manufacturing strategy, change over time, simple to calculate and understand, and able to stimulate performance [Ghalayani 96]. Eccles [Eccles 91] mentioned this shift of emphasis on financial measures from being the foundation of a performance measurement system to become just a part of a broader set of measures as revolutionary. This highlights the magnitude of change that has taken place in this phase.

However, financial measures cannot be discarded altogether. They are useful to assess the overall performance of a company: how well the management is utilising it's assets to increase shareholder value. After all, what the shareholders are ultimately interested in is the return on their investment. Therefore there is the necessity to create a comprehensive performance measurement system that combines financial and non financial measures in the right proportion and in the right way [Eccles 92].

Table 2.2 summarises some of the important differences between traditional and non-traditional performance measures.

Traditional performance measures	*Non-traditional performance measures*
Based on traditional accounting system	Based on company strategy
Mainly financial measures	Mainly non-financial measures
Lagging metrics (weekly or monthly)	On-time metrics (hourly or daily)
Complex	Simple and easy to use
Have a fixed format	No fixed format (depends on needs)
Do not vary over time	Vary over time
Intended mainly for monitoring performance	intended to improve performance

Table 2.2: Comparison between traditional and non-traditional performance measures *Adopted from [Ghalayini 96]*

Commenting on the application of performance measures in the industry, Schmenner and Vollman [Schmenner 94] described two types of errors made by companies in doing so:

(a). using wrong measures to motivate people ('false alarms'): This will result in the organisation moving towards a wrong direction measuring things that may not be in line with it's goals and objectives. The ultimate impact would be the frustration among the stakeholders when they do not get the expected results. On the other hand the management will waste time and resources on unproductive activities when a 'false alarm' is sounded. Mostly financial measures fall into this category.

(b). failing to use the right measures ('gaps'): Failure to use the appropriate measures would result in the organisation's inability to monitor whether it is performing in line with it's strategy. Mostly non-financial measures fall into this category.

2.3.2 Characteristics of Effective Performance Measures

Performance measures can be studied hierarchically. The measures become increasingly specific as they extend down the organisation. For example, from long-term shareholder wealth or return on investment at the corporate level through market share at the division level to attaining scheduled production at the cell level. By this [Keegan

94] illustrated increasing speciality, short planning horizons and emphasis on cost performance down the hierarchy.

Another important aspect [Keegan 89] highlighted is the ability of the measures to represent the multidimensional environment of an organisation. To achieve this, the performance measures must be capable of evaluating internal and external factors as well as cost related and non-cost related factors as shown in Figure 2.6.

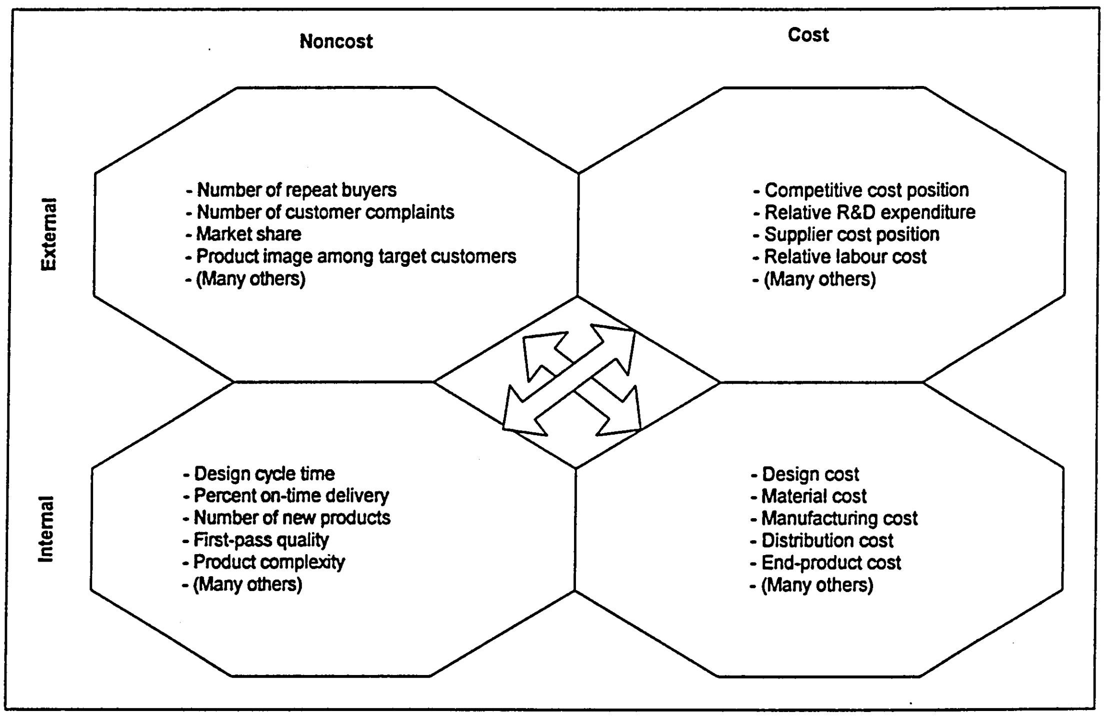


Fig. 2.6: Multidimensional nature of performance measures
Adopted from [Keegan 89]

Neely et al [Neely 94b] have categorised strategies as being quality-based, price-based, time-based and flexibility-based. Accordingly, the performance measures should also be based on the four factors:

- quality (e.g. finished product quality, inprocess quality)
- cost (e.g. turnover per employee, output per man)
- time (e.g. delivery lead time)
- flexibility (e.g. product/machine change over times)

Maskell [Maskell 89] also introduced a similar classification by stating that a company's competitiveness can be enhanced by improving quality, reducing lead times, reducing costs and enhancing production flexibility. By analysing these performance indicators the management of a firm can judge whether they are on line with the strategy so that ultimately they can reach their goals and objectives. In this respect, it is very important to introduce measures that are congruent with the competitive stance. Otherwise the firm would head towards disaster when top management assumes that they are performing well by analysing a set of performance measures that are completely incongruent with their strategy.

Since much is written about the linkage between the strategy and performance measures, it is worth investigating its practical application by companies. Based on a study involving over 800 firms, Neely et al [Neely 94] attempted to test the hypothesis that 'managers of small and medium-sized UK manufacturing firms attribute greatest importance to the performance measures which closely match their firm's manufacturing task'. In essence, their objective has been to investigate whether the performance measures identified as important by a firm are consistent with its strategy. The respondents to their questionnaire have been asked to identify, from a selection of criteria including quality, reliability, price, delivery lead time and wide product range, the criterion that they consider as most important to win orders. Then they have also been asked to identify the measure they consider as most important form a given list of performance measures. The significance of the differences has been tested using the χ^2 test. Their results show that this hypothesis holds true for the firms competing on quality or time. But it is not true for the firms competing on price where they perceive on-time delivery as the most important measure. In the absence of sufficient data to determine the reason for this phenomenon, the authors attempt to speculate on possible reasons. One of the credible possible reasons put forward by them is that, once the order has been won by the sales, the emphasis of manufacturing is to get the product to the customer on time. However, more empirical evidence is needed to determine the exact reasons.

Gregory [Gregory 93] added another dimension to performance measures: external measurement of a company by it's customers with respect to cost, quality, delivery and speed. They are undoubtedly the most crucial indicators that show the success or failure of an organisation. However, they have not been adapted by most of the organisations because of the practical difficulties in assessing the performance in this manner. Even though some information can be gathered through a market research, the results tend to be biased or inaccurate. Most of these indicators are qualitative rather than quantitative. As such these measures can be used to supplement a decision making process which is based on internal measures.

2.3.3 Manufacturing Performance Measures

Based on a survey involving 80 manufacturing companies in Belgium, Gelders et al [Gelders 94] identified the following as key performance criteria for manufacturing: quality, delivery time, lead-time, production volume, delivery reliability, manufacturing cost, capacity utilisation, inventory levels and logistics costs. They represent a balanced view between financial and non-financial measures. They have further found out that, of these measures, quality, production volume, manufacturing cost and inventory levels were the four most important indicators reported to senior management. Although broader criteria are used for reporting purposes, more specific measures are used to monitor the performance within the manufacturing organisation. These vary from process lead-times and set-up times to production volume per day. It has been observed that these companies still employ performance measurement mainly for reactive purposes such as control and hierarchical reporting. Minimal importance is placed on proactive objectives such as problem analysis, improvement programmes and motivation. In several metalworking companies, they have noted, the measures used are not compatible with their overall strategy.

The case described by [Gelders 94] represents a generalised view of the manufacturing performance indicators used in industry. In practice, the specific indicators should be customised to suit the requirements of the industry concerned. De Toni et al [De Toni 94] suggested that manufacturing performance measures introduced should be related to the type of production and the complexity of product. The two general types of production they have identified are intermittent (job shop) and repetitive (line) production. Product complexity can be either high or low. This classification leads to four different types of measures to be used for different combinations. They suggested, for example, for a product like steel, with low product complexity and repetitive production, the appropriate performance measures would be throughput time, quality conformance, production costs and capacity utilisation.

Linking performance measures to product life cycle Kaplan [Kaplan 83] reported that manufacturing performance measures for a product in the early stages of the product life cycle are more complex than those for a mature product. This requires measurements over a longer period of time and it is necessary to have appropriate measures for each stage in the product life cycle. At present there are not much measures for products in the early stages of life cycle. According to Kaplan, 'such measures could include the ability of a manufacturing plant to:

- introduce new products
- vary product characteristics quickly as customer preferences and new technological possibilities become known
- deliver new products at high quality levels
- deliver new products on predictable delivery schedules.'

The development of the World Class Manufacturing (WCM) concept [Schonberger 86] contributed immensely to the development of new performance measures. WCM includes 'a new approach to product quality, just-in-time production techniques, change in the way that the work force is managed and a flexible approach to customer requirements' [Maskell 89]. The approach to quality in WCM differs from the conventional approach in that it focuses on the causes of quality problems rather than merely detecting them. The ultimate objective is zero defects. The human resources aspect of WCM emphasises the need for changes in the way work force is managed. More responsibility is to be given to the employees in production quality assurance and scheduling by promoting a team approach to work. WCM requires 'flexibility and responsiveness to customers' needs'. Time also has become a major measure for the world-class competitors to differentiate themselves in the 1990s [Roth 90].

A new set of performance measures have emerged with the implementation of WCM. Even though these measures have been used by the companies for a long time, the importance attached to individual measures have been changed to suit a WCM approach. Maskell has identified seven common characteristics of these new performance measures:

- Directly related to the manufacturing strategy
- Primarily use non-financial measures

- Vary between locations
- Change over time
- Simple and easy to use
- Fast feedback
- Intended to teach rather than monitor

2.3.4 Integrated Performance Measurement Framework Design

Extending the definition of a performance measure, Neely et al [Neely 95] have defined a performance measurement framework as a set of inter-related performance measures which quantify both the efficiency and effectiveness of actions. They are combined cohesively together to represent the total effect of all the measures. Even though the area of performance measurement has extensively been researched, only a few firms use structured methodologies to design performance measurement frameworks [Neely 96]. Figure 2.7 depicts the framework for a performance measurement system as suggested by them.

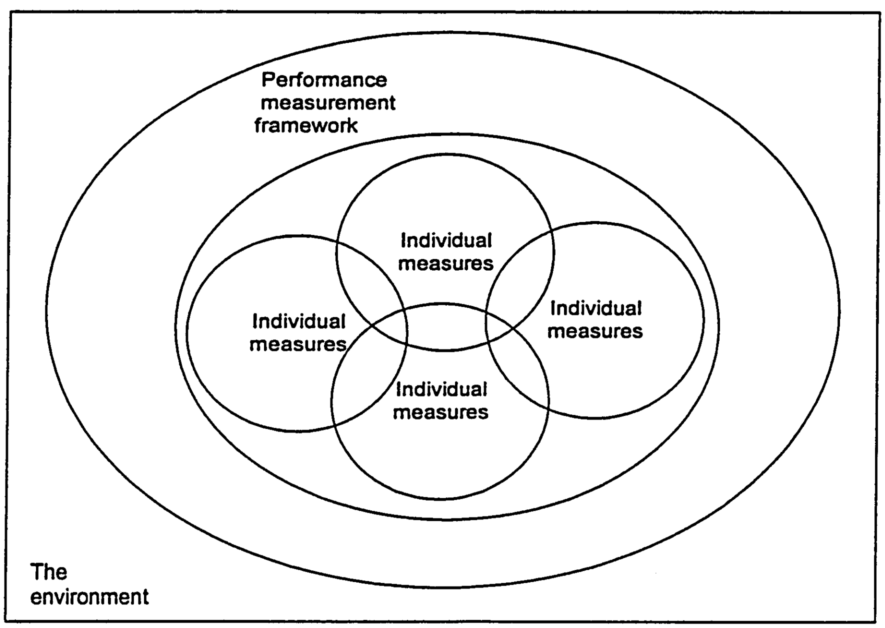


Fig. 2.7 : A framework for integrated performance measurement
Source: [Neely 96]

There are several well documented performance measurement systems developed by academics as well as companies.

The balanced score-card technique introduced by Kaplan and Norton [Kaplan 92] integrates four different ways of looking at performance to produce a more comprehensive view (Fig. 2.8):

- the shareholder perspective: how the shareholders view the performance
- the internal business perspective: what the company should excel at
- the customer perspective: how the customers view the company
- the innovation and learning perspective: how to continue to improve and create value.

The balanced scorecard includes financial as well as operational measures on customer satisfaction, internal processes and improvement activities. One important characteristic of the method is that it adopts only a handful of critical measures.

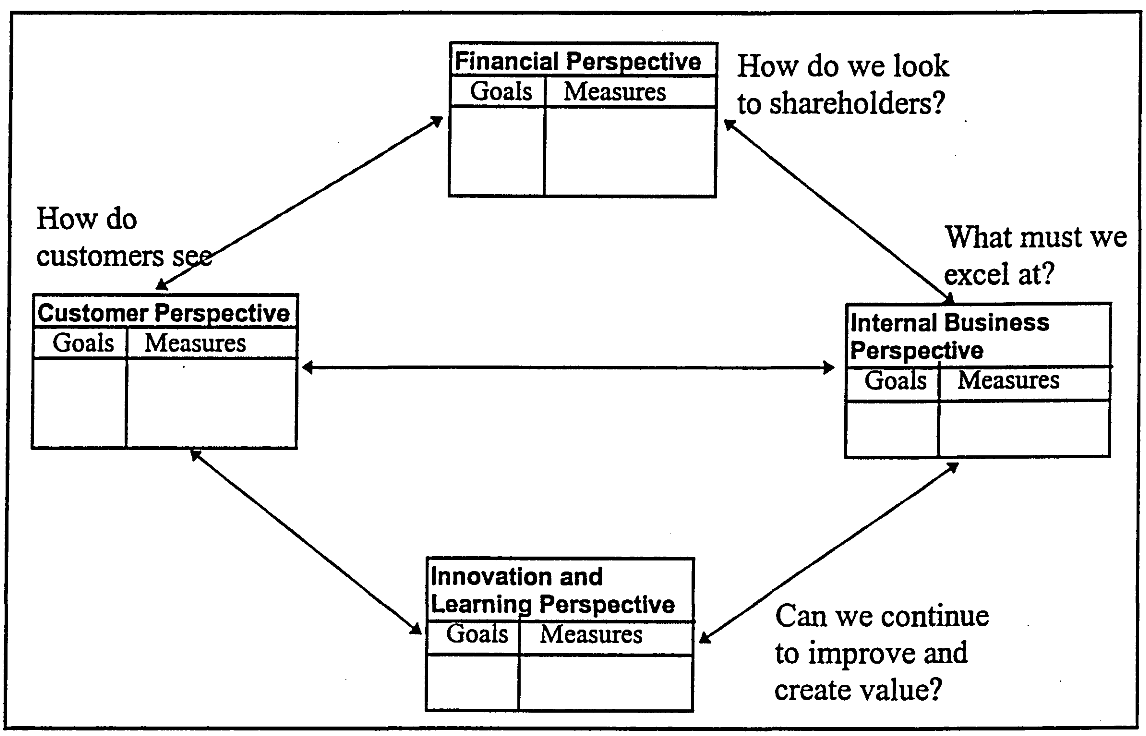


Fig. 2.8 : The balanced score-card approach
Source: [Kaplan 92]

The Strategic Measurement Analysis and Report Technique (SMART) developed by the Wang Corporation can be considered as a performance measurement framework that falls into the 'new' measures category [Cross 88]. It was first implemented in their printed circuit board assembly plant at Lowell. It attempts to capture the requirements of non-traditional measurements systems in that it relates the operations to strategic goals, integrates financial and non-financial measure for use of operating managers, and focuses on future developments of the business.

A four-level pyramid of objectives and measures that link strategies and operations serves as the framework on which this system is built (Fig. 2.9). At the top level of the pyramid is the vision for the corporate strategy. Second level consists of objectives for each division defined in the form of market and financial terms. The next level is composed of more tangible operating objectives and priorities for each Business Operating System defined in terms of customer satisfaction, flexibility of the system and productivity. At the foundation of the pyramid are the operational measures of quality, delivery, process time and cost. The argument is that , for any operational department, the major objective should be to increase quality and delivery, and to decrease process time and cost. SMART attempts to measure the performance of the business as a whole rather than the performance of each individual part.

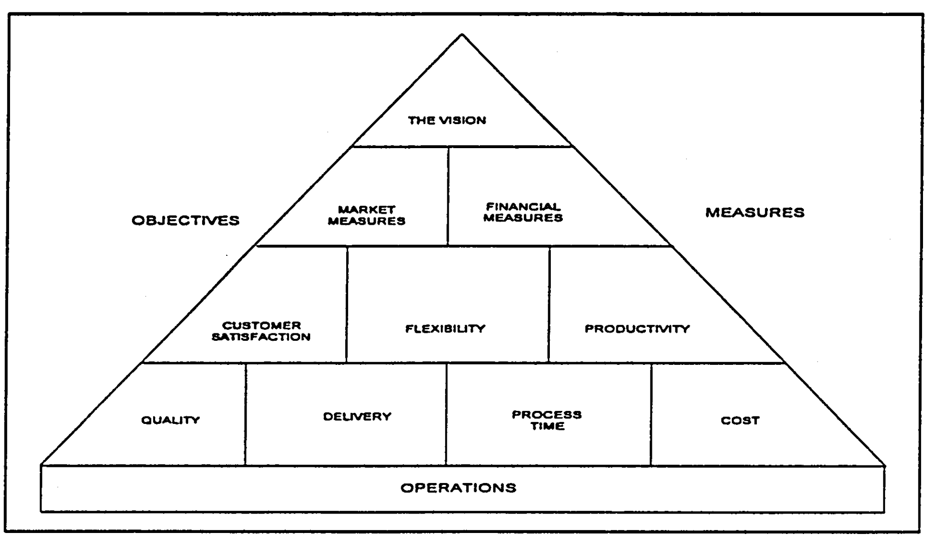


Fig. 2.9: The Performance Pyramid *Source: [Cross 88]*

2.4 Evaluating Global Manufacturing Capabilities

2.4.1 The Global Manufacturing Futures Survey

The development of globalised operations has led to detailed and wide-ranging studies on the subject of manufacturing competitiveness of different countries. The global manufacturing futures survey is one of such major surveys carried out covering several geographical areas [Ferdows 86]. This survey has been carried out annually for several years since 1982 with the involvement of large manufacturers in Western Europe, Japan and North America. INSEAD of France, Waseda University of Japan and Boston University of USA respectively have conducted the survey in these regions.

The objective of the survey has been to build an international data base to study the following aspects concerning large businesses:

- the strategic directions and competitive priorities these manufacturers are setting for themselves;
- their current concerns;
- what they are doing or planning to do to improve their manufacturing capabilities.

The data collection for the survey has been through a detailed questionnaire mailed to the senior manufacturing managers of the companies involved.

This study looks at the above factors at a broader level: regional and industry level. At a regional level they have identified the rank ordering of competitive priorities in each region (Table 2.3).

Europe	North America	Japan
Consistent quality	Consistent quality	Low prices
High performance products	Dependable deliveries	Rapid design changes
Dependable deliveries	High performance products	Consistent quality
Low prices	Fast deliveries	High performance products
Fast deliveries	Low prices	Dependable deliveries
Rapid design changes	After-sales service	Rapid volume changes
After-sales service	Rapid design changes	Fast deliveries
Rapid volume changes	Rapid volume changes	After-sales service

Table 2.3 : Competitive priorities in several regions (1984 survey)

2.4.2 World-wide Manufacturing Competitiveness Study

The world-wide manufacturing competitiveness study conducted jointly by Anderson Consulting, University of Cambridge and Cardiff Business School has investigated into the manufacturing performance and management practices of 71 automotive component manufacturers in Europe and North America [Oliver 95]. They used two criteria of measurement at the country level: productivity and quality. Non-financial measures are used for cost evaluations to avoid problems related to exchange rate fluctuations and differences in accounting practices in various countries. Quality is measured at various point of the supply chain to account for the quality incoming materials, in-process quality and the quality of the final product. In country comparisons, Japan is in the lead with USA following in both productivity and quality. The performance of the European companies are very much behind that of their Japanese counterparts.

At the plant level, they attempted to classify the plants involved as world class performers and non-world class performance based on the above two criteria. The exact measure used for productivity is the annual output of finished units divided by annual labour hours. Quality is measured in term of parts per million claimed to be defective by customers. 13 out of the total 71 plants they surveyed have qualified to be termed as world class performers. Using plants making seats and exhausts as example, they found that there is a 2:1 difference in performance between world class performers and others in terms of productivity. In case of quality, the difference is 9:1 and 16:1 for plants making seats and exhausts respectively. There is a marked difference in case of plants making breaks, where the ratio is 170:1.

2.4.3 An Integrated Framework for Global Manufacturing Capability Evaluation

Measuring the competitiveness of countries or regions has been the theme of most studies into global manufacturing. Studies carried out at plant level mainly concentrated on comparing individual plants which may perform the same task. In a global context what is essential is specific and structured information about a changing industry, its sub-industries and other related sectors. They should be able to project this information within the overall context of global socio-economic and technological trends to forecast potential capabilities.

The objective of this study is to develop a Manufacturing Capabilities Model to measure, compare and project manufacturing performances of a company if it supplies to a particular market using products manufactured in different locations, taking into account of global developments in industrial sub sectors.

Factors such as competitive markets, developments in manufacturing processes and government policies that contributed towards the globalisation process can have an influence on the performance of a company. Whist some of them have a direct influence on the performance, others influence indirectly (Fig. 2.10).

In case of global operations the production process itself has a large impact on capabilities. When different production stages are carried out in different countries it is essential to ensure that these individual operations contribute to achieve the best overall capability. Irrespective of whether the operations are at global level or domestic level, capabilities can be measured using performance measures. However, the selection of measures depends on the scope of operation. Therefore manufacturing performance measures and the production process are the two key elements in the study of manufacturing capabilities in general.

Plant locations and market locations are two other vital factors to be considered. They have a major bearing on the competitiveness, mainly in terms of cost and time. Location of plants close to the markets ensure lower transportation costs and shorter delivery lead times. However, these have to be viewed in tandem with other costs such as raw materials and labour costs. By locating plants in some countries companies can enjoy a wide range of government incentives. These range from duty waivers for imported material to tax holidays. Location of plants can, in some instances, be used to circumvent trade barriers imposed by governments.

The emerging trends resulting from industrial factors such as technological trends and environmental issues may lead to future changes in performance and represents the future potential of an industry. The projection of the capabilities is based on the present manufacturing capabilities and the potential of the industry.

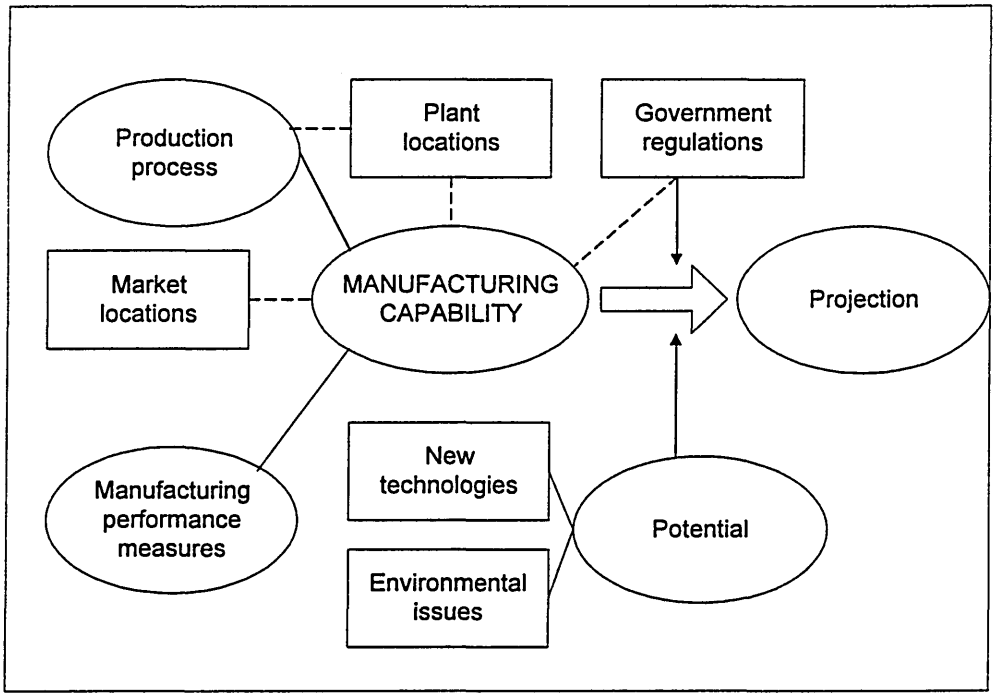


Fig.2.10: Factors to be considered in evaluating capability

The essential requirement in evaluating global manufacturing capabilities is to capture the overall impact of all the above factors.

2.4 Summary

Whatever the way a company globalised its operations, in terms of competitiveness it should be at least on par with competitors to survive in the global market. Different firms assign different priorities for elements of competitiveness such as cost, quality, dependability and flexibility. This in turn depends on the strategy of the firm concerned. Those who follow the trade -off model of building competitiveness attempt to build one capability at the expense of another depending on the current requirements. The advocates of cumulative model build capabilities one after the other in a pre-determined order. However, it was observed that prioritisation of capabilities according to the market requirements achieves the correct balance.

Irrespective of the way competitiveness is achieved, its progress should be monitored throughout. Performance measurement is the tool for measuring how well a company is faring in terms of its capabilities. The traditional financial factor based performance measures have now been extended with a new set of measures that suit the current environment. The main characteristic of these measures is their congruence with the company strategy. This makes performance measurement an appropriate tool to use in evaluating manufacturing capabilities.

Companies engaged in, or contemplating the idea of, global manufacturing require methodologies or tools to assess and predict their competitiveness in the global market. After reviewing past work, an integrated framework is introduced to cater to these requirements. Based on this framework, the next chapter will present a conceptual model that can be used to measure, compare and project manufacturing performances of a company involved in global operations.

Chapter 3

The Manufacturing Capabilities Model

3.1 Introduction

The objective of this chapter is to introduce a conceptual model that can be used to measure, compare and project manufacturing performances of a company involved in global operations. This Manufacturing Capabilities Model is conceptually represented by a cuboid, with the three axis representing process, performance and potential. Section 3.2 of the chapter outlines the model framework with brief introductions of model parameters. Key features of the model are explained.

Sections 3.3 to 3.5 present detail descriptions of process, performance and potential parameters respectively. Analysis of a production process to identify the constituent sub-processes is explained with reference to the steel, clothing and machine tool industries. In the model, performance measures are arranged under the categories of cost, quality, delivery and flexibility. The different levels at which performance can be measured with different levels of detail are explained with possible measures to be used in each case. These detailed measures are then related to each stage of the production process to identify meaningful relationships between them in measuring performance at a given stage. The overall performance of a production route is evaluated based on these performance figures. The process-performance plane represents a single state of technology. Potential axis denotes the possible changes in performance in response to changes in technology. This is explained using the technological advances in the industries concerned.

3.2 Model Development

3.2.1 The Conceptual Model

Based on the factors discussed in Section 2.4.3, a generic conceptual model was developed to measure, compare and project the manufacturing performances of companies when they use different production routes to perform various stages of the manufacturing process. In a global manufacturing context, a company can gain much competitive advantage if it manages to distribute these production stages strategically among different production plants in such a way that the best overall performance is achieved.

Conceptually the model is represented by a cuboid whose three axes relate respectively to performance, process and potential (the 3 Ps) as shown in Figure 3.1.

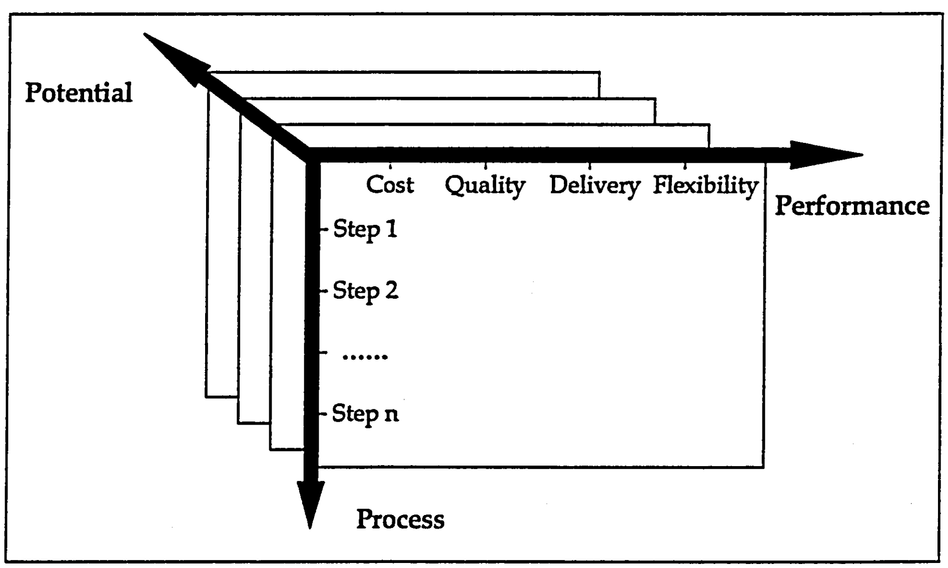


Fig. 3.1: The Conceptual Model

The potential axis is composed of a discontinuous series of process-performance planes. The sections to follow will discuss the model in a generic sense.

3.2.2 Model Parameters

The performance-process plane represents the performance related to the existing technology in use. The 'performance' axis consists of performance parameters which are organised under four broad categories of manufacturing competitiveness: cost, quality, delivery and flexibility. These are further sub-divided hierarchically to different levels of detail in measuring performance. For example, delivery measure is sub-divided into three categories: inbound delivery performance, production lead times and outbound delivery performance. Outbound delivery performance, in turn, is studied in terms of delivery lead times and percentage on-time deliveries.

The 'process' axis is industry-specific. It represents major process routes related to the industry under consideration. A production process can be studied as a series of inter-related production stages arranged for performance in a given sequence. The term 'production process' is used here to describe the overall operation of producing a particular product. Steel-making is the process that is used to make steel products. Production stages are the positions where the production process can broadly be broken down to distinct sub-processes. These sub-processes have their own characteristics such as distinctive technologies to identify them separately from the others. For example, melting, casting, hot rolling, cold rolling and customising are separate stages in steel-making. These production stages, in turn, may be composed of several production steps: distinctive operations that need to be performed in a particular stage. Hot rolling of a steel ingot to produce a coil, for example, involves slabbing, roughing and finishing operations.

The process-performance axes together are used in the calculation of the manufacturing capabilities at different levels or as a single indicator. The aim of having these two axes is to identify and record the performance measures specific to each of the steps in the production process. It is not essential to assign performance measures to each of these steps under each and every performance criteria. Only the process-performance relationships that can be used to reasonably represent and have a considerable impact on the overall performance are considered appropriate for the analysis.

The 'potential' axis is made up of a collection of performance-process planes. It is used to project the changes in performance when a company decides to employ a different type of technology.

A detailed discussion of each of performance, process and potential axes are provided in Sections 3.3 to 3.5.

3.2.3 Features of the Model

This model differs from other work in the area in that it attempts to measure and compare manufacturing performance at each major stage of the production process route as well as taking the entire production route as a whole in a global context. This is to enable a company to compare the manufacturing performances of different production route combinations encompassing different plants in different countries.

A manufacturer can use this generic model under several contexts.

- To compare different configurations of plants as a complete value chain in order to decide on the one that gives the best overall manufacturing performance.
- To compare different plants those perform the same part of the production process. In this case, the plants can either be compared as a part of the complete production chain up to that point or as separate

units.

- To compare the manufacturing performances with other manufacturers if the required data are available.

3.3. Production Process

3.3.1 Analysis of a Production Process

The process of producing a particular item can be visualised as a series of sub-processes. The output of one process becomes one of the inputs to the immediate next process, which may be performed in another plant. In a global manufacturing context, the Transnational Vertical Integration Strategy discussed in Section 1.2.5 uses this approach. It is concerned with performing different parts of the production process in a sequential manner in different countries to achieve the best overall performance.

Each production stage may have inputs common to all the processes as well as its own unique inputs. Labour and energy are two good examples for common inputs although differences such as skill levels required and the source of energy used can be expected in those as well. Pick [Pick 89] captured the complete value adding process from natural resources to the final product in Figure 3.2.

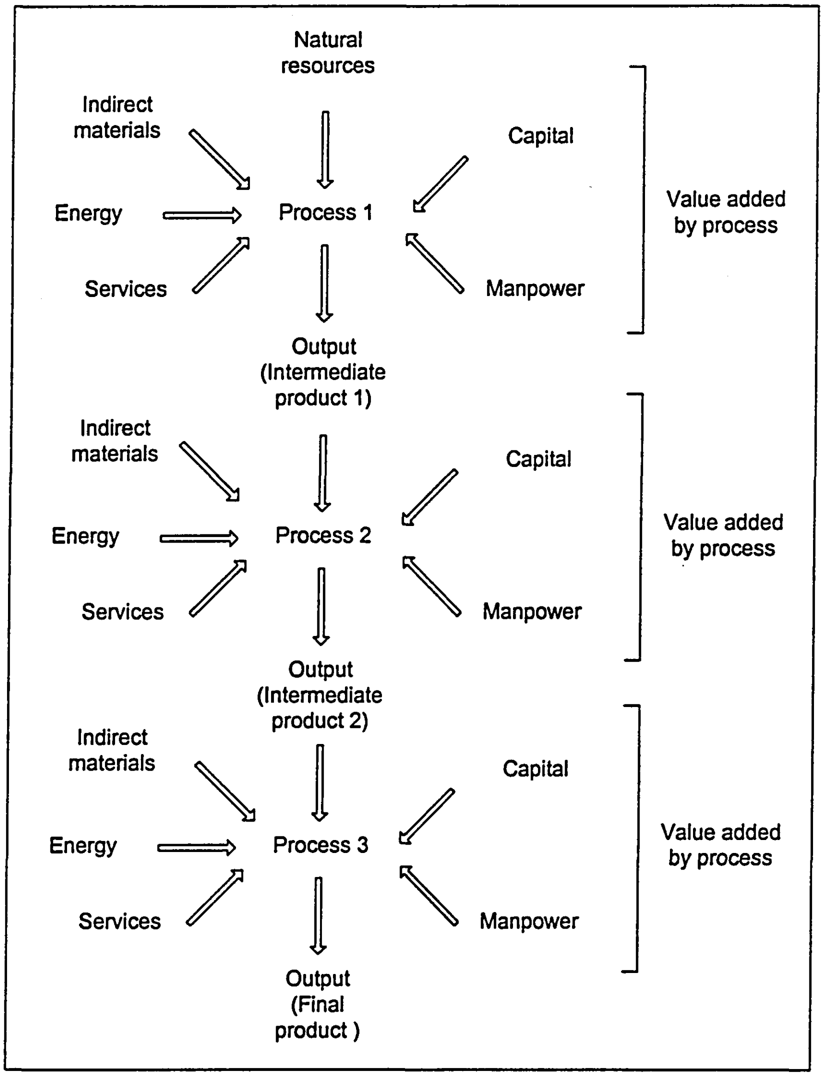


Fig. 3.2: Production flow from natural resources to final product
Source: [Pick 89]

In global manufacturing, transportation of semi-finished products between plants is an additional vital factor to be considered in the analysis.

The analysis of a production process for the model involves identifying the possible points where the process can be broken down into separate production stages (See Section 3.2.2). Due consideration needs to be given to the practicalities in doing so because this involves transferring semi-finished materials between plants. This is particularly important in global manufacturing when it involves long-haul transportation of semi-finished materials from one plant to another plant in some other country for further processing. The form, size or the nature of the product may dictate this.

Since the process is considered as a sequential chain with an order of precedence, the performance of one process will affect the performance of the subsequent processes. In this context, the importance of breaking down the process into component production stages is that the company can, by comparing several plant location alternatives, decide on the configuration that would give the best manufacturing performance. However, when deciding on a production route for a particular product, it is the overall performance that is important, rather than the performances of individual plants.

3.3.2 The Steel-making Process

Figure 1.6 in Chapter 1 illustrated the complete production process of the steel industry, from the input of basic raw materials to customising the final product. The diagram shows the intermediate products at each stage and how they are used as the inputs to the next stage. This entire process can be grouped into five key stages as illustrated in Figure 3.3.

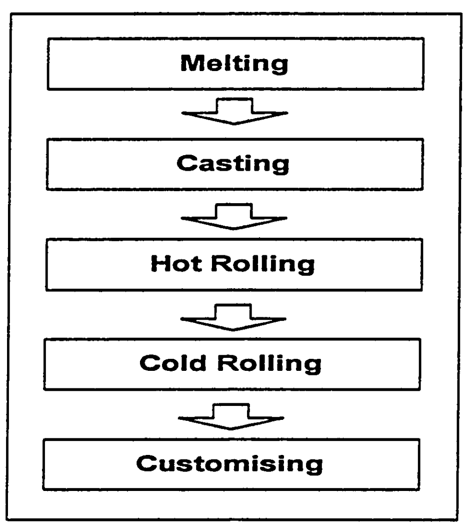


Fig. 3.3: Major production stages in the steel-making process

These key stages are distinct sub-processes on their own, with different technologies. Some of these stages can, again, be analysed further to identify the production steps they are composed of. For example, slabbing, roughing and finishing are three production steps under hot rolling.

Even though melting and casting are two distinct processes on their own, it is practically impossible to carry out these two operations in two distant plants. The transportation of molten steel to another far away plant for casting is out of question because of obvious reasons. In such situations, those processes have to be carried out at the same location even if another plant displays better performance in casting.

3.3.3 Clothing Manufacturing Process

Clothing is an industry with low capital intensity and relatively unsophisticated technology. Average plant sizes are small. The manufacturing process can be represented by six distinct stages as illustrated in Figure 3.4.

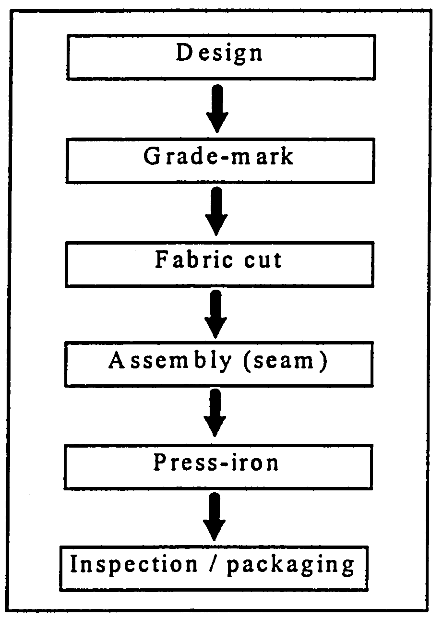


Fig. 3.4: Production process in clothing industry
Source: [Bolisani 96]

Designing clothing is a specialised operation that requires highly skilled labour. Companies engaged in global operations generally keep this in-house at a parent company plant. Grade marking refers to the preparation of pattern templates of different garment sizes based on the original design. In most cases, the tendency is to keep this operation in-house. Fabric cut can generally be carried out in another plant in the production chain. However, when quality is a critical factor, especially in the case of designer garments, this operation is also kept in-house. The rest of the operations are highly labour intensive and carried out mostly in developing countries. Bundling cutting and assembly operations would reduce logistics problems.

3.3.4 Machine Tool Manufacturing Process

A modern machine tool can be viewed as being composed of three different types of components or sub-assemblies: mechanical structure, power transmission and measurement units, and the software interface. The machine tool production process can be captured in three major stages: design, fabrication and assembly (Figure 3.5).

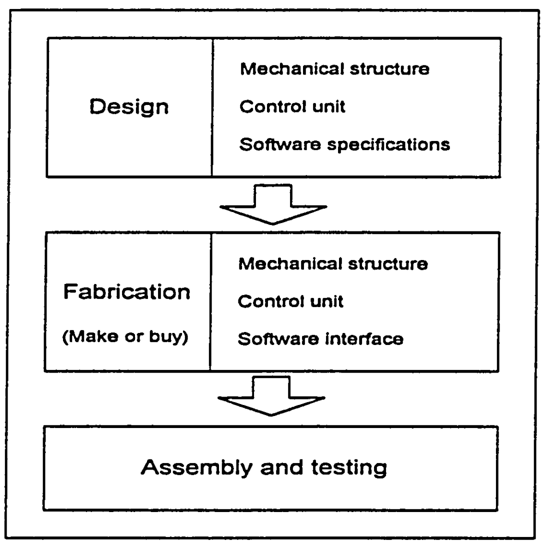


Fig. 3.5: Machine tool manufacturing process

Designing is the crucial activity in the process because it has direct impact both on the performance of the machine as well as on the performance of the manufacturing activities. This involves configuration design of the mechanical components such as body frame, transfer device and holder, and the design of control and measuring units.

Design of specifications for interface between control units and mechanical components is also a part of the process. The selection of machines, materials, tooling and assembly methods is based on the design of the machine tool concerned. Fabrication is the process of forming mechanical and control parts. Various processes such as casting, forging, moulding and joining may form mechanical parts. The make or buy decision is generally concerned with fabricating control units.

Assembly involves putting together all the sub-assemblies and components to produce the complete machine. Software interface links mechanical components and control unit together.

3.4 Performance Measures

As outlined in Section 3.2.2, performance measures are hierarchically organised with the four major performance criteria of cost, quality, delivery and flexibility at the highest level. An array of performance measures has been suggested by both academics and practising managers on a wide area of applications. However, the selection of a large number of measures for analysis would complicate the model, especially at the validation stage. It is vital, therefore, to select only the key measures that would reasonably represent the overall manufacturing performance. The inclusion of multiple variables in an analysis is important because single item indicators fail to represent the performance adequately.

General applicability in most industries is a major main characteristic of the measures selected for the model. However, the architecture of the model allows adding new measures at the appropriate positions or changing them according to their requirements without affecting the validity of the model.

3.4.1 Cost

Manufacturing cost and transportation costs are considered to be the primary elements for cost evaluation. In global operations, however, other factors such as tariffs and taxes would make significant differences in the cost structure in different countries. The effects of these factors should also be taken into account when calculating the total cost. Manufacturing cost composes of materials cost, energy cost, labour cost and plant consumable cost. It can be expressed in non-financial productivity parameters. Compared with monetary figures, productivity parameters are process-oriented and less commercially sensitive. They can be converted to monetary data specific to a location.

- Material cost

Materials cost can be expressed in terms of the units of raw materials required in producing a unit of output. For example, the material cost associated with steel melting using an electric arc furnace can be defined as the amount of scrap in kilograms consumed per tonne of liquid steel output. The average value for the period under consideration is used for calculations.

- Labour cost

Labour cost can be expressed as the number of labour hours required in producing an accepted unit of output. Average number of workers employed multiplied by the average man-hours per worker per year corresponding to the particular industry in the country can be used to estimate the total number of man-hours worked. For example, RSI [RSI 94] survey on the steel industry has used a general figure of 2000 man-hours per worker per year in their calculations.

- Energy cost

Energy cost is measured in terms of the units of energy required to produce one unit of the output. For example, in case of electric arc furnaces, it is the number of kilowatt-hours of electricity consumed per tonne of steel melted.

- Consumable cost

Plant consumable consumption is measured as the units of the major consumable material consumed in the course of producing one unit of the output. Using the same example of electric arc steelmelting, the consumable productivity can be expressed as the kilograms of electrodes consumed in melting a tonne of liquid steel.

- Transportation cost

Co-ordination of logistics in a cost-effective manner is particularly important to realise the major advantages of globalised manufacturing. Considering transportation costs is vital because the benefits achieved by manufacturing cost reduction can be significantly offset by transportation costs involved. This is important particularly in the case of the steel industry where transportation costs can be as high as 10% of the production cost. The element of the transportation cost considered here relates to out-bound transportation. Inbound material costs are considered to include transportation costs as well.

3.4.2 Quality

Noci [Noci 95] identified, among others, completeness, measurability and precision as key attributes to be considered in any quality performance evaluation framework. Quality measures employed in this model are classified according to in-bound, in-process and out-bound qualities to account for the quality of incoming materials, in-process parts and finished products respectively.

- In bound quality

Potentially, the inbound quality of raw materials can be measured by a consistency factor, which describes the variance in quality of different lots of a material purchased for a particular application. De Toni et. al. [DeToni 95] introduced a measure called Vendor Quality Rate (VQR), which can be calculated as:

$$VQR = U_{acc} / (U_{acc} + w_1 U_{r1} + w_2 Ur_2 + w_3 U_{r3}) \ldots\ldots\ldots \ldots\ldots\ldots\ldots (3.1)$$

where; U_{acc} = Number of accepted units

U_{r1} = Number of units rejected for minor defects

U_{r2} = Number of units rejected for more relevant defects

U_{r3} = Number of units rejected for major defects

w_1, w_2, w_3 are weights of importance (for example, 0.5, 1, 3 respectively).

However this formula serves only as a guideline in developing a formula that suits the requirements of a particular production process. The level of precision of the measure needed for some processes may not require the classification of rejects into three groups (e.g. selecting scrap for melting steel). The weights w_1,w_2 and w_3 given to each category also depend on process requirements.

- In process quality

In-process quality represents the quality levels achieved in manufacturing the products. Two quantitative indicators are used in the model to measure manufacturing quality conformance:

  - the number of units conforming to the quality standards as a percentage of the total number of units produced (CU/PU)

- the number of units produced correct at the first time without need for rework (FTC).

Achieving a high level of in-process quality would, in turn, contribute to cost reductions by way of reduced waste and less labour costs. Manufacturing products correct at the first time, without the need for rework, is a major in-house quality factor emphasised in literature.

- Outbound quality

Outbound quality measure represents the customers' perception about the quality of a product. Customer response can be viewed as the best judgement of the quality of a product. However, this is difficult to be expressed in quantitative terms due to its subjective nature. The measure suggested here is the average number of customer complaints per a certain amount of output. Repeat sales, customer base are other indirect measures that can be used to measure the quality of the final product.

3.4.3 Delivery

'Time' has become a major competitive priority especially in the 1990s [Tunc 92]. This includes shorter delivery lead times as well as reliable deliveries. In an operational point of view, the production times and the delivery lead times throughout the production chain are considered for the lead time aspect of this model. On-time delivery by the suppliers and the company's own on-time delivery record are used for the delivery reliability aspect. For long-haul transportation, on-time delivery should imply on-time arrival and receipt of goods by the customers rather than ex-factory. Detailed analysis of delivery performance in the model is carried out under three sub-categories: inbound, production and outbound.

- Inbound deliveries

This is concerned with the reliability of on-time receipts of raw materials and semi-finished goods for processing at plants. On-time delivery is particularly important in global manufacturing when semi-finished products are transferred between plants for further processing. Production schedules of plants further down in the production chain can be affected by delivery reliability of preceding plants. Therefore inter-plant deliveries should also be included in the measurement of delivery reliability. The measure suggested here is the percentage of the goods received on time. As for inter-plant deliveries, the on-time receipt measure at the recipient plant can serve as the on-time deliveries measure of the supplying plant, when the latter is the sole supplier of that product to the former.

- Production lead time

Production time is part of the total lead time and any reduction here would in effect contribute to the total lead time reduction. Elimination of manufacturing bottlenecks and better production planning are some of the possible methods to reduce the total production time.

- Outbound deliveries

Outbound delivery performance could be the most important of the three classifications because it directly affects the customer, either internal or external. The measures used to represent outbound delivery performance in the model are the delivery lead-time and the percentage on time deliveries. In the internal value chain, the delivery lead times and reliability of the up stream processes affect the production schedules of the downstream processes. Delivery lead times depend on the distance and the transport modes available to the down stream plants and markets.

3.4.4 Flexibility

In a broad context, flexibility can be defined as the ability of a system or a facility to adjust to changes in its internal and external environment. Manufacturing flexibility has become an essential competitive element in the global market. Japanese manufacturers demonstrated this by shifting their focus to flexibility as a competitive priority after achieving desired standards in quality (See Section 2.4.1). However, is difficult to be measured quantitatively. Different authors have suggested different types or dimensions of flexibility [Das 96][Chambers 92][Gerwin 93][Sarker 94]. In this model, product flexibility and the volume flexibility are used as the measures to represent flexibility.

- Product flexibility

The ability of a company to respond to changes in market requirements can be gauged by the variety of products they can introduce. The number of products a company is capable of producing and the number of products introduced per year are used to measure product flexibility.

- Volume flexibility

Volume flexibility measures the ability of the company to change its volume of output responding to changes in demand. With the high capital intensive nature of industries such as steel, it is always not possible to increase capacity rapidly in response to demand increases. Reducing plant set-up times can contribute to better utilisation of facilities resulting in volume increases. Therefore, plant set-up time is used here as a short-term measure of volume flexibility.

The complete set of measures selected to use in this model are shown in a hierarchical form in Figure 3.6. This hierarchy of measures can be applied to any industry in general. However, the actual criteria of measuring them may differ from industry to industry.

Within an industry also, the measurement criteria need to be customised to suit each individual production stage/step. The relative importance of each measure also depends on the production stage/step concerned.

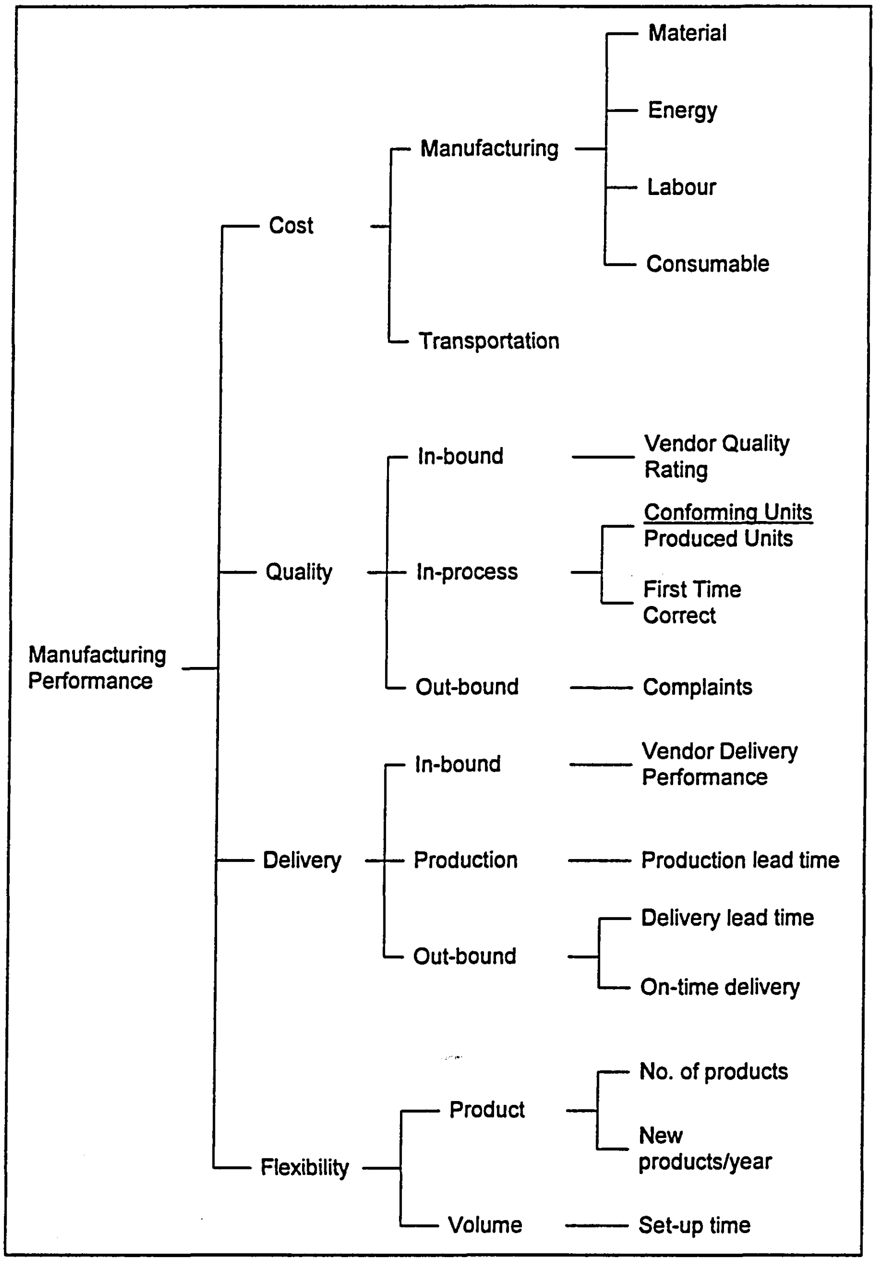


Fig. 3.6: Performance measures hierarchy

3.4.5 Mapping Process and Performance Measures

The proposed model measures and compares overall performance of alternative plant configurations by analysing performance at each major production stage/step. It is, therefore, necessary to map the performance measures to each stage/step to establish process-performance relationships (Table 3.1). However, all the measures listed may not be relevant to each and every production step/stage. The important process-performance relationships that can contribute to the computation of the overall performance of a particular production stage/step need to be identified.

When the entire production process is considered, inter-relationships can be found between measures selected for consecutive production stages/steps. For example, the delivery reliability (on-time delivery) of process stage i could serve as the vendor delivery reliability measure of stage $i + 1$. Identification of these measures reduces the data collection effort, and assists in confirming the consistency of data.

Tables 3.2 to 3.4 contain the process-performance relationships established for steel, clothing and machine tool industries respectively. This will be further studied in respect of steel industry for model implementation.

	Cost					Quality				Delivery				Flexibility		
	manufacturing				transportation	in-bound	in-process		out-bound	incoming	production	delivery		product		volu
Process	materials	electricity	labour	plant consu.	dist. to/from mkts	VQR	CU/PU	FTC	complaints	vendor del. perf.	prod. time	del. lead time	on time del.	products	new products/yr	set-
Stage 1																
-Step 1																
-Step 2																
Stage 2																
-Step 1																
-Step 2																
-Step 3																
..																
Stage n																
..																
-Step m																

VQR= vendor quality rating CU/PU= conforming units/prod. units FTC= first time correct

Table 3.1: Process-performance relationship map

Process	Cost					Quality				Delivery				Flexibility		
	manufacturing				transportation	in-bound	in-process		out-bound	incoming	production	delivery		product		volume
	materials	energy	labour	plant consu.	dist. to/from mkts	VQR	CU/PU	FTC	complaints	vendor del. perf.	prod. time	del. lead time	on time del.	products	new prod./yr	set-up tim
Process	units/t	units/t	t/man	units/t	km		%	%	no.	on time del(%).	mts	(to core mkts)	%	no.	no.	mts
steelmelting	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
Ladle																
casting	x	x	x		x	x	x	x	x	x	x	x	x			x
reheating																
slabbing mill	x	x	x	x		x	x	x	x	x	x		x	x		x
roughing mill	x	x	x	x		x	x	x	x	x	x		x	x		x
shear																
finishing mill	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
cooling/descaling																
coiling																
coil build up																
annealing & pickling	x	x	x				x	x			x					
cold rolling	x	x	x	x			x	x	x		x	x		x	x	x
final annealing	x	x	x				x	x			x			x	x	
bright annealing	x	x					x	x			x					
coiling																
slitting	x	x	x				x	x			x					
packag./w.housing		x			x		x	x	x		x	x	x			

VQR= vendor quality rating CU/PU= conforming units/prod. units FTC= first time correct 'x'= denotes positions where indicators could be assigned

Table 3.2: Process-performance relationships for the steel industry

Process	Cost					Quality				Delivery				Flexibility		
	manufacturing				transportation	in-bound	in-process		out-bound	incoming	production	delivery		product		volume
	materials	electricity	labour	plant consu.	dist. to/from mkts	VQR	CU/PU	FTC	complaints	vendor del. perf.	prod. time	del. lead time	on time del.	products	new products/yr	set-up tin
Design			x				x	x	x		x		x	x	x	
Grade-mark																
Fabric cut	x		x		x	x	x	x	x	x	x	x	x	x	x	x
Assembly	x	x	x		x	x	x	x	x	x	x	x	x	x	x	
Press-iron																
Insp./Packaging																

VQR= vendor quality rating CU/PU= conforming units/prod. units FTC= first time correct 'x'= denotes positions where indicators could be assigned

Table 3.3: Process-performance relationships for the clothing industry

Process	Cost					Quality				Delivery				Flexibility		
	manufacturing				transportation	in-bound	in-process		out-bound	incoming	production	delivery		product		volu
	materials	electricity	labour	plant consu.	dist. to/from mkts	VQR	CU/PU	FTC	complaints	vendor del. perf.	prod. time	del. lead time	on time del.	products	new products/yr	set-
Design			x				x	x	x		x		x	x	x	
Fabricate																
-Mechanical	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
-Control	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Buy																
-Mechanical	x					x			x	x				x	x	
-Control	x					x			x	x				x	x	
Assembly	x	x	x		x	x	x	x	x	x	x	x	x	x	x	

VQR= vendor quality rating CU/PU= conforming units/prod. units FTC= first time correct 'x'= denotes positions where indicators could be assigned

Table 3.4: Process-performance relationships for the machine tool Industry

3.5 Potential

As discussed in Section 3.2.2, the process - performance plane denotes the performance with the existing technologies employed at plants under review. In a single analysis, technologies used in different alternative routes under review need not necessarily be similar. This is in view of existing plants being compared. The 'potential' axis denotes the changes in capabilities in response to changes in the environment. It can be used to project the manufacturing performance of a company if it adopts a different type of technology. Introduction of new technology may bring improvements in one or more performance criteria. At the same time, it may not deliver the same results with respect to other criteria. For example, it may restrict flexibility while improving on quality. The ability of the using the model to analyse performance at each performance criteria, in addition to the analysis of the overall performance, makes it possible to understand the shifts in performance.

The projection could be based on either actual performance figures related to a similar facility elsewhere or forecast based on general production figures relevant to that technology. A company considering introducing new technology for a particular process could use this to judge if justifiable improvements in capabilities could be achieved through that. However, this assessment should be used only as a part of the complete comparison process which should include other project analysis techniques such as return on investment and pay back period.

The need for introducing new technology may not arise purely on performance improvement basis. In global operations, companies may need to introduce new technologies to comply with environmental regulations in different countries. Environmental regulations are becoming more stringent in the developing countries as well in keeping with those in developed countries.

Steel is a major industry that is undergoing major changes due to technological as well as environmental requirements. To be competitive in mid 1990s and beyond steel plants have to, among other requirements,

- be environmentally friendly and energy efficient
- introduce state of the art technology at low cost with better process control [Chatterjee 95]

This underscores the emphasis to be placed on technological and environmental factors in realising the future potential of the industry. Clear and well thought strategies are necessary to deliver cleaner and high quality steels at low cost.

There has been continuous development in the steel-making technology to this end, especially in the last decade or two. Most notable in the recent past is the development of direct reduction techniques for reducing iron ore to iron in a more energy efficient and eco-friendly manner as cleaner inputs for steel plants. Reducing solid ore using natural gas can produce direct reduced iron (DRI). This serves as an efficient and cleaner alternative for scrap used in electric arc furnaces [Edington 97]. Midrex is a commercial process currently being used for producing DRI. Hot briquitted iron (HBI) is another direct reduced product that can be used in EAFs as well as BOFs. The smelting reduction is a process that can be used to produce liquid iron for BOFs in a smaller scale and an energy efficient manner than using a blast furnace. Smelting reduction is a more environmentally friendly process than the blast furnace iron-making because of the considerably low amount of emissions. Corex is a commercial process for smelting reduction that is gaining popularity.

However, it is important to note that the choice of these technologies depends mainly on the factors such as the availability and costs of raw materials (e.g. ore and scrap) and energy sources (e.g. natural gas and electricity).

Casting is the other area where some major developments have taken place over the last few years and still continuing. The development of near net shape casting techniques has simplified the rolling process by eliminating a number of intermediate steps. Thin slab casting and thin strip casting are two major developments in casting that eliminate the need to apply roughing for the former and both roughing and finishing for the latter. This contributes to substantial reductions in energy consumption.

The potential for performance improvements through new technologies is limited in the clothing industry in view of its low level of technological sophistication. However, there are developments in the application of microelectronic technology, especially in non-sewing operations such as grading and cutting material. Satellite technology is used to transmit a design from a parent company to a plant in a far away region within seconds.

As far as the machine tool industry is concerned, the future potential for the development of capabilities in terms of technological advances lies in the development of high precision, high speed and more flexible machines [Leng 97]. Open architecture controls, near net-shape tooling and lightweight machines are some of the new developments in this respect.

3.6 Summary

This chapter proposed the Manufacturing Capabilities Model that can be used by companies to measure, compare and project their manufacturing performances if they supply to a particular market using products manufactured in different locations. The model was conceptually presented in the form of a cuboid whose three axes related to process, performance and potential.

A manufacturing process can be analysed by identifying the constituent sub-processes of it. The analysis should include identifying the inter-relationships between sub-processes as an internal value chain with the output of one sub-process being one of the inputs to the next in sequence. The analysis of the steel-making process revealed five distinct sub-processes: melting, casting, hot rolling, cold rolling and customising. These, in turn, can be broken down into individual production steps. Similar analysis can be made of clothing and machine tool production processes.

Performance can be studied under the categories of cost, quality, delivery and flexibility. The manufacturing performance of a company studied in terms of its abilities to perform major steps of production provides the basis for the measurement and comparison of its manufacturing capabilities. This relates to a particular state of technology employed by companies under review. Companies need to introduce new technologies to sustain competitiveness and to comply with new environment protection regulations. Potential represents the changes in manufacturing capabilities in response to the changes in technology.

Chapter 4

Performance Evaluation

4.1 Introduction

The evaluation of manufacturing capabilities requires the development of a multi-attribute analytical method, which quantitatively accounts and relates various interdependent performance and process factors to a single score. This chapter introduces the performance evaluation technique for the model and uses an hypothetical example to demonstrate the evaluation methodology.

Section 4.2 presents the technique used in model evaluation. The selected technique, Analytic Hierarchy Process (AHP) is studied in detail to understand its mathematical basis and the way it can be related to the model. This section contains an outline of the evaluation methodology with descriptions on major steps involved.

Section 4.3 is used to demonstrate the evaluation process based on a hypothetical example. It attempts to compare the performances of two production routes comprising of three production stages. All steps involved in the production process are demonstrated using notations.

4.2 Selection of the Evaluation Technique

The Manufacturing Capabilities Model aims to quantify the overall manufacturing performance of alternative production routes in order to make comparisons and projections. It requires the development of a multi-attribute analytical method which quantitatively accounts and relates various interdependent performance and process factors to a single score. The inclusion of multiple variables is important because single item indicators limit the ability to generalise the application of the model in different industries. However, there is no one right way to combine these multiple variables, especially when each variable measures a different sub-dimension of a concept, and not the concept as a whole.

Two multi-criteria analytical techniques were studied to select the appropriate evaluation technique for the model: Analytic Hierarchy Process (AHP) and Data Envelopment Analysis (DEA).

AHP basically is a decision- aided method for analysing complex, unstructured and multiple-attribute problems [Partovi 92]. It attempts to decompose a complex multiple-factor problem by transforming it into a hierarchy. At the highest level of the hierarchy is the overall objective, with next levels representing the criteria and sub-criteria upon which the outcome of the objective depends. The relative importance of these criteria are calculated using pair-wise comparison where the relative importance of criteria or sub-criteria are compared with respect to the next higher level. The lowest level of the hierarchy is composed of decision alternatives. AHP has successfully been applied in a variety of production and operations management problems from product design and supplier selection to bench marking [Partovi 90].

DEA has originally been developed as a method for evaluating relative efficiency of Decision Making Units (DMUs) performing basically the same task [Joro 98]. Initially used in economics and operational research applications, DEA has been developed based on a mathematical programming methodology [Kozmetsky 98][Norman 91]. The concept of DEA emanates from the basic idea that the efficiency of an organisation's activities can be measured by its ability to transform the inputs into desired outputs. Thus, a DMU's measure of efficiency can be defined as the ratio of weighted sum of outputs to the weighted sum of inputs. Based on this ratio, firms can be classified as being DEA efficient and non-efficient. It has been applied to assess the efficiency of a variety of institutions such as banks and industrial firms. In recent times it has gained popularity as a tool to analyse the competitiveness of national industries and national economies.

After reviewing the two techniques for their relevance to the purpose of this study, it was concluded that AHP closely matches the requirements of the Manufacturing Capabilities Model due to its following characteristics:

- hierarchical approach in analysing a problem
- ability to conduct pairwise comparisons of criteria
- availability of supporting software.

4.2.1 Analytic Hierarchy Process

Analytic Hierarchy Process has been developed as a decision support technique by Dr. Thomas L Saaty in 1970s [Saaty 89]. It is a technique that helps to make multi-objective, multi-criterion and multi-factor decisions with any number of alternatives. One of the notable strengths of this technique is its ability to accommodate financial and non-financial as well as qualitative and quantitative measures in the analysis. Its widest applications have been in multi-criteria decision making, planning and resource allocation, and conflict resolution [Saaty 87].

AHP attempts to decompose a complex multiple-factor problem by breaking it into its smaller constituent parts and then calling for simple pairwise comparison judgements to develop priorities in each hierarchy. As displayed in Figure 4.1, a typical hierarchy is composed of an objective, criteria and sub-criteria, and decision alternatives at successive levels.

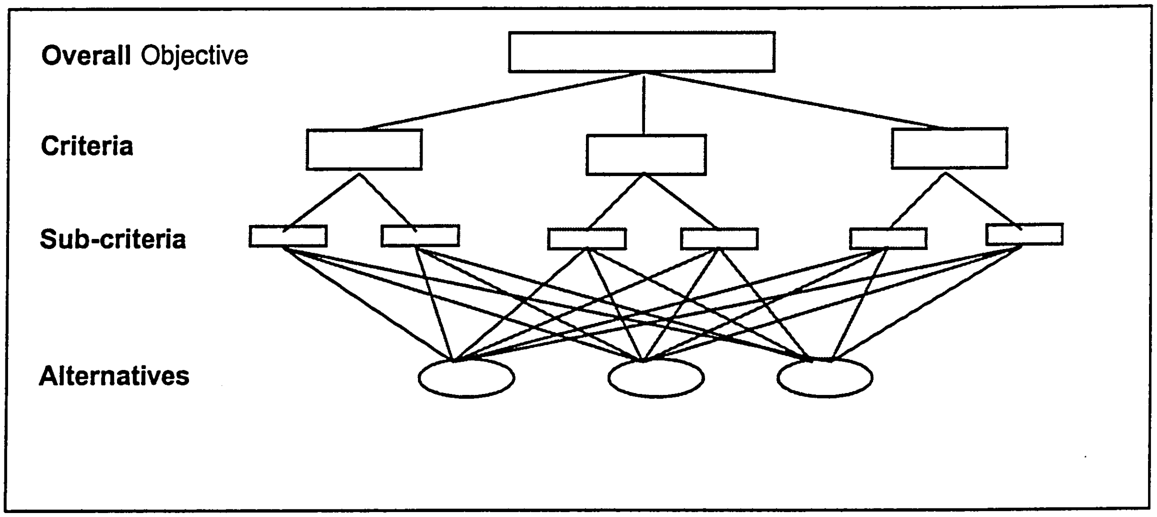


Fig. 4.1 : A typical hierarchical model in AHP

The mechanism of this technique can be captured in three steps:

- Decomposition

  - Description of the problem as a hierarchy

- Prioritisation

  - Pairwise comparison of the criteria in reference to each of the elements of the level immediately above.

- Synthesis

  - Calculation of results

Pairwise comparison of the criteria in reference to each of the elements of the level immediately above is carried out based on a relative scale of 1 to 9 as detailed in Table 4.1. These pairwise comparisons are recorded in the form of a matrix of n^{th} order, where n is the number of criteria to be compared.

Score	Description
1	Equal importance
3	Moderate importance of one over another
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

Table 4.1 : Scale of relative importance
Source: [Saaty 86]

Narasimhan [Narasimhan 83] has identified some of the major features of AHP as follows:

- Provides a systematic and structured approach for a largely subjective decision process.
- Delivers information about implicit weights placed in evaluation criteria as a by-product.
- Use of computers makes it possible to conduct sensitivity analysis on the results.

4.2.2 Mathematical Foundation of AHP

The mathematical foundation of AHP is based on four axioms [Saaty 89]. They are:

1. Reciprocal condition axiom :

   This derives from the thesis that, if alternative or criterion A is n times preferred to B, then B is 1/n times as preferred as A.

2. Homogeneity

   Elements of a particular level of hierarchy must be comparable in order to express meaningful intensities of preference.

3. Independence

   Criteria are assumed independent of properties of the alternatives for the purpose of expressing preferences.

4. Expectations

Any change in the hierarchy demands re-evaluation of the preferences.

Saaty [Saaty 86] provided a comprehensive explanation on the relevance and validity of the axioms and explained how the theory of AHP is derived from these axioms.

4.2.3 Calculation of Priorities

Once the matrix containing the pairwise comparisons is complete (See 4.2.2), the next step is to compute the vector of priorities from this matrix. The priority values are calculated by solving the following matrix equation :

$$A * W = \lambda_{\max} * W \qquad (4.1)$$

where:

A = matrix of pairwise comparison values

W = the eigenvector of priorities

λ_{max} = largest eigenvalue of matrix A.

Based on the above formula, the eigenvector of priorities, W, can be calculated by performing an iterative computation on the pairwise comparison matrix, A [Zahedi 86] [Saaty 88]. However, this is a tedious and time consuming process, sometimes beyond manual computation. There are several commercial software packages such as Expert Choice, Criterium and HIPRE + based on this method to carry out these computations [Buede 92].

To avoid the complexities of calculating the priority values Saaty [Saaty 88] introduced four crude methods of estimating the priorities vector. The most accurate of them is to multiply the n elements in each row and take the n^{th} root and then normalise the resulting numbers. Put in mathematical terms, under this method the vector of priorities is obtained by normalising the principal eigenvector of the comparisons matrix. It should be noted, however, that these values are only estimates of lesser degrees of accuracy. This study uses the eigenvalue method described earlier, which is supported by available commercial software.

4.2.4 Consistency of Judgements

One major feature of AHP is its ability to measure the degree to which the pairwise comparisons are consistent [Partiovi 92]. This measure, termed as Consistency Ratio (C.R.), detects inadvertent misjudgements in pairwise comparisons.

In case of the situation where the pairwise comparison matrix A is composed of exact measurements, rather than subjective judgements, then these comparisons can be considered as fully consistent. When a positive reciprocal matrix (A) of order n is consistent, its largest eigenvalue, λ_{max} should be equal to n [Saaty 88]. In case of inconsistency $\lambda_{max} \geq$ n. The measure of average deviation from consistency, termed as Consistency Index (C.I.) can, therefore, be calculated as follows:

$$C.I. = \lambda_{\max} - n / (n-1) \qquad (4.2)$$

This consistency index is then compared with the average random consistency index (R.I.) of a randomly generated reciprocal matrix of the same order to calculate the Consistency Ratio for the pairwise comparison matrix A.

$$C.R. = C.I. / R.I. \qquad (4.3)$$

Table 4.2 contains the R.I. values derived by Saaty [Saaty 88] for matrices of order 1-10 using a sample size of 500 based on the 1-9 scale, with reciprocals forced.

Order	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 4.2: Random Index for matrices of order 1-10.
Source: [Saaty 88]

A judgement is accepted as consistent when C.R is 0.10 or less. Otherwise the pairwise comparison matrix has to be reviewed for inconsistencies [Zahedi 86]. Commercial software packages available for AHP have the capability to calculate the C.R.

4.2.5 Previous Applications of AHP

Since the introduction of AHP in 1970s, its creator Saaty has used the technique in a multitude of applications ranging from resource allocation and transport planning to conflict resolution [Saaty 85]. Apart from Saaty, many other users, including researchers, academics and practitioners alike have successfully applied this technique in a variety of situations [Zahedi 86].

Ample evidence is available on the use of AHP in business and, particularly operations environments. At the business level, Lee et. al. [Lee 95] have used AHP to develop a model, which they have termed as the Analytic Hierarchical Performance Model (AHPM), to compare the performances of divisions within an organisation. This model analyses both financial and non-financial performance and combines both to present a single score for overall comparison. Chan and Lynn [Chan 91] also confirmed the applicability of AHP in this area by formulating several case studies. With the operations perspective, Partovi [Partovi 92] used this technique to determine the activities to be benchmarked in a manufacturing concern based on major criteria of cost, quality, delivery and flexibility. Mohanty and Venkataraman [Mohanty 93] developed a model to select automated manufacturing systems for a company considering strategic, technological and social factors involved. Narasimhan [Narasimhan 83] used the AHP methodology to device a system to select the best supplier of a particular product for an organisation based on the major criteria of pricing structure, delivery, quality and service. Partovi et. al [Partovi 89] demonstrated that this technique can be applied in various areas of operations management by using examples of possible applications ranging from facility location decisions and facility layout decisions to preventive maintenance frequency decisions.

4.3 Evaluation Process

4.3.1 Overview

Given below is a brief description of the mechanism of the evaluation process applied in this model. All the steps involved in arriving at final results are explained. Even though the details of the intermediate steps are explained, the users of the model are not expected to perform them manually. Specialist software such as Expert Choice can be used to perform these tasks.

The evaluation using AHP is carried out in three steps:

1. **Prioritisation of performance criteria**

   The relative importance scores of main performance criteria and their sub-divisions judged according to market and industry requirements are used to assign weighting to them.

2. **Normalisation of manufacturing performance measures**

   The manufacturing performance measures calculated using the data obtained from production records and other related sources are normalised before making comparisons. Normalisation would take away the effect of units and denominations used in measurement.

3. **Calculation of indices**

   Overall indices are calculated based on the prioritised and normalised figures mentioned above.

This process is illustrated in Figure 4.2.

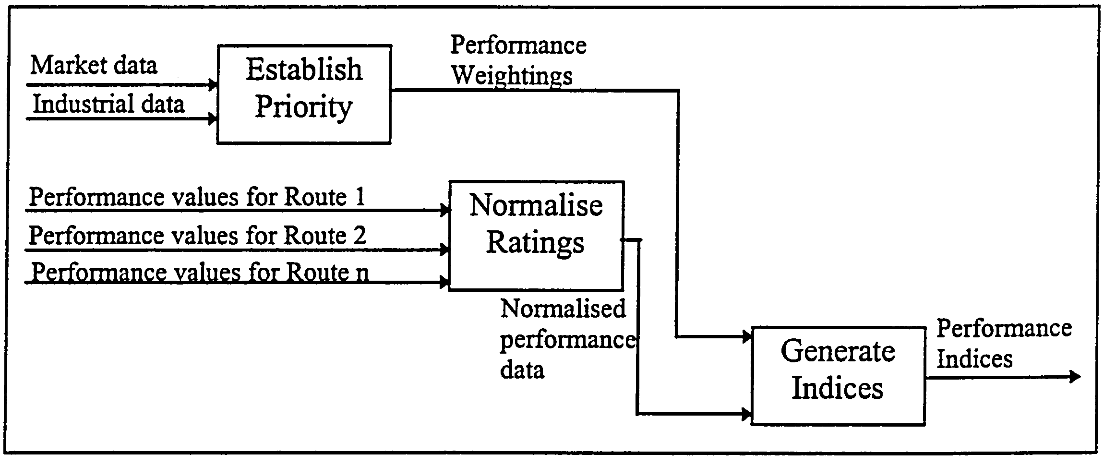


Fig. 4.2 : The evaluation framework

The general evaluation process is demonstrated here using a simplified hypothetical example. A process type industry is used for this example assuming a scenario in which a company is comparing two possible production routes of manufacturing a particular product. It is assumed that the production process consists of three major production stages. The production facilities are distributed in different countries as shown in Figure 4.3. The target market is in yet another country in the region.

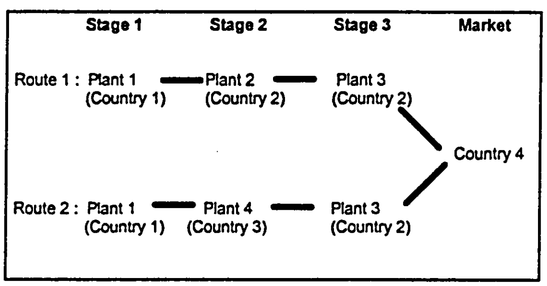


Fig. 4.3 : Example - Alternative Production Routes

4.3.2 Manufacturing Data

This example demonstrates how the performance of the production process as a whole can be evaluated is by measuring the performance at the final stage of the production. Performance measures discussed in Section 3.4 are illustrated using variable names such as c_1 for cost measure in Route 1 , $q1_1$ for VQR measure in Route 1, $q2_2$ for CU/PU measure in Route 2 (Fig. 4.4). These values are the performance measures discussed in Section 3.4 . They can be obtained through actual manufacturing data from the records maintained by the companies. The methods of converting these manufacturing data into performance measures have been discussed in Section 3.4.

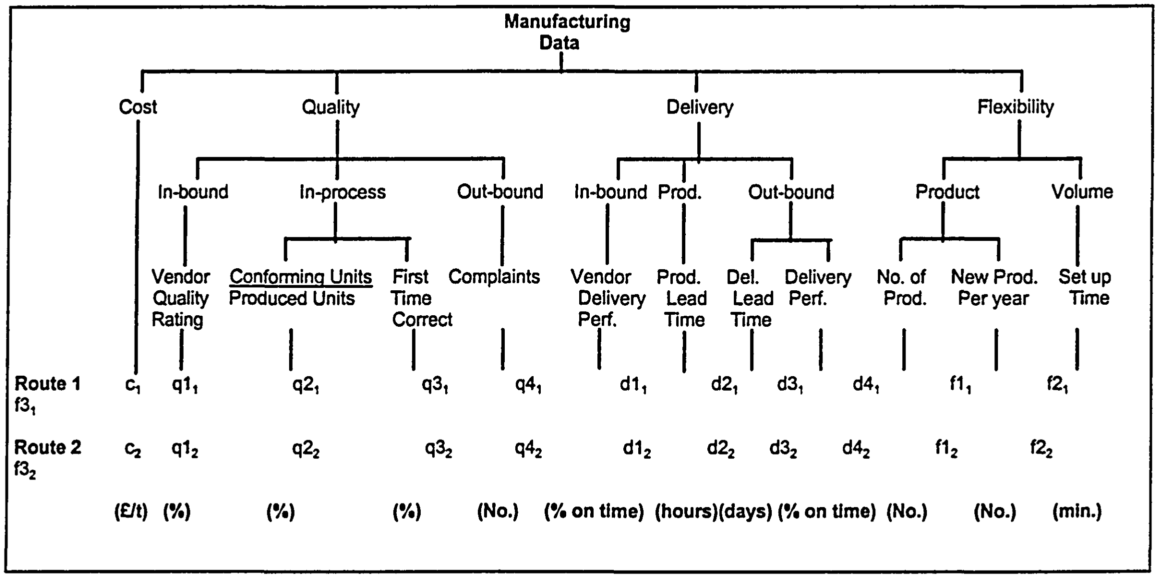


Fig. 4.4 : Manufacturing Data

These data represent the cumulative effect of the outputs of preceding production steps. For example, the cost parameter at this stage includes all the manufacturing costs, transportation costs as well as tariffs and taxes incurred in the preceding production steps. Similarly, the out-bound quality and on-time delivery figures of the previous stage can be used as the incoming material quality and vendor delivery performance data for this stage.

4.3.3 Prioritisation of Criteria

The first step in the evaluation process is to assess the relative weightings for each criteria and sub-criteria in the hierarchy with respect to its immediate higher level. First, the relative weightings of the top level criteria, viz. cost, quality, delivery and flexibility, are calculated based on their relative in competing in a target market. User is expected to provide the relative importance of each competitive priority with respect to others based on his/her perception about the market requirements using the scale described in Section 4.2.2. For example, if the user assumes that cost can be ranked as strong when compared with flexibility, a score of 5 is given for this comparison (Figure 4.5). AHP then uses an iterative computation process to translate these paired comparison data into absolute weights to represent the overall relative importance of each of the priorities (See Section 4.2.4). The resultant vector (w_1,w_2,w_3,w_4) provides the relative importance of the four competitive priorities in relation to that particular market.

	Cost	Quality	Delivery	Flexibility	Weight
Cost	1	a	b	5	w_1
Quality	1/a	1	d	e	w_2
Delivery	1/b	1/d	1	f	w_3
Flexibility	1/5	1/e	1/f	1	w_4

Fig. 4.5 : Prioritisation of criteria

This procedure is repeated for all the subsequent sub-criteria.

4.3.4 Normalisation of Manufacturing Performance Data

The next step is to assess the performance of each route based on each performance measure. Qualitative data is analysed using the same method described in Section 4.2.4. However, quantitative data, which are mostly used in this model, are analysed using the method of normalisation. The normalisation procedure is adopted here because of the necessity to allow different types of data to be integrated together in order to arrive at an overall score. This is demonstrated here using one measurement, on-time delivery performance. Table 4.3 shows the percentage on-time deliveries made by the specific plant in each route. These data are normalised and the results used for comparison.

	% on time deliveries	Normalised Value	Notation used in the example
Route 1	$d4_1$	$d4_1/(d4_1 + d4_2)$	$nd4_1$
Route 2	$d4_2$	$d4_2/(d4_1 + d4_2)$	$nd4_2$

Table 4.3: The Normalisation of data

This procedure is repeated for the other measures except for those whose values are inversely proportional to better performance. They include cost, customer complaints, production lead time, delivery lead time and set-up time. In such cases the reciprocal of the value is normalised in order to maintain the consistency of the comparison. The complete picture of the hierarchy after the prioritisation and normalisation procedures is shown in Figure 4.6. It shows the weightings of the criteria and sub-criteria as well as normalised performance measures.

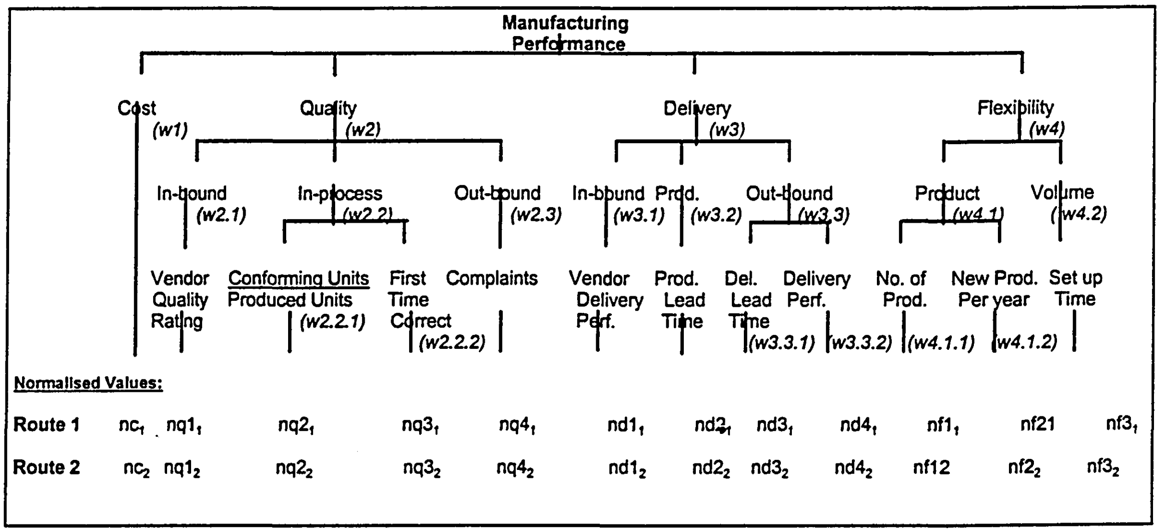


Fig. 4.6 : Data after Prioritisation and Normalisation

4.3.5 Final Ratings

The final ratings are calculated by taking the summation of each normalised value of performance multiplied by the weight of the corresponding criteria or sub-criteria in the next higher level, starting from the lowest level (Fig. 4.7). This model provides the facility to compare the performances at the highest level competitive priorities as well as at individual components of them.

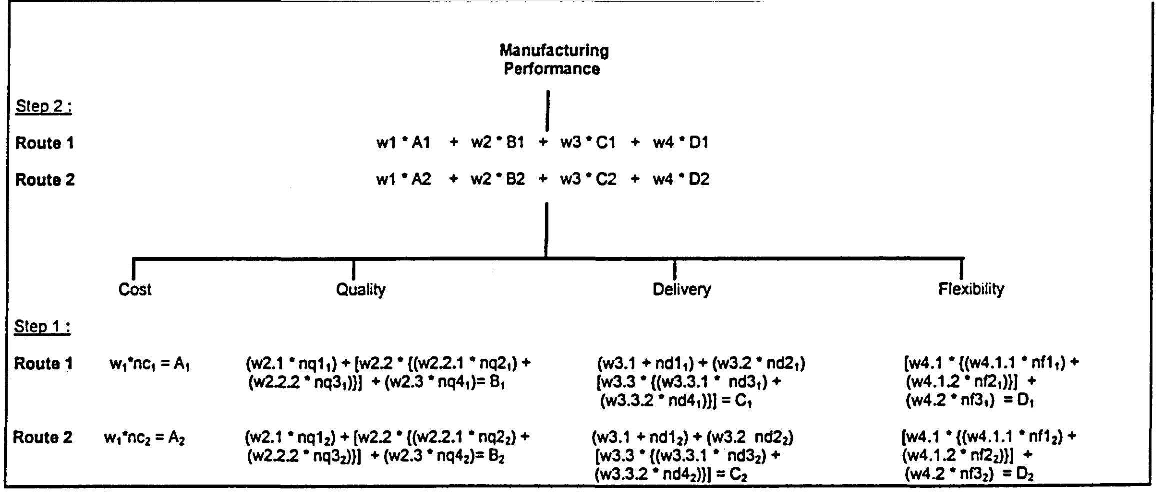


Fig. 4.7 : Overall Ratings

One key feature of this model is its ability to make comparisons at each stage of the production process taking to the cumulative effect of the preceding production stages. This will assist companies in assigning specific production steps to plants by taking into account their contributions to the overall performance as a complete production chain.

4.4 Summary

One of the main features of this model is the use of multiple variables to measure manufacturing capability. That necessitated using an analytical tool that can quantitatively relate these measures to calculate a single score to make comparisons. As the features offered by AHP suits the requirements of this study it was selected as the evaluation technique. AHP is a multi-attribute decision tool that is capable of analysing complex problems by transforming them into hierarchies. The availability of commercial software supporting this technique makes the calculation procedures easier.

The application of this technique in the evaluation process is demonstrated using a hypothetical example. Two alternative production routes consisting of three major production stages were compared using notations as data for demonstration purposes.

Chapter 5

Model Implementation

5.1 Introduction

This chapter describes the manner Manufacturing Capabilities Model is implemented based on the requirements of the steel industry.

Section 5.2 relates the process-performance parameters of the model to the steel industry by identifying specific measures under each performance criteria for individual stages of the steel-making process. Different measures are identified for alternative technologies used at different stages, where applicable. This section also introduces the questionnaire designed to collect information for model validation in the steel industry. The required data range from managers' perceptions about market requirements to actual production data extracted from company records. The composition of the questionnaire with regard to these requirements is discussed.

Section 5.3 introduces the software developed for model implementation. This software was built on Microsoft Excel and Expert Choice packages, with visual Basic for Applications (VBA) enhancing the user interface. This section discusses the main components of the software and illustrates how the two packages are inter-related.

Section 5.4 presents the user interface. This interface built on Excel allows the user to enter production data as an input. The corresponding performance measures are calculated and displayed for transferring to Expert Choice for further calculations.

Section 5.5 describes the Expert Choice model that calculates the final ratings based on Analytic Hierarchy Process. This can be considered as the core of this software. Steps involved in the calculations are demonstrated.

5.2 Steel-making Capability Model

The Manufacturing Capabilities Model discussed in Chapter 3 was implemented based on the requirements of the steel industry. The steel-making stages outlined in Section 3.3.2 are adopted for the process axis. The general performance measures selected in Section 3.4 are customised to suit the specific needs of the industry. The resultant process-performance matrix for the steel industry (See Table 3.2 in Section 3.4.5) provides the basis for identifying the essential measures that can adequately represent the performance of a particular production stage.

Traditionally, productivity and yield are the two primary performance measures used in the steel industry [Jin 88]. Materials productivity measures the quantity of raw materials required to produce a tonne of liquid steel. Labour productivity expresses steel output per man-hour. Energy productivity indicates the amount of energy required per unit output.

In the model, performance measures identified in Section 3.4 are studied according to the specific requirements of the steel industry. The measures are selected in such a way that they:

- adequately represent the performance of process step concerned, and
- preserve the logic of the general model framework.

Performance measures selected for individual production stages are discussed in detail in the following sections.

5.2.1 Melting

Two different sets of measures have been identified to include both Electric Arc Furnace (EAF) and Basic Oxygen Furnace (BOF) melting processes that are considered under the model. Even though most of the measures are common to both processes, there are a few distinct measures for each process with regard to cost. These different cost related measures used in respect of EAF and BOF melting are detailed in Table 5.1.

Measure	Measurement criteria	
	EAF	BOF
Materials	scrap (in kg) per tonne of steel	liquid iron (in tonnes) per tonne of steel
Energy	electricity (in kWh) per tonne of steel	oxygen (in m^3) per tonne of steel
Labour	man-hours per tonne of steel	man-hours per tonne of steel
Consumable	electrodes consumed (in kg) per tonne of steel	Not applicable
Transportation	Not applicable	Not applicable

Table 5.1: Cost related measures for EAF and BOF steel-making

The rest of the measures are common to both processes (Table 5.2).

Measure	Measurement criteria
Vendor Quality Rating	Calculated based on Formula 4.1 in Chapter 4
Conforming Units/Produced Units	Total production less rejects
First Time Correct	Total production less restricted misfits
Vendor on-time delivery	Percentage of time delivery schedules were adhered to by suppliers
Production lead time	Tap-to-tap time/capacity of the furnace
Delivery lead time	Does not apply
On-time delivery	Percentage time delivery schedules were met
Number of products	Number of the types of steels melted
New products per year	Number of new types added to the range during the period concerned
Set-up times	Average set-up time of the furnace

Table 5.2: Quality, delivery and flexibility related performance measures for steelmelting.

5.2.2 Casting

The inclusion of both types of casting methods, i.e. ingot casting and continuous casting, necessitates selecting separate measurement criteria according to the method. Similar to melting, most of the measures, with the exception of cost, are common for both processes (Tables 5.3 and 5.4).

Cost measure	Measurement criteria	
	Continuous Casting	Ingot Casting
Materials	molten steel (in tonnes) per tonne of steel cast	molten steel (in tonnes) per tonne of steel ingots cast
Energy	electricity (in kWh) per tonne of steel	Not applicable
Labour	man-hours per tonne of steel cast	man-hours per tonne of steel cast
Consumable	Not applicable	Not applicable
Transportation	Distance to next plant	Distance to next plant

Table 5.3: Cost related measures for continuous and ingot casting.

Measure	Measurement criteria
Vendor Quality Rating	Customer complaints in melting
Conforming Units/Produced Units	Total production less rejects
First Time Correct	Amount cast correct first time without need for rework
Vendor on-time delivery	Percentage of time
Production lead time	Casting speed
Delivery lead time	Time to transport the cast steel to rolling plant
On-time delivery	Percentage times the delivery schedules were met
Number of products	Not applicable
New products per year	Not applicable
Set-up times	Average plant set-up time

Table 5.4: Quality, delivery and flexibility related performance measures for casting

5.2.3 Rolling

The performance measures used for all rolling operations, viz. slabbing, roughing, finishing and cold rolling, are generally similar (Table 5.5). However, the following may not apply for all the operations:

- transportation cost and delivery lead time apply only for finishing and cold rolling
- vendor on-time delivery performance corresponds to the on-time delivery reliability of the previous process, only if both processes are carried out at the same location.

Factor	Performance measure assigned
Materials	Tonnes of steel input for tonne of rolled product
Energy	Electricity consumption (in kWh) per tonne of steel rolled
Labour	Man-hours per tonne of steel rolled
Consumable	Rolls consumed per tonne of steel rolled
Transportation	Distance to next plant in the value adding chain
Vendor Quality Rating	Calculated based on Formula 4.1
Conforming Units/Produced Units	Total production less rejects
First Time Correct	Amount cast correct without need for rework
Vendor on-time delivery	Percentage of time materials were received on time
Production lead time	Exit speed of the rolling mill
Delivery lead time	Time to transport the rolled product to the next plant in the value adding chain
On-time delivery	Percentage times the delivery schedules were met
Number of products	Number of products the rolling mill can process
New products per year	Number of new products added to the range during the period under consideration
Set-up times	Average time for changing rolls

Table 5.5: Performance measures for rolling operations.

Input materials for slabbing, roughing/finishing and cold rolling operations are ingots, slabs and coil/sheets respectively

5.2.4 Data Collection

The model demands collection of a wide array of production data covering all the major sub-processes involved in manufacturing a particular product. As many performance measures required by the model may not be available in directly extractable manufacturing records, they are calculated based on other regular production data maintained by companies. The development of a detailed questionnaire facilitates comprehensive data collection. Consequently, a self-administered, delivery and collection questionnaire was developed for the steel industry based on Table 3.2, which maps the performance measures to specific stages of production .

A large part of the questionnaire was designed with a special interest in flat product manufacture. It covers all of the major steel-making steps and their associated alternative technologies. To avoid commercial sensitivity, the questions address general production issues. Wherever possible, complementary questions have also been included to ensure the accuracy of data. For example, technical data related to a production stage can be used as a cross-reference to verify the accuracy of production data.

The questionnaire (Appendix B) consists of two parts. Part 1 aims to collect production related data. The first section aims to collect general information about the company, its production facilities, product range, and customer base. This will provide useful background information about the company being studied. Additionally, it provides details of the proximity to markets, both for raw materials and for finished products, which affects transportation costs as well as delivery lead times.

The second section is used to establish the level of technology employed in the plants. It contains vital technological data that could directly be used in calculating performance measures or that could supplement other data. One other use of data collected at this level is in the projection of the trajectory of technological development.

The final section can be considered as the core of the questionnaire as it is specifically designed to collect the production data necessary to compute the performance measures used in the model. Questions are included for collection of data related to steel-making sub-processes from melting to customising (See Tables 5.2 to 5.6). The questionnaire collects data pertaining to a particular year. Data related to some main factors such as the total production and raw materials consumption during the same period in the previous year are also collected to verify the consistency by comparing the changes. However, use of these questions is optional, as these figures do not constitute a part of the input to the model.

Part 2 of the questionnaire is designed to gather qualitative information about how the managers perceive the importance of different performance criteria, when compared with each other in relation to a market or production stage. The 1-9 scale of AHP discussed in Section 4.2.1 provides the basis for expressing the importance of criteria and sub-criteria. At the highest level is the comparison of the importance of the four major performance criteria with respect to a particular market. When comparing two criteria, the user is expected to judge the degree of importance of one criterion in relation to other based on the 1-9 scale. For example, if cost is viewed as moderately more important than quality, the corresponding value of 3 should be selected from the scale.

These relative importance figures collected through the questionnaire are used in the prioritisation procedure of AHP to calculate the relative weights of criteria and sub-criteria.

5.3 Software Implementation

5.3.1 Overview

The calculation of manufacturing capability indices entails handling a large amount of data which involves two stages of computations: First, to convert the manufacturing data into performance measures, and secondly to calculate performance indices based on the performance measures and the relative importance of performance criteria using the AHP techniques.

There are several commercially available software which support decision making based on AHP [Buede 92]. Criterium, Expert Choice (EC), HIPRE 3+ are capable of running on both DOS and Windows platforms. There are noticeable differences among the three packages in the areas such as display of the hierarchy, elicitation of values, display of results and the user interface. Criterium and HIPRE 3+ allow to build hierarchies of up to 21 and 20 levels respectively. Expert Choice limits it to 7 levels, which is quite sufficient for any model. The superior graphical and numerical comparison features available for the elicitation of criteria weights and the diversity of the results analysis and sensitivity analysis facilities made EC the package best suited for the requirements of this model.

However, this model cannot be implemented based on EC alone, as it is not compatible to all model requirements. What is required is a complete software programme that can perform all the functions from performance measures calculation to final results analysis with EC as the engine that performs AHP based calculations. The rationale behind the development of this software is explained in the following sections. The user guide shown in Appendix B demonstrates step-by-step instructions to use the software.

5.3.2 Software Organisation

The model implementation software was developed based on Microsoft Excel with Visual Basic for Applications (VBA) as the tool for designing user interfaces.

The user input received in the form of production data is stored in different worksheets of an Excel workbook. The performance measures calculated based on these data are displayed in a separate sheet. Unfortunately, EC is limited by its ability to import input data directly from other applications. Due to this shortcoming, performance measures are copied to Expert Choice as inputs via the clipboard.

Data related to the importance of each performance criterion against the other is entered directly to the EC model for prioritisation. EC performs the calculation of performance indices based on the performance measures and priorities. The is exported to Excel for display and analysis. Figure 5.1 shows how these two packages are used and interrelated in different parts of the software.

The user can analyse a problem in three contexts:

- performance of the complete production process as a whole route
- performance of a particular production stage as a part of the whole vale chain
- performance of plants as stand alone units.

The results can be displayed as an overall summary, under competitive priorities or in full detail.

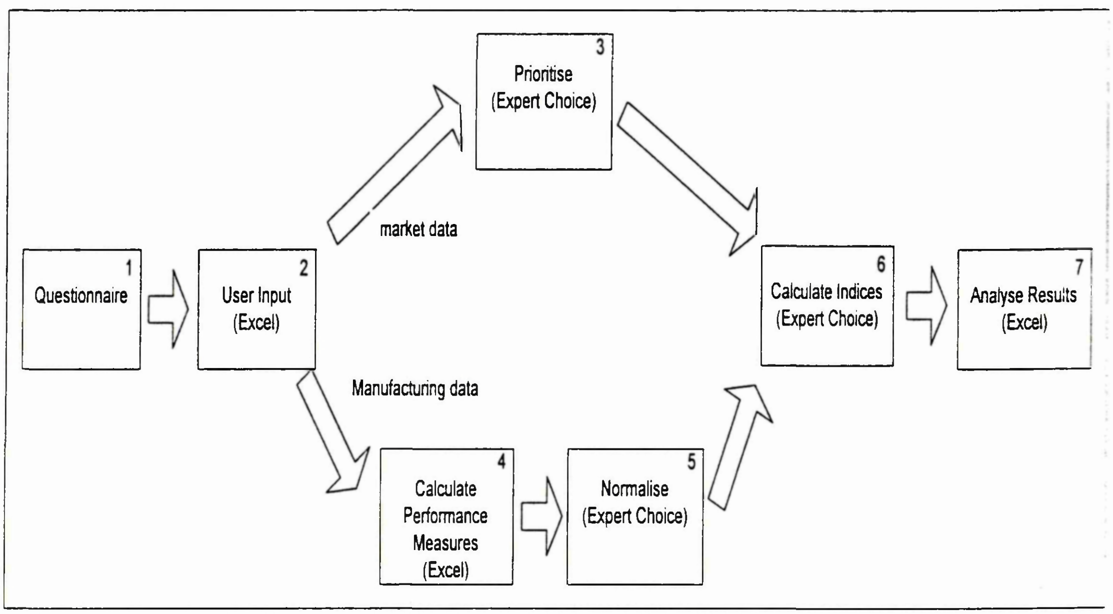


Fig. 5.1: Information flow in the software programme

5.3.3 Files Structure

The Excel component of the software is comprised of two files, viz. *Intro.xls* and *Templ.xls*. *Into.xls* is invoked when the programme is started to guide the user through the initial options of creating a new model or selecting an existing one. *Templ.xls* file contains the basic template. When creating a new file, Templ.xls is copied to the file name given by the user. This file will store the data and record the results for display.

The structure of the *Templ.xls* (workbook) is shown in Figure 5.2. The details of each component are as follows:

- **Module 1:**

This contains programme coding required to execute user interface commands. All the commands are based on Visual Basic for Applications (VBA) code.

- **Dialogue Sheets:**

These sheets are used to capture user responses when there are several options available to the user. Selection of a display option is an example.

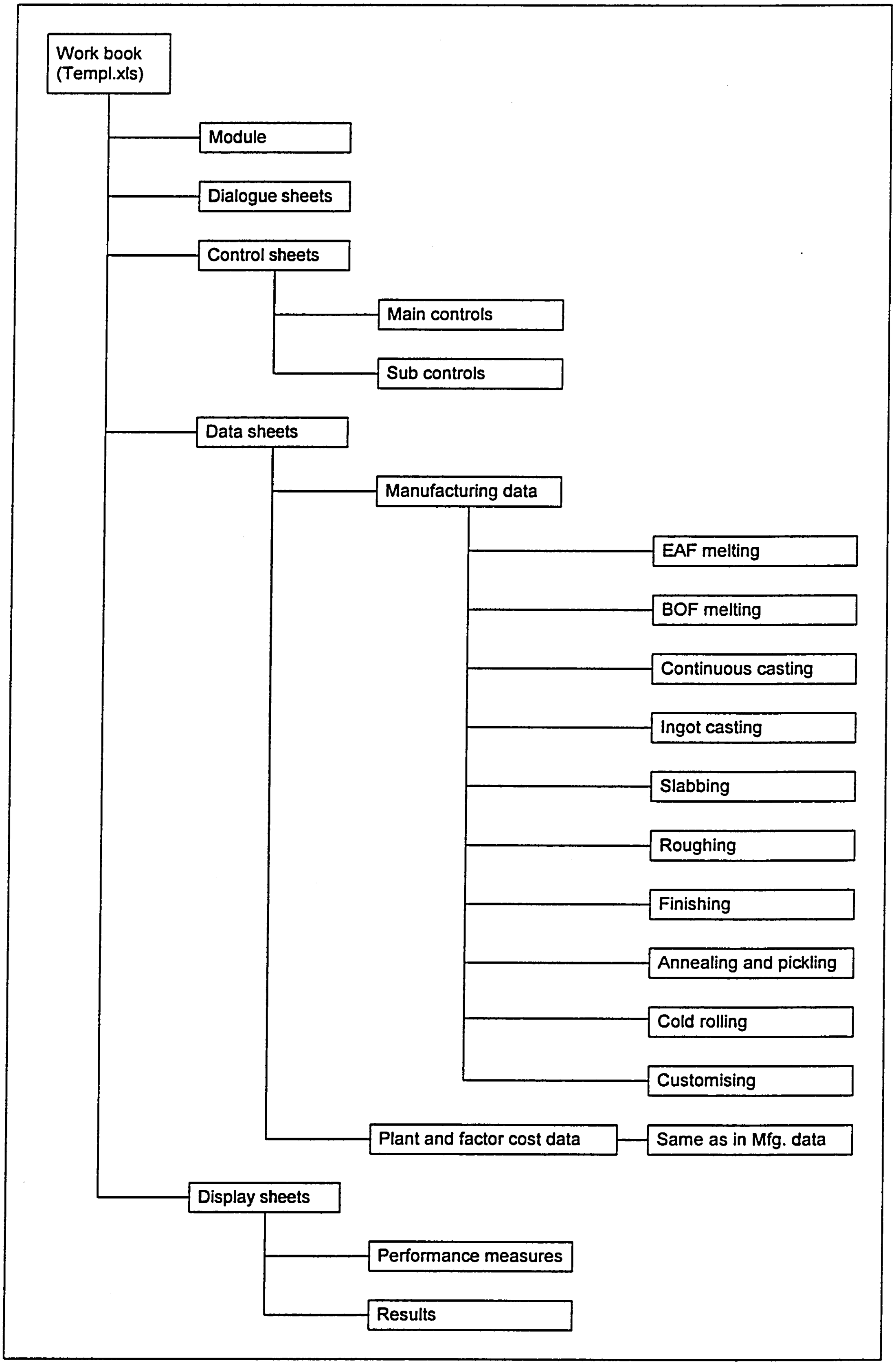


Fig. 5.2: Structure of *Templ.xls* file

- **Data Sheets :**

These worksheets hold manufacturing data and the factor cost data input by the user (Step 2 in Figure 5.1). Manufacturing data and factor cost data are held in separate sheets due to limitations in Excel 5 data forms facility. Data related to each process stage/step are held in separate sheets.

- **Display Worksheets:**

Performance measures calculated based on the manufacturing data are displayed in a worksheet (Step 4 in Figure 5.1). These figures are input into the EC model, either manually or via the clipboard. Results worksheet displays the performance indices for the alternative routes (Step 7 in Figure 5.1). User can select the display options according to the level of details they require.

The layouts of the worksheets are manually pre-formatted. Manual formatting has mainly been used in the preparation of data sheets. In addition to the layout of these worksheets, the contents of cells which contain the unit costs of raw materials have also been pre-formatted with the formulae required to calculate the contents therein. They have been formatted to automatically receive the unit raw materials costs from the preceding production step. Accordingly, the user has the option to change this figure, if necessary.

The EC component contains the AHP model library which are used as templates for model generation. Calculation of performance indices is carried out in EC (Steps 6 of Fig. 5.1). The results so obtained are exported to the Excel model for display under several options (see above).

5.4 User Interface

5.4.2 Creating a model

Once the software is invoked by opening *Intro.xls* in the Excel window, the user is given the option to either call an existing model or create a new one. When creating a new model s/he is prompted to provide a name for the file to contain the model. Then *Templ.xls* that contains all the modules, dialogue sheets and worksheets will be copied to a file containing the given name. It will contain all the commands and data sheets necessary to run the model. *Intro.xls* will be closed. The user is then prompted to give the number of routes or plants to be compared, and their locations. Then the general control window that contains the command boxes for the basic operations to be performed will appear (Fig. 5.3).

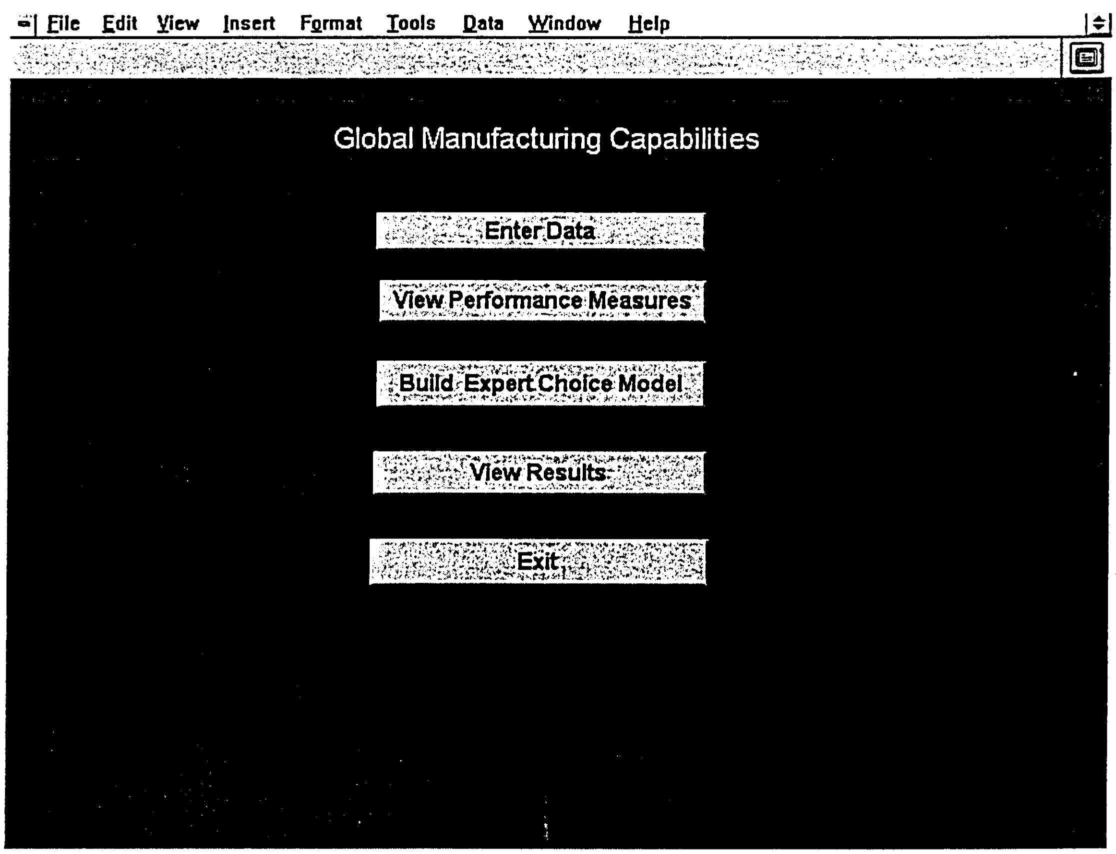


Fig. 5.3: The control window

Five commands are available in this window:

- **Enter Data**: To enter the manufacturing and factor cost data related to the routes to be compared.

- **View Performance Measures**: To view the performance measures that are to be used as input to the EC model.

- **Build Expert Choice Model**: To call the Expert Choice programme and build the EC model based on the templates available. This can be used to edit the model also, if necessary.
- **View Results**: To view the final ratings in Excel after importing the results from EC.
- **Exit**: To quit the programme.

5.4.2 Data Entry

Data entry is performed using data forms, a built in facility available in Excel. Once this option is selected, a dialogue box would appear to select the process step related to which the data is to be entered. It is important to start entering data from the first production step in the selected process route because some information from one process step is automatically transferred to the next step in the value chain. In case of processes where more than one technology is available, this dialogue box lists them to select the appropriate process. The manufacturing data and factor cost data have to be entered separately. This is due to the limitations in the built-in forms facility available in Excel 5 which does not provide the capability to customise the form. However the later versions of Excel offer this capability.

Figure 5.4 displays the data entry form for electric arc furnace manufacturing data. This being a custom form displays several options such as 'criteria' which are not relevant to this model. Once the data related to particular route has been entered user can move to the next one by pressing ‘ Find next’ button and complete entering data by pressing ‘Close’. To build the profile of a complete route, data relating to each process step has be entered in the order that the production is carried out.

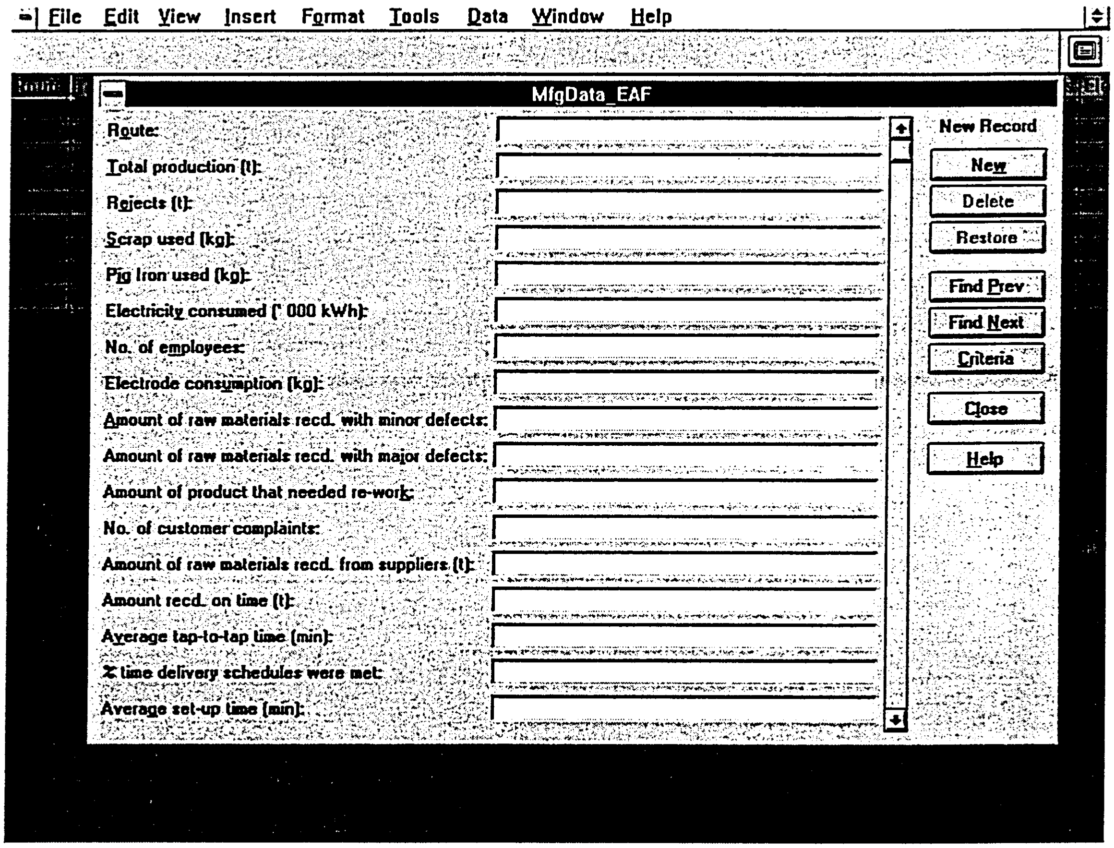


Fig. 5.4: The data entry form

5.4.3 Performance Measures Display

This allows the user to view the performance measures related to a particular manufacturing process step. These are calculated based on the manufacturing data and plant and factor cost data entered earlier. The performance measures displayed here serve as input data for the Expert Choice model.

Three display options are available.

1. To compare the whole route.

- Displays the performance measures at the final stage of the process.

2. To compare plants at a particular stage of production as a part of the value chain.

   - Displays the performance measures at a selected stage of production taking into consideration the preceding stages of the process also.

3. To compare plants at a particular stage of production as stand alone units.

   - Displays the performance measures at a selected stage of production without considering the preceding stages of the process.

Figure 5.5 displays a typical performance measure display screen. These measures have to be transferred to the EC model as input.

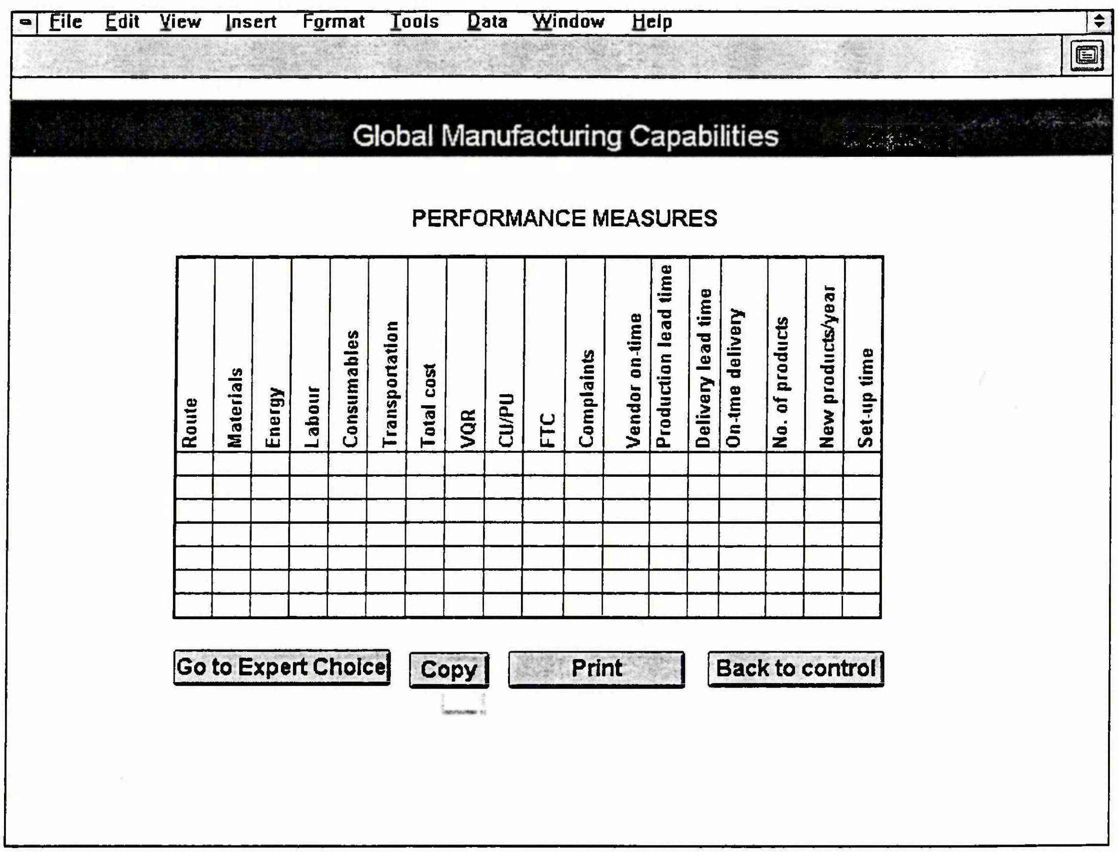


Figure 5.5: Performance measures display

5.5 Expert Choice

5.5.1 Creating an EC model

This can be considered as the core of this software because it is the Expert Choice that performs the calculation of performance indices based on the Analytic Hierarchy Process. Expert Choice, developed by the Expert Choice Inc., is a full pledged decision package on its own. Users can easily build their own models using EC with the help of the well-compiled user guide accompanying the package.

To simplify this further, a model library was developed for different scenarios that can arise under the Manufacturing Capabilities Model. This contains models with the same criteria in the hierarchy, but with different number of alternative routes. For example, MODEL2.EC1 can be used for comparing two routes, MODEL3.EC1 for three routes and so on. These can be used as templates in building new models and saved under different file names. It is necessary to create a separate model for each step of production to be analysed. The initial screen of a typical model file is shown in Figure 5.6.

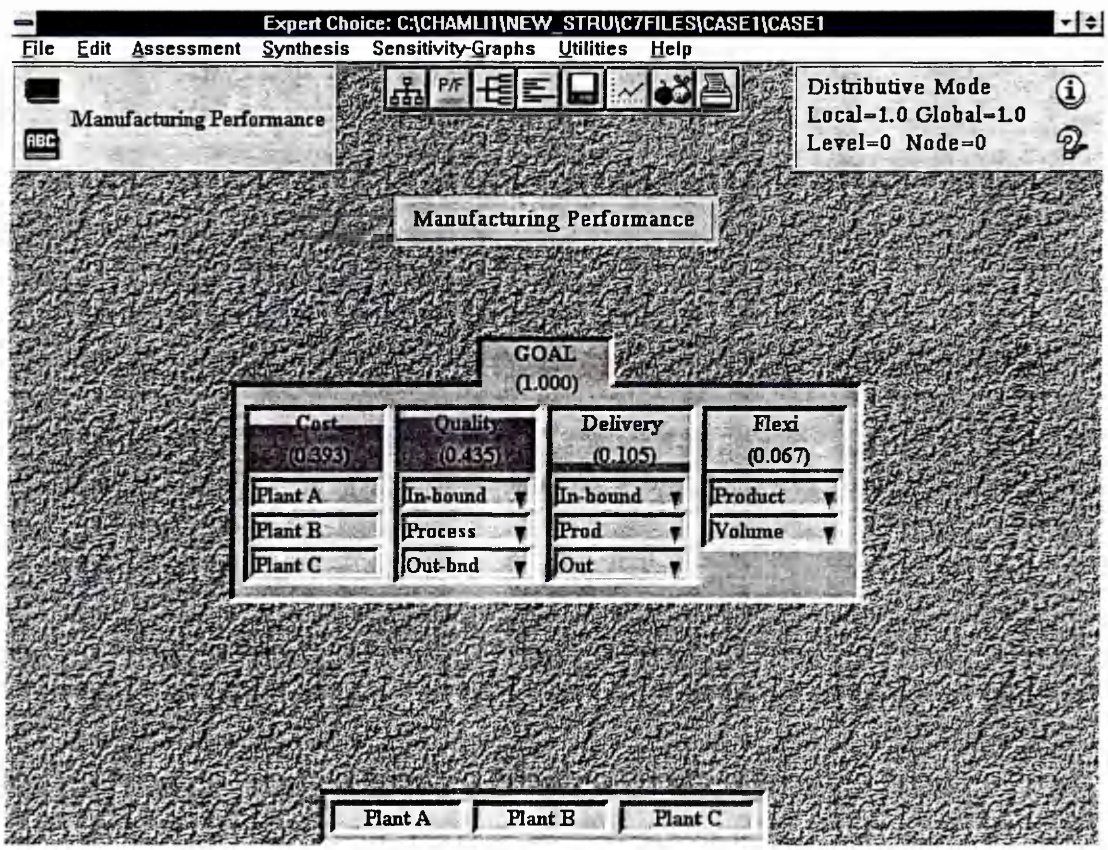


Fig. 5.6: Initial screen of an EC model file.

5.5.2 Prioritisation of Criteria

The next step in developing the EC model is to prioritise the criteria. That is to ascertain the importance of each criterion relative to the others. Information for this is collected through Part Two of the questionnaire. The pairwise comparison facility provided in EC is used in the prioritisation. Three alternative ways are available in EC for this purpose: verbal, graphical and numerical. It should be noted that selection of any option does not affect the final outcome. Therefore, the user is free to decide on the option he/she prefers. However, to preserve the objectivity of the analysis, the numerical option has been selected here with the view of collecting data through the questionnaire. Under this option there are two data entry formats: matrix and questionnaire. Part Two of the questionnaire is designed in such a way that data from it can directly be used on the questionnaire mode.

Figure 5.7 displays a typical data entry screen for prioritisation.

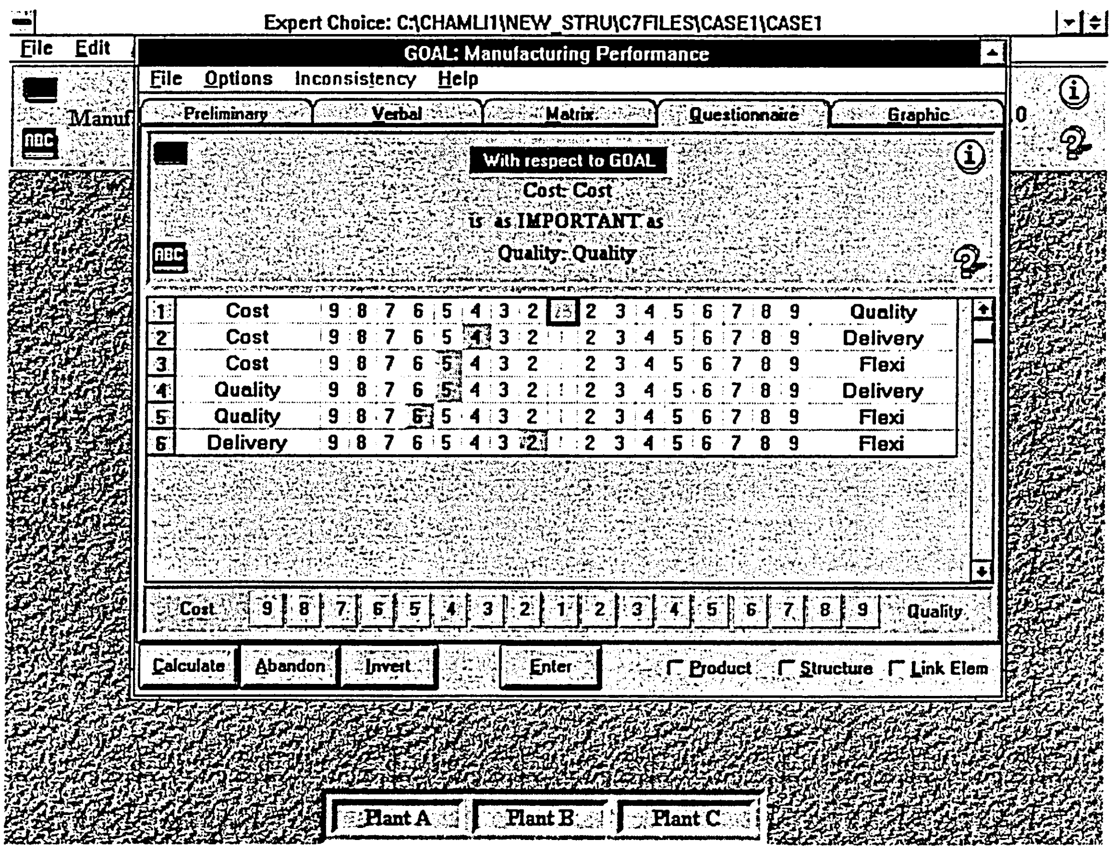


Figure 5.7: Prioritisation data entry screen

The pairwise comparison in this screen is based on the 1-9 scale of relative importance of AHP. The user has to select from the scale, the relative importance of a criteria shown on the left-most column of a row compared with the factor shown on the right-most column. A relative importance figure of 1 denotes equal importance. Figures to the left of the screen denote favourable importance towards the criteria to the left and vice versa. The 'Calculate' command button is used to calculate the weights of criteria based on these relative importance figures. The resultant priorities for the criteria in that level will be displayed as shown in Figure 5.8.

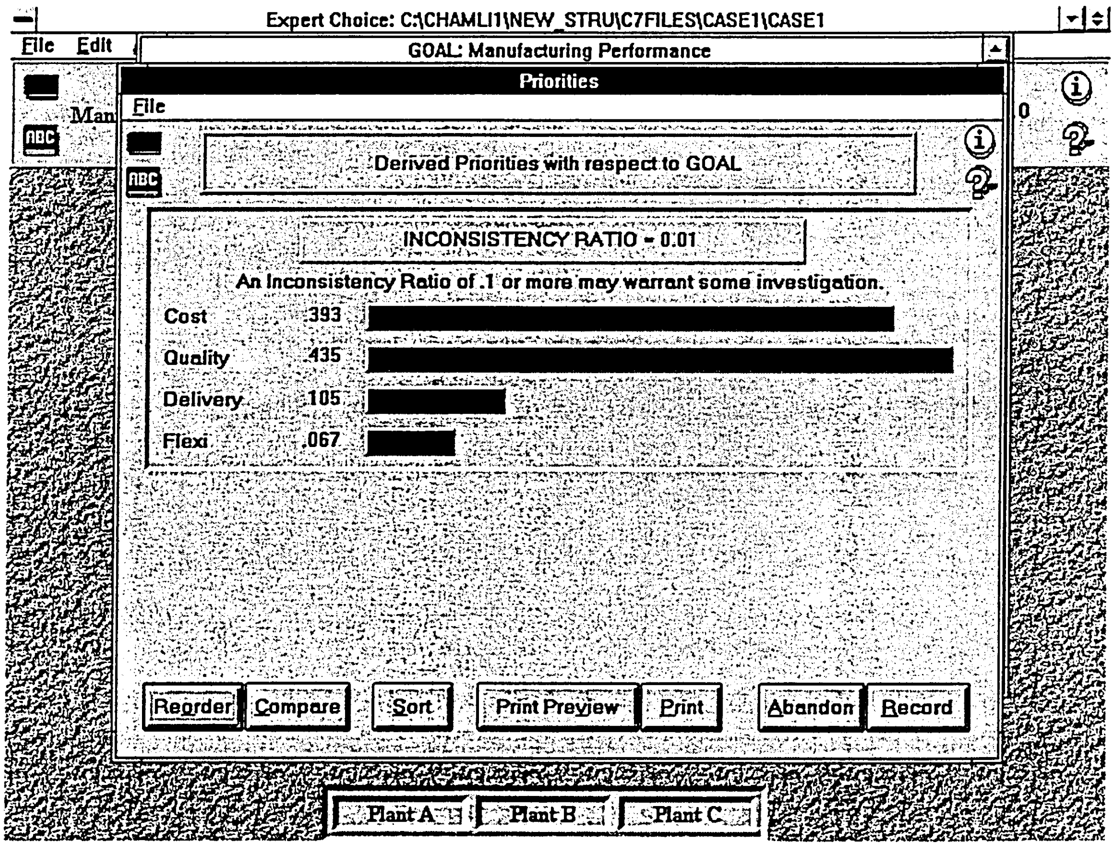


Fig. 5.8: Priorities

In addition to the priorities another important detail contained in the screen is the consistency ratio. For a judgement to be considered consistent, this ratio has to be less than 0.1. The 'Record' button at the right hand corner of the screen is used to record the priorities in the model hierarchy.

This prioritisation procedure has to be repeated for each sub-criterion contained in the model.

5.5.3 Normalisation of performance measures

Manufacturing performance measures calculated earlier (as discussed in Section 2.2) serve as inputs here. To make meaningful comparisons it is necessary to convert them to ratios that do not contain measurement units. This process is called normalisation.

From the main menu Assessment and then Data commands are to be selected to start the normalisation process at the relevant node in the hierarchy.

Two methods are available to enter data here: typing in at the appropriate place and importing via the Windows clip board.

In case of data where a higher value is less desirable than a lower value, priorities should be inverted. The best example for this is a parameter such as cost: the higher the cost the less desirable it is. Press the 'Invert' command button for such data after entering such data.

5.5.4 Results display

The results from EC are exported to Excel for analysis. The 'Exporting a model to spreadsheet' utility available in EC is used for this purpose. EC exports the model in Lotus 1-2-3 format and the programme converts it to an Excel worksheet to extract the results. Excel is used to allow the user to view results under different criteria, which is not possible in EC.

- The overall summary

  To view the overall performance index for routes or stages compared.

- Results under competitive priorities

    To view results under each of the four broad performance criteria of cost, quality, delivery and flexibility, with the relative weightings of each of them.

- Detailed results

    To view results in detail under all criteria and sub-criteria.

5.6 Summary

Being an industry with a global reach, steel industry provides an ideal ground for implementing the Manufacturing Capabilities Model. The manufacturing performance of companies in this industry in a global scale can be compared throughout the production process, from steel melting to customising the final products. The initial step for this is to identify the important performance measures related to each stage/step of the production process. The actual measures used vary from one production stage to another, and even from one alternative technology to another in the same stage as well.

These performance measures may not be available in the records of most companies in a directly extractable form. Therefore, they need to be calculated based on general production data. A well-complied questionnaire is useful in collecting data in view of the large volume of data involved. The questionnaire developed for data collection for this model consists of two main parts. Part 1 collects production related data. Part 2 records the perceptions of the users with regard to the relative importance of performance criteria.

The implementation of the model is based on computer software to facilitate easy analysis of data. Expert Choice, a software package based on AHP provides the core of implementation software in calculating the capability indices. Microsoft Excel with

Visual Basic for Applications provide the user interfaces. Results can be obtained in terms of manufacturing performance comparisons between alternative production routes.

Chapter 6

Model Validation

6.1 Introduction

This chapter presents the validation of the Global Manufacturing Capabilities model through two case studies related to the steel industry.

Section 6.2 provides the background information on the collection of industrial data from China for model validation. It elaborates on data collection using the questionnaire described in Section 5.2.4 and provides general information as well as technical information in respect of the selected plants.

Section 6.3 contains the production and market related data in respect of electric arc steel melting. These data are used on both cases.

Section 6.4 presents Case 1. The manufacturing capabilities of three electric arc meting facilities are measured and compared as a single stage in the production process. Calculation of performance measures, prioritisation of performance criteria and the evaluation of the final ratings are discussed.

Section 6.5 contains Case 2 which attempts to measure and compare the manufacturing performances of two alternative production routes. It attempts to determine the plant configuration that brings the best manufacturing performance.

Section 6.6 discusses the findings of the validation process.

6.2 Steel-making Plants

The unparalleled potential for the growth in the Chinese Steel industry, coupled with the massive interest of foreign investors in the market presents a perfect environment to validate the Manufacturing Capabilities Model. A survey based on the questionnaire described in Section 5.2.4 was conducted by Central Iron and Steel Research Institute and China Economic Reform Society. Four general steel-making companies and a special tube-making company took part in the study. The geographical distribution of the plants of the respective companies is illustrated in Figure 6.1.

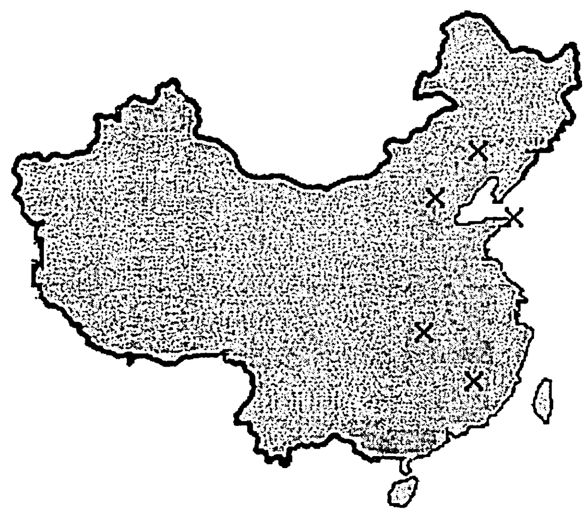


Fig. 6.1: Geographical distribution of companies that responded to the questionnaire

The summary of the production capacities and employment of the manufacturing plants of these companies is in Table 6.1.

Plant	No. of employees		Melting Capacities		Other facilities available			
	Factory	Administration	BOF	EAF	In	CC	HR	CR
A	5,544	2,840	700,000	30,000	√	√	√	
B	8,972	1,285	350,000	350,000	√	√	√	√
C	35,986	14,565	2,200,000	1,030,000	√	√		
D	10,948	2,064		395,000	√	√	√	√
E	4,977	2,271		600,000		√		

IC= Ingot casting; CC= Continuous casting; HR= Hot rolling; CR= Cold rolling

Table 6.1: Summary of plant resources

Information from three of the participating plants were selected to form the cases for validation. Further evidence from published data obtained from various government and technical sources as well as hypothetical figures applicable to the industry supplement the information collected through the questionnaire. A report published by the Ministry of Metallurgical Industries in China contains most of the productivity figures for major steel companies in China [MMI 96]. These figures are used in the analysis in view of their consistency, which was confirmed by cross comparison with the figures obtained from the questionnaire.

Brief profiles of the plants selected for further study are as follows:

- Plant A

Plant A is an integrated plant whose production is mainly based on basic oxygen furnaces, with support from electric arc melting. Latest additions of both types of plants were made in 1980s. There are two continuous casting machines in operation, each with four strands capable of making steel billets. 3-high roughing mill and finishing mill consist of 2 stands and 3 stands respectively. Total turnover of the company in 1995 amounted to £120 million, with £5.61 million as value added.

- Plant B

Plant B is also an integrated plant complete with both basic oxygen and electric arc melting facilities. Continuous casting is carried out using two casting machines each complete with three strands capable of producing steel billets. The 1995 total turnover of the company was £170 million, out of which £32.5 million was the value added.

- Plant C

Plant C is the largest of the three, employing more than 50,000 people. This integrated mill also has facilities for electric arc melting. However, the equipment used are very old compared to the other two plants. The two five-ton electric arc and the latest basic oxygen furnace were installed in 1904s and 1950s respectively. Eight continuous casters with four strands and one with 2 strands are in use. Of the 1995 total turnover of £354.7 million, value added amounted to £139.7 million.

6.3 Plant Performance Data

The data related to electric arc melting are common to both cases presented in the chapter.

- Cost measures

Table 6.2 displays the productivity data related to the three plants.

Input	**Unit**	**Plant A**	**Plant B**	**Plant C**
Scrap	kg/t	949.23	790.22	970.19
Iron	kg/t	124.96	243.81	50.16
Labour	manhrs/t	26.04	4.17	3.86
Electricity	kWh/t	633.90	591.05	485.67
Consumable	kg/t	8.08	6.09	5.34

Table 6.2: Productivity data

The manufacturing cost is computed by taking the sum of productivity costs multiplied by unit costs of inputs. The unit costs appropriate for this case are listed in Table 6.3.

Input	Unit	Cost
Scrap	£/kg	0.0875[1]
Pig iron	£/kg	0.0666[2]
Electricity	£/kWh	0.08[3]
Labour	£/ hour	0.15[4]
Electrodes	£/kg	1.125[1]

1. Conversion based on £1=$1.60 (1995) ; Source: [RSI 95]
2. Source: [Metal 98] 3. Personal communication
4. An assumed 50% increase on 1986 rate ; Source: [UNIDO 98]

Table 6.3: Unit costs of inputs

Transportation cost is ignored in this situation as it involves on-site transportation only.

The resultant total cost figures for the three plants are shown in Table 6.4.

Plant	Total Cost (£)
Plant A	132.44
Plant B	120.24
Plant C	109.16

Table 6.4: Total cost

- **Quality Measures**

Table 6.5 displays the quality related measures.

Factor	Unit	Plant A	Plant B	Plant C
VQR	%	99.62	99.23	99.50
CU/PU	%	99.00	99.66	99.77
FTC	%	99.80	99.00	98.85
Complaints	per 10,000 t	15	4	8

Table 6.5: Quality related measures

Quality of incoming materials, represented by Vendor Quality Rating (VQR) is calculated based on Formula 3.1 in Chapter 3.

- **Delivery**

Table 6.6 contains the data related to delivery performance, which were obtained using the questionnaire and the MMI report.

Factor	Unit	Plant A	Plant B	Plant C
Vendor on-time	%	100.00	99.50	99.80
Production lead time	min.	43.60	4.16	17.36
On time delivery	%	95.00	90.00	88.00

Table 6.6 : Delivery related data

- **Flexibility measures**

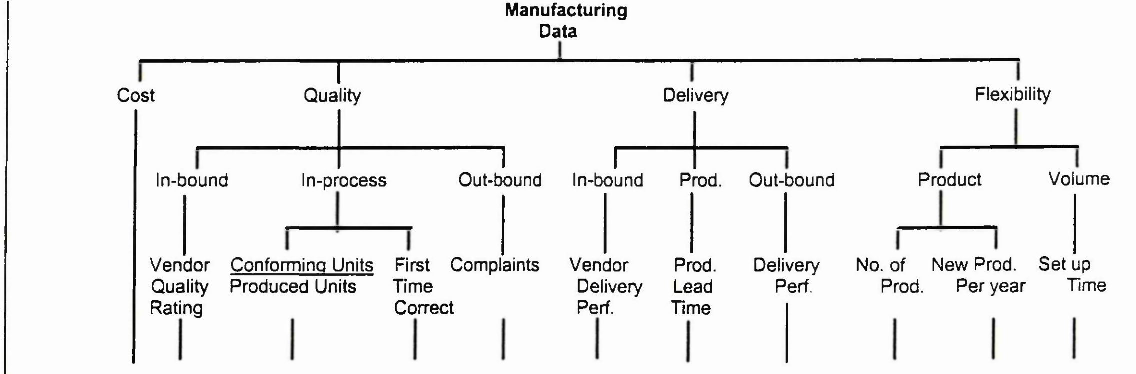
Table 6.7 contains the data related to flexibility.

Factor	Unit	Plant A	Plant B	Plant C
No. of products	No.	15	25	30
New products/ year	No.	05	08	06
Set-up time	min.	25	20	32

Table 6.7: Flexibility related data

6.4 Case 1: Individual Plant Performance

The Case 1 aims at validating the model in the context of comparing the manufacturing performance at a single stage of the production process. The electric arc melting capabilities of the above three plants are compared with reference to a particular market in the region. Manufacturing data relevant to the case are presented in Section 6.3. The performance hierarchy with the data for three alternative plants is illustrated in Figure 6.2.



	Cost	Vendor Quality Rating	Conforming Units / Produced Units	First Time Correct	Complaints	Vendor Delivery Perf.	Prod. Lead Time	Delivery Perf.	No. of Prod.	New Prod. Per year	Set up Time
Plant A	132.44	99.62	99.80	99.80	5	100.00	43.60	95.00	15	5	25
Plant B	120.24	99.23	99.66	99.00	4	99.50	4.16	90.00	25	8	20
Plant C	109.16	99.50	99.77	99.85	8	99.80	17.36	88.00	30	6	32
	(£/t)	**(%)**	**(%)**	**(%)**	**(No.)**	**(% on time)**	**(min)**	**(% on time)**	**(No.)**	**(No.)**	**(min)**

Figure 6.2: Performance data

6.4.1 Main Performance Criteria Prioritisation

Prioritisation of the four major performance criteria of cost, quality, delivery and flexibility is based on how the management perceive the relative importance of each of these criteria in relation to a particular market. Part Two of the questionnaire serves as the mode of collecting this information. This is further enhanced by published data from the Global Manufacturing Futures Survey (See Section 3.4.1). The Global Manufacturing Futures Survey ranked the competitive priorities of top companies in different geographical regions according to the emphasis placed on them by the management. Competitive priority rankings of South Korean companies are used for the derivation of relative importance of each performance criteria in view of the relevance to the Far Eastern region. The magnitudes of preferences used in the pairwise comparisons of the four major performance criteria based on the 1-9 scale are consistent with the rankings of the Global Manufacturing Futures Survey (Table 6.8).

	Cost	Quality	Delivery	Flexibility
Cost	1	1	4	5
Quality		1	5	6
Delivery			1	2
Flexibility				1

Table 6.8: The Relative importance of main performance criteria

The above pairwise comparison figures are prioritised to assign weightings to these performance criteria. These intermediate results together with the input data can be displayed as illustrated in Figure 6.3.

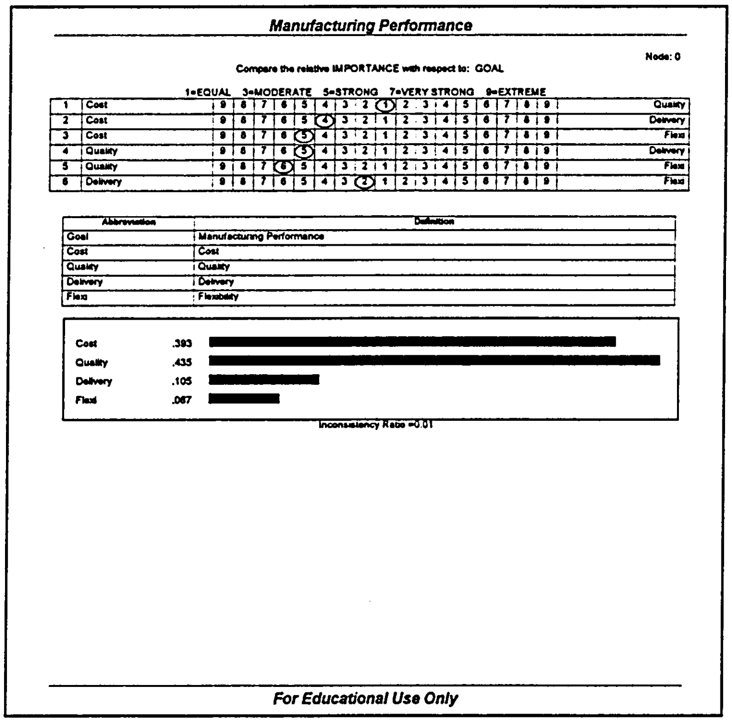


Figure 6.3 : Prioritisation at the top level

The inconsistency ratio of less than 0.1 indicates that the pairwise comparison judgements are consistent.

6.4.2 Sub-criteria Prioritisation

The relative importance of the subdivisions of these four main performance criteria are judged based on operational requirements. In the absence of actual data from questionnaires, hypothetical relative importance values have been used in respect of all the subdivisions as shown in Tables 6.9 to 6.13. These tables display both the relative importance data as well as resultant relative weightings.

	In-bound	In-process	Out-bound	Relative Weightings
In-bound	1	1/5	1/6	0.081
In-process		1	1/2	0.342
Out-bound			1	0.577

IR=0.03

Table 6.9 : Relative importance and weightings of quality sub-categories

	CU/PU	FTC	Relative Weightings
CU/PU	1	3	0.750
FTC		1	0.250

IR=0.00

Table 6.10 : Relative importance and weightings of in-process quality sub-categories

	In-bound	Production	Out-bound	Relative Weightings
In-bound	1	2	1/4	0.208
Production		1	1/4	0.131
Out-bound			1	0.661

IR=0.05

Table 6.11 : Relative importance and weightings of delivery sub-categories

	Product	Volume	Relative Weights
Product	1	3	0.750
Volume		1	0.250

IR=0.00

Table 6.12: Relative importance and weights of flexibility sub-categories

	No. of Products	New Products per year	Relative Weights
No. of Products	1	4	0.800
New Products per year		1	0.200

IR= 0.00

Table 6.13 : Relative importance and weightings of product flexibility sub-categories

6.4.3 Results

The user interface provides several options under which to display and print the results (See Section 5.4.6). Figure 6.4 displays the results generated by the software under the second option, i.e. under four main performance criteria.

Global Manufacturing Capabilities

Ratings

	Cost	Quality	Delivery	Flexibility	Overall
Weight	0.39	0.44	0.11	0.07	
Plant A	0.30	0.23	0.31	0.26	0.27
Plant B	0.34	0.47	0.39	0.35	0.40
Plant C	0.36	0.30	0.31	0.39	0.33

Overall Inconsistency **0.01**

Figure 6.4 : Results under major performance criteria

According to the results, Plant B displays better performance than the other two with respect to the performance criteria considered in the model. Even though the difference is marginal compared with Plant C in respect of cost, the clear lead in quality which has the highest weighting makes the performance of Plant B outstanding. The overall inconsistency ratio of 0.01 denotes the consistency of judgements.

6.5 Case 2: Performance of a Production Route

The aim of Case 2 is to validate the model in the context of measuring and comparing the manufacturing performances of alternative production routes with different plant configurations. Two alternative production routes encompassing Plants A and B described in Section 6.2 are analysed (Figure 6.5). It involves a scenario where cold rolled products are manufactured for a market close to Plant A.

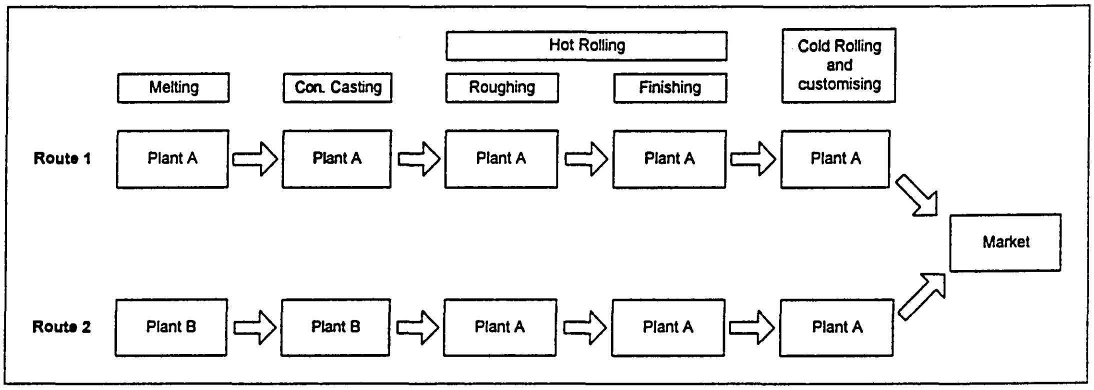


Fig. 6.5: Alternative production routes

It is assumed that Plant A has all the facilities up to cold rolling and customising. However, Plant B has limited rolling facilities. In order to meet market demand, semi-finished material are transferred to Plant 2 for further processing. This case attempts to measure and compare the manufacturing performance of the above two plant configurations in supplying to the market concerned. Production stages only up to roughing mill are considered.

6.5.1 Melting

Data from Case 1 are utilised for the analysis at this stage. The revised results for the comparison of Plants 2 and 3 are displayed in Figure 6.6.

Global Manufacturing Capabilities

Ratings

	Cost	Quality	Delivery	Flexibility	Overall
Weight	*0.39*	*0.44*	*0.11*	*0.07*	
Route 1	***0.47***	***0.33***	***0.46***	***0.39***	***0.40***
Route 2	***0.53***	***0.67***	***0.54***	***0.61***	***0.60***

Overall Inconsistency	***0.02***

Fig. 6.6: Performance comparison at the melting stage.

These results point to a distinctively high performance in Route 2 in every category.

6.5.2 Casting

Molten steel is transferred to the continuous caster for casting into billets at this stage.

Manufacturing measures for this stage is in Table 6.14

Measure	Route 1	Route 2
Materials (t/t)	1.04	1.08
Energy (kWh/t)	78.00	98.00
Labour (manhrs/t)	0.19	0.38
Transportation (£)	0.00	12.63[1]
Total cost (£)	**169.20**	**159.54**
VQR	15	4
CU/PU (%)	99.47	99.85
FTC (%)	95.00	99.68
Complaints	8	6
Vendor on time delivery (%)	90.00	88.00
Production time (min/m^3)	4.80	4.60
Delivery lead time (days)	1	1.5
Delivery reliability (%)	85.00	95.00
Set-up times (min)	40.00	20.00

1. Source: [CNC 98]

Table 6.14: Performance measures for casting stage

The raw material cost for the casting operation is the same as the total manufacturing cost for the melting process because the on-site transportation cost involved is negligible. The number of customer complaints for the melting stage is used as the inbound quality measure for the casting stage. Vendor delivery reliability measure relates to the delivery reliability of the previous stage. CU/PU value is extracted from the MMI report. The speeds of the casting machines are used the basis to calculate the production lead times. Casting speeds measured in terms of the length cast in a minute are converted to steel volume per minute and this value, in turn, is expressed as time required to cast a unit volume for comparison purposes. Outward transportation cost for Route 2 was estimated based on the actual rail transportation cost in China for a 10-tonne container.

The weightings for the four main performance criteria are assumed to be similar for all the production stages as they are judged based on market requirements.
The relative weightings for sub-criteria are calculated based on hypothetical figures that reflect the requirements of the production stage.

Route 2 outperforms Route 1 in terms of these measure at the casting stage as well (Fig. 6.7).

Global Manufacturing Capabilities

Ratings

	Cost	Quality	Delivery	Flexibility	Overall
Weight	*0.39*	*0.44*	*0.11*	*0.07*	
Route 1	***0.49***	***0.43***	***0.45***	***0.33***	***0.45***
Route 2	***0.51***	***0.57***	***0.55***	***0.67***	***0.55***
				Overall Inconsistency	***0.01***

Fig. 6.7: Performance comparison at the casting stage.

Significant quality performance improvements in Route 1 has contributed to the increase in its overall performance.

6.5.3 Roughing

This stage the first opportunity to transfer semi-finished products to other plants for further processing. In this Case, the billets produced at Plant B are considered for transfer to Plant A for further processing.

Table 6.15 summarises the manufacturing performance measures related to this stage.

Measure	Route 1	Route 2
Materials (t/t)	1.02	1.02
Labour (man-hours/t)	0.21	0.21
Energy (kWh/t)	278.00	278.00
Total cost (£)	**194.87**	**197.64**
VQR	8	6
CU/PU (%)	99.85	99.85
FTC (%)	94.77	94.77
Complaints	10	4
Vendor on-time delivery (%)	85	95
Production time (s/m)	0.31	0.31
On time delivery percentage	95.00	95.00
No. of products	15	25

New products/ year	5	8
Set-up times (min)	60.00	60.00

Table 6.15: Performance measures for roughing

The raw materials cost for Route 2 includes the cost of transporting billets from Plant B to Plant A, leading to an increase in the total cost over Route 1. The rest of the factor costs are common to both routes. The energy cost is considered to include the cost of re-heating as well.

When all operations up to the roughing mill are considered, Route 2 displays better performance than Route 1 in terms of the factors considered in the model (Fig. 6.8).

Global Manufacturing Capabilities

Ratings

	Cost	Quality	Delivery	Flexibility	Overall
Weight	*0.39*	*0.44*	*0.11*	*0.07*	
Route 1	***0.50***	***0.37***	***0.50***	***0.46***	***0.44***
Route 2	***0.50***	***0.63***	***0.50***	***0.54***	***0.56***
				Overall Inconsistency	***0.01***

Fig. 6.8: Performance comparison at the roughing stage.

In a manufacturing performance perspective, it would be advantageous to adopt Route 2. This is, however, only one of many factors to be considered in making a decision.

6.6 Discussion

Case 1 successfully validates the Manufacturing capabilities Model in the context of measuring and comparing manufacturing performance at a single production stage. Significant variations were observed in the overall performance of the three electric arc melting facilities compared. However, no significant differences were observed when considered individually under each main performance criteria, except for quality. This leads to the conclusion that the main reason for the variations in the overall performance is caused by the differences in the weightings of the performance criteria.

When prioritising the four main performance criteria, equal importance was placed on cost and quality (See Table 6.8). However quality was rated as more important when compared with delivery and flexibility resulting in a relative weighting of 0.435 compared to 0.393, 0.105 and 0.067 of cost, delivery and flexibility respectively. Therefore, Plant B, which had better performance in terms of cost achieved the highest overall performance rating despite being the second best in terms of cost and flexibility. When quality parameter is analysed further it can be observed that out-bound quality sub-category is rated as more important than in-bound and in-process sub-categories. The resultant high weighting contributes to the higher overall quality rating of Plant B which has the best out-bound quality of the three plants compared.

When the cost parameter is considered, one of the main reasons for observing similar performances of all the plants is the application of same unit input costs to all three plants. In a global context, however, wider differences can be expected of most of the unit input costs.

Case 2 validates the model in the context of evaluating the capabilities of a complete production route. Comparison of two alternative production routes producing the same product led to the identification of the best route configuration in terms of overall manufacturing performance. This case demonstrates how the manufacturing capabilities can be evaluated in an internal value chain, with the performance of upstream activities affecting the performance of subsequent activities downstream.

The comparison data for the steel melting stage are similar to those in Case 1. Route 2, where Plant B performs the melting operation, displays better performance.

At the next stage, i.e. casting, improvements can be observed of the relative performance of Route 1. This is mainly due to the improvements in the ratings with respect to cost and quality. The relative improvement of the cost rating of Route 1 was brought about by the increase in the total cost of Route 2. The transportation cost involved in transporting semi-finished products from Plant 3 to Plant 2 mainly contributed to this cost increase. Route 2 has improved in terms of outbound quality to increase the quality rating. Wide differences can be expected in respect of two measures in a similar situation in a global context where large distance transportation of materials can be involved. In addition to the total cost being increased, delivery lead time also increases. The overall impact of these increases, however, depends on the relative weightings given to these measures.

At the final stage of this analysis, it can be observed that the overall performance of Route 2 is significantly better than that of Route 1. Therefore, in terms of manufacturing performance, it can be concluded that it would be advantageous if Plant A receives semi-finished materials for roughing from Plant B, instead of producing in-house. Even though it increases the total cost of the output of Plant B, this is an option worth considering, specially if there is spare melting and casting capacity at Plant B.

It was observed in Case 2 how the performance of upstream activities can affect the subsequent activities down the production process. However, detailed investigations are necessary to model some of these factors. For example, modelling of the link between the on-time receipt of materials and the on-time delivery of the output will yield more precise performance comparisons.

6.7 Summary

The manufacturing capabilities model was validated under two contexts:

- comparing capabilities at a single stage of the production process
- comparing manufacturing performances of alternative production routes as a whole.

Industrial data related to the steel industry in China was used in model validation.

Case 1 successfully validated the model in the first context by comparing the manufacturing performances of three electric arc furnaces located in different parts of China. Although no significant differences were observed under each major performance criteria, there were some variations in the overall capabilities. This is due to the relative weights given to the performance criteria based on market requirements. However, wider differences can be expected when comparing plants in different countries.

Case 2 validated the model in the context of comparing performance of alternative production routes by evaluating the performance of two alternative route configurations. Comparing the manufacturing capabilities of different production route configurations can help identify the combination that yields best manufacturing performance. Of the two routes compared in Case 2, significant variations could be observed at each production stage when arriving at the overall performance of the route.

Chapter 7

Conclusions

The need for business models that will provide companies with structured and systematic methodologies to facilitate global manufacturing decisions is strongly felt with the increasing competition in global markets. Although the past studies on manufacturing competitiveness between different nations provide valuable insight into the advantages and disadvantages of locating plants in different countries, companies require more specific sector-related information to aid decision making. The Manufacturing Capabilities Model introduced in this thesis contributes towards addressing this need. It provides a structured methodology that will assist companies to measure, compare and project their manufacturing performances when supplying to a particular market using products manufactured in different locations.

7.1 Manufacturing Capability Evaluation

Evaluation of capabilities under the four basic competitive priorities of cost, quality, delivery and flexibility in this model provides a more comprehensive view on global manufacturing performance than the traditional cost based models. The final aim should be to reflect the achievement of a company's strategic objectives. Prioritisation of performance criteria, therefore, helps achieving a more representative view of the overall performance.

The implementation of the model based on Analytic Hierarchy Process facilitates prioritisation of performance criteria by pairwise comparison of their relative importance. It is unique in its ability to combine qualitative pairwise judgements with quantitative performance measures to generate a single score to represent the overall manufacturing performance. Measures with different characteristics can meaningfully be linked together through normalisation. Analysis of manufacturing performance in the form of a hierarchy enables comparison of capabilities at different levels. Prioritisation, however, is a subjective process depending on individual judgements. The degree of importance placed on the performance criteria by different individuals even in the same organisation may vary and a collective view would be more appropriate in such situations. Software such as TeamEC support group decision making based on Analytic Hierarchy Process.

The questionnaire designed for the model supports systematic collection of data for model implementation in the steel industry. It is comprehensive in that it collects data for both performance measures calculation as well as performance criteria prioritisation. Ability to verify the validity of important data through supplementary questions on both production related and technical aspects promotes data accuracy. The sensitive nature of the information it intends to collect can, however, result in below average return rates when administered to outside companies. Nevertheless, a company can successfully use it internally, and in potential partner companies when studying feasibility for joint ventures.

7.2 Contribution to Knowledge

The key contribution to knowledge is the structured methodology proposed to measure, compare and project manufacturing capabilities of a company within the global context of the entire production process, taking into account the performances at each individual stage. As demonstrated in Case 2 in Section 6.5, this enables comparison of the competitiveness of different production route configurations encompassing different plants in different locations. Companies can, by comparing performances of alternative plants combinations that perform different stages of the production process, select the one that yields the best overall manufacturing performance. The reflection of effects of some performance aspects of one production stage or step on the performance of the next stage/step in the production chain enhances the rationale of overall comparison of production routes. The build up of value in this internal value chain is denoted by the cost parameter.

At the production stage level, the model could be used to assess the competitiveness of different plants in terms of manufacturing performance. This was demonstrated in Case 1 where the performances of three electric arc melting plants were compared. At this level, in addition to overall performance comparisons, the productivity figures themselves provide useful information about the efficiency of plants.

The software developed based on the model facilitates practical application of this methodology by steel-making companies. The questionnaire provides the means of collecting data for this purpose.

7.3 Further Work

A structured methodology to measure, compare and project manufacturing capabilities in a global context was introduced as an outcome of this research work. Its appropriateness was established based on industrial case studies. However, there is scope for further work.

- This structured methodology was validated based on industrial data from China. However, a comprehensive validation based entirely of actual industrial data could not be achieved due to the sensitive nature of the data required. A comprehensive field study has to be carried out in a selected company with the use of the software to further validate the model in the steel industry. Particularly the projection of capabilities in response to changes in technology has to be tested.

- Application of the model in other industries such as clothing and machine tool.

- The possibility and the requirement of extending the performance criteria to include other criteria such as responsiveness has to be evaluated in view of the newly emerging global factors.

- In a much wider context, the possibility of broadening the performance criteria to investigate global manufacturing operational factors such as supply chain management can be studied.

References

[Bolt 88] BOLT, J.F. Global Competitors: Some Criteria for Success. *Business Horizons*, January - February 1988, pp. 34-41.

[Bosilani 96] BOSILANI, E. AND SCARSO, E. International Manufacturing strategies: Experiences from the Clothing Industry. *International Journal of Operations & Production Management*, 1996, Vol. 16, No. 11, pp. 71-84.

[Buckley 88] BUCKLEY, P. J., PASS, C. L. AND PRESCOTT, K. Measures International competitiveness: A Critical survey. *Journal of Marketing Management*, 1988, Vol. 4, No. 2, pp. 175-200.

[Buede 92] BUEDE, D. M. Software Review: Three Packages for AHP: Criterium, Expert Choice, and HIPRE 3+. *Journal of Multicriteria Methodologies*, 1992, No. 2, pp. 119-121.

[Chambers 92] CHAMBERS, S. Flexibility in the Context of Manufacturing Strategy, in Voss, C. A. (ed.) *Manufacturing Strategy: Process and Content*. London: Chapman & Hall, 1992.

[Chan 91] CHAN, Y. L. AND LYNN, B. E. Performance Evaluation and the Analytic Hierarchy Process. *Journal of Management Accounting Research*, 1991, Vol. 3, pp. 57-87.

[Chatterjee 95] CHATTERJEE, A. Recent Developments in Ironmaking and Steelmaking. *Ironmaking and Steelmaking*, 1995, Vol. 22, No. 2, pp. 100-104.

[CNC 98] Rail Transportation News Item. http://web3.asia1.com.sg/timesnet/data/cnc/docs/cnc0399.html (01.07.98).

[Cohen 89] COHEN, M. A. AND LEE, H. L. Resource Deployment Analysis of Global Manufacturing and Distribution Networks. *Journal of Manufacturing Operations and Management*, 1989, Vol. 2, pp. 81-104.

[Corbett 93] CORBETT, C. AND WASSENHOVE, L. V. Trade-offs? What Trade-offs? Competence and Competitiveness in Manufacturing Strategy. *California Management Review*, Summer 1993, pp. 107-122.

[Cross 88] CROSS, K. F. AND LYNCH, R.L. The 'SMART' Way to Define and Sustain Success. *National Productivity Review*, 1988/89, Vol. 8, No. 1, pp. 23-33.

[Das 96] DAS, S. K. The Measurement of Flexibility in Manufacturing Systems. The *International Journal of Flexible Manufacturing Systems*, 1996, Vol. 8, pp. 67-93.

[De Toni 94] DE TONI, A., NASSIMBENI, G. AND TONCHIA, S. A Framework for operations Performance Measurement in Management-by-Process Organisations. In Platts et al (eds.) *Operations Strategy and Performance*. Cambridge: Cambridge University Press, 1994.

[De Toni 95] DE TONI, A., NASSIMBENI, G. AND TONCHIA, S. An Instrument for Quality Performance Measurement. *International Journal of Production Economics*, 1995, Vol. 38, pp. 199-207.

[Dicken 92] DICKEN, P. *Global Shift: Internationalisation of Economic Activities*. Liverpool: Paul Chapman Publishing, 1992.

[Dunning 92] DUNNING, J. *The Globalisation of Business*. New York: Routledge, 1992.

[Eccles 91] ECCLES, R. G. The Performance Measurement Manifesto. *Harvard Business Review*, January- February 1991, pp. 131-137.

[Eccles 92] ECCLES, R. G. AND PYBURN, P. J. Creating a Comprehensive System to Measure Performance. *Management Accounting*, October 1992, pp. 41-44.

[Edington 97] EDINGTON, J. The New World of Steel. *Ironmaking and Steelmaking*, 1997, Vol. 24, No. 1, pp. 19-28.

[Evans 96] EVANS, M. Modelling Steel Demand in the UK. *Ironmaking and Steelmaking*, 1996, Vol. 23, No. 1, pp. 17-24.

[Fawcett 92] FAWCETT, S. E. Strategic Logistics in Co-ordinated Global Manufacturing Success. *International Journal of Production Research*, 1992, Vol. 30, No. 4, pp 1081-1099.

[Fawcett 93] FAWCETT, S. E. Conversion System Cost Characteristics in Global Manufacturing. *International Journal of Production Research*, 1993, Vol. 31, No. 3, pp. 647-664.

[Ferdows 89] FERDOWS, K., MILLER, J. G., NAKANE, J. AND VOLLMANN, T. E. Evolving Global Manufacturing Strategies: Projections into the 1990s. in [Sheth 89].

[Ferdows 90] FERDOWS, K. AND DE MEYER, A. Lasting Improvements in Manufacturing: In Search of a New Theory. *Journal of Operations Management*, 1990, Vol. 9, No. 2, pp. 168-184.

[Fine 85] FINE, C. H. AND HAX, A. C. Manufacturing Strategy: A Methodology and an Illustration. *Interfaces*, 1985, Vol. 15, No. 6, pp. 28-46.

[Fitzgerald 95] FITZGERALD, F. World Steel Industry. *Ironmaking and Steelmaking*, 1995, Vol. 22, No. 3, pp 190-196.

[Fitzgerald 96] FITZGERALD, F. World Steel - Towards a Truly Global Industry?. *Ironmaking and Steelmaking*, 1996, Vol. 23, No. 3, pp 202-210.

[Gelders 94] GELDERS, L., MANNAERTS, P. AND MAES, J. Manufacturing Strategy, Performance Indicators and Improvement Programmes. *International Journal of Production Research*, 1994, Vol. 32, No. 4, pp. 797-805.

[Gerwin 93] GERWIN, D. Manufacturing Flexibility: A Strategic Perspective. *Management Science*, 1993, Vol. 39, pp. 395-410.

[Ghalayini 96] GHALAYINI, A. M. AND NOBLE, J. S. The Changing Basis of Performance Measurement. *International Journal of Operations & Production Management*, 1996, Vol. 16, No. 8, pp. 63-80.

[Ginzberg 89] GINZBURG, V. B. *Steel-rolling Technology: Theory and Practice*, New York: Marcel Dekker, Inc., 1989.

[Gregory 93] GREGORY, M. J. Integrated Performance Measurement: A Review of Current Practice and Emerging Trends. *International Journal of Production Economics*, 1993, Vol. 30-31, pp. 281-296.

[Hamel 88] HAMEL, G. AND PRAHALAD, C.K. Do You Really Have a Global Strategy?. *Harvard Business Review*, July-August 1985, pp. 139-148.

[Hayes 84] HAYES, R. H. AND WHEELWRIGHT, S. C. *Restoring Our Competitive Edge: Competing through Manufacturing*. New York: John Wiley & Sons, 1984.

[Hill 89] HILL, T. *Manufacturing Strategy*. Homewood: Irwin, 1989.

[Hogan 94] HOGAN, W. T. *Steel in the 21st Century*, New York: Lexington Books, 1994.

[IISI 98] INTERNATIONAL IRON AND STEEL INSTITUTE *Short and Medium Term Outlook for Steel Demand - Annual Report of the Secretary General*, http://www.iisi.org/steelnews/outlook_oct98.htm (12.08.98).

[Irving 93] IRVING, W. R. *Continuous Casting of Steel*, London: The Institute of Materials, 1993.

[ISSB 97] INTERNATIONAL IRON AND STEEL INSTITUTE *World Steel Statistics: April 1997*, Croydon: ISSB Ltd, 1997.

[Jin 88] JIN, J, X. Productivity Improvement in Chinese Iron and Steel Industry. *Steel Times International*, May 1988, pp. 52-53.

[Joro 98] JORO, T., KORHONEN, P. AND WALLENIUS, J. Structural Comparison of Data Envelopment Analysis and Multiple Objective Linear Programming. Management Science, 1998, Vol. 44, No. 7, pp. 962-970.

[Kaplan 83] KAPLAN, R.S. Measuring Manufacturing Performance : A New Challenge for Managerial Accounting Research. *The Accounting Review*, 1983, Vol. 58, No. 4, pp. 686-705.

[Kaplan 92] KAPLAN, R. S. AND NORTON, D. P. The Balanced Scorecard - Measures That Drive Performance. *Harvard Business Review*, January - February 1992, pp. 71-79.

[Keegan 89] KEEGAN, D. P., EILER, R. G. AND JONES, C. R. Are Your Performance Measures Obsolete?. *Management Accounting*, June 1989, pp. 45-50.

[Kim 92] KIM, J. S. AND WARD, P. T. Manufacturing Competence and Business Performance: A Framework and Empirical Analysis. *International Journal of Operations and Production Management*, 1992, Vol. 13, No. 10, pp. 4-25.

[Klassen 94] KLASSEN, R.D. AND WHYBARK, D.C. Barriers to The Management of International Operations. *Journal of Operations Management*, 1994, Vol. 11, pp. 385-396.

[Kozmetsky 98] KOZMETSKY, G AND YUE, P. Comparative Performance of Global Semiconductor Companies. *Omega*, 1998, Vol. 26, pp. 153-175.

[Lee 95] LEE, H., KWAK, W. AND HAN, I. Developing Business Performance Evaluation System: An Analytic Hierarchical Model. *The Engineering Economist*, 1995, Vol. 40, No. 4, pp. 343-357.

[Leong 90] LEONG, G. K. , SNYDER, D. L. AND WARD, P. T. Research in the Process and Content of Manufacturing Strategy. *OMEGA*, 1990, Vol. 18, No. 2, pp. 109-122.

[Leng 97] LENG, D. M. *Global Manufacturing Capability of Machine Tool Industry*. M.Sc. Thesis, Sheffield Hallam University, 1997.

[Leong 90] LEONG, G. K., SNYDER, D. L. AND WARD, P. T. Research in the Process and Content of Manufacturing strategy, *OMEGA*, 1990, Vol. 18, No. 2, pp. 109-122.

[Leong 94] LEONG, G. K. AND WARD, P. T. The Six Ps of Manufacturing Strategy. *International Journal of Operations and Production Management*, 1994, Vol. 15, No. 12, pp. 32-45.

[Maskell 89] MASKELL, B. Performance Measurements for World Class Manufacturing. Articles 1-4, *Management Accounting*, May-September 1989.

[Materials 90] *Materials Handbook Vol. 1: Properties and Selection - Irons, Steels and High Performance Alloys*, Ohio: ASM International, 1990.

[Meffert 91] MEFFERT, H. AND BLOCH, B. Globalisation Strategies: Their Implementation. *Industrial Management and Data Systems*, 1991, Vol. 91, No. 5, pp. 3-9.

[Metal 98] Web posting, http://metal-finishing.com/classifieds/metal/messages/13537.htm (22.09.98)

[Minor 94] MINOR III, E. D., HENSLEY, R. L. AND WOOD Jr, D. R. A Review of Empirical Manufacturing Strategy Studies. *International Journal of Operations and Production Management*, 1994, Vol. 14, No. 1, pp. 5-25.

[MMI 96] MINISTRY OF METALLURGICAL INDUSTRIES, CHINA *Statistics on Chinese Iron and Steel Industry* (in Chinese). Beijing: MMI, 1996.

[Moffat 94] MOFFT, B. The Changing World of Steel. *Ironmaking and Steelmaking*, 1994, Vol. 21, No. 3, pp. 191-197.

[Mohanty 93] MOHANTY, R. P. AND VENKATARAMAN, S. Use of Analytic Hierarchy Process for Selecting Automated Manufacturing Systems. *International Journal of Operations and Production Management,* 1993, Vol. 15, No. 6, pp. 45-57.

[Narasimhan 83] NARASIMHAN, R. A Analytical Approach to Supplier Selection. *Journal of Purchasing and Materials Management*, 1983, pp. 27-32.

[Neely 94] NEELY, A., MILLS, J., PLATTS, K., GREGORY, M. AND RICHARDS, H. Realizing Strategy Through Measurement. *International Journal of Operations & Production Management*, 1994, Vol. 14, No. 3, pp. 140-152.

[Neely 95] NEELY, A., GREGORY, M. AND PLATTS, K. Performance Measurement System Design: A Literature Review and Research Agenda. *International Journal of Operations & Production Management*, 1995, Vol. 15, No. 4, pp. 80-116.

[Neely 96] NEELY, A., MILLS, J., PLATTS, K., GREGORY, M. AND RICHARDS, H. Performance Measurement System Design: Should Process Based Approaches be Adopted?. *International Journal of Production Economics*, 1996, Vol. 46-47, pp. 423-431.

[Noble 95] NOBLE, M. A. Manufacturing strategy: Testing the Cumulative Model in a Multiple Country Context. *Decision Sciences*, 1995, Vol. 26, No. 5, pp. 693-721.

[Noble 97] NOBLE, M. A. Manufacturing Competitive Priorities and Productivity: An Empirical Study. *International Journal of Operations and Production Management*, 1997, Vol. 17, No. 1, pp. 85-99.

[Noci 95] NOCI, G. Accounting and Non-accounting Measures of Quality-based Performances in Small Firms. *International Journal of Operations & Production Management*, 1995, Vol. 15, No. 7, pp. 78-105.

[Norman 91] NORMAN, M AND STOKER, B. Data Envelopment Analysis: The Assessment of Performance. New York: Wiley, 1991.

[Oliver 95] OLIVER, N., JONES, D. T., DELBRIDGE, R., LOWE, J., ROBERTS, P. AND THAYER, B. *World-wide Manufacturing Competitiveness Study : The Second Lean Enterprise Report*, London: Andersen Consulting, 1995.

[Partovi 90] PARTOVI, F. Y., BURTON, J. AND BANERJEE, A. Application of Analytical Hierarchy Process in Operations Management. *International Journal of Operations and Production Management,* 1990, Vol. 10, No. 3, pp. 5-19.

[Partovi 90] PARTOVI, F. Y., BURTON, J. AND BANERJEE, A. Application of Analytical Hierarchy Process in Operations Management. *International Journal of Operations and Production Management*, 1990, Vol. 10, No. 3, pp. 5-19.

[Partovi 94] PARTOVI, F. Y. Determining What to Benchmark: An Analytic Hierarchy Process Approach. . *International Journal of Operations and Production Management,* 1994, Vol. 14, No. 6, pp. 25-39.

[Pick 89] PICK, H. J. The Build-up of Value in Manufacturing and Construction and in the Industry. *Engineering Costs and Production Economics*, 1989, Vol. 16, pp. 49-68.

[Porter 86a] PORTER, M.E. *Competition in Global Industries*. Boston: Harvard Business School Press, 1986.

[Porter 86b] PORTER, M. E. Changing Patterns of International Competition. *California Management Review*, 1986, Vol. 28, No. 2, pp. 9-34.

[Rodrik 97] RODRIK, D. Has Globalisation Gone Too Far?. *California Management Review*, 1997, Vol. 39, No. 3, pp. 29-53.

[RSI 94] PLUMMER, C., ALCH, T. W. AND ADAMS, R. G. *Stainless Steel Flat Rolled Production Costs: A World Perspective*. Exton: Resource Strategies, Inc., 1994.

[Saaty 85] SAATY, T. L. Transport Planning with Multiple Criteria: The Analytic Hierarchy Process Applications and Progress Review. *Journal of Advanced Transportation*, Vol. 29, No. 1, pp. 81-126.

[Saaty 86] SAATY, T. L. Axiomatic Foundation of the Analytic Hierarchy Process. *Management Science*, 1986, Vol. 18, No. 32, No. 7, pp. 841-855.

[Saaty 87] SAATY, R. W. The Analytic Hierarchy Process - What It Is and How It Is Used. *Mathematical Modelling*, 1987, Vol. 9, No. 3-5, pp. 161-176.

[Saaty 88] SAATY, T. L. *The Analytic Hierarchy Proces*. New York: McGraw-Hill, 1988.

[Sarker 94] SARKER, B. R., KRISHNAMURTHY, S. AND KUTHETHUR, S. G. A Survey and Critical Review of Flexibility Measures in Manufacturing Systems. *Production Planning and Control*. Vol. 5, No. 6, pp. 512-523.

[Schemenner 94] SCHMENNER, R. W. AND VOLLMANN, T. E. Performance Measures: Gaps, False Alarms and the 'Usual Suspects'". *International Journal of Operations & Production Management*, 1994, Vol. 14, pp. 283 - 295.

[Schonberger 86] SCHONBERGER, R. J. *World Class Manufacturing*, New York: Free Press, 1986.

[Schully 93] SCHULLY, J. AND FAWCETT, S. E. Comparative Logistics and Production Costs for Global Manufacturing Strategy, *International Journal of Operations and Production Management,* 1993, Vol. 13, No. 12, pp. 62-78.

[Sheth 89] SHETH, J. AND ESHGHI, G. *Global Operations Perspectives*. Ohio: South-Western Publishing Co., 1989.

[Shi 94] SHI, Y. AND GREGORY, M.J. International Manufacturing Strategy: Structuring world-wide Manufacturing Network. *Working Paper 94(11)*. Cambridge University Manufacturing Engineering Group, 1994.

[Shi 98] SHI, Y. AND GREGORY, M. International Manufacturing Networks - To Develop Global Competitive Capabilities. *Journal of Operations Management*, 1998, Vol. 16, pp. 195-214.

[Skinner 69] SKINNER, W. Manufacturing - Missing Link in Corporate Strategy. *Harvard Business Review*, May - June 1969, pp. 136-145.

[Skinner 71] SKINNER, W. The Focused Factory. *Harvard Business Review*, 1971, May-June 1974, pp. 113-121.

[Swamidass 87] SWAMIDASS, P. M. AND NEWELL, W. T. Manufacturing Strategy, Environmental Uncertainty and Performance: A Path Analytic Model, *Management Science*, 1987, Vol. 33, No. 4, pp. 509-524.

[Swinden 80] SWINDEN, D. J. *The Arc Furnace: A Monograph*. London: Electricity Council, 1980.

[Tayles 94] TAYLES, M. AND DRURY, C. New Manufacturing Technologies and Management Accounting Systems: Some Perceptions of UK Management Accounting Practitioners. *International Journal of Production Economics*, 1994, Vol. 36, pp. 1-17.

[Tunc 92] TUNC, E. A. AND GUPTA, J. N. D. Is Time a Competitive Weapon Among Manufacturing Firms?. *International Journal of Operations and Production Management*, 1992, Vol. 13, No. 3, pp. 4-12.

[UK Steel 97] UK STEEL ASSOCIATION, *UK Steel Industry: A Success Story*, London: UK Steel Association, 1998.

[UNIDO 98] UNIDO Country Statistics: China, http://www.unido.org/services/statistics/statcountry42d.htm (14.09.98)

[Verter 92] VERTER, V. AND DINCER, M. C. An Integrated Evaluation of Facility Location, Capacity Acquisition, and Technology Selection for Designing Global Manufacturing Strategies. *European Journal of Operational Research*, 1992, Vol. 60, pp.1-18.

[Vokurka 96] VOKURKA, R. J. AND DAVIS, R. A. Improving Manufacturing Competitiveness: A Case Study. *Competitiveness Review*, 1996, Vol. 6, No. 1, pp. 68-77.

[Vos 91] VOS, G.C.J.M. A Production-allocation Approach for International Manufacturing Strategy. *International Journal of Operations and Production Management*, 1991, Vol. 11, No. 6, pp. 125-134.

[Voss 95] VOSS, C. A. Alternative Paradigms for Manufacturing Strategy. *International Journal of Operations and Production Management*, 1995, Vol. 15, No. 4, pp. 5-16.

[White 96] WHITE, G. P. A Meta-analysis Model of Manufacturing Capabilities, *Journal of Operations Management*, 1996, Vol. 14, pp. 315-331.

[Worldsteel 98] INTERNATIONAL IRON AND STEEL INSTITUTE *Toward the 21st Century*, http://www.worldsteel.org/economics2/consumption.htm (14.07.98).

[Zahedi 86] ZAHEDI, F. The Analytic Hierarchy Process - A Survey of the Method and its Applications. *Interfaces*, 1986, Vol. 16, No. 4, pp. 96-108.

[Zahra 93] ZAHRA, S. A. AND DAS, S. R., Building Competitive Advantage on Manufacturing Resources. *Long Range Planning*, 1993, Vol. 26, No. 2, pp. 90-100.

Software Manuals

- Expert Choice User Guide, Pittsburgh: Expert Choice, Inc.
- Microsoft Excel Visual Basic User's Guide, Seattle: Microsoft Corporation.
- CORNELL, G. AND STRAIN, T. *Visual Basic 4 Nuts and Bolts for Experienced Programmers*. California: McGraw-Hill, 1995.
- WELLS, E. *Developing Microsoft Excel Solutions*. Seattle: Microsoft Corporation, 1995.

List of Publications

1. Pushpakumara, C and E K Lo, Evaluation Models for Global Manufacturing, International Manufacturing Workshop, University of Cambridge, 23-24 September, 1996

2. Pushpakumara, C and E K Lo, Capability Evaluation in Global Steelmaking, 32nd International MATADOR Conference, University of Manchester Institute of Science and Technology, 10-11 July 1997.

3. Lo, E K, Z Dai and C Pushpakumara, Performance and Partnership in Global Manufacturing, 14th International Conference on Production Research, Osaka, Japan, 4-8 August 1997.

4. Lo, E K and Pushpakumara, C, Performance and Partnership in Global Manufacturing - Modelling Frameworks and Techniques, International Journal of Production Economics, Forthcoming.

Evaluation Models for Global Manufacturing

Research Questionnaire

Information collected from this questionnaire will be used for academic purposes only and will be held confidential.

Global Manufacturing Research Group
School of Engineering
Sheffield Hallam University
Sheffield S1 1WB
United Kingdom

August 1996

Part 1

Section A : Company Details

1. Name of the company : ....

2. Address : ....
   ....
   Tel : ....
   Fax: : ....

3. Main areas of business : ....

4. Issued share capital : ....

5. Total number of employees
   a. administrative : ....
   b. factory : ....

6. Steel production facilities available *(Please tick what is available)*

		annual capacity
a. Coking	☐	........................tonnes
b. Sintering	☐	........................tonnes
c. Blast furnace	☐	........................tonnes
d. Converter furnace	☐	........................tonnes
e. Electric Arc melting	☐	........................tonnes
f. hot rolling of flat products	☐	........................tonnes
g. cold rolling of flat products	☐	........................tonnes

7. What is the method of casting (please tick the method used)
   a. ingot casting ☐
   b. continuous casting ☐
   c. both ☐

8. What are the major scrap supply markets (Country and City, in the order of quantity supplied)

   a. ....
   b. ....
   c. ....

9. If steel for rolling is received from another plant(s) or supplier(s) please give locations (Country and city) in the order of the quantities received:

	hot rolling	cold rolling
a.	....	....
b.	....	....
c.	....	....

10. What are the major markets for finished rolled products

	hot rolled	cold rolled
a.	....	....
b.	....	....
c.	....	....

11. Percentage of times delivery schedules were met:
    - cast products : ....
    - hot rolled products : ....
    - cold rolled products: ....

12. How many new products were introduced in 1995 :
    - new hot rolled products ....
    - new cold rolled products ....

Section B : Plant details

1 Melting

1.1-1 Electric Arc Furnace

(a) Capacity of the furnace *(tonnes)* ....
(b) Scrap capacity (m^3) ....
(c) Tap-to-tap time *(mts)* ....
(d) Melting time (mts) ....
(e) Weight of an electrode *(kg)* ....
(f) Transformer power rating (KVA) ....
(g) Manufacturer of the furnace ....
(h) Year of installation ....

1.1-2 Converter Furnace

(a) Capacity of the furnace *(tonnes)* ....
(b) Hot metal capacity (tonnes) ....
(c) Scrap capacity (tonnes) ....
(d) Tap-to-tap time *(mts)* ....
(e) Oxygen blowing time (mts) ....
(f) Melting time (mts) ....
(g) Manufacturer of the furnace ....
(h) Year of installation ....

1.2 Casting

If continuous casting is not available please move onto Part 2.2

1.2.1 Continuous caster

(a) Number of casting machines ....
(b) Please give details of each machine:

No. of strands	strand size	casting speed*(m/min)*	average setup time (mts)
....	....	....	....
....	....	....	....
....	....	....	....

2 Hot rolling

If only slabs are used for rolling please move onto 2.2

2.1 Slabbing mill

(a) What is the rolling capacity of the mill (tonnes/hour) ....

(b) Number of stands ....

(c) High/stand (eg. 4 high, 6 high) ....

(d) What are the maximum dimensions of slabs that can be rolled:

width *(mm)*	....
thickness *(mm)*	....

(e) On average how many tonnes can be rolled in the total roll life :

backups *(tonnes)*	....
work rolls *(tonnes)*	....

(f) On average how long does it take to change rolls:

backups (mts)	....
work rolls *(mts)*	....

(g) Who are the main suppliers of rolls:

<u>Supplier</u>	<u>Country</u>	<u>types of rolls supplied</u>
1..	....	....
2.	....	....
3.	....	....

2.2 Reheating furnace

(a) Please give the details of slab reheating furnaces currently used:

	No.
Batch type	.....
Continuous type	.....

If batch type furnaces are available please give the following details:

	No.	Capacity(ies) (tonnes/hour)
Fuel fired furnaces	....	....
Electrical resistance furnaces	....	....
Induction furnaces	....	....
Dual fuel furnaces	....	....

If continuous type furnaces are available please give the following details:

	No.	Capacity(ies) (tonnes/hour)
Pusher furnaces	....	....
Rotating hearth furnaces	....	....
Walking beam furnaces	....	....
Walking hearth furnaces	....	....
Roller -hearth furnaces	....	....

2.3 Roughing Mill and Finishing mill

(a) What are the maximum dimensions of slabs that can be rolled:

width ....

thickness ....

(b) Number of stands in:

roughing mill ....

finishing mill ....

(c) High/stand (eg. 4 high, 6 high) in :

roughing mill ....

finishing mill ....

(d) What is the maximum exit speed *(in m/s)*

(e) On average how many tonnes can be rolled in the total roll life :

backups *(tonnes)* ....

roughing work rolls *(tonnes)* ....

finishing work rolls *(tonnes)* ....

(f) On average how long does it take to change rolls:

backups (mts) ....

work rolls *(mts)* ....

(g) Who are the main suppliers of rolls:

Supplier	Country	type of rolls supplied
1...	....	....
2.	....	....
3.	....	....

3 Cold rolling

(a) What is the maximum width possible (mm) ....

(b) Number of stands

(c) High/stand (eg. 4 high, 6 high) ....

(d) On average how many tonnes can be rolled in the total roll life :

backups *(tonnes)* ....

work rolls *(tonnes)* ....

(e) On average how long does it take to change rolls:

backups (mts) ....

work rolls *(mts)* ....

(f) Who are the main suppliers of rolls:

Supplier	Country	types of rolls supplied
1...	....	....
2.	....	....
3.	....	....

Section C : Manufacturing

Please give the following details relating to the year from 1st January to 31st December 1995:

1 Melting and casting

1.1-1 Electric Arc Furnace

(a) How many tonnes of liquid steel were melted (including rejects) ....
(b) What was the corresponding figure in the previous year ....
(c) How many tonnes of scrap were used ....
(d) What was the corresponding figure in the previous year ....
(e) How many tonnes of iron were used ....
(f) What was the corresponding figure in the previous year ....
(g) How many tonnes of scrap were rejected before melting due to poor quality ....
(h) How many tonnes of scrap were identified as of different composition to the specification ....
(i) How many tonnes of liquid steel were declared as complete misfits ....
(j) How many tonnes of liquid steel were declared as restricted misfits ....
(k) How many tonnes were completely rejected ....

(l) How many people were employed in the melting shop i.e. EAF and Ladles (including crane operators) ....
(m) What was the average tap - to - tap time achieved during the period ....

(n) How many units of electricity were consumed in the EAF *(in kwh)* ....

(o) What was the corresponding figure in the previous year ....

(p)Total tonnes of electrodes replaced during the year ....

(q) How many batches of scrap were received from suppliers during the period ....

(r) How many batches were received on schedule ....

(s) What is the average set-up time (min.) ....

1.1-2 Converter

(a) How many tonnes of liquid steel were melted (including rejects) ....
(b) What was the corresponding figure in the previous year ....
(c) How many tonnes of scrap were used ....
(d) What was the corresponding figure in the previous year ....
(e) How many tonnes of liquid iron were used in 1994 and 1995 ....
(f) How many tonnes of liquid steel were rejected due to poor scrap quality ....

(g) How many tonnes of liquid steel were declared as complete misfits ....

(h) How many tonnes of liquid steel were declared as restricted misfits ....

(i) How many people were employed in the melting shop (including crane operators) ....

(j) What was the volume of oxygen consumed in the converter in 1994 and 1995 *(in m^3)*

1994 ....

1995 ....

(k) Percentage time delivery schedules for liquid iron were met ....

(l) What is the average set-up time (min.) ....

1.2 Casting

If only ingot casting is available please skip 1.2.1 and move onto 1.2.2

1.2.1 Continuous Caster

(a) How many tonnes of liquid steel were transferred to be cast ....

(b) How many tonnes of semi finished products were cast (including defects):

slabs ....
billets ....
blooms ....
strip ....
others (please specify) ....

(c) How many tonnes were cast without any defects at the first time ....
(d) What is the amount made correct after reworking *(in tonnes)* ....
(e) Tonnes of steel left as scrap for remelting during the year ....

(f) Amount of electricity consumed in the continuous caster *(in kwh)* ....
(g) How many employees are attached to the section ....
(h) How many customer complaints were received during the year ....
Out of that,
number related to problems in melting ....
number related to problems in casting ....
number that cannot be directly attributable to any of the above ....
(i) Percentage times production schedules were met ....
(j) Average set-up time (min.) ....

1.2.2 Ingot casting

(a) How many tonnes of liquid steel were transferred to be cast in ingots ....
(b) How many tonnes of ingots were cast (including defects) ....
(c) How many tonnes were cast without any defects ....
(d)Tonnes of steel ingots sent back for remelting during the year (rejects) ....

(e) How many tonnes of ingots were rejected due to :

internal defects ....
surface defects ....

(f) How many employees are attached to the ingot casting section ....

(g) How many customer complaints were received during the year ....

Out of that,
number related to problems in melting ....
number related to problems in casting ....
number that cannot be directly attributable to any of the above ....

(h) Percentage times production schedules were met ....

2 Hot rolling

2.1 Reheating furnace

(a) Amount of energy used during the year

electricity *(kwh)* ....
gas *(m^3)* ....
liquid fuel *(l)(please specify)* ....
others *(please specify)* ....

(b) How many employees are attached to the reheating furnace section ....

If only slabs were used please skip 2.2 and goto 2.3

2.2 Slabbing mill

(a) How many tonnes of steel ingots were used for rolling during the year ....
(b) What was the corresponding figure in the previous year ....
(c) Out of that how many tonnes were rejected due to major defects before rolling ....
(d) How many tonnes were accepted with minor defects ....
(e) How many employees are attached to the slabbing mill ....
(f) What is the total output as good rolled products in the slabbing mill in 1995?. *(tonnes)* ....

(g) Out of the above, how many tonnes needed re-working before completion of rolling at the slabbing mill due to:

surface defects ....
internal defects ....
dimensional inaccuracies ....
other defects *(please specify)* ....

(h) What are the main causes of these defects? *(Please give ratings , 1 being the main cause for defects)*

problems in reheating process .... ☐
quality of rolls used .... ☐
unsatisfactory setting up of rolls .... ☐
others *(please specify)* :
.... ☐
.... ☐

(i) How many tonnes were completely rejected at the roughing mill and used for re-melting due to :

surface defects ....
internal defects ....
dimensional inaccuracies ....
other defects *(please specify)* ....

(j) What are the main causes of these defects? *(Please give ratings , 1 being the main cause for defects)*

problems in reheating process .... ☐
quality of rolls used .... ☐
unsatisfactory setting up of rolls .... ☐
others *(please specify)* :
.... ☐
.... ☐

(k) How many units of electricity were consumed in the slabbing mill *(in kwh)* ....

2.3 Roughing mill

(a) How many tonnes of steel slabs were used for rolling during the year ....
(b) What was the corresponding figure in the previous year ....
(c) Out of that how many tonnes were rejected due to major defects before rolling ....
(d) How many tonnes were accepted with minor defects ....

(e) What is the total output as good rolled products in the roughing mill in 1995 (after shearing)?. *(tonnes)* ....

(f) Out of the above, how many tonnes needed re-working before completion of rolling at the roughing mill due to:

surface defects ....
internal defects ....
dimensional inaccuracies ....
other defects *(please specify)* ....

(g) What were the main causes of these defects? *(Please give ratings , 1 being the main cause for defects)*

problems in reheating process .... ☐
quality of rolls used .... ☐
unsatisfactory setting up of rolls .... ☐
others *(please specify)* :
.... ☐
.... ☐

(h) How many tonnes were completely rejected at the roughing mill and used for re-melting due to :

surface defects ....
internal defects ....
dimensional inaccuracies ....
other defects *(please specify)* ....

(i) What were the main causes of these defects? *(Please give ratings , 1 being the main cause for defects)*

problems in reheating process .... ☐
quality of rolls used .... ☐
unsatisfactory setting up of rolls .... ☐
others *(please specify)* :
.... ☐

(j) How many units of electricity were consumed in the roughing mill *(in kwh)* ....
(k) How many employees are attached to the roughing mill ....
(l) Percentage of time production schedules were met ....

2.4 finishing mill

(a) How many tonnes of transfer bars were used for rolling during the year ....

(b) What was the corresponding figure in the previous year ....
(c) Out of that how many tonnes were rejected due to major defects before rolling ....
(d) How many tonnes were accepted with minor defects ....

(e) What is the total output as good rolled products in the finishing mill in 1995 (after shearing)?. *(tonnes)* ....

(f) Out of the above, how many tonnes needed re-working before completion of rolling at the finishing mill due to:

surface defects ....
internal defects ....
dimensional inaccuracies ....
other defects *(please specify)* ....

(g) What were the main causes of these defects? *(Please give ratings , 1 being the main cause for defects)*

problems in reheating process .... ☐
quality of rolls used .... ☐
unsatisfactory setting up of rolls .... ☐
others *(please specify)* :
.... ☐
.... ☐

(h) How many tonnes were completely rejected at the finishing mill and used for re-melting due to :

surface defects ....
internal defects ....
dimensional inaccuracies ....
other defects *(please specify)* ....

(i) What were the main causes of these defects? *(Please give ratings , 1 being the main cause for defects)*

problems in reheating process .... ☐
quality of rolls used .... ☐
unsatisfactory setting up of rolls .... ☐
others *(please specify)* :
.... ☐
.... ☐

(j) How many units of electricity were consumed in the finishing mill *(in kwh)* ....
(k) How many employees are attached to the finishing mill ....
(l) Percentage of time production schedules were met ....

3 Cold rolling

3.1 annealing and pickling

(a) How many tonnes of steel coil were received for cold rolling ....

(b) In how many batches were they received ....

(c) Out of that, how many batches were received on schedule ....

(d) Out of the total quantity of steel coil received, how many tonnes were detected as unsuitable for rolling and completely rejected ....

(e) How many tonnes were found to be with minor defects and used for rolling after reworking ....

(f) What is the capacity of the annealing and pickling line:

Annealing (tonnes/hour) ....
Pickling (tonnes/hour) ....

(g) How may litres of acid were used during the year :

Acid	litres
....	....
....	....

(h) How many units of electricity were consumed in the annealing and pickling line during the year *(kWh)* ....

(i) How many employees were attached to the annealing and pickling section ....

(j) What was the average steel yield loss during annealing and pickling ....

3.2 cold rolling

(a) How many tonnes of coil/plate were used for rolling during the year ....
(b) What was the corresponding figure in the previous year ....
(c) Out of that how many tonnes were rejected due to major defects before rolling ....
(d) How many tonnes were accepted with minor defects ....

(e) What is the total output as good rolled products in the mill in 1995 (after shearing)?. *(tonnes)* ....

(f) Out of the above, how many tonnes needed re-working before completion of rolling at the finishing mill due to:

surface defects ....
internal defects ....
dimensional inaccuracies ....
other defects *(please specify)* ....

(g) What were the main causes of these defects? *(Please give ratings , 1 being the main cause for defects)*

- problems in reheating process .... ☐
- quality of rolls used .... ☐
- unsatisfactory setting up of rolls .... ☐
- others *(please specify)* :
  - .... ☐
  - .... ☐

(h) How many tonnes were completely rejected at the mill and used for re-melting due to :

- surface defects ....
- internal defects ....
- dimensional inaccuracies ....
- other defects *(please specify)* ....

(i) What were the main causes of these defects? *(Please give ratings , 1 being the main cause for defects)*

- problems in reheating process .... ☐
- quality of rolls used .... ☐
- unsatisfactory setting up of rolls .... ☐
- others *(please specify)* :
  - .... ☐
  - .... ☐

(j) How many units of electricity were consumed in the cold rolling mill *(in kwh)* ....

(k) How many employees are attached to the finishing mill ....

(l) Percentage of time production schedules were met ....

4 Customising and warehousing

(a) How many tonnes of steel coil/sheet were received for slitting during the year ....

(b) What was the corresponding figure in the previous year ....

(c) How many tonnes of steel were left as scrap for remelting during the year ....

(d) How many employees are attached to this section ....

(e) How many tonnes of steel coil/sheet were issued to the warehouse/market as finished products ....

(f) What was the corresponding figure in the previous year ....

(g). Number of customer complaints received ....

Part 2

Please indicate the importance you place in the following factors with respect to the types of products you supply . (1= equally important, 3 = moderately more important, 5 = strongly more important, 7 = very strongly more important, 9 = extremely more important. Please note that intermediate levels also can be used to provide more accurate levels of discrimination).

1. Please complete the following section considering the products you are supplying or intending to supply to market *A*.

Note : **Cost** includes all manufacturing, transportation costs and taxes and duties etc.
Quality includes in-bound, in-process and final product quality.
Delivery considers delivery lead time as well as reliability.
Flexibility includes both product and volume flexibilities.

	1	2	3	4	5	6	7	8	9
(a). How important is ***cost*** compared to ***quality***?.	☐	☐	☐	☐	☐	☐	☐	☐	☐
(b). How important is ***cost*** compared to ***delivery***?.	☐	☐	☐	☐	☐	☐	☐	☐	☐
(c). How important is ***cost*** compared to ***flexibility***?	☐	☐	☐	☐	☐	☐	☐	☐	☐
(d). How important is ***quality*** compared to ***delivery***?.	☐	☐	☐	☐	☐	☐	☐	☐	☐
(e).How important is ***quality*** compared to ***flexibility***?	☐	☐	☐	☐	☐	☐	☐	☐	☐
(f). How important is ***delivery*** compared to ***flexibility***?	☐	☐	☐	☐	☐	☐	☐	☐	☐

2. With respect to overall quality,

(a). How important is ***in-bound quality*** compared to ***in-process quality***?.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

(b). How important is ***in-bound quality*** compared to ***out-bound quality***?.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

(c). How important is ***in-process quality*** compared to ***out-bound quality***?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

3. With respect to in-process quality,

How important is maintaining high product yield compared to making products correct first time?.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

4. With respect to delivery performance,

(a). How important is ***in-bound delivery performance*** compared to ***production lead time performance***?.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

(b). How important is ***in-bound delivery performance*** compared to ***out-bound delivery performance***?.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

(c). How important is ***production lead time performance*** compared to ***out-bound delivery performance***?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

5. With respect to out-bound delivery performance,

   How important is ***on time delivery reliability*** compared to ***delivery lead-time*** ?.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

6. With respect to flexibility,

   How important is ***product flexibility*** compared to ***volume flexibility*** ?.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

7. With respect to product flexibility,

   How important is ***the number of products in the range*** compared to ***the number of new products introduced in the year*** ?.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

MANUFACTURING CAPABILITY MODEL

User Guide

School of Engineering
Sheffield Hallam University

July 1998

Overview

This software facilitates the user to enter data related to different production routes and get the results in the form of performance measures and indices. User-friendly interfaces will guide the user through this process. Most of the front end facilities such as data entry and calculation of performance measures are based on Microsoft Excel 5. Expert Choice software performs the calculation of performance indices based on these measures. Our aim was to design an integrated software which binds together both packages as one unit. In other words, to transfer the data automatically from Excel to EC and then get the results from EC to Excel for customised display and analysis. Unfortunately, EC does not fully support this facility. This forced us to leave the user to interact with both packages simultaneously at certain stages. However, this guide will take the user through the whole process without much difficulty.

Organisation of Sections

Sections 1 and 2 deal with the data preparation and display in Excel 5 as input for the AHP model.

Section 3 describes the Expert Choice part of the software. It will explain how to create a model in Expert Choice, calculate performance indices and then export the results back to Excel.

Sections 4 and 5 deals with results display and analysis.

Please refer to the accompanying handbook for the complete software development methodology and structure.

1.0 Start-up

Click on the 'GMC model' icon in Windows Programme manager to start the programme. This will take you to the start-up screen (Fig.1).

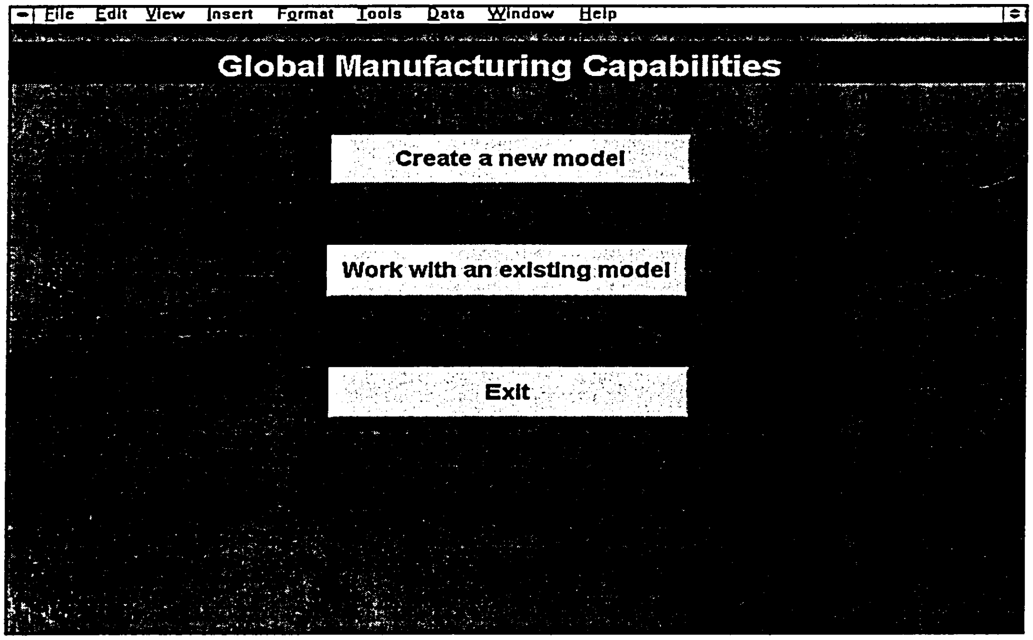


Fig. 1 : Opening screen

The start-up screen has three options.

- Create a new model
  To create a new model to evaluate a particular set of alternative production routes

- Work with an existing model
  To add to or edit an existing model

- Exit
  To exit from the programme

1.1 Creating A New Model

Steps:

1. Click on the "Create a new model" command button.
2. In the next window, type in a file name in which to store the model, and select the directory where you want to store it.
3. Enter the number of routes to compare in the next input box.
4. Enter the details of the routes in the subsequent windows.

Then you will be taken to the main menu which will be described in Section 2

1.2 Opening An Existing Model

Steps:

1. Click on the "Work with an existing model" command button.
2. In the next window, select the directory and the file name and press OK. Only the files with extension ".xls" will be listed.

Then you will be taken to the main menu which will be described in Section 2.

2.0 Using A Model

Once a model file is created, there are three operations to be carried out before obtaining results.

- Data entry
- Performance measures calculation
- Expert Choice model building

These have to be followed in that order to complete an analysis in case of working with a new model file. The control window (Fig. 2) that appears after creating or opening a model contains the commands for these operations.

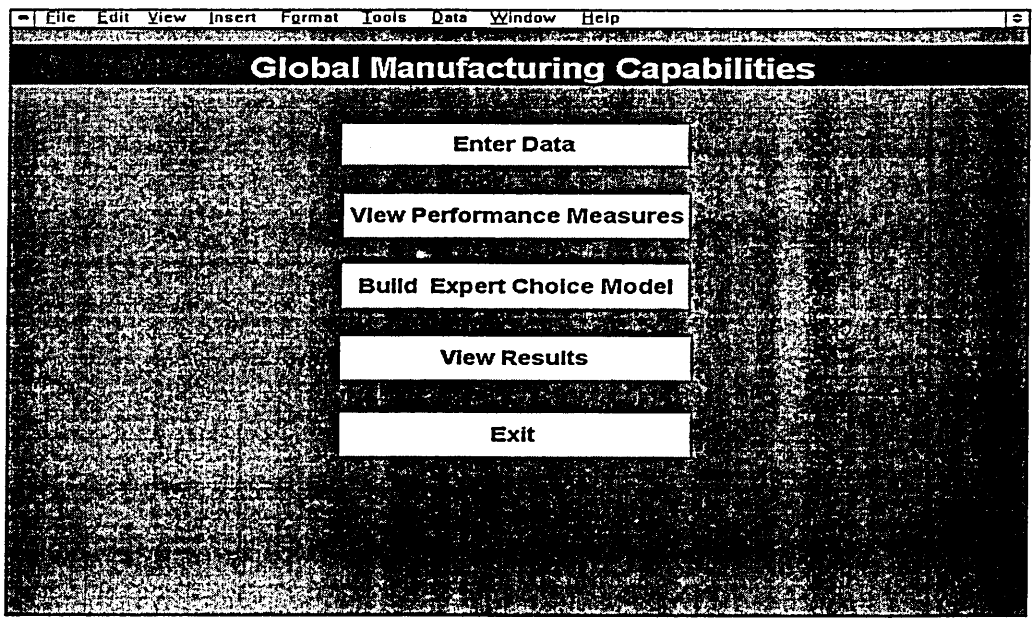


Fig. 2 : Control Screen

2.1 Data Entry

This option is used to enter the manufacturing data and plant and factor cost data collected through the questionnaire. Data entry is using the data forms, a built in facility in Excel 5.

Steps:

1. Click on the 'Enter Data' command button.

2. Select the process to enter data. It is important to start entering data from the first production process in the selected process route because some information from one process is automatically transferred to the next process in the value chain.
   In case of processes where alternative technologies are listed, select the appropriate technology.

Manufacturing data, and plant and factor cost data have to be entered separately.

This is because of the limitations in the built-in forms facility available in Excel 5. Only a limited number of fields can be accommodated for proper on-screen display. These forms can be customised to suit user needs in later versions of Excel.

3. In the data from that appears next, enter the data related to the route number displayed in the first field ('Route Number'). Press 'Next' command button once all the data for a particular route has been entered. Continue this step until data for all the routes have been entered and press 'Close' command button to close the data form.

4. Repeat the steps 2 and 3 to enter data related to other processes. If you comparing only a particular process, not the whole production route, go to step 5 instead.

5. Press 'Back to control' command button to return to the control screen.

2.2 Performance Measures Display

This allows the user to view the performance measures related to a particular manufacturing process step. These are calculated based on the manufacturing data and plant and factor cost data entered earlier. The performance measures displayed here serve as input data for the Expert Choice model.

Three display options are available.

1. To compare the whole route.
   - displays the performance measures at the final stage of the process.

2. To compare plants at a particular stage of production as a part of the value chain.
   - displays the performance measures at a selected stage of production taking into consideration the preceding stages of the process also.

3. To compare plants at a particular stage of production as stand alone units.
   - displays the performance measures at a selected stage of production without considering the preceding stages of the process.

- **To compare the whole route.**

Steps:

1. Click on the 'View Performance Measures' command button.

2. From the window that appears next, select the option 'Compare the whole route'.

3. You will get the results as shown in Figure 3. The options available to you next will be discussed in Section 3.

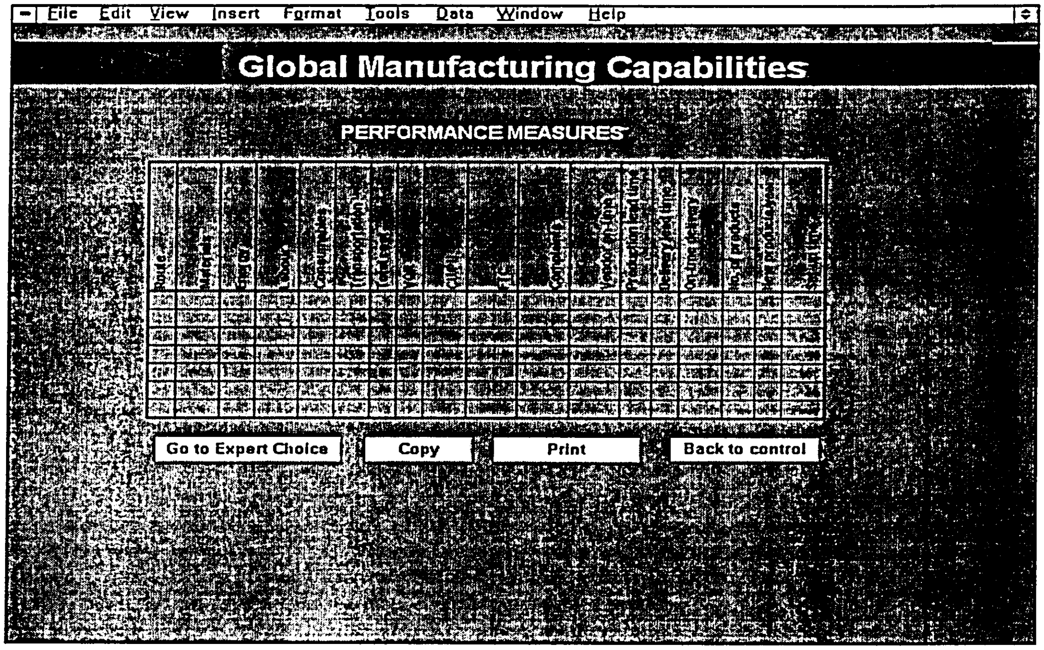


Fig. 3 : Performance Measures Display

- **To compare plants at a particular stage of production as a part of the value chain**

Steps:

1. Click on the 'View Performance Measures' command button.

2. From the window that appears next, select the option 'Compare plants as a part of the whole value chain'.

3. Select the process you want to compare from the next window.

4. You will get the results as shown in Figure 3. The options available to you next will be discussed in Section 3.

- **To compare plants at a particular stage of production as stand alone units.**

Steps 1 -3 are same as above expect for step 2 where you have to select the option 'Compare plants as stand alone units'. Enter the unit raw materials cost when prompted.

The performance measures displayed here are the inputs to the EC model. Section 3 will discuss the methods available for the user to transfer these data to the EC model.

3.0 The Expert Choice Model

This can be considered as the core of this software because it is the Expert Choice that performs the calculation of performance indices based on the Analytic Hierarchy Process. Expert Choice, developed by the Expert Choice Inc., is a full pledged decision package on its own. Users can easily build their own models using EC with the help of the well compiled user guide accompanying the package.

To simplify this further, we have included a model library for different scenarios that can arise under the Manufacturing Capabilities Model. This contains models with the same criteria in the hierarchy, but with different number of alternative routes. For example, MODEL2.EC1 can be used for comparing two routes, MODEL3.EC1 for three routes and so on.

The sections to follow will provide a complete step-by-step guide for this task.

3.1 To Activate Expert Choice

Click 'EC Model' command button either from the control screen or the performance measures display screen. This will take you to the EC package. Here also the user can either create a new file or work with an existing model. New files are created using the model library provided. For example, MODEL2.EC1 contains the template for comparison of two routes and MODEL3.EC1 for three routes etc.

It is necessary to create a separate model for each stage of production of which you wish to compare the performance.

3.2 Creating/Opening Expert Choice Models

- **Creating A New Model**

Steps :

1. From the main menu, select File and then New.

2. Type in a file name in which to store the new model . The extension '.EC1' is added automatically.
3. From the next dialogue box , select 'From the model library'.

4. Select the appropriate model template from the list. (e.g. MODEL2.EC1 for two routes, MODEL3.EC1 for three routes etc.). Now the new model file is ready for data input.

- **Opening An Existing File**

1. From the main menu, select File and then Open.

2. Select the directory and then the file name and click OK to open the file.

You can view the structure of the model sideways by selecting from the man menu, Utilities, then View Model Sideways and then From Node. Click 'Exit' to return to the main menu.

The initial screen once a model is created or opened would appear as shown in Figure 4.

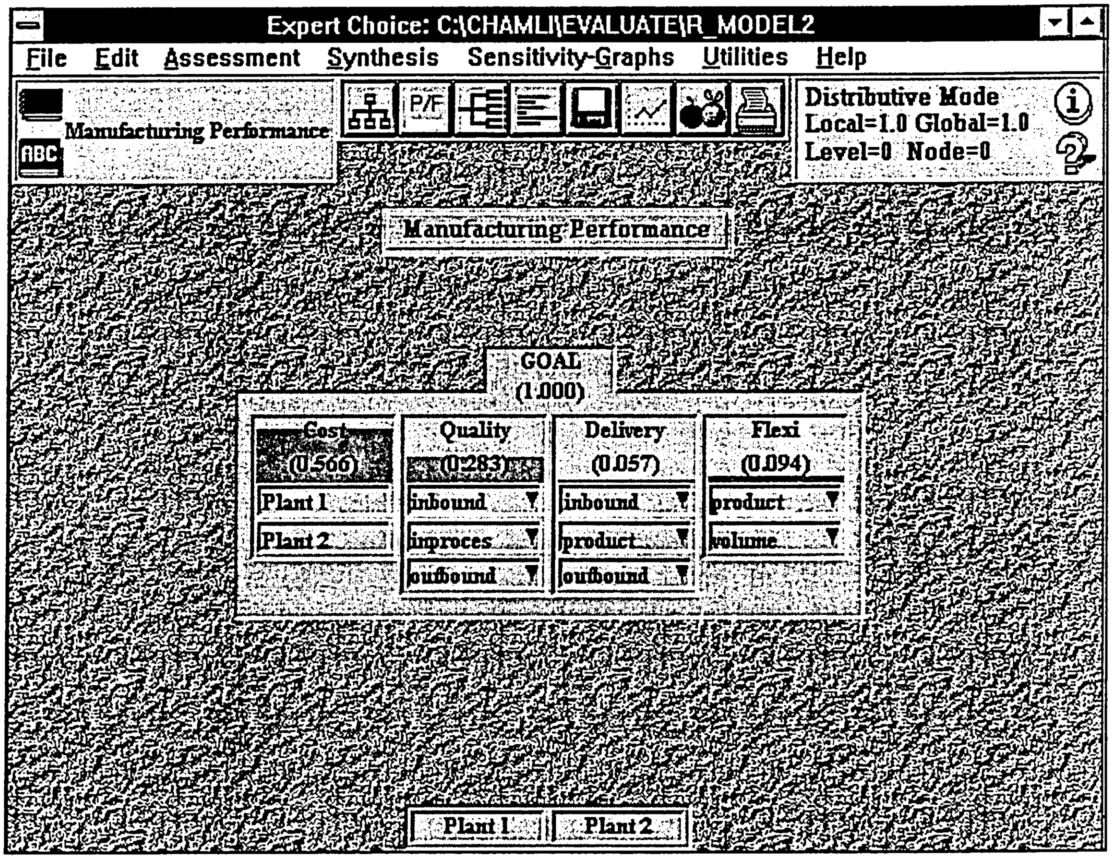


Figure 4 : Initial screen of a model file

3.3 Data input and assessment

If we refer back to the structure of the MC model, the manufacturing performance is analysed under four broad categories, viz. cost, quality, delivery and flexibility. in AHP, we call them criteria. There are several levels of sub-criteria under this. The production routes we compare are the alternatives.

The next step in developing the EC model is to prioritise the criteria. That is to ascertain the importance of each criteria relative to the others. Information for this is collected through Part Two of the questionnaire.

- **Prioritisation of Criteria**

The pairwise comparison facility provided in EC is used in the prioritisation. Three alternative ways are available in EC for this purpose : verbal, graphical and numerical.. It should be noted that selection of any option does not affect the final outcome. Therefore, the user is free to decide on the option he/she prefers. However, to preserve the objectivity of the analysis, we have selected the numerical option. Under this option there are two data entry formats : matrix and questionnaire. Part Two of the questionnaire is designed to provide data for this purpose. Once again, users with a greater knowledge about the relative importance of the criteria can select his/her own method for data entry. The questionnaire we have developed enables anyone to enter data collected through it.

Steps :

1. From the main menu, select Assessment, and then Pairwise.

2. If you are entering the data into this model for the first time, follow all the following steps. If you are editing the data already entered, skip step 3.

3. Select Importance as Type and Numerical as Mode from the dialogue sheet and then click OK .

4. From the next screen, select Questionnaire from the command buttons below the menu.

5. The next screen (Fig. 5) presents each of the pairwise relationships in a series of rows with the default judgement highlighted. Select the appropriate judgement by clicking on the relevant number as marked in the questionnaire.

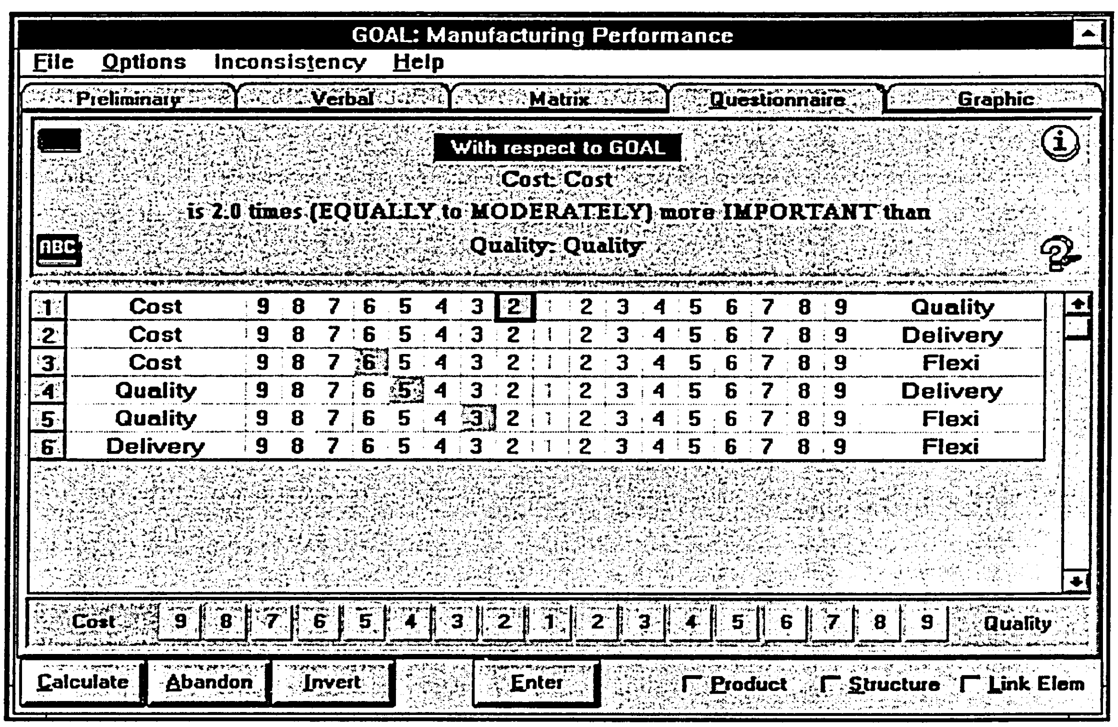


Fig. 5 : Prioritisation

6. Once all the judgements are entered Press Calculate.

7. The next screen that would appear (Fig. 6) will contain the normalised figures for that particular set of data. Press 'Record' command button to store these figures.

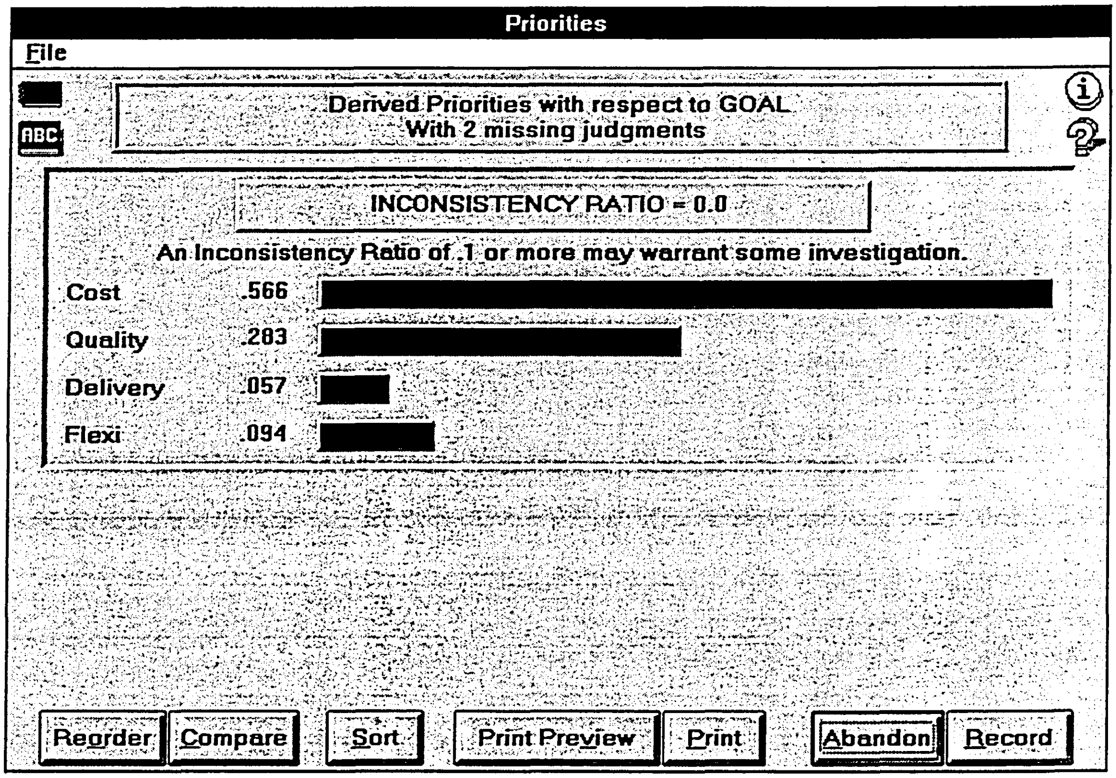


Fig. 6 : Prioritisation Results

The consistency of the judgements entered are measured by a factor called the Consistency Ratio (CR) (Please refer to the handbook for more details about CR). For consistent judgements the Consistency Ratio should be below 0.1 . The <u>relative importance of the factors have to be reconsidered in the event of CR > 0.1 .</u>

When the priorities for key categories are calculated it is necessary to repeat the task for sub-categories.

Steps:

1. Go back to the initial screen (Fig. 4).

2. Double Click on the main criteria under which you have the required sub-criteria. Select the node that holds the relevant sub-criteria by double clicking on it.

3. Select Assessment and then Pairwise.

4. Repeat the procedure as for the main criteria.

Repeat this procedure for all the other sub-criteria as well.

The steps discussed so far complete the prioritisation of criteria and sub-criteria of the model. The next step is to analyse the manufacturing performance of alternative routes under each of these criteria. Manufacturing performance measures calculated earlier (as discussed in Section 2.2) serve as inputs here. To make meaningful comparisons it is necessary to convert them to ratios that do not contain measurement units. This process is called normalisation.

- **Normalisation of Performance Measures**

Steps:

1. Select the node you want to enter data into.

2. From the main menu, select Assessment and the Data.

3. The data entry screen will appear (Fig. 7). The commands available under this is discussed later in this chapter.

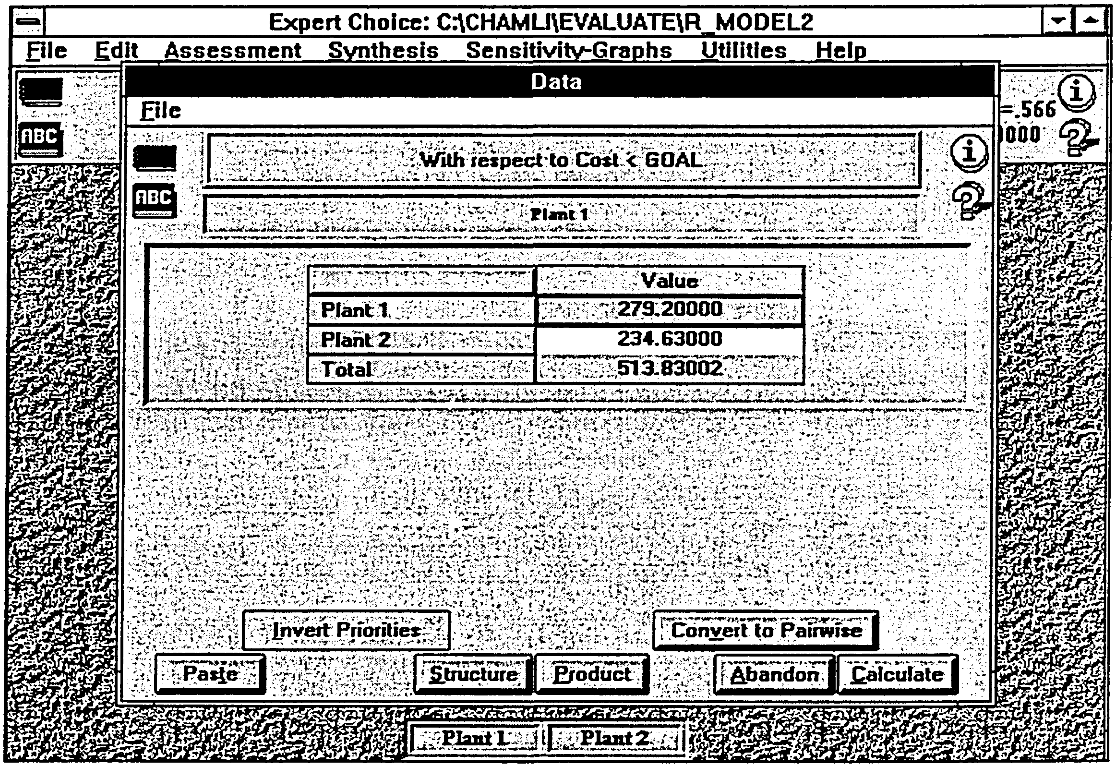


Fig. 7 : Normalisation

4. Two methods of data entry are available : typing in at the appropriate place and importing via the Windows clip board.

Unfortunately EC does not have the facility to import directly from the source. Hence this tedious way of copying to the clipboard and then pasting it to the EC model. This involves moving between the two packages using the < Alt > < Tab > keys on the key board.

- **To enter data by typing in:**

(a). Using <Alt> <Tab> keys, change to the Excel window.

(b). If you are already in the performance measures display screen, print the page using the 'Print' command button. If you are in the command screen, go to the performance measures display following the steps described in Section 2.2. Print the page.

(c). Move back to the EC window using <Alt> <Tab> keys again. Enter the figures against each alternative route.

- **To enter data via the clipboard:**

(a). Using <Alt> <Tab> keys, change to the Excel window.

(b). If you are already in the performance measures display screen, block the cells where the data related to that particular node are held, and copy them to the clipboard using the 'Copy' command button available on the screen. If you are in the command screen, go to the performance measures display following the steps described in Section 2.2 and copy the data as described above.

(c). Move back to the EC window using <Alt> <Tab> keys again. Locate the cursor at the point where you want to start pasting the data and click on the 'Paste' button.

5. **Important : In case of data where a higher value is less desirable than a lower value, priorities should be inverted. The best example for this is a parameter such as cost: the higher the cost the less desirable it is. Press the 'Invert' command button for such data after entering such data.**

   The parameters that should be inverted in this model are : Cost, Customer complaints, Delivery lead time, Production lead time and Set-up time.

6. Click on 'Calculate' to convert the data into priorities.

7. The next screen that would appear will contain the normalised figures for that particular set of data. Press 'Record' command button to store these figures.

8. Repeat these steps until you have entered all the data.

4. Obtaining Results

To analyse the results according to our requirements, the output is exported to Excel. However, the sensitivity analysis is carried out in EC itself making use of its built in facilities.

4.1 Exporting The Results To Excel:

Once the indices are calculated the results can be exported to Excel for display under several options.

Steps:

1. From the main menu of EC, select Utilities and then Export model(s) to Spreadsheet.

2. Type in a name for the output file. The extension for this file would be ".wks.".

3. From the next window, select the file name of your current EC model (of which you are going to export the results).

Important : Select only the name of the file you want to export.

4. Press 'Export' command button.

5. Press 'Exit' when finished.

4.2 Results Display

Results can be displayed under three options:

1. Summary results

   This will display the overall results for the alternative routes or plants compared.

2. Results under competitive priorities.

   This will display the results for the alternative routes or plants compared under the major criteria : Cost, Quality, Delivery and Flexibility.

3. Detailed results

   The detailed display of results under all the criteria and sub-criteria.

Steps:

1. From the control sheet, select the 'View Results' command button.

2. Select the name of the ' *.wks' file that holds the results exported from EC.

3. Select the display option from the next dialogue box.

4. The results would be displayed on the next screen (Fig. 8). Press 'Print' to print the output or 'Back to Control' to return to the control screen.