MODELLING, ANALYSIS AND DESIGN OF COMPUTER INTEGRATED MANUFACTURING SYSTEMS

Volume I of II

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October-1998

A thesis submitted for the
DEGREE OF DOCTOR OF PHILOSOPHY
MECHANICAL ENGINEERING DEPARTMENT, THE UNIVERSITY OF SHEFFIELD

بسم الله الرحمن الرحيم

In the Name of Allah, Most Gracious, Most Merciful.

ACKNOWLEDGEMENTS

I would like to express my appreciation and thanks to my supervisor Professor Keith Ridgway for devoting freely of his time to read, discuss, and guide this research, and for his assistance in selecting the research topic, obtaining special reference materials, and contacting industrial collaborations. His advice has been much appreciated and I am very grateful.

I would like to thank Mr Bruce Lake at Brook Hansen Motors who has patiently answered my questions during the case study.

Finally, I would like to thank my family for their constant understanding, support and patience.

To my parents, my wife and my son.

ABSTRACT

In the present climate of global competition, manufacturing organisations consider and seek strategies, means and tools to assist them to stay competitive. Computer Integrated Manufacturing (CIM) offers a number of potential opportunities for improving manufacturing systems. However, a number of researchers have reported the difficulties which arise during the analysis, design and implementation of CIM due to a lack of effective modelling methodologies and techniques and the complexity of the systems.

The work reported in this thesis is related to the development of an integrated modelling method to support the analysis and design of advanced manufacturing systems.

A survey of various modelling methods and techniques is carried out. The methods SSADM, IDEF0, IDEF1X, IDEF3, IDEF4, OOM, SADT, GRAI, PN, IOA, MERISE, GIM and SIMULATION are reviewed. The majorities of these contain graphical components and therefore, fulfil basic modelling requirements. In addition, these methods represent a comprehensive sample of manufacturing systems modelling methods. A manufacturing system comprises different sub-systems including physical, information and decisions sub-systems. These sub-systems can be modelled using a combination of the methods described i.e. GRAI for decision systems, IDEF0 for physical systems, simulation for dynamic aspects, etc.

A novel framework for comparing the modelling methods selected is developed using a number of factors derived from CIM and modelling requirements. The study discovered that no single modelling method or technique could model all the different aspects of a manufacturing system or achieve integration between system domains at both static and dynamic levels. As a result, it was concluded that there was a need for an integrated modelling method for the analysis and design of complex manufacturing systems.

To overcome these problems, a novel integrated modelling method called GI-SIM has been developed. The method is composed of four modelling components GRAI grid, IDEF0, IDEF1X and SIMAN/ARENA. GI-SIM integrates these four tools to form a complete method, which combines the advantages of existing modelling methods and eliminates their shortcomings.

The method developed is evaluated using a case study carried out in a UK company manufacturing electric motors. It is also tested for the design and specification of CIM system components (CAD, CAPP, CAM, etc.). The case studies demonstrate that GI-SIM achieves two important types of modelling integration; the first is a vertical integration between different levels of abstraction (conceptual, structural and dynamic) and the second is a horizontal integration between five modelling domains (decision, functional, information, physical and dynamic). In addition, the method is easy to learn and use, and sufficiently flexible to model any system function according to its related objectives.

The findings of this research and recommendation for future research are presented in the final chapter.

RESEARCH PAPERS

The following papers have been published as a direct result of this research:

International Journals:

Al-Ahmari A.M.A. and Ridgway K. (1998) "An Integrated Modelling Method to Support Manufacturing Systems Analysis and Design" Accepted for publication in Computers in Industry.

Refereed International Conferences:

Al-Ahmari A.M.A. and Ridgway K. (1997) "Computerised Methodologies for Modelling Computer Integrated Manufacturing Systems" Proceedings of the 32nd International MATADOR Conference, Manchester, pp 111-116.

Al-Ahmari A.M.A. and Ridgway K. (1998) "Modelling of Manufacturing Systems for SMEs" Proceedings of the 1st International SMESME Conference, Sheffield, pp 29-33.

Al-Ahmari A.M.A. and Ridgway K. (1998) "The Development of an Integrated Modelling Method for Manufacturing Systems Analysis and Design" 3rd International Conference - Managing Innovative Manufacturing (MIM '98), University of Nottingham.

Conferences and seminars:

Al-Ahmari A.M.A. (1998)"GI-SIM Modelling Method" 5th International AUGRAI Workshop, University of Strathclyde, August 24th-25th.

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INTRODUCTION

1.1. Background Of The Research

Industrial organisations must respond to their rapidly changing marketplace and to the new technologies being implemented by their competitors (Bray 1988). Manufacturing change can be an effective competitive weapon if it is well planned and supported by powerful modelling methods and technologies. Many factors such as reduced lead time, greater flexibility, improved communications and co-ordination with suppliers, increased productivity, improved design and greater manufacturing control. can make industrial organisations far more competitive in the future. Various authors and practitioners have suggested that Computer Integrated Manufacturing (CIM) will improve manufacturing, making it faster and more competitive (Bray 1988, Guetari and Nguyen 1997, Pleinevaux 1997, Vail 1988, Nicholson 1991, Weatherall 1992).

CIM has become a very important manufacturing strategy because of the enterprise-wide integration it supports. Rembold et al (1993) suggested that the manufacturing systems of the future would need to be flexible and programmable. Most manufacturing companies do not know how to design and implement CIM (Scoggins 1986) and it would be a disaster if they developed incorrect specifications for their advanced manufacturing technologies. CIM projects must be supported by effective modelling methods and techniques to assist the organisations to adopt and implement systems specifications which correspond to their needs (Doumeingts et al. 1995a). Rembold et al (1993) stated that "manufacturing systems of the last decade of this century and the first decade of the next century will be test-beds of the Computer Integrated Manufacturing (CIM) concepts of the future".

From the above it is clear that the effective modelling, analysis and design of CIM is a key issue.

1.2. The Need For Modelling Methods

The previous section indicates that there is a need for new manufacturing systems that can achieve the business and manufacturing objectives of industrial organisations, and that CIM is a strategy that can achieve these objectives.

Brandimarte and Cantamessa (1995) reported that the need for a modelling method is particularly relevant with complex manufacturing systems such as CIM. They also indicated that many different modelling methods and techniques are being used, but nearly always within a specific cultural area and applied to a limited set of CIM problems. It has been found that the conception and design of modelling methodologies and techniques is one of the major challenges in analysing and designing CIM systems. Doumeingts et al. (1995b) concluded that the only way to design an adequate CIM system was to use a modelling method which involves and mobilises all the people concerned, and took into account decisions, functions, information and resources, as well as other factors such as economic and social aspects.

The limitations of current CIM modelling methods have been addressed by various researchers. Aguiar and Weston (1995) concluded that there has no single modelling method which provided a complete support for decisions along the integration manufacturing enterprise life cycle. They identified a number of gaps, such as the lack of a good formalism which must be filled.

Brandimarte and Cantamessa (1995) reported that current modelling methods do not pay sufficient attention to important aspects of CIM that need deep integration of many components and elements. Chadha et al (1991) also mentioned that existing modelling tools do not satisfy all the requirements of complex manufacturing systems.

Many authors have agreed on the need for an integrated modelling method for the analysis and design of manufacturing systems. Pandya (1995) suggested that a combination of tools could be used to model a complete system environment because there was no modelling tool which could be used to give proper results. Colquhoun et al (1993) found that interfaces and integration between existing modelling methods such as IDEF0 and dynamic modelling had not received sufficient attention.

It is clear that there is a need for an integrated method to support the analysis and design of CIM systems. An integrated modelling method can be created by selecting, developing and integrating existing modelling methods and techniques to support CIM (Aguiar and Weston 1995).

As a result of complex CIM requirements and the limitations of current modelling methods and techniques, a need has been identified for new modelling approaches which combine the advantages of existing methods and eliminate their shortcomings.

1.3. Aims And Objectives Of The Research

This research aims to develop a novel integrated modelling method to support the analysis and design of CIM systems. This integrated method is configured using existing methods and techniques to meet the modelling needs of CIM systems. Components of the modelling method developed use a number of factors identified from a review of CIM analysis and design requirements, and an evaluation of existing static and dynamic modelling methods and techniques.

The research develops uses a novel integration of modelling domains, according to levels of abstraction using a combination of static and dynamic modelling approaches. This is necessary to capture the different characteristics of manufacturing systems. The integrated method provides the main modelling concept as a formal method for conceptual, structural and analytical modelling. Figure 1.1 illustrates the main concept of the modelling method presented.

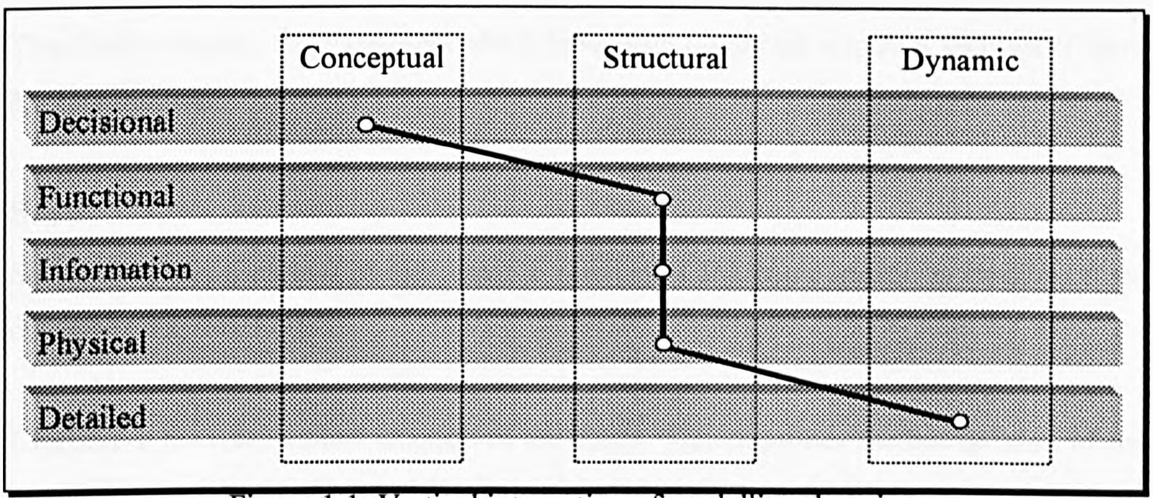


Figure 1.1. Vertical integration of modelling domains.

This modelling concept will facilitate modelling procedures based upon user requirements, related to different sub-systems, and the integration between selected tools which serve different levels of abstraction.

To achieve the aims of the research, the following objectives were identified:

- Review basic manufacturing systems and identify basic system types investigating the needs of manufacturing organisations and the relevance of CIM.
- Review and evaluate existing modelling methods and techniques for the analysis and design of CIM systems.
- Develop a novel integrated modelling method capable of analysing and designing CIM systems.
- Develop a novel computerised tool to support aspects of the modelling method developed.
- Evaluate and validate the modelling method developed for the analysis of manufacturing systems in a case study company.
- Evaluate and validate the modelling method developed for the design of CIM system specifications.
- Contribute to the research literature on advanced manufacturing systems analysis and design.

1.4. Thesis Structure

This thesis contains eight chapters which have been organised into four sections (Figure 1.2), as follows:

Section-1

Section-1 gives a review of the research area and CIM components. It involves three chapters (chapters 1-3):

Chapter-1 provides an introduction to the thesis. This describes the background of the research undertaken and identifies the need for an integrated modelling method for CIM systems analysis and design. This chapter also describes the organisation of the thesis.

Chapter-2 briefly reviews the basic concept of manufacturing systems and existing classifications of manufacturing systems are reviewed. The needs of manufacturing organisations are discussed and the introduction of CIM as a new manufacturing strategy is reviewed. This chapter establishes three important points for the research:

- Current manufacturing systems are moving towards batch production;
- Changes in manufacturing industries are inevitable and strategies to support these changes should be developed;
- CIM is one option which can be used to meet the challenges of manufacturing systems.

This Chapter also reviews CIM and its components. The objective of this review is to consolidate the background to CIM, its definitions, benefits and the concept of integration between different system components. Computer-Aided Design (CAD), Computer-Aided Process Planning (CAPP), Computer-Aided Manufacturing (CAM), Production Planning and Control (PPC) and their related themes are described. The role of these sub-systems in the CIM environment is also presented in this chapter. In general, this chapter answers several important questions. These questions are:

- What is CIM?
- Why should CIM be implemented?
- What are child-strategies of CIM strategy?
- How can the concept of integration be understood?

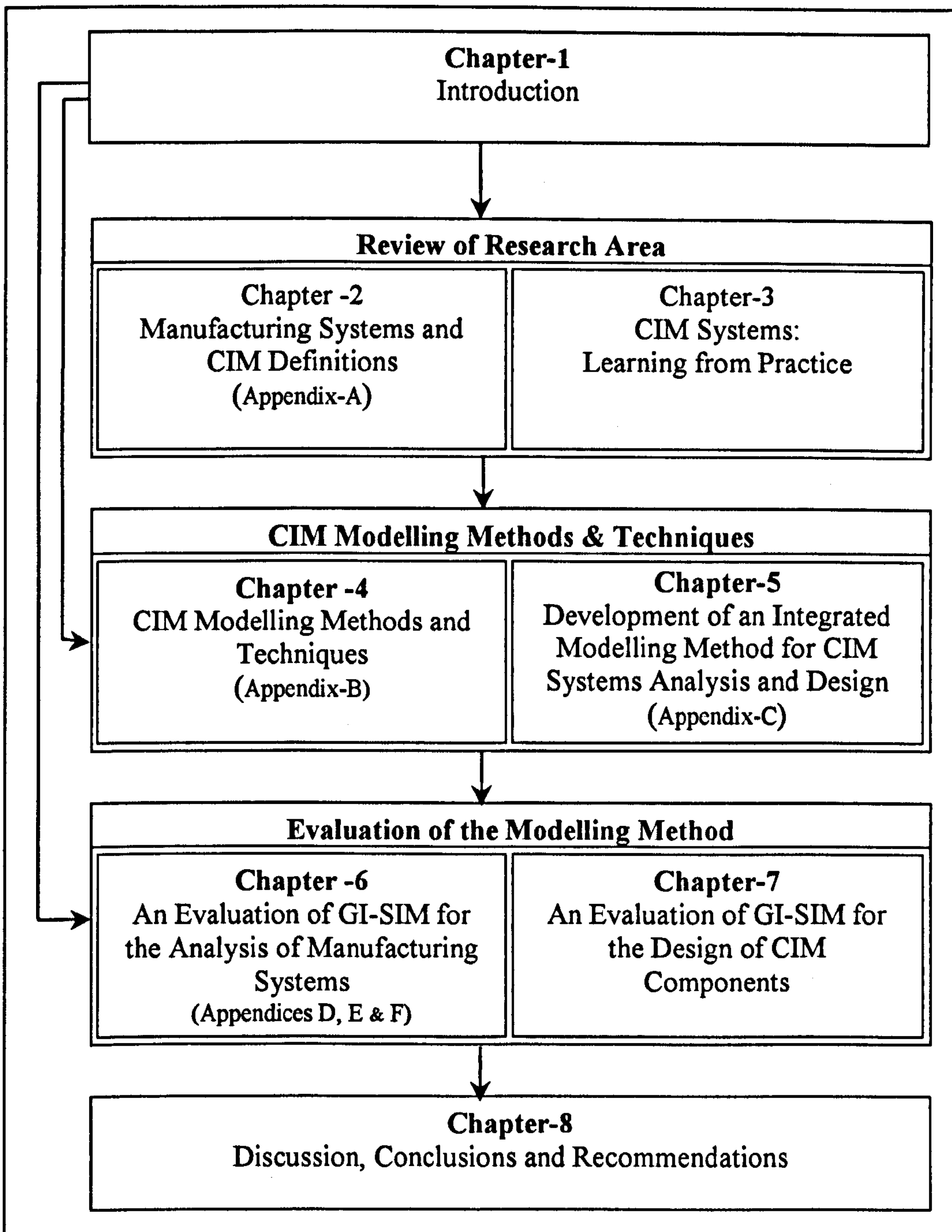


Figure 1.2. Thesis Structure.

Chapter-3 presents a detailed survey of manufacturers who have adopted CIM systems. The objective of this survey is to study the success and failure of CIM and to identify the barriers to success. The main aims of this chapter are to:

- Review past experience of implementation;
- Identify the reasons for the success and failure of CIM;
- Identify the main obstacles to CIM success.

Section-2

Section -2 comprises two Chapters 4 and 5:

Chapter-4 presents a detailed survey of existing conceptual modelling methods and techniques, and simulation tools. It defines the modelling concept, classification and the reason for modelling. A variety of modelling methods and techniques are reviewed including SSADM, IDEF0, IDEF1X, IDEF3, IDEF4, OOM, SADT, GRAI, PN, IOA, MERISE and GIM. A number of comparison and evaluation issues related to modelling methods are reviewed. Dynamic modelling of manufacturing systems i.e. simulation modelling is also reviewed. The chapter illustrates the importance of simulation in analysing and designing different aspects of manufacturing systems, discussing various steps of the process of simulation and the attributes of different simulation languages. A number of manufacturing simulators are discussed, including SIMAN/ARENA, SIMFACTORY, SLAM II, PC Model and ProModel. This chapter also discusses the selection of simulation tools and the role of simulation in CIM system design. Finally, a framework for comparing the CIM modelling methods and techniques is developed using selected factors related to manufacturing systems and modelling requirements.

Chapter-5 describes the development of a novel integrated modelling method (GI-SIM). It argues the need for a new modelling method and discusses the components selected for inclusion in the method developed. Modelling procedures and the formulation of different method factors are also described. Finally, this chapter gives details of a novel computerised tool developed to support the modelling method developed.

Section-3

Section-3 comprises two chapters 6 and 7:

Chapter-6 describes a case study application of the new modelling method using information collected during industrial visits. The objective of this chapter it to give a background to the case study company and the different manufacturing activities currently operating. It aims to collate basic details for the analysis and design phases.

GI-SIM was applied for the analysis of operational manufacturing systems. It combines the static and dynamic concepts of modelling to consider the systems used in the company selected. The objectives of this chapter are to:

- Identify and analyse problems in the existing manufacturing systems of the company.
- Evaluate and validate the use of the GI-SIM method for the analysis of manufacturing systems.

Chapter-7 describes the design of CIM components using the GI-SIM modelling method. A set of operational functions of CIM systems are selected for consideration in this chapter. These functions are 'To Design', 'To Plan', and 'To Make'. which are supported by four different components of CIM: CAD, CAPP, PP&C and CAM. The main objectives of this chapter are to:

- Establish design specifications for CIM system components in the company selected.
- Evaluate and validate the use of the GI-SIM method for the design of CIM systems.

Section-4

This section comprises Chapter-8 which contains a discussion and outlines evaluation of the modelling method adopted. The thesis presents the link between case where static and dynamic modelling techniques have been integrated to produce a comprehensive method for analysing and designing manufacturing systems. The thesis ends with conclusion and recommendations for future work.

CHAPTER-2

MANUFACTURING SYSTEMS AND CIM DEFINITION

2.1. Introduction

This chapter discusses the basics of manufacturing systems. It presents the main terms related to manufacturing systems including system and manufacturing definitions. Several classifications of manufacturing systems are reviewed in this chapter. The chapter also includes a description of current trends in industrial change and identifies the need for new strategies which can assist manufacturing industry to survive in this competitive era. Computer Integrated Manufacturing (CIM) is suggested as a global strategy for manufacturing enterprises. The reasons supporting the selection of this strategy are discussed and CIM definitions and its main benefits are presented.

2.2. System Definition

Before describing manufacturing systems, it is necessary to consider the meaning of the word 'system'. This term is widely used but as yet there is no generally agreed definition. The word 'system' is used in many disciplines and areas of research (McMillan and Gonzalez 1973). This term (system) appeared in 1619, meaning 'organised whole' (Hitomi 1994). Hitomi (1996) suggested that a system could be characterised by four attributes:

1. Assemblage. A system involves a group of distinguishable units.

2. Relationships. A system group should have relationships between these units.
3. Goal seeking. A system should perform determined functions or aim at a number of objectives.
4. Adaptability to environment. A system should adapt to its surroundings or external environments.

Beishon and Peter (1976) suggested that a major cause of difficulty in understanding the term (system) is the confusion between a system as existing 'objectives' in the real world and the idea of a system in people's mind. However, there is semi-agreement about the system definition. Most definitions agree that a system is a set of components with relationships between them, operating as a whole, to reach a set of objectives.

2.3. System Classifications

Systems are classified in different ways depending upon several aspects which are different from one system to another. McMillan and Gonzalez (1973) classified systems using three perspectives: systems can be natural or man-made, systems can be open or closed, and systems can be adaptive or non adaptive. Systems have also been classified using their component relationships or environmental status (dynamic and static). A manufacturing system is an example of a complex system with many objectives and involving many internal sub-systems and components. This work will concentrate on the internal working of a manufacturing facility.

2.4. Manufacturing Systems

The original meaning of the word 'manufacturing' was 'to make things by hand' (manu factum) (Hitomi 1994). Nowadays, the meaning of manufacturing is different, the term means the transformation of raw materials into finished products. Table 2.1 illustrates a brief historical development of manufacturing.

Date	Manufacturing Development
Ancient times	Wheel, lever, pulley, cutting implements, assemblies e.g. water wheel, carts.
Middle ages	Windmill, mechanical clock.
Pre 1800	Completely custom – craftsman.
1800s	English system – Introduction of general purpose machines that could be used for a variety of products.
1900s	Pre-specified worker motion – moved the control totally to the hand of management.
1913	Moving assembly line for Ford Model T.
1924	Mechanised transfer line for machining automobile engine components in England
1946	First electronic digital computer (ENIAC).
1950s	▪ Numerical Control (NC) machine developed at MIT. ▪ Identical procedures produce different results on same machine at different times. Emphasised outliners instead of mean performance. ▪ First industrial robot designed.
1960s	▪ Solid state integrated circuit developed ▪ First Unimate robot installed to unload parts in die-casting operations. ▪ Automatically Programmed tooling (APT) Developed, a programming language for NC machines. ▪ First flexible manufacturing system installed.
1970s	▪ Combination of the versatility of general purpose machines with the precision and control of special purpose machines. ▪ Microprocessor developed. ▪ Computer language for programming industrial robots developed.
1980s	▪ Computer Integrated Manufacturing developed ▪ Cellular Manufacturing Systems appeared.
1990s	▪ Agile Manufacturing /Mass Customisation ▪ Virtual Manufacturing Systems

Table 2.1 Historical Development of Manufacturing

Three stages of manufacturing development can be observed from the above table. In the first stage, manufacturing was dependent upon the human hand and the human brain. In the second stage, the human hand was replaced by manufacturing machines but the human brain was still needed. Nowadays, in the third stage, the human brain has been replaced by programmable machines, integrated with operational machines (Goldhar and Schlie 1991).

The Term 'manufacturing systems' can be defined as a number of tasks and components connected to each other to transform raw materials to semi-finished or finished products, using different strategies, techniques and processes. Hitomi (1994) suggested that manufacturing (or production) systems could be considered in three aspects structural, transformational and procedural aspects. The structural aspects are based upon the static definition of the system. According to this aspect a manufacturing system can be defined as a unified collection of hardware which involves workers, production facilities, materials and other supplementary devices. The transformation aspect of manufacturing systems is based upon the functional definition of the system.

The manufacturing systems definition can be defined, based upon this aspect, as the transformation of the production factors such as raw materials into finished products. The procedural aspect of manufacturing systems refers to the procedural definition of the system, so based on this, manufacturing system can be defined as the operating procedures of production including planning, implementation and control. Based upon these three manufacturing system definitions, Figure 2.1 can be derived.

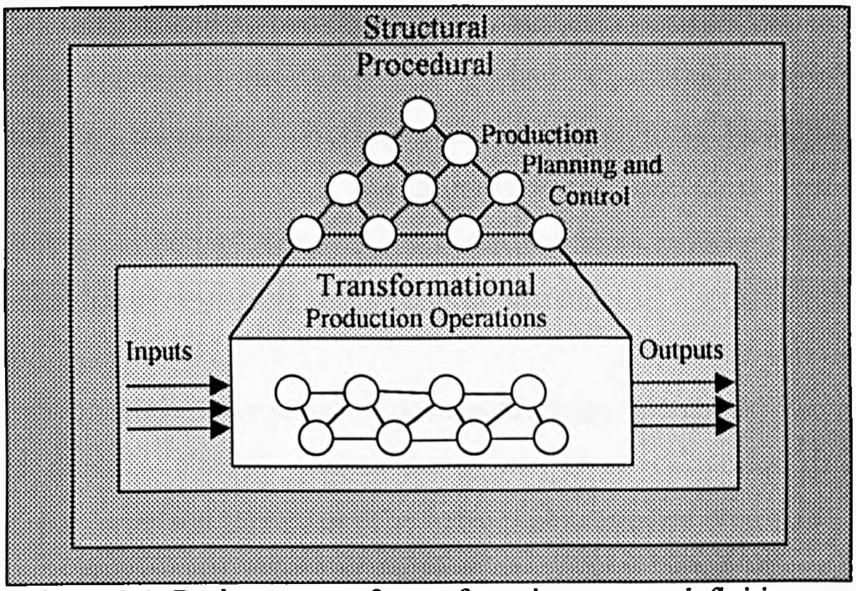


Figure 2.1. Basic aspects of manufacturing system definitions.

When Nicholson (1991) presented a simple input/output model of manufacturing systems as illustrated in Figure 2.2, he recognised that manufacturing composing complex, multidimensional systems, provides a rich source of challenging and systematic problems with common objectives but conflicts at all levels of decision making.

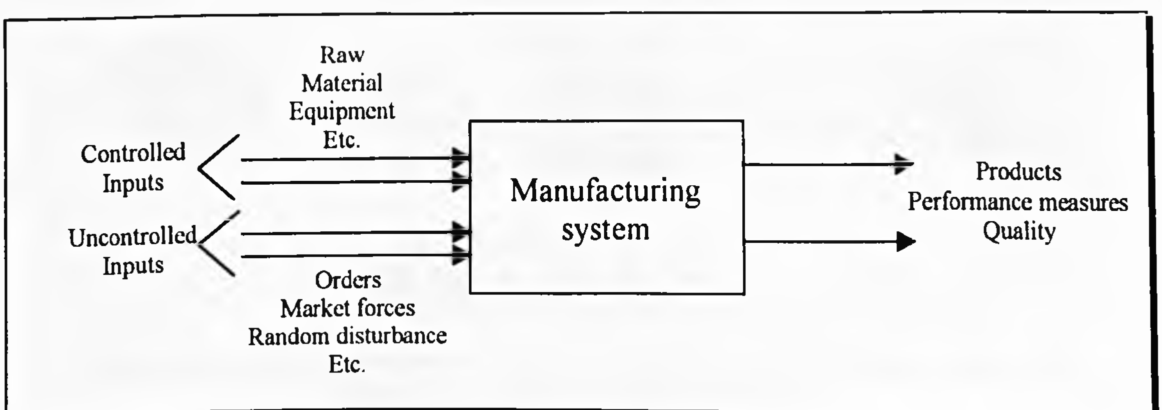


Figure 2.2. Input/output representation of manufacturing system (Nicholson 1991).

2.5. Types of Manufacturing Systems

Manufacturing systems can be classified into several types based upon a variety of schemes identified in the supporting literature. Using these schemes, manufacturing systems can be classified according to:

1. Time function of manufacturing process output. In this scheme, manufacturing systems are categorised into two types, continuous and discrete. Continuous systems involve the continuous production of product. Continuous manufacturing is represented by chemicals, plastics, petroleum and food industries. Discrete manufacturing systems involve the production of individual items. Discrete manufacturing can be represented by cars, machine tools and computers. The focus of this research will be discrete manufacturing systems.

2. Transformation of natural resources (or manufacturing operations). Groover (1987) used this term to classify manufacturing into three categories namely, basic producer, converter and fabricator. The basic producer takes original resources and transforms them into raw materials which can be used by other manufacturers. For example, aluminium producers transform aluminium into ingots. The converter takes the output of a basic producer and transforms these materials into other products and some final components. For example, aluminium ingots are converted into bars or aluminium sheets. The fabricator produces and assembles final products. The aluminium bars or sheets are then converted into machined products. This scheme of manufacturing systems is shown in Figure 2.3.

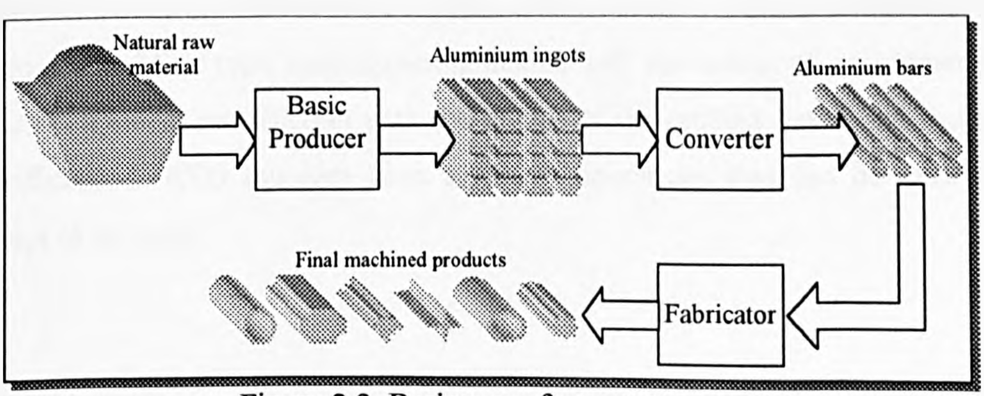


Figure 2.3. Basic manufacturer types.

3. Types of transformation process. In this classification scheme, manufacturing systems can be categorised into assembly and non-assembly systems. The assembly system joins individual parts or components in sub-assemblies or final assemblies. In the non-assembly type, materials are processed to produce individual parts or components. This type includes machining, moulding, fabrication, etc.

4. Production volume. This scheme refers to the quantity of products made and classifies manufacturing systems into three types namely; mass, batch and jobbing systems. This classification is normally associated with discrete manufacturing systems. A mass production system produces a high volume of products and is characterised by its special purpose equipment. The batch manufacturing system is characterised by small batches produced. The goal of batch manufacturing is often to meet continuous customer demand on general purpose equipment. This type of manufacturing system is a very important part of manufacturing industry. It has been estimated that 75% of the UK and USA manufacturing products are produced using batch manufacturing systems (Papadopoulos et al. 1993). Jobbing manufacturing systems involves low production often to meet specific customer orders.

5. Production planning and inventory policies. In this scheme, the manufacturing classification is based upon policies such as Make-To-Stock and Make-To-Order as illustrated in Figure 2.4. Using the concept of this scheme, Bertrand and Muntslag (1993) identified four types of manufacturing Make-To-Stock (MTS), Make-To-Order (MTO), Engineer-To-Order (ETO) and Assemble-To-Order (ATO). The MTS type suggests that production is based upon calculated or well known demand. Customer orders are delivered from stock and production work is initiated by stock shortages. In MTO type, manufacturing begins with the receipt of a customer order. ETO is an extension of MTO with the design of the product based upon customer specifications. ATO involves core assembly operations that can be initiated on receipt of an order.

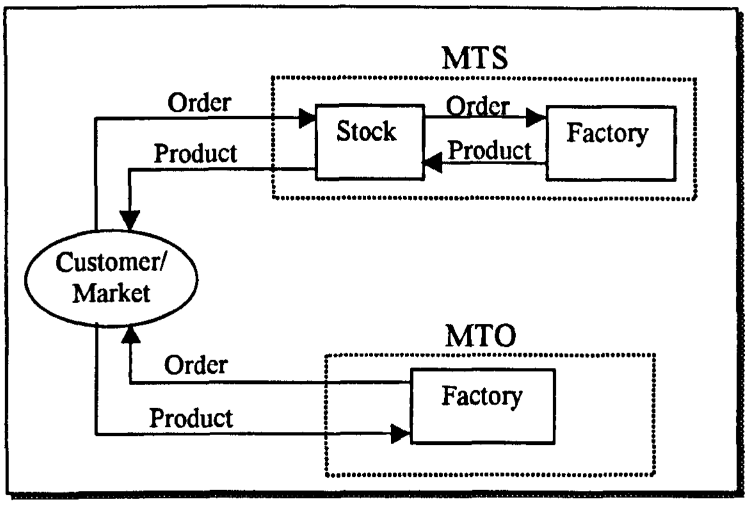


Figure 2.4 MTS & MTO manufacturing systems

6. Workflow (or system structure). In this scheme, manufacturing systems are divided into four types: job shop, project shop, cellular system and flow line. The following section provides more details about these manufacturing systems.

2.5.1 Job Shop Manufacturing System

In a job shop, machines with the same function or similar material processing capabilities are grouped together in specialised work centres (El-rayah and Hollier 1970, Chryssolouris 1992). For example, all lathes represent a turning work centre, milling machines are grouped in another work centre (Chase and Aquilano 1985). Machines of this type are usually general-purpose machines which can produce a large variety of product types. A work piece travels from one work centre to another according to the production plan as shown in Figure 2.5. The job shop type is typically used in jobbing and batch production (El-rayah and Hollier 1970 and Groover 1987).

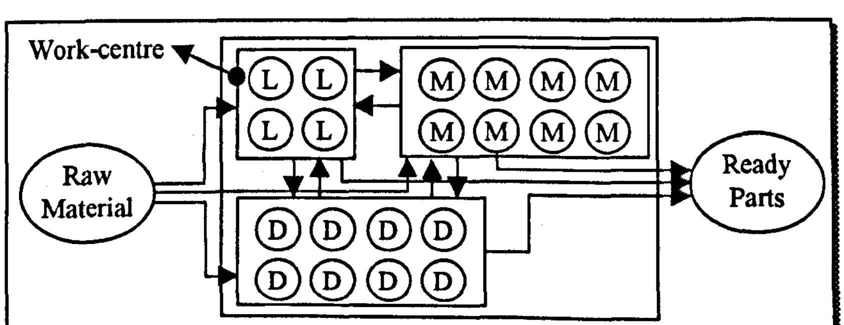


Figure 2.5. Job shop manufacturing system.

2.5.2 Project Shop Manufacturing System

In the project shop manufacturing, a product remains fixed in a particular location due to product size and/or weight, during the manufacturing processes. Labour materials and equipment are brought to the product position as needed. This type of manufacturing systems can be found in aircraft and shipbuilding industries (Hicks 1994). Figure 2.6 shows a typical project shop manufacturing system.

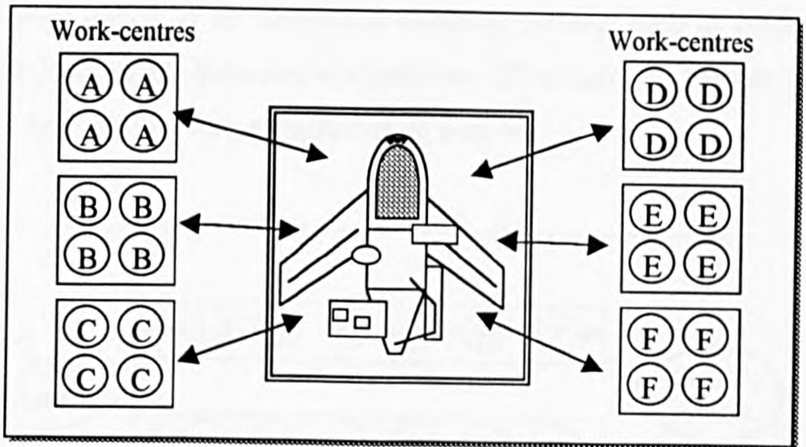


Figure 2.6 Project shop manufacturing

2.5.3 Cellular Manufacturing Systems

A cellular manufacturing system is based upon the philosophy of Group Technology (GT) (Gupta 1993 and Rajamani et al 1990). The concept involves grouping parts which have similar manufacturing requirements into families and grouping machines that produce these families into cells. Hence, every manufacturing cell contains a group of machines that can produce a certain family of parts (Logendran 1991). The aim of a cellular manufacturing system is to reduce set-up times, flow times, inventory levels and market response time (Salvendy and Wu 1993). Figure 2.7 illustrates a typical cellular manufacturing system.

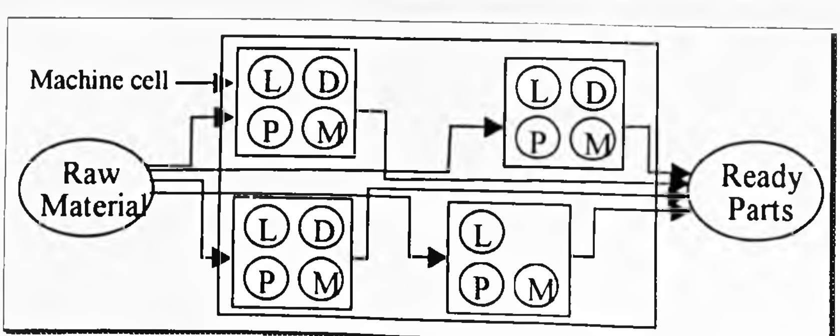


Figure 2.7. Cellular manufacturing system

The cellular manufacturing system can produce medium –volume/medium variety parts more economically than other types of manufacturing systems (Choobineh 1988).

2.5.5. Flow line Manufacturing System

In flow line manufacturing, machines and other equipment are arranged according to the process sequences of the product to be produced e.g. assembly lines. Flow line machines are often linked by an automated handling system, such as conveyors, which move the Work-In-Progress between workstations. (El-rahah and Hollier 1970). Figure 2.8 illustrates a typical flow line manufacturing system.

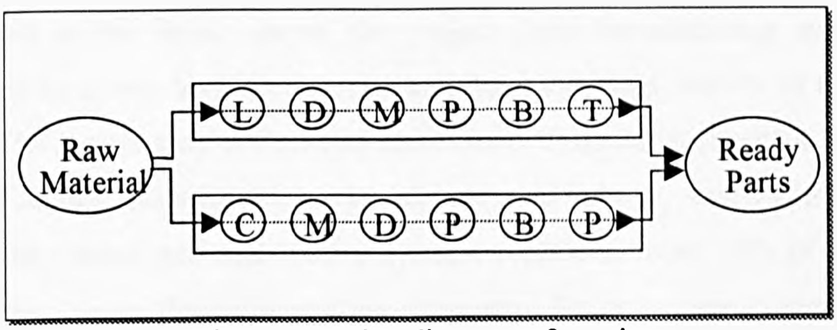


Figure 2.8. Flow line manufacturing

2.6. Manufacturing Systems Review

It has been noticed that manufacturing systems are moving from mass to low volume production owing to market changes and special customer orders. Customers have become more sophisticated, ordering a wide variety of high quality goods at competitive prices. Moving towards a jobbing shop system requires the systems to be more flexible. In MTO systems, the manufacturer tries to interact more closely with the customer. In addition, a trend moving from MTS to MTO has been observed over the past two decades. Figure 2.9 illustrates a combination of manufacturing system types discussed.

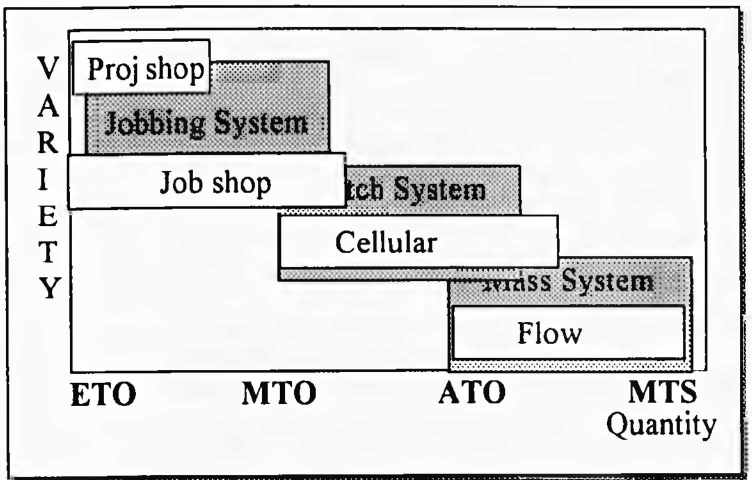


Figure 2.9. Types of manufacturing systems

As illustrated in the figure above, the project shop manufacturing system can be characterised by a very high product mix and flexibility, high variety of task and high unit costs. The project shop system also shares some characteristics with a jobbing shop. Batch and cellular manufacturing systems are mid-volume, mid-variety production systems. Mid-volume and mid-variety systems represent about 75% of discrete part manufacturing; hence, flexibility is a very important factor in these systems. MTO and ATO are located in the area of batch and cellular manufacturing systems. This indicates that these systems should receive more attention and development. Mass production and flow line systems are characterised by high-volume and low-variety. These systems would satisfy with the MTS production. Table 2.2 illustrates a comparison of various manufacturing systems.

Factor	Production type				
	Project shop	Jobbing	Batch & Cellular	Mass & Flow line	Continuos production
Flexibility of the process	High ←				Low
Number of set-ups	Variable	Many ←			→ Few
Capacity	Small →				Large
Technology	Universal →		General →		Special
Dominant utilisation	Labour →				Plant
Control of operations	Complex		Very complex	←	Straight forward
Operation times	Long ←				Short
Capacity control	Difficult ←				Easy
Productivity control	Difficult ←				Easy
Bottlenecks	Many ←				Few
Amount of capital investment	Low/High →	Low →			High
Finished part inventory	Low ←				High
WIP	High	High	Very high	Low	Low
Product/service range	High diversity →				Standard
Order size	Low →				High
Volume of operations	Low →				High
MTS	No	No	Some	Yes	Yes
MTO	Yes	Yes	Yes	Some	No
Layout	Fixed position layout	Process layout	Cell layout	Product layout	Product layout

Table 2.2. Comparison of manufacturing system types.

2.7. Manufacturing Strategy

This era, symbolises a new difficult reality, this is the impact of industrial competition (Hill 1993). Due to increasing competition and shorter product life cycles, manufacturing industries are forced to present and develop more and better products and seek means, strategies and tools that can be used to achieve their goals and consolidate their future. Manufacturing organisations must be able to adapt quickly to these new competitive conditions and take advantage of all the available strategies and technologies to help them stay competitive (Torkzadeh and Sharma 1991).

Numerous conferences, articles and groups have addressed issues related to the changing nature of manufacturing (Solberg 1988). Bessant (1994) reported that the 1980s represented an increasingly problematic decade for manufacturing systems and evidence suggests that in the next decade the environment will become even more challenging. Ziarati (1991) suggested that a variety of factors conspire to force manufacturing organisations to become more agile, flexible and responsive if they wish to survive. This is the result of increasing competition and globalisation. Lim and Nee (1993) emphasised the reason forcing manufacturing enterprises to continue improving their strategic competitive advantage through increased flexibility and cost-effectiveness is to remain competitive in a changing world economy. Levary (1996) urged manufacturing organisations to change quickly to be successful in today's competitive global environment.

There is a need to develop manufacturing strategies which can meet the demand of the current economic conditions, i.e. take significant market share, reduce lead times, increase profit, reduce costs, improve quality etc. (Barker and Powell 1989). To achieve these, organisations must believe in change and develop and select a suitable strategy. Several contributors define the term strategy such as: " A strategy is a plan of attack, methodology, [procedure, process] or approach. A strategy is a series of steps defining a pattern of action to be followed by an individual or a group in achieving a purposeful activity." (Nadler 1971). Staughton et al (1992) indicated a number of different contributions to understanding the role of manufacturing strategy. These contributions deal with the decision-making aspects, the presence of a specific plan and the orientation of the organisation. Carrie et al (1994) defined strategy as the plan to reach the goals.

Buffa (1984) (cited by Hitomi 1996) mentioned that manufacturing strategy consists basically of:

- The minimum-cost/ high-availability strategy and
- The highest-quality/flexibility strategy.

This cannot be achieved using traditional manufacturing strategies. To achieve manufacturing goals, new strategies that meet the challenges of contemporary manufacturing technologies and operations must be adopted.

As a result of renewed emphasis on manufacturing methods, a number of comprehensive strategies are receiving wide spread attention (Mellichamp et al. (1990). One possible way of producing a significant strategic performance improvement is the adoption and effective implementation of CIM. The CIM strategy opens up major opportunities not only for improving planned goals but also for more radical alternatives, doing things which have never been done before or doing them in ways which were hitherto not possible (Ziarati 1991). Thomas and Wainwright (1994) and Ngwenyama and Grant (1994) suggested that CIM has been identified as a key to meeting the challenges of manufacturing in the 1990s. They support their suggestion with the fact that manufacturing industries can provide competitive advantage through the achievement of strategic and operational objectives. Guetari and Nguyen (1997) emphasised that CIM implementation is a strategic choice.

2.8. CIM Strategy

CIM is the key to survival for many industries requiring to continue competitively by producing high quality products at the right time and at acceptable costs, to satisfy the fast changing market (Nicholson 1991). In 1988 Vail suggested that CIM was one of the fastest growing fields. It is not a single concept or tool but integration of the elements of the system as a whole. In the CIM system all the technology and strategies are based on an integration.

CIM is a strategy for economical production by effective utilisation of different data resources via computer-based methods. Without doubt CIM systems, with their long-term impact, require alignment of business and manufacturing strategy (Guetari and Nguyen 1997). Pleinevaux (1997) envisaged the current view of CIM as appearing to represent a strategic panacea for the organisation being studied.

It has been mentioned in previous sections that there is a global movement toward batch manufacturing. It has been estimated that over 70% of manufacturing industry is carried out on batch production. This requires a high level of manufacturing flexibility which plays a very important role in this type of production. Levary (1992) defined manufacturing flexibility as the efficiency with which a manufacturing system reacts effectively to changes in the organisation. He primarily divided manufacturing flexibility into product flexibility and volume flexibility. The product flexibility is the efficiency with which a manufacturing process can be effectively converted to produce another product and/or products having special features. Volume flexibility is the efficiency with which a manufacturing process can be converted from producing one lot size of a given product to producing larger or smaller lot sizes of the same product. Browne et al. (1988) identified eight types of manufacturing flexibility: machine flexibility, process flexibility, product flexibility, routing flexibility, volume flexibility, expansion flexibility, operation flexibility and production flexibility. It has been found that CIM has the widest potential applicability in manufacturing environment in producing products on a batch basis (Vail 1988).

However, developments in CIM systems are proceeding rapidly, and the general consensus is that they are essential for survival in highly competitive world markets, and for progress toward the fully automated 'factory of the future' (Nicholson 1991).

In fact, the strategies of CIM cover the basic areas of manufacturing systems through the different system components such as CAD, CAM, PPC, CAQ and CAPP. All these components represent child-strategies under a CIM system global strategy.

2.9. CIM Definition

Before moving into any discussion about CIM systems, it is necessary to define CIM. The phrase Computer Integrated Manufacturing was coined by Harrington in 1973 to be a logical direction for growth in manufacturing; others produced the abbreviation CIM (Mitchell 1991). CIM means different things to different people (Aletan 1991); hence, it would be very difficult to find a well established definition for this term. Boaden and Dale (1986a) reported that a definition of CIM in itself could be the subject of a complete paper. However, many definitions of CIM have been reported. The following are some examples of CIM definitions:

"Represents the integrated applications of computer technology to manufacturing in order to achieve the business objectives of the firm".

Browne et al 1988.

"The process of using computers and communications networks to transform an island of automation into a highly interconnected manufacturing system that can co-operate in executing assigned tasks".

Aletan 1991.

"The integration and co-ordination of design, manufacture and management using computer-based systems".

Tie and Cilin 1992.

"A computer integrated system involving the overall and systematic computerisation of the manufacturing process. Such systems will integrate computer aided design, computer aided manufacturing and computer aided engineering, testing, repair and assembly by means of a common database".

ESPRIT definition 1982 (cited by Browne et al. 1988).

"A flexible market-adaptive strategic manufacturing system which integrates three different functions and systems - design, production and management - through the information network with computers".

Hitomi 1996.

"The integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organisational and personal efficiency".

Meabi and Singh 1997.

"A strategy consisting of physical components and the conceptual methodology to integrate the components".

Ingerosoll Engineers 1985.

"CIM refers to a global approach in - an industrial environment - which aims at improving industrial performance. This approach is applied in an integrated way to all activities, from designing to delivery and after-sale, and uses various methods, means and techniques (computer and automatic techniques) in order to simultaneously improve productivity, decrease costs, meet due dates, increase product quality, secure flexibility at local or global level in a manufacturing system, and involve every actor. In such an approach, economic social, and human aspects are at least as important as technical aspects".

Dumeingts et al. 1995a.

"The application of information and manufacturing technology, plans and resources to improve the efficiency and effectiveness of a manufacturing enterprise through horizontal, functional and external integration".

McGaughey and Roach (1997).

"The entire [manufacturing] system, from product definition and raw material acquisition to the disposition of the final product, is carefully analysed such that every operation and element can be designed to contribute in the most efficient and effective way to the achievement of the clearly enunciated goals of the enterprise".

Mize and Palmer 1989 (cited by Bedworth et al.1991).

2.9.1 A Discussion on CIM Definitions

The problem of defining CIM has been discussed by many contributors. Boaden and Dale (1986b) outlined this problem and allotted a complete paper entitled, 'What is Computer Integrated Manufacturing?' to this propose. According to their study, CIM definitions have been divided into ten categories:

1. The computerisation of the main functions of an organisation.
2. A philosophy or tool for strategic management.
3. Viewing the organisation as part of a total business unit.
4. An exercise in information management.
5. A computer system running from a single database.
6. A closed loop feedback system for an organisations.
7. A system to enable a better response by the organisation to market situations.
8. An integrated CAD/CAM system.
9. The use of the most advanced manufacturing technology.
10. A system with its biggest impact on people.

The authors classified these ten items into three main classes A, B and C:

(A) Total organisation definitions (1,2 and 3).

(B) Information systems definitions (4, 5, 6 and 7).

(C) Single fact definitions (8, 9 and 10).

As illustrated in Figure 2.10, the definitions of CIM have been broken-down by class and category. It can be noted that the largest class of definition is class 'C' and the largest category is category '9'. Categories 1, 3, 8 and 9 have been the most popular, as illustrated in Figure 2.10.

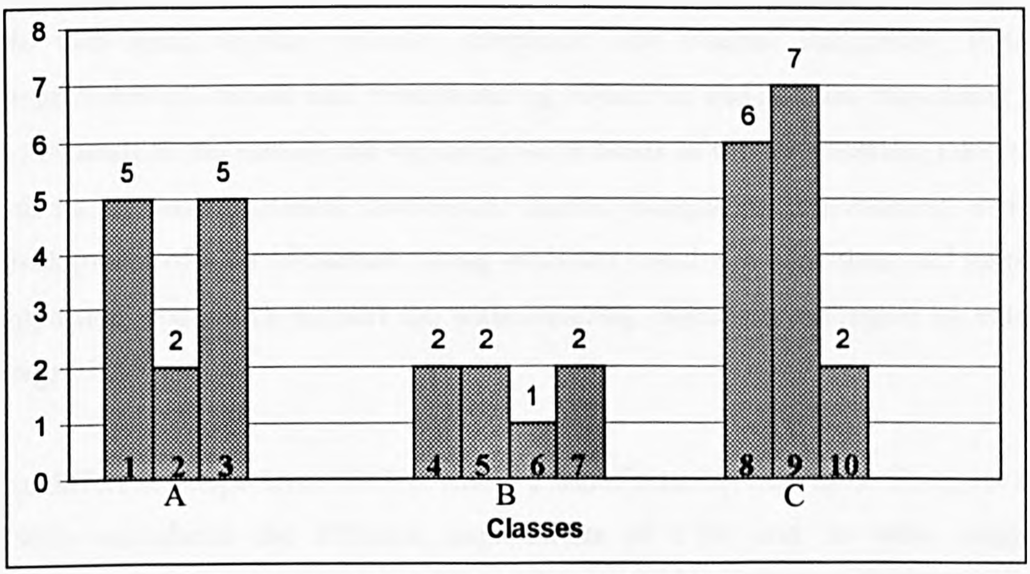


Figure 2.10 Classes of CIM definitions.

2.9.2 Reasons for the Different Definitions of CIM

The main reasons for the existence of different CIM definitions fall into two main categories: the different viewpoints about the integration concept and the different perspectives of CIM within manufacturing enterprises.

1. The different viewpoints about the term 'integration'. Platts's article (1995) set out to identify different types of integration. He reviewed work by Das (1992) who classified integration into two types: resource-oriented integration and activity-oriented integration. The resource-oriented integration is concerned with physical entities and includes computer and network integration, equipment integration, facilities integration and material integration. Activity-oriented integration is concerned with the processes which occur in a business and includes process integration, information integration, decision-tool integration, control integration and product integration. Platts (1995) also reviewed O'Sullivan's attempt in 1992 to classify integration. O'Sullivan broke down integration into two broad areas based upon the system designer's viewpoint. These two areas are social integration and technical integration. Social integration includes the integration of people, their ideas and the decision-making process. Three elements have been identified for this: management integration, system designer integration and user integration. Technical

integration is related to technical sub-systems and includes information integration, data integration and equipment integration. Platts himself categorised integration into two basic aspects: external integration and internal integration. External integration is concerned with manufacturing objectives and policies responding both to the needs of the market and the competitive needs of the organisation, taking into account any environmental constraints. Internal integration is concerned with the development of a set of manufacturing practices which are consistent and mutually supportive, and which support the manufacturing objectives addressed by external integration.

2. The different perspectives of CIM within a manufacturing enterprise. Forrester et al. (1995) considered the different implications of CIM and its wide range of perspectives. According to that study, the following perspectives have been reported:

- Strategic perspective. Depending upon this perspective, CIM is considered as strategically important as it contributes positively to the competitive edge of a company through reducing costs, improving quality, enabling variety production, reducing product introduction items, cutting delivery times and improving delivery reliability.
- Social perspective. From this perspective, CIM is considered to be a controversial issue when one considers the contradictory nature of the benefits. Hence, it has been shown that the development of advanced manufacturing technology and computer based systems for business and production is seen as a key influence in the development of contemporary manufacturing economies.
- Organisational development perspective. This considers CIM as a development concept to integrate and communicate different functional aspects of an organisation. Attempting to work together, more often than not, prompts conflicts.
- Technical perspective. From this perspective the CIM system is considered as the latest evolution of technology in the workplace in the areas of design engineering, production management systems and machine automation.

Kumara et al. (1992) suggested that manufacturing systems can be categorised from a CIM perspective into a conjunction of three basic processes: the design process, the implementation process and the integration process. They presented subdivisions for the above processes, as follows:

1. The design process

a Product design

i. Conceptual design

ii. Product characteristics

iii. Design specifications

iv. Duality specifications

v. Concurrent design processes

b Process design

i. Process characteristics

ii. Process design specifications

iii. Process and operation planning

c Quality design

i. Characteristics of quality

ii. Tolerance analysis

iii. Quality control system design

d System design

i. Optimisation

ii. Material management systems

iii. Production planning and control systems

iv. Inspection systems

v. Distribution and logistics systems

vi. Functional systems

vii. Integrative information systems

2. The implementation process

i. On-line real time diagnostics and control systems

ii. Off-line diagnostics and control systems

3. The integration process

i. Integration of monitoring and control

ii. Integration of planning and control

iii. Integration of design and implementation process

Many other definitions of CIM have been generated based upon the integration between system functions and computers. Scheer (1994) reported that until the start of 1980s a definition of CIM narrowly related to manufacturing and product development in which 'CIM=CAD+CAM' in Japan and USA.

Because the strategic business level issues will drive the whole process, it must be remembered that the business is more than just the manufacturing function (Rogers et al. 1992).

The CIM definition adopted by this research is not restricted by the sophisticated computer hardware and software or limited to transfer of information between system functions, but incorporates these aspects within a wider concept embracing the integration of all manufacturing sub-systems. When the full flows of information, decisions, materials and processes are considered, it is clear that the wider system involving an organisation's external aspects, such as customers and vendors, should be taken into account. Hence, CIM should be considered and defined in its widest sense by including relationships with these external factors. Such a definition may resemble that proposed by Dumeingts et al. (1995a) "CIM refers to a global approach in - an industrial environment - which aims at improving industrial performances. This approach is applied in an integrated way to all activities, from designing to delivery and after-sales, and uses various methods, means and techniques (computer and automatic techniques) to simultaneously improve productivity, decrease costs, meet due dates, increase product quality, secure flexibility at local and global level in a manufacturing system, and involve every actor. In such an approach, economic social and human aspects are at least as important as technical aspects".

2.10. Why CIM?

CIM is needed to generate and support flexible strategies that are very required to meet rapid market changes. These changes involve a great variety of products coupled with shorter product life cycles. Hence, industrial organisations must learn how to shorten the lead time of products from order to delivery. Awareness of manufacturers about the integrated manufacturing systems contributes to the enhancement of manufacturing enterprise competitiveness and improves decision-making (Singh and Weston 1996).

A consensus of opinions about the CIM mission and benefits undoubtedly becomes very evident. Davis et al. (1990) reported that there has been a renewed interest in manufacturing research due to two main reasons: increasing global competition which needs improving manufacturing efficiencies and the advances of computer capabilities. They emphasised that to address these needs organisations are increasingly turning to the implementation of CIM.

Gaafar and Bedworth (1994) reported that the CIM and concurrent engineering were introduced to help companies remain competitive and better utilise their capabilities and resources. Utilisation is one of the full integration results and is the way with which enterprises can achieve responsiveness or become close to their customer (Youssef 1992).

Many benefits have been reported by CIM users and researchers as the result of successful implementation of CIM as a manufacturing strategy:

1. Greater flexibility (McGaughey and Roach, 1997, Ramesh et al., 1990, Groover, 1994, Barad and Nof, 1997, Browne et al, 1988, Kosturiak and Gregor, 1995).
2. Reduced lead times (Rembold et al. ,1993, Groover, 1994, Gunasekaran et al. 1994, Dowlatshahi 1994, NEDO 1985, Kochan and Cowan 1986).
3. Reduced inventories (Kaltwasser 1990, Kochan and Cowan 1986, McGaughey and Roach 1997, Gunasekaram et al. 1994, Bedworth et al. 1991, Ingerssoll Engineer 1985).
4. Increased Productivity (Rembold et al. 1993, Dowlatshahi 1994, Kosturiak and Gregor 1995, Sun and Riis 1994, Groover 1994).
5. Improved customer service (Bedworth et al. 1991, NEDO 1985, McGaughey and Roach 1997, Kaltwasser 1990).
6. Improved quality (Badiru 1990, Koshiba et al. 1993, Kaltwasser 1990, Kochan and Cowan 1985, Spur et al. 1990, Weissflog 1991, Ramesh et al. 1990).
7. Improved communications with suppliers (McGaughey and Roach 1997).
8. Better product design (Kochan and Cowan 1985, McGaughey and Roach 1997).
9. Greater manufacturing control (Kosturiak and Gregor 1995, Kochan and Cowan 1985).
10. Supported integration (Altan 1991, Spur et al. 1990, Ingersoll Engineers 1985).
11. Reduced costs (Rembold et al. 1993, Badiru 1990, Bedworth et al. 1991, Groover 1994, Wessflog 1991).
12. Increased utilisation (Dowlatshahi 1994, Kochan and Cowan 1986, Ramesh et al. 1994).

13. Reduction of machine tools (Gunasekaran et al. 1994).
14. Less floor space (Koshiba et al. 1993, Dowlatshahi 1994).
15. Improved competitiveness (Badiru 1990, Kaltwasser 1990, NEDO 1985, Sun and Riis 1994, Bedworth et al. 1991, Singh 1996, Hitiomi 1996).

CIM benefits are clearly related to each other, e.g. greater flexibility is directly related to reduced manufacturing lead time, improved quality and competitiveness. Spur et al. (1990) presented the role of integration in achieving enterprise goals and suggested that there are three categories of CIM goals in a hierarchical structure, as depicted in Figure 2.11.

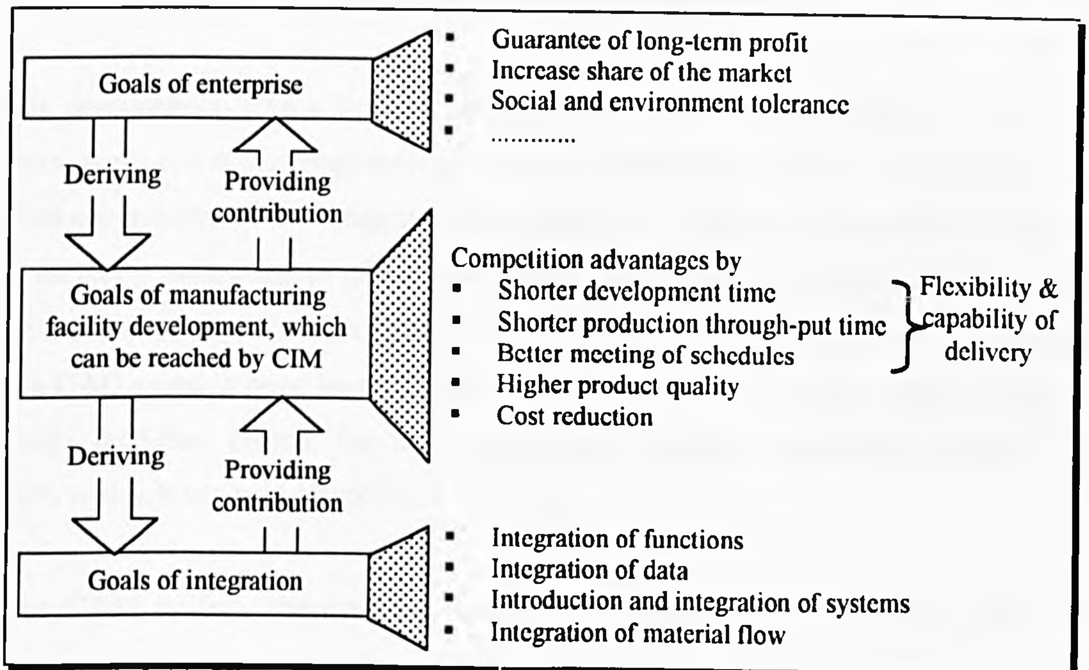


Figure 2.11. Hierarchy of goals within the CIM-introduction (Spur et al. 1990).

2.11. CIM Components

CIM includes all the functional areas of manufacturing organisation. Each functional area should be integrated with the others. The major components of CIM are Computer Aided Design (CAD), Computer Aided Process Planning (CAPP), Computer Aided Manufacturing (CAM), Computer-Aided Quality Control (CAQ) and Production Planning and Control (PP&C). Figure 2.12 shows a simple representation of CIM components and a general logic of CIM integration. A brief description of the CIM system components is presented in Appendix-A.

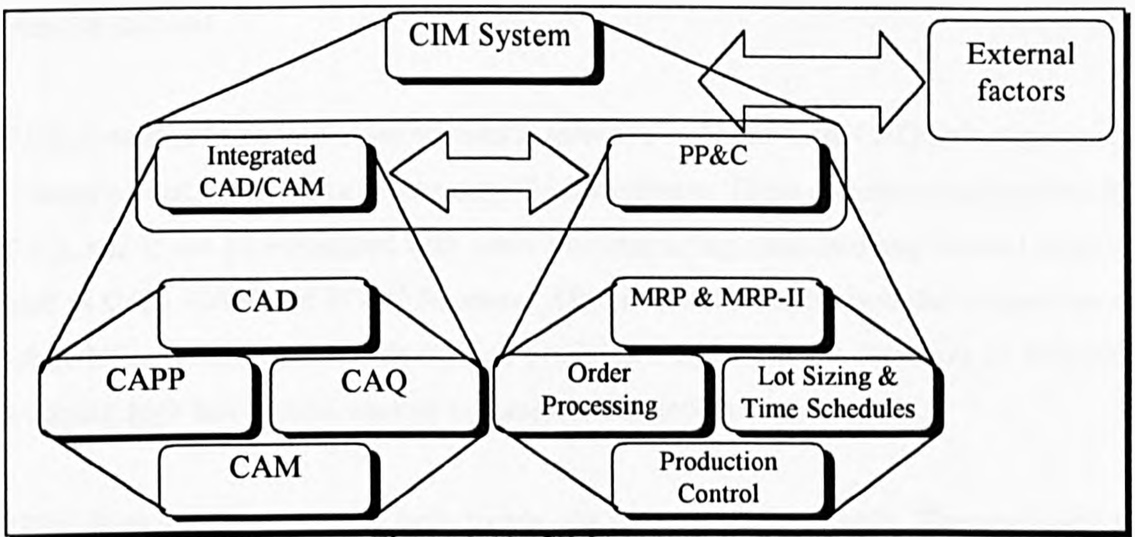


Figure 2.12. CIM components.

These components have a very important role in the CIM environment. In the CAD system, there are many requirements for a well integrated CAD, but no system on the market can achieve all the integration requirements. Building an integrated CAD system will certainly contribute to global integration. The integration between CAD systems can be achieved by interfacing different tools to form a more complete CAD package. Some CAD systems have high graphical capabilities and others have good engineering analysis facilities. Hence, the development of integration interfaces between CAD system will achieve many benefits.

In the CAM system, the evolution of the NC machine was the driving force after CAD/CAM developments. It should be noted that the integration of the organisation's technical facilities such as CAD with CAM would not even be achieved without advanced CAM technologies such as CNC, DNC, robots, etc.

CAPP represents a link between the engineering and manufacturing activities and CIM cannot be achieved without CAPP in many industries. The CAPP system provides a means and procedure to close the gap between these activities using Group Technology concepts (GT). GT is a key element of different CIM components, because it provides a formal concept and procedure for dealing with information about parts and methods of classifications. CAPP has been found to be the application that makes most uses of GT concepts. Most current research in CAPP concentrates on the development of techniques that can be used to automate process planning activities and integrate CAPP with CAD/CAM.

CAQ consists of two important elements: software and hardware. CAQ software is used to analysis and control data received by CAQ hardware. There are many applications for CAQ, and it can be connected with other manufacturing databases and control systems such as CAD, CAM and PP&C databases. Hitomi (1996) emphasised the importance of CAQ, because of recent trends in high production speed, quick detection of defective products, high labour cost, on-line process control and so on.

PP&C is characterised by two main trends: the push and pull methods. The push method can be represented by MRP systems that are based upon the actual and future demands. The difference between MRP and MRP II is that MRP II includes the integrated PP&C activities. The pull approach can be represented by JIT/Kanban systems. These systems are used to produce parts as required "manufacture on call". The system starts at the final stage of assembly and sends back a request to the preceding production stages. The integration of PP&C elements will eliminate many drawbacks of planning and control. For example, the integration of (Capacity Requirement Planning) CRP and MRP systems would solve the major problems of CRP. The major problem of CRP is that it lacks methods that can be used to optimise production throughout the factory. It is too difficult to calculate exactly when every job will finish and the load on each production stage. This integration can be achieved using feedback links between CRP and MRP. Without integration, the shop floor order due dates are calculated by the MRP system, using fixed lead-time. This is likely to be inaccurate because the actual lead times will be restricted by actual work on the shop floor.

Kosturiak and Goegor (1995) present a new concept TPC (Total Production Control) that contributes in achieving the new requirements of manufacturing system integration, as illustrated in Figure 2.13. The TPC integrates the following activities:

- Production planning and control.
- Production system analysis and continuous improvement process.
- Production system analysis, re-design and modernisation.

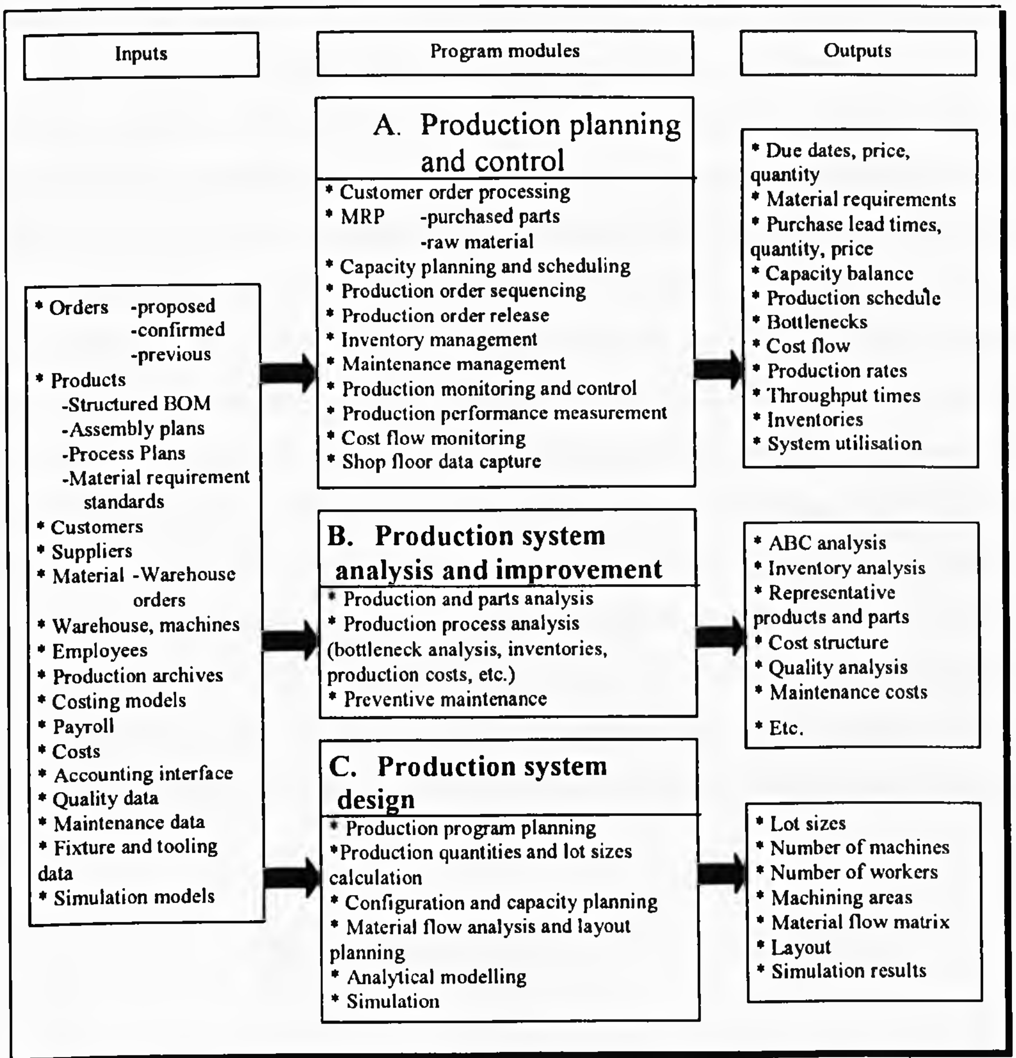


Figure 2.13. TPC - a simplified structure (Kosturiak and Gregor 1995)

2.12. Component Integration

Most of the current research in manufacturing system integration can be classified into four categorises (Sarin and Das 1994):

1. Integration of management with CAD, CAM and PP&C.
2. Integration of CAD with CAM.
3. Integration of CAM with PP&C.

Integration of CAD, CAM, CAPP and PP&C is the first step in a CIM strategy. In CAD, a product can be designed on design workstations and using a suitable CAD package. The design information can be stored in general and local databases to be used for other CAD tasks such as finite element modelling, engineering analysis and performance evaluation. This information can also be used for other manufacturing elements such as, CAPP, CAM, CAQ and PP&C. CAPP can use design data to produce process plans and machine part programs. These programs can be transformed automatically to CAM elements (CNC machines) on the shop floor to start the manufacturing operations. Other elements of the CAM system such as industrial robots, handling systems, AGV systems and AS/RS should be able to communicate with one another or with their control system (Vernadat 1994). The PP&C elements such as MRP II, JIT, Kanban, scheduling systems, control systems and capacity planning should be included and integrated to other manufacturing sub-systems in the CIM environment. Ragowsky and Stern (1997) reported that CIM provides the information necessary for JIT, Kanban, OPT and other techniques that minimise inventories on-hand while maximising delivery performance and activity utilisation. Hasin and Pandey (1996) analysed the present characteristics of the integration between CAD and MRP II. They pointed out that the integration strategy for CIM can be based upon the determination of common features and characteristics of the sub-systems that can be shared to formulate an integrated solution, as illustrated in Figure 2.14.

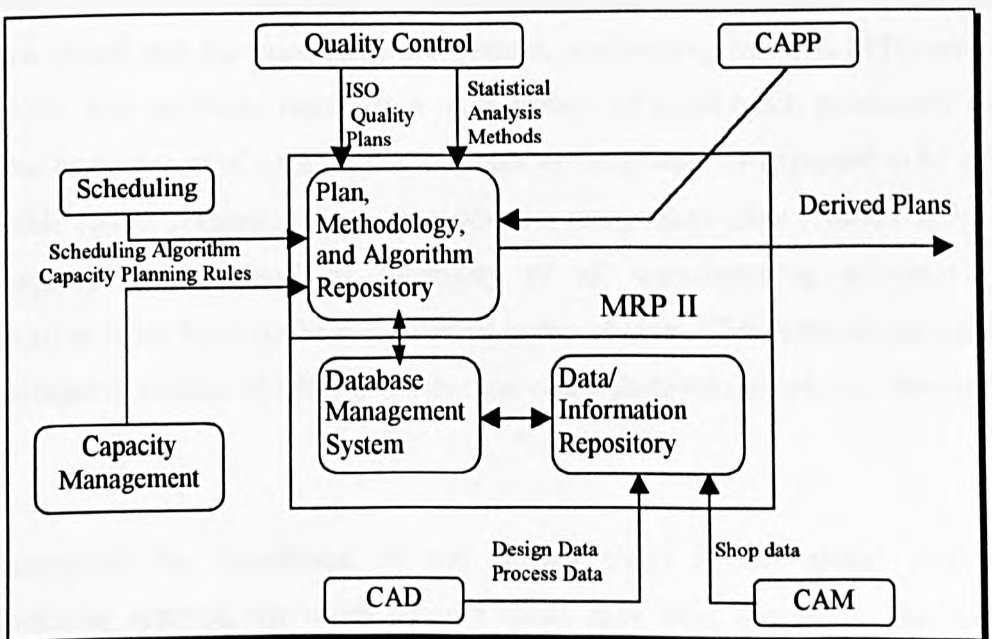


Figure 2.14. MRP II system's architecture for integration (Hasin and Pandey 1996).

Harhalakis et al. (1990) presented a generic model for the integration of CAD, CAPP and MRP II. They pointed that the CIM should not be understood as integration of CAD and CAM but should include integration of the high level manufacturing functions. It is generally accepted that CIM aims to achieve an effective integration of the different activities of an organisation (Hassard and Forrerter 1997).

The CIM strategy has major child-strategies that should be understood and integrated. The misunderstanding of the basic concepts of CIM and its components leads to many technological and organisational problems.

2.13. Conclusion

In this Chapter the general concepts of manufacturing systems have been presented. These have included the basic definitions and types of a manufacturing system. It can be seen that the manufacturing system is not only the transformation of the raw material into saleable final products, but much broader and complex owing to the large number of interrelated activities. Manufacturing systems have been classified based upon their basic processes into three categories: basic producer, converter and fabricator. The problem of this classification is that some organisations possess a high degree of vertical integration, which means that their operations involve all three categories (Groover 1987). When describing the other classifications of manufacturing systems, it has been noted that the manufacturing systems are moving towards MTO and batch production. This tendency results in a wide variety of small batch production and the lead time from receipt of order to the shipment of the product is expected to be as small as possible (quick response) in order to where a competitive edge (Hitomi 1996). This also requires a high level of flexibility of all manufacturing activities. Other classification types have not been addressed in this chapter. This refers to the wide field of classification studies which is under current research development, e.g. see McCarthy 1995.

To accompany the assessment of the current trend in the global market and manufacturing systems, the organisation's needs have been described. This indicates that, the manufacturing organisation should be changed and seek effective strategies for survival. It has been found that new technologies play an important role in building these strategies. The general consensus is that these manufacturing enterprises should be changed and should adopt CIM strategy. The fact that CIM is a successful manufacturing strategy which could be the only possibility of consolidating manufacturing competitiveness has been discussed.

This Chapter has reviewed and discussed the global view of CIM and its major components to establish a good background and understanding. Unfortunately, it has been difficult to find a consensus definition for CIM; many contributions in the literature attest to this statement. In this Chapter, two main reasons have been suggested for the difficulty of identifying a CIM definition. The first reason refers to the different viewpoints about the term "integration"; and the second refers to the different perspectives of CIM concept and goals. It has been concluded that CIM should not be restricted to specific manufacturing functions. CIM is a direction, not a destination; it is an integrated strategy, not a set of technical aspects or systems; it is a concept, not a computer package; it should be designed and configured and not purchased or transferred.

Most of the published reports focus on the technological aspects at an early stage of the development of CIM (Gunasekaran 1997). Therefore, CIM could not be considered as an integrated manufacturing strategy when the role of the other factors such as organisational activities is ignored. It is generally accepted that CIM aims to achieve an effective integration of the different activities of an organisation (Hassard and Forrester 1997).

After reviewing the various definitions of CIM, the definition proposed by Dumeingts et al (1995a) is accepted as the most appropriate definition "*CIM refers to a global approach in - an industrial environment - which aims at improving industrial performance. This approach is applied in an integrated way to all activities, from designing to delivery and after-sale, and uses various methods, means and techniques (computer and automatic techniques) in order to simultaneously improve productivity, decrease costs, meet due dates, increase product quality, secure flexibility at local or global level in a manufacturing system, and involve every actor. In such an approach, economic social, and human aspects are at least as important as technical aspects*". For the purpose of the study the research will concentrate on the internal aspects of CIM.

In order to understand the nature and content of CIM, the next chapter will examine some real applications of CIM and investigate a number of problems and barriers associated with its design and implementation.

CHAPTER-3

CIM: LEARING FROM PRACTICE

3.1. Introduction

This chapter reviews and discusses a number of surveys which have been carried out to identify the current state of CIM implementation. The surveys are also analysed to identify the problems and obstacles to CIM implementation. Several case studies describing the successes and failures of CIM implementation are also reviewed. The objectives of this chapter are to:

- Assess the current tools of implementation;
- Identify the different industrial perceptions of CIM;
- Identify the problems and obstacles to successful CIM implementation.

3.2. CIM Applications

Many studies have been carried out on organisations who have adopted and implemented a CIM strategy. Several surveys concerned with the subject are evaluated in this section.

Fossum and Ettlie (1990) examined six organisations that have implemented computer systems for integration and control of factory operations. In their study, they concentrated on the relationships between management information systems and manufacturing. Table 3.1 summarises the results of the survey.

Cases	Lessons learned	Success/failure	Derived proportion
PGAS Inc.	Applying knowledge at the right time and good people communication are key success factors.	Success. Meeting objectives, including 99.9 percent inventory accuracy. Less than one-year payback.	The management information system (MIS)-manufacturing relationship is improved when each function can contribute significantly to the implementation with the skills each have.
BAA Inc.	Have management information system and manufacturing users do what they are best at doing	In process. User satisfaction thus far. Less than one-year payback.	Using a pilot system development methodology accelerates the development of well-defined requirements and improves the MIS-manufacturing relationships.
Northrop Inc.	Designer "expert" does not work.	Success. Savings of over $20 million.	Adopting a group requirement development process reduces conflict at MIS-manufacturing interface.
Integrated Paper Company	Everyone is a user	Aspects of success and failure. Something fails when it is not used.	MIS (new breed) is decentralised in the best development, with all manufacturing personal as users.
CCAS Inc.	System requirements definition cannot be delegated to management information system (MIS). Even decentralised, "manufacturing" MIS.	Aspects of success and failure. Meeting some, but not all, objectives. System not used to full potential.	The system development process is extended when manufacturing users do not contribute equally (with MIS and the software supplier) to the requirements definition.
PWAS Inc.	(Not applicable)	Failure. Management information systems-Manufacturing stand-off on system acquisition	The definition of system requirements in an integrated environment is a function which must be shared by those who understand computer technology and those who understand the many functions of manufacturing.

Table 3.1. Summary of MIS-Manufacturing case experiences (Fossum and Ettlie 1990).

In the above study, it was found that all the manufacturing organisations considered had enjoyed the same degree of success with the implementation of factory management and control systems. The study recommended that the development of tools to promote the development of requirement specifications should be the focus of both users and technology vendors for prompting successful modernisation. The authors found that three of the cases provide examples of the use of methods and tools which supported the development of requirements.

Ingersoll Engineers (1985) studied sixteen company profiles which determine the level of progress various companies had made towards introducing CIM, the business approach each adopted and their future plans. The companies selected by Ingersoll Engineers were spread throughout Europe, USA and Japan. These companies were well known and active in advanced technology and reputedly active in CIM. This survey indicated that every company had a different image of CIM. Table 3.2 combines and presents the results of the Ingersoll study.

Table 3.2 Results of Ingersoll Engineers study evaluating CIM implementation in several international organisations (derived from Ingersoll Engineers 1985).

Industry	Technology record	CIM achievement	Business approach	CIM plan
Manufacturers CNC machines for FMS. Manufacturers FMS cells and FMS assembly based on robotics.	Skilled manufacturers of: - CNC machines - Flexible assembly robots - FMS cells	None	Company has concentrated on product development and its customer did not express an interest in CIM. Customers wanted a bottom-up approach which the company also took.	To develop a mostly design and management-oriented CIM.
Power turbine manufacturer. Half of business is spares and rebuild.	NC machines fitted with intelligent terminals. GT cells. Engineering database using GT codes (made up of parts families, shape sub-structure, gross properties, dimensional and notational data). MRP. LOCAM process planning. ORACLE (Relational database). Database management systems (HOMS).	2D and 3D defining part families. Stored on mainframe. Input of part code automatically produces an NC program which is downloaded at CNC machines. Link between mainframe and CAD for stress analysis and NC data storage. On-line factory management system for handling material request, receipt and operation and labour monitoring using shop floor terminals.	$15m on CIM system over next two years but each part has to be justified on ROI. (CIM department in support of company strategy).	Interactive graphics. CAE.
Agricultural components manufacturing	Group technology. FMS. CAD/CAM.	Automated storage and material handling. Full logistic control of materials for tractor assembly. (Goods receiving > stores > assembly > stores > despatch). Shop floor data collection system based on lighten identification of operators and work used to monitor production inventory, cost and labour (time and attendance monitoring).	ROI will impede CIM development. Concerned with effects of CIM on people and organisation. Waiting for a turnkey CIM system. Mini and micros to be used.	Policy of buying technology rather than developing their own.
Computer manufacture and manufacture of PCBs and electrical circuits.	CAD/CAM. NC machine. FMS. Computerised process planning.	Very little but has established a network between head office and remote factories.	Started using mainframes for accounts and payroll then extended use to inventory and production control.	Plan to create a decentralised engineering database.
Heavy electrical equipment manufacture, consumer electronics and industrial electronics.	CAD/CAM. NC machines. Computerised process planning. Mainframe.	Very little but achieved data transfer between CAD and the mainframe.	Integration is being pushed through for the heavy engineering division but will take 10-20 years to finalise.	Plans to install a wide area network to connect head office to regional offices. Set up a total information systems division to establish standard for languages and methods for CIM.
Manufacture machine tools and related electronic equipment.	CAD/CAM. NC machines. FMS. Computerised process planning.	Making little headway but has established a database for business systems, i.e. production control, purchasing, stock control, etc.	Started with an FMS and a CAD system and then transmitted data between the two by the use of floppy disks.	Plans to transmit data directly from the CAD system to the FMS and intend to introduce more FMS cells.
Earth moving equipment manufacture. World wide corporation - catalogue products.	FMS. Advanced island of automation including: • Robotic applications	Standardised on computer hardware manufacture - make CIM achievement easier.	Strategic justification of projects based on overall plant, cost and delivery.	Following a policy of standardisation.

	• CAD/CAM • Process planning • Simulation • MRP	Single corporate department to set company standards. Database philosophy - no duplication of data. Distributed databases but common libraries.		
Domestic appliance manufacture.	Completely new product (rationalised replacement model range). New designs. New production methods. Automated with robots.	On-line programmable controllers with diagnostic and trouble-shooting capabilities linked to a central controller. Includes on-line quality control testing. In process inventory monitoring. Electronic order entry system. Sub contract CAD/CAM for product design and tooling design.	Studying the market requirements, designing a product which meets the requirements, finding the best way to manufacture and using technology as appropriate. Emphasis on simplicity of product, of approach, of factory layout.	High sensitivity of market to price and quality is a limiting factor.
Tool and die plant of major car manufacturer.	CNC machines. Co-ordinate measuring machines. NC laser cutting. Electro-discharge machining.	Data collected from a clay model using a co-ordinate measuring machine, smoothed by a mini computer which is passed to a CAD. This produces an NC program which is downloaded to a supervisory machine on the shop floor. CAD integration of draw die geometry. CAD and co-ordinate measuring of finished die is linked in a feedback loop. DNC link to shop floor machines.	Investment justification is 30% payback within the first year.	Growth is limited due by the business approach.
Heavy electrical industry including turbines, etc.	Robotic and automation cells. 600 CAD/CAM workstations. 253 modules control software (MAAPICS and COPICS). OPT.	CAD/CAM/CNC machine linking with automatic machine and production monitoring. Flexible sheet metal profiling system driven from CAD. MIS (Manufacturing Information System, CAD/CAM and CAE).	Productivity improvement. No CIM plans, but has corporate systems integration group. Movement away from mainframes to distributed computing. Concerning in analysing the organisational structures, people activities, time and inventory management.	Size and complexity of organisation limits the growth of CIM.
Space products.	CAE. CAD/CAM. Automated store. Generative part process planning. Distributed database.	Tried to establish a monolithic database but it became four divisional databases. It took four years to create. Building a totally integrated system for the engineering, manufacture and test of printed circuit boards.	In this industry, progress is driven by the technology, usually with an individual champion for each technology. Departments are elitist and preserve their independence. This creates incompatibilities of equipment with considerable communication barriers.	A 30 man team been set up to implement CIM.
PCB manufacture. Computer hardware manufacture.	Automated electronic assembly. Automated storage. Production monitoring and control.	CAD/CAM link supplying part programs to automatic electronic assembly m/cs. AS/RS of parts with controlled make up and supply of parts to the shop floor to meet the schedule. In process production monitoring and production control using presentation of current status.	Committed to CIM both as a user and a supplier.	A plan has been drawn up for long-term.

Worldwide organisation supplying consumer products such as lighting and batteries, also equipment for industry.	Advanced in most areas of manufacturing technology, in particular robots and variable transport systems.	None.	High costs technology difficulties limits CIM progress.	Have concentrated on establishing equipment and communications standards for use throughout their corporation and will continue to do so.
Car body manufacture and assembly.	Robotic applications. FMS. AGV wire guided handling systems. CAD/CAM. CAE.	Very little actual progress. Its interpretation of CIM includes only CAE, CAD/CAM, CNC and off-line robot programming, not business systems.	A radical shortening of design lead times and setting up of the production facility. Integration of design and manufacturing facilities.	Plans include off-line programming and simulation of automated manufacturing cells incorporating the use of robots. They will establish a department for CIM development.
Suppliers of assembly robots and fully integrated assembly systems. Manufacturers of NC co-ordinate measuring machines.	No advanced technology used although the company manufactures advanced technology systems.	None.	Emphasis on product and systems engineering.	Just starting to consider advanced technology such as CAD. Customers have little awareness of CIM and this lack of demand has impeded CIM development by equipment suppliers.
Special machine tool and cutting tools manufacturer. Mostly one-off build.	CNC machines. QNC co-ordinate measuring machines. FMS. CAD/CAM. Company wide database information system.	Pre-sale linked through CAD/CAM as bases for routing NC programming and QNC performance assurance including simulation for collision checking. Automatic link to business systems through BOM. Master schedule drives engineering , purchasing and manufacturing systems. It is the master schedule and BOM which drive the machine shop, purchasing and stock room.	Strong leadership, harsh rationalisation and simplification in pursuit of CIM.	To continue to invest in CIM to enhance the current high level of integration.

Sakakibara and Matsumoto (1991) described CIM implementation in a plant manufacturing electronic car components. These products include electronic fuel injection, automatic air conditioning, skid control, transmission control, suspension control, etc. They suggested that their plant (Kota plant) was required to meet customer needs quickly and produce satisfactory products in terms of quality, cost and delivery to overcome tough competition and maintain growth. Their products are produced under high variety and different batch sizes. The authors reported that one of the solutions to their requirements was to implement CIM in their plant.

The CIM project at Kota plant was started by developing the manufacturing systems from a point at the process level (spot). The level was upgraded to a line then to an entire process level (area) including parts manufacture, inventory and inspection. The last stage of the plant development was the introduction of CIM, to upgrade the production system at plant level (cubic) to keep up with modern trends such as product variety and frequent changes. Figure 3.1 illustrates the stages of CIM development stages in the Kota plant.

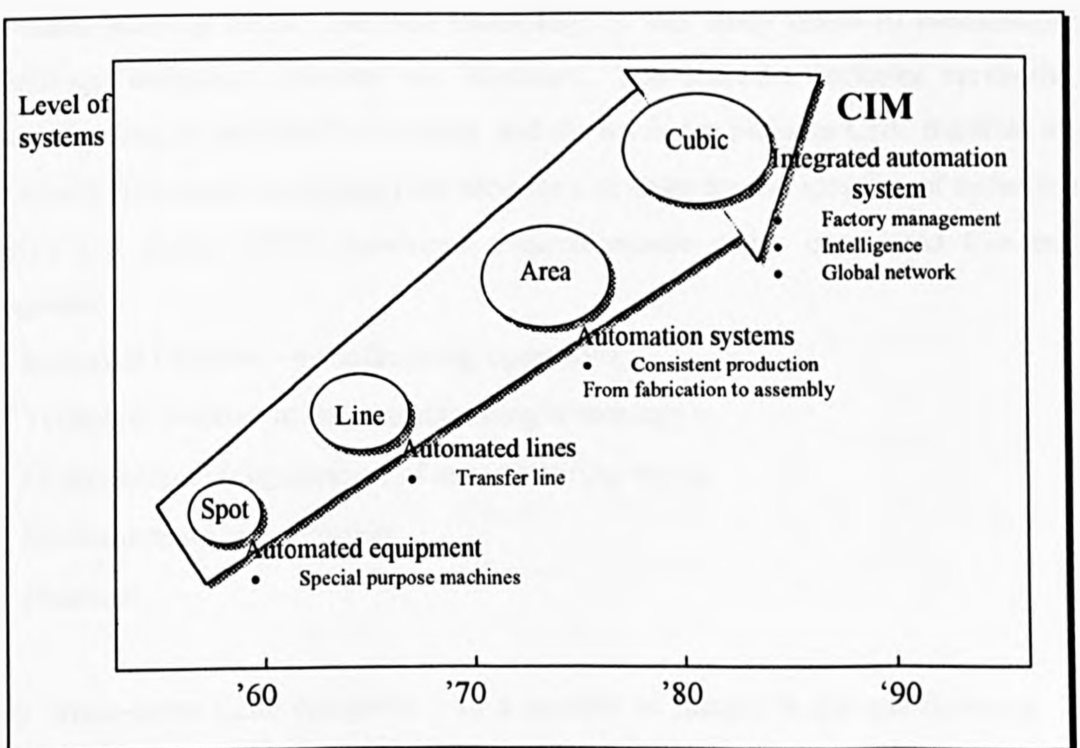


Figure 3.1 Evolution of CIM in Kota plant.

Kota would like to make their plant a global centre for their electronic business development; hence they have decided to complete a CIM plant for electronic car components under the concept of an 'Integrated electronics factory in pursuit of an ideal

JIT system'. They have built a CIM plant called 'UTOPIA KOT' incorporating the following concepts:

1. Pursue an ideal JIT environment;
2. Make the most of the information network: co-operating with other functions such as sales, engineering and production departments and speeding information flow;
3. Build up known-how: develop and make active use of in-house products;
4. Make an easy-to-use system with sufficient reflection and feedback from the operational level;
5. Establish a production system of higher productivity and quality: develop an integrated automated line for electronic components.

Sakakibara and Matsumoto (1991) anticipated that the car-electronic business will be even tougher in the future; hence, they need to strengthen their plant more and more according to CIM concepts and implement the global integration step by step.

Pandya and Satyre (1996) presented the findings of a survey which investigated the decision-making process involved in the implementation of new technology within the UK manufacturing sector. The new technology in this study refers to manufacturing technology including software and hardware. The software includes spreadsheet, database packages and MRP II systems, and the hardware includes CNC machine tools and robots. The study emphasised the need for a strategy for the adoption of technology. Pandya and Satyra (1996) developed a questionnaire which considered five major categories:

- Industrial relations - manufacturing operations;
- Technical (relative to the manufacturing technology);
- Organisational (organisation of manufacturing work);
- Environmental and pollution;
- Financial.

They broke-down these categories into a number of factors in the questionnaire. The questionnaire was divided into three parts based upon the following:

- The reasons for implementing the new technology.
- The degree to which the factors (financial factors, background of organisation, image of the brand) would affect the organisation's decisions to import new manufacturing technology.

- The organisation's priorities for the next two years.

They analysed the results of the questionnaire in different ways: analysis per group of factors and according to company size. Table 3.3 presents a summary of the results and ranks the factors identified in order of importance.

Factor	Importance
Design flexibility	Quite important
Improving product quality	Quite important
Reduce the product price	Quite important
Decrease scrap (environmental issues)	Quite important
Standardise manufacturing	Quite important
Reduce overheads and non-value adding costs	Quite important
Reduce scrap	Quite important
Enable skilled staff movement between machines	Quite important
Reduce WIP and stocks	Important
Delivery performance	Important
Simplify/improve control over production process	Important
Improve management control	Important
Improve security	Below average importance
Replace men by machines	Below average importance
Support an automation policy	Below average importance

Table 3.3. Important factors to AMT in industrial organisations (Pandya and Satyra 1996).

By comparing the factors identified in the above study with CIM benefits presented in chapter-2, it can be concluded that the CIM strategy meets these organisational requirements.

Lay (1993) presented an analysis of how companies in Germany have planned and implemented their CIM structures. The findings of the study indicated that CIM projects were primarily intended to reduce lead times. Other objectives such as increased flexibility or improved quality were considered far less important. German organisations were predominantly trying to reach their goals by implementing new technologies, and the personnel and organisational dimensions of CIM appeared to play an important role.

Many other organisations are turning to CIM as a strategy for sustaining competitive advantage. Recent studies demonstrate practitioner recognition of the importance of CIM as a competitive weapon. McGaughey and Roach (1997) reported a number of surveys concerned with implementing CIM. Their review of these studies can be summarised in the following points:

- 81% of executive and manager in US manufacturing industries regarded CIM as essential or very important as a competitive weapon;
- 66% felt that CIM was an important cornerstone for world-class manufacturing;
- 134 IS (Information Systems) managers in manufacturing organisations identified system integration of operations with other areas of the organisation as their most pressing concern;
- 40% of American manufacturers have one or more elements of CIM in place;
- 75 American manufacturing vice-presidents ranked key strategic and tactical issues facing American manufacturers in the next three or five years, which included:
    - Process technology (adopting new process technology and integrating it with other manufacturing systems);
    - Inter-functional integration (integration of functional areas to achieve better co-ordination);
    - Product planning (providing effective and efficient process capabilities);
    - Manufacturing planning and control (matching methods with desired results);

In the UK, NEDO (1985) produced a study concerned with Advanced Manufacturing Technology. This study demonstrated that manufacturing companies who successfully implemented new technology decided on the change for a number of reasons; the most common reasons were:

- To survive increased competition;
- To increase their market share;
- To increase profitability;
- To replace old and inefficient equipment;
- To meet market demands for shorter lead times and better quality;
- To introduce new products faster.

In addition, many other studies stressed the importance of using state-of-art technology such as CIM to achieve organisational goals.

However, adopting CIM has been accompanied by many problems in many manufacturing organisations and led to sustained high costs (McGaughey and Roach, 1997, Attran 1996). These poor experiences have made many organisations reluctant to implement CIM. Some CIM failures have also been reported, e.g. it has been estimated that the failure rate for AMT, such as CIM, may be 50% to 75% for US organisations

(McGaughey and Roach 1997). Hence, many organisations are reluctant to develop and implement a CIM strategy. This may refer to two major factors: the high failure rates for CIM in organisations who have already implemented it and other obstacles and problems related to developing and implementing CIM systems. The next section describes the various obstacles to CIM and reviews recent studies of CIM implementation.

3.3. Obstacles to CIM Implementation

Researchers and practitioners of CIM strategy have identified many obstacles to successful CIM implementation. These factors have a direct or indirect impact on CIM progress. A great deal of research work is still required to investigate these problems and complexities and derive the appropriate solutions.

3.3.1 CIM Complexity

Complexity is often reported as one of several barriers to implementing a CIM strategy (Bessant 1985, Fossum and Ettlie 1990). Lin et al (1992) described CIM as a very broad and complex mix of concepts and strategy including the integration of many elements such as computers, machines and the management of the business. System complexity increases relative to the number of system activities and elements interrelated. Doumeingts et al. (1995a) reported that CIM is extremely complex, because it involves not only technical aspects but also economic, social and human aspects. CIM complexity may refer to the general difficulty of the interrelationship between several components and elements. Zeidner (1990) linked the size and complexity of CIM to that of the enterprise "...the size and complexity of a CIM system depends largely upon the size and complexity of the enterprise, its complexity is compounded by a variety of other factors. CIM systems consist of a collection of software package distributed across a network of computing hardware throughout the enterprise. The distributed nature of CIM software systems is a major source of complexity and inflexibility...". Therefore, CIM complexity means different things to different people and there are many viewpoints of CIM complexity.

3.3.2 The Integration Barrier

The development of viable technical interfaces which allow different control systems to communicate and talk to each other is one of the most critical problems of manufacturing system integration (Gupta 1996, Besant 1985). There is a relationship between concepts of the integration problem and incompatibilities between system components and elements. Therefore, system incompatibilities can be considered the main reason for the problem of integration. In addition, integration is not purely technical but includes other organisational aspects such as the integration of information systems. Weissflog (1991) considered the CIM data integration problem and identified a number of barriers to integration. These barriers included:

- Inadequate representation of data required for different elements of CIM;
- Informal expressing of the data interdepencies among the various fractions of CIM including data development process control;
- Incompatibility of data exists owing to individual and incompatible data definitions and formal representation of constructing common data to different system applications;
- Complexity of data structures such as BOM.

Schulte et al. (1992) also believed that the major problem of CAD and CAM lay in the representations and transformation of information among design and manufacturing activities.

Recently, Mejabi and Singh (1997) considered the problem of integration in CIM. This attempt tried to analyse the integration by dividing the integration concept into three categories: integration of control and decision making, information flow and data integration and action integration. That study also presented a framework for enterprise-wide integration to link manufacturing elements within complex and large-scale organisations.

3.3.3 Lack of Understanding of CIM and its Potential

The lack of manufacturing and CIM knowledge is one of the most significant obstacles to CIM success (Fossum and Ettlie 1990, McGaughey and Roach 1997). Shin (1996) reported that conflicting definitions of CIM within organisations, caused a lack of co-ordination among divisions. This was one of the problems identified as being commonly present in CIM projects in Korea. Lei and Sabol (1991) emphasised that the implementation of CIM in many US organisations stumbled because of difficulties in understanding the technology and organisational impediments.

3.3.4 Cost Justification Using Traditional Methods

The conventional methods of cost justification are considered to be a critical obstacle to CIM progress. Gunasekaran (1997) mentioned that traditional methods of cost justification generally fail to detect the many benefits of CIM strategy. Morris and Morris (1994) found in their survey that cost justification was a serious factor affecting the progress of CIM. Bolland and Goodwin (1988) reported that the inability to financially justify the investment dominated other concerns, such as, risk, lack of interest and a poor understanding of the benefits, as an explanation for not going a head to a head with CIM adoption.

3.3.5 Lack of Management Support and Commitment

Attran (1996) identified that ignorance and lack of management support as important obstacles to the success of CIM implementation. McGaughey and Roach (1997) divided the lack of management support into two obstacles: one related to top management and the other related to functional management. Other recent studies illustrate that the lack of management support and commitment is a significant barrier to CIM implementation (Fossum and Ettlte 1990, Moriss and Morris 1996). Thomas and Wainwright (1994) also suggested that the main obstacles to CIM success could be managerial or organisational and Ohsen (1992) emphasised that without complete management support and commitment the CIM project will fail.

3.3.6 Inadequate Planning

Lack of proper planning for CIM not only hampers its effectiveness when fully implemented, but also does not provide adequate insights into the benefits which can be achieved (Sarkis and Lin 1994). Therefore, effective organisational plans must exist to achieve the desired business goals (Attran 1996). The planning step is important in traditional manufacturing system projects, so due to the higher investment and design complexity of CIM, it is essential to improve the planning aspects of the CIM at the early stages of design. Inadequate planning of CIM strategy causes critical problems in decision-making for CIM development and implementation. Fossum and Ettlie (1990) noted that a formal CIM plan is one of the factors ranked as important and of significant help to CIM implementation.

3.3.7 Inadequate System Design

Decision making about CIM design represents a critical factor inhibiting CIM progress. This may be due to the lack of proper design tools and methodologies that can be used to select and design new systems. Jones et al. (1989) suggested that the design barriers to CIM are related to decisions that are made external to the factory.

In CIM design, it is necessary to have the foresight to consider the changes that may occur to the system during its life cycle and provide for mechanisms that will enable the modification of the system without a complete re-design (Litt 1990). It has been reported recently (Gunasekaran 1997) that despite the arguments regarding CIM flexibility, the experience in practice is that automation is frequently too rigid to adapt to changing market needs and the manufacturing of the new products. This indicates the importance of introducing flexibility of during the building of new CIM systems.

3.3.8 Inadequate Analysis of Organisation's Needs

Some manufacturing organisations inadequately analyse their needs. This problem may have many dimensions that impact on organisational growth and development strategies. Hence, organisation requirements must be described and analysed in detail when building functional specifications. Without these specifications the CIM vendors and builders will not be able to include the necessary features.

3.3.9 Resistance to Change

The lack of understanding of CIM is closely related to the resistance of humans to change. The human factor is very important to the success or failure of the new technology and/or strategy. When CIM is introduced, every department, manager, supervisor, operator, designer, etc. is asked to give information, develop databases and change work systems. Many people understand that CIM eliminates humans and does not support them. Weatheral (1992) reported that it is necessary to build up an awareness of CIM and that the innovation must be communicated to all levels of the company. Recently, Mital (1997) considered the role of humans, and emphasised that they are essential to contemporary manufacturing and will remain so far for the foreseeable future. He also considered the role of humans in the CIM environment and outlined a systematic procedure for allocating functions to humans and machines/automated equipment. The study identified many roles and goals for human intervention.

3.3.10 Lack of Proper Modelling methods and Techniques

It has been identified that CIM is very complex composed of many interrelated elements. Hence, the need for adequate modelling methods and tools to design and analyse CIM systems exists. Hassard and Forrester (1997) reported that the existing methods for the analysis, design and development of CIM bring with them a number of shortcomings such as:

- A failure to link the development and operation of CIM to other important strategies such as corporate and marketing strategies;
- A neglect of organisational aspects during designing and implementing CIM systems;
- Existing modelling methods are mainly designed to be used in large organisations, so little attention has been paid for modelling Small and Medium Sized Enterprises (SMEs);
- Methods tend to be of a structural or architectural type: they are not process-oriented and so provide little by way of guiding principles for system design;
- Methods tend to prescribe a structure rather than providing the adopter of CIM with means of analysing and evaluating systems and strategies.

Chen et al. (1990) reported that even the most sophisticated methods and techniques for CIM design and analysis are useless unless they are integrated with other supports. Therefore, CIM modelling methods are needed to describe the operations and activities that occur within the growing number of increasingly complex CIM components. These needs will be discussed in detail in the next chapter.

3.4. Recent Studies of CIM Obstacles

Several articles and reports have investigated the obstacles, barriers or problems to CIM success such as Bessant (1985), Ingersoll Engineers (1985), NEDO (1985), Bolland and Goodwin (1985), Morris and Morris (1994), Attran (1996), and McGaughey and Snyder (1994).

Recently, problems and obstacles to CIM have been surveyed and analysed. Two major studies, which have been carried out by McGaughey and Roach (1997), and Gunasekaran (1997) are reviewed in this section.

McGaughey and Roach (1997) investigated practitioner perceptions of problems and complexities inhibiting CIM progress. In their survey, one hundred and one participants ranked the importance of barriers believed to influence CIM success. They used statistical methods to analyse their findings and grouped the results into four groups: commitment of resources, strategic concerns, organisational receptivity, and human resistance to change. Table 3.4 shows the results of the factor analysis of the obstacles perceived to have major impact on CIM success.

Table 3.4. Findings of survey study identifying obstacles to CIM (McGaughey and Roach 1997).

Factor	Obstacle
Commitment of resources	1. System incompatibility. 2. Inadequate equipment. 3. Unrealistic expectation. 4. Inadequate system design. 5. Key people are usually over committed. 6. Inadequate funding. 7. Inadequate communications. 8. Lack of people with technical experience. 9. Insufficient education and training of managers and workers. 10. Management averse to risk of investing in new technology.
Strategic concerns	11. Inadequate planning. 12. Inadequate leadership. 13. Lack of top management support and commitment. 14. Inadequate analysis of user needs.
Organisational receptivity	15. Inadequate organisation structure. 16. High cost of CIM. 17. Cost justifying with conventional methods. 18. Corporate cultures no right for CIM.
Human resistance to change	19. Human resistance to change.
Uninterpretable	20. Failure to understand CIM and its potential. 21. Lack of functional management support and commitment.

Gunasekaran (1997) reviewed the literature available on the implementation of CIM with the objective of gaining an insight into the integration and adaptability issues such as strategic perspectives, and technological, operational, behavioural and organisational issues. That review identified the most critical and pressing issues in the practical implementation of CIM. Table 3.5 summarises the results of the study carried out by Gunasekaran.

Table 3.5. Review of previous CIM research: factors affecting the implementation of CIM (Gunasekaran 1997).

Issues	Manufacturing industry	Integration		Adaptability	
		Problems	Strategic/policies/ Technologies	Problems	Strategic methods
Strategic issues	General	Absence of total management system	Top management support	Lack of knowledge about CIM	Highly skilled workforce
	General	Barrier to automation, Lack of investment justification methods	New cost accounting systems (ABS).	Lack of co-operative supported work and justification methods	Activity based costing Training in sophisticated and proven functional analysis.
	General	Management of information, Mechanical integration	Compatibility of MIS, CAD/CAM, ISO 90001, logistics planning.	Information	Building CIM teams, Common database, A time-based implementation, Computer supported collaboration.
	FMS	Alignment between business and manufacturing strategies, flexibility	Capital investments, CAD/CAM, FMS, top management support.	Top-down business oriented strategy.	Team efforts, Human competence re-engineering
	Manufacturing	Lack of information technologies	Organisational system design.	Handling variability	Investment in flexible technologies
	Manufacturing	Lack of user involvement and tolerance	Innovation, Gradual implementation process	Organisational learning and change.	Implement enough of the technology, users involvement and tolerance

Organisational issues	General	Absence of total management system	Top management involvement, Reorganisation	Lack of knowledge of CIM, Discouraging measurement system	Highly skilled workforce, Training and education, ABC
	Manufacturing	Lack of human machine interaction	Infrastructure flexibility, Compatibility, Organisational change. Communication	Lack of business process characteristics and quality of work life	Self-autonomous teamwork, Joint optimisation of technology and organisation
	Manufacturing	Lack of integration technologies	Organisational system design	Handling variability and conflicts.	Investment in flexible technologies
	Manufacturing	Lack of user involvement and tolerance	Innovation	Organisational learning and change	Implement enough of the technology
Behavioural issues	General	Lack of flexibility and reduced work force	Manned control room, Employee participation	Lack of motivation	Computer training and training in self management and conflict management
	Manufacturing	Safety requirements	User participation, Use of sensors on the shop floor, Top management support, Organisational change	Difficulty in operation and maintaining the CIM system	Account for human factors in the early stage of planning CIM system, Proper training, Human machine interaction, Safety enablers
	Manufacturing	Lack of human involvement in the implementation of CIM	Organisational change, team work	Resistance to change efforts	Training with the help of suppliers, Job enrichment
	Manufacturing	Lack of co-operation	Collective intensive scheme. Logistics re-engineering	Lack of action-oriented studies	Workers' pride and positive attitude, Evaluation and training
	General	Lack of top management support	Executive training on CIM	Risk of production loss	Gradual implementation
	Manufacturing	Installing an integration business system	Management involvement, personality and strength of the project manager	MRP II system installation	Education and training.
Technological issues	Manufacturing	Incompatible computer systems	Computers, Standards in data communication, Robots, CAD/CAM, AGVs	Insufficient internal skills	Education and training in new technologies
	General	Lack of-co-operation between and management information systems and manufacturing	Bottom-up approach to production operations by integrating systems and devices on the shop floor	Lack of management information system	Top management involvement in the process of selecting software and hardware
	General	Lack of integration enterprise engineering	Information engineering approach, FMS, Robot, AGVs, EDI, CE.	Inability to migrate to future technology	Top management commitment and worker involvement
	Manufacturing	Lack of infrastructure	Build interfaced systems	Lack of understanding and co-operation	Global sharing of data, Training and education
	General	Communication systems	Radio, Frequency data communication system	IT strategy must offer a consistent approach	Reliable vendors Material handling systems
	Lumber industry	Short tool life, Frequent job changes and long set-up times	Computerisation and communication quality improvements	Lack of co-operation from employees	Empowerment, job enrichment, Incentives, Training and education

Operational Issues	Manufacturing	Lack of communication system and integration	Computers, Automation, Standardisation, Protocols	Market needs, Quick response, Competitive price	Highest and fastest potential payoffs, Top management, Integration of all components
	Service industry	Integration of all functional areas, Total integration of all functional technology.	Computer integration	Lack of suitable information systems and technology	Global information technology, Single-source data entry, a similar 'look and feel' for all applications 'user seductive' interface, online education
	General	Integration of all functional areas	Functional integration by computers, Prototyping	Lack of infrastructure	Program integration, Concurrent engineering, collaborative co-ordination
	Manufacturing	Integrated factory using various technologies	Networking, Automation	Multiple vendors software security	Skilled workers in networking and software
	General	Environment problems	Organisational structuring, computers		Systems development life cycle approach

3.5. Discussion and Conclusion

This chapter has reviewed previous research work concerned with CIM implementation in industrial organisations. Different problems and obstacles to CIM progress have been identified by many researchers and practitioners.

However, the following points can be concluded from this chapter:

- The introduction of new technology or adoption of new strategy should be preceded by a review of similar existing systems. This would be helpful and provide a valuable learning experience. In addition, the real cases give obvious examples of the advantages and disadvantages of the strategy being selected or planned. Learning from practice can be achieved through many resources such as survey studies, practitioner interviews and project proceedings and reports.
- Not all manufacturing organisations that have implemented CIM have enjoyed the same degree of success.
- All of the experience suggests that the process of developing a good manufacturing strategy is difficult in its own right and probably impossible without the involvement of several important factors such as knowledgeable users, management support and CIM experience.
- Despite the great advances made in recent years in manufacturing and computing technologies, CIM is still very complex and may get more complex in the future.

- The CIM strategy should fully support the objectives of the business strategy. This may be achieved by an adequate analysis of the organisation's needs, and the proper planning for CIM to use full the potential and benefits of this strategy.
- Implementing CIM requires basic foundations to be established in the organisation being considered. To put in place these basic foundations, several changes may be important such as redesigning and restructuring organisation functions before implementing or developing the new technology. Modelling methods and techniques play a very important role in redesigning and restructuring organisational systems, including information decision and physical systems, and defining functional specifications.
- Problems and obstacles to CIM success are closely related to each other. For example, lack of understanding of CIM leads to increased system complexity and integration problems. Judd et al. (1990) reported that much of the difficulty could be traced to the complexity involved in the integration of computers and manufacturing processes.
- A major study carried out by Ingersoll demonstrates that the lack of a detailed strategy was a major factor in the failure to implement CIM.
- The chapter demonstrates that modelling methods and techniques should be given more attention. Modelling methods have an obvious contribution to make in solving many obstacles to CIM implementation. Without appropriate modelling methods, analysing, designing and planning CIM and its components is a very complex task. The next chapter will review several modelling methods and methodologies which have been widely used for modelling manufacturing systems and computer integrated manufacturing.

CHAPTER-4

CIM MODELLING METHODS AND TECHNIQUES

4.1. Introduction

This chapter discusses important themes related to CIM systems modelling. Several modelling terms such as method, tool, technique and a methodology have been used to denote the modelling concept. These terms are defined in this chapter. The modelling concept has been used for several purposes; therefore, this chapter presents some classifications of modelling and illustrates the role of modelling in CIM systems. The complexity of CIM modelling is also discussed.

During the review of previous work it was found that many modelling methods could be used for the analysis and design of CIM systems. This chapter reviews these methods and discusses their strengths and weakness.

Computer simulation plays an important role in modelling the dynamic aspects of manufacturing systems. Appendix-B reviews simulation modelling concepts, its importance as a modelling method, its advantages and disadvantages. Different types of simulation language and manufacturing simulators are discussed. The selection of the most appropriate simulation tool for a manufacturing application is a difficult problem which is discussed in detail in Appendix-B.

4.2. Modelling

Savolainen et al. (1995) indicated that the term "modelling" means different things to different people - even within the context of CIM. Therefore, many different definitions for modelling are available. In general, modelling is the activity that concerns the construction of system models, either for analysis or design purpose. Hence, analysis models refer to a description of an existing system and design models refer to new system specifications and development.

Models of a system are representations with the specific purpose of helping to understand some aspects of the systems, by emphasising relevant features and de-emphasising irrelevant ones (Planche 1992). The Oxford Dictionary defines a model as " a representation of something, usually smaller than the original; or a simple description of a system". A model is an abstraction, a representation of a part or a whole of a real system which can be used to represent some aspects of a system such as the information sub-system, decision sub-system or physical sub-system.

Other terms such as methodology, method, technique and tool are widely used in modelling. Because of the problems and conflicts of understanding the basic concepts of these terms, and to use these terms correctly, it is necessary to define them in this section. Doumeingts et al. (1995) reported that the term " methodology" means a set of methods which includes reference models, modelling formalisms and a structured approach. Czernik and Quint (1992) define a methodology as "theories about methods and their scientific applications". The term "methodology" can be definied as a collection of procedures, techniques, tools and other supports such as rules and documentation aids which will help the system analyst and designer to implement system models.

A method can be understood as a problem solving process described as a system of rules or a collection of procedures (techniques) that support system analysis and/or design (Czernik and Quint 1992). A technique is a way of doing a particular activity in the system being modelled. A technique may use one or more tools. The distinction between a technique and a tool is that a tool is an ordinary problem solving procedure which usually exists as a software product. Both techniques and tools are means or features used in methodologies.

4.2.1 Classification of Models

Models have been classified in different ways based upon different factors ranging from tangible to abstract, correspondence to the system being modelled or their static and dynamic behaviour.

McMillan and Gonzalez (1973) classified models into three main categories: physical, schematic, and mathematical models. A physical model retains some entities of the system being modelled and can be constructed from a set of physical objects. Schematic models are representations in pictorial form and include various degrees of abstraction such as flow diagrams. Elements such as lines, symbols, etc. are used in this type of model. Mathematical models consist of sets of equations that give solutions which explain or predict changes in the state of the system.

Planche (1992) divided models into three main types ranging from the more tangible to the more abstract. The three types are the physical model, the logical model and the conceptual model. Planche's definitions of these are:

- The physical model also called the implementation model, describes the system: data flows, processes, automated components and manual components;
- The logical model also called the essential model, models data and the processes which manipulate them; this model can be used as the basis of the physical model and disregards any reference to material resources;
- The conceptual model also called the semantic model, describes the basic contents of the logical model, that is, information and how it is connected; this model disregards the data manipulation described at the logical level. Figure 4.1 illustrates each type of model with its own specific components.

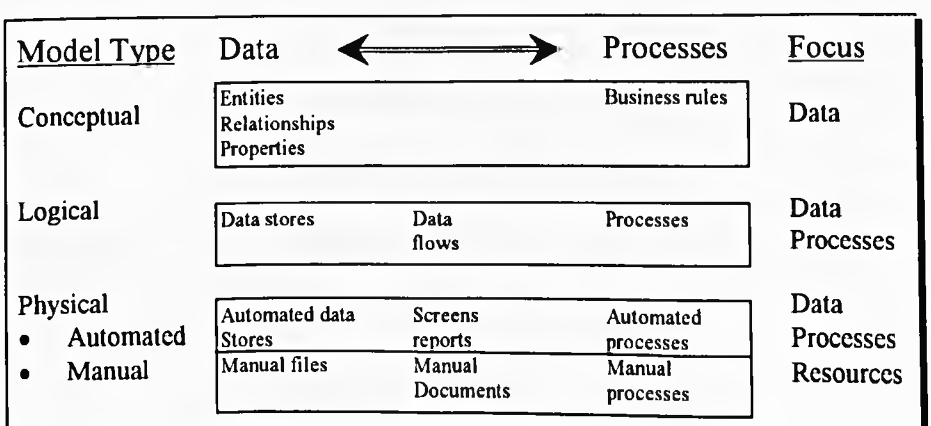


Figure 4.1. Components of various types of models (Planche 1992).

Askin and Sandridge (1993) classified models into two main groups: physical models and mathematical models. They classified mathematical models in two different ways based upon model output (descriptive such as simulation models or prescriptive such as linear programming models) and computational form (analytical such as queuing theory or experimental such as simulation models). Doumeingts et al (1995a) also distinguished between structured models and simulation models "... the structured models define the basic concepts, the elements and the relations between these elements from a static point of view. Simulation models, take the concept defined in the structural models and introduce the time factor: they take the dynamic evaluation of the model into account...". Wang and Bell (1992) classified modelling methods along three main dimensions: modelling objective, abstraction levels and modelling formalisms. In the modelling objectives, models are classified according to the way they are used to deal with the system objectives (evaluative, evaluative/generative and generative). In the abstraction levels, modelling methods vary in terms of the logical details which can be contained within the corresponding models. The abstraction levels can be structural, approximate or detailed. In Modelling formalisms, the modelling method classification is based upon the way in which manufacturing knowledge is presented. Modelling formalisms can be algorithm, graph, Markov chain, simulation technique or artificial intelligence. Figure 4.2 illustrates that classification of modelling methods.

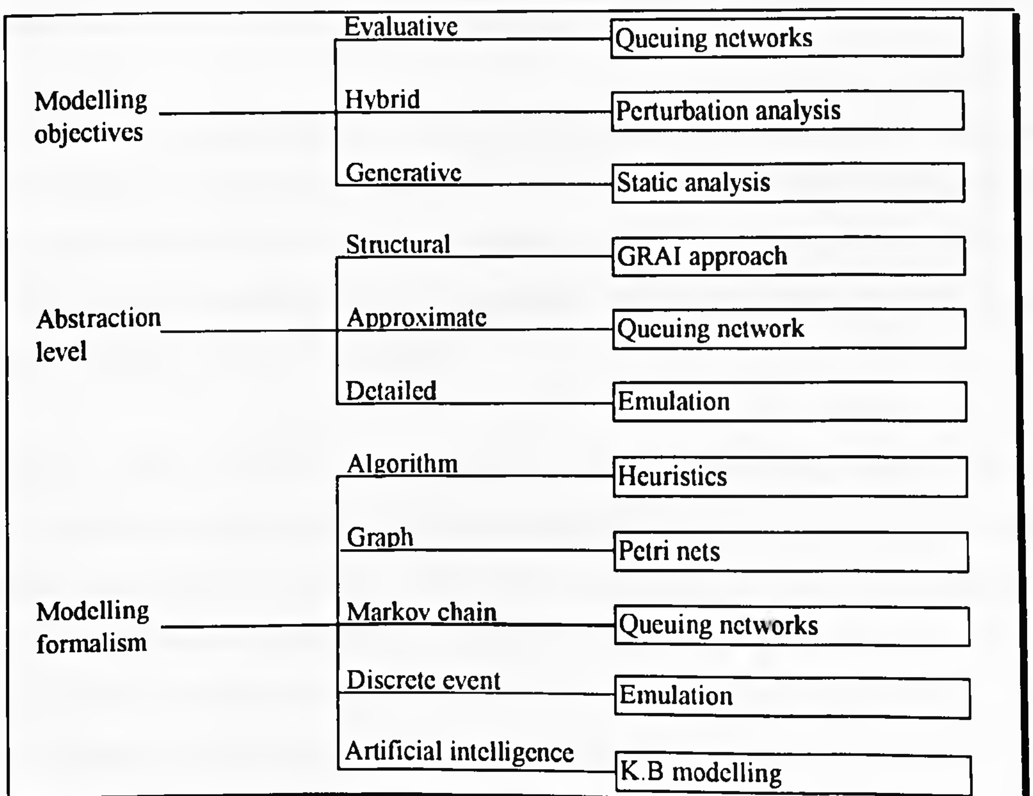


Figure 4.2. Classification of modelling methods (Wang and Bell 1992).

4.2.2 Reasons for Modelling

The need for modelling methods is particularly relevant with complex systems such as CIM systems (Brandimarte and Cantamessa 1995). Salvolainen et al. (1995) reported that models are mainly used for two reasons:

1. Models are helpful to understand existing systems. Therefore, each time an analyst and designer start an action, they will need a formalised description of the problem domain.
2. During the different phases of a system development life-cycle, the target system is modelled at several levels of abstraction leading to a consolidated system implementation phase.

The above reasons for modelling are focused on understanding and simplification of the system being modelled. Askin and Sandridge (1993) reported five primary uses of modelling:

1. Optimisation: obtaining the best value for decision variables;
2. Performance prediction: examining and checking potential plans;
3. Control: aiding the selection of desired control rules;
4. Insight: providing a better understanding and representation of the system being modelled;
5. Justification: aiding selling decisions and supporting viewpoints.

In CIM, there are three important development stages, namely, analysis, design and implementation. Powerful modelling methodologies and techniques are requested to achieve the requirements of these development stages. To understand the concept of analysis, design and implementation, the question "what are systems analysis, design and implementation?" must be answered.

It should be noted that the system modelling, analysis and design are inseparable notions. Modelling is used to describe system means; therefore, a model is the analyst's description of a system. A system analysis can be defined as a stage in development cycle in which a real-world problem is examined to understand its requirements without planning the implementation stage (Savolainen et al. 1995). The system analysis phase should consider several system aspects to determine why the problem exists and why certain methods of work were adopted. The results of the analysis phase are used for designing the new systems. During the design phase, decisions are made about how problems can be avoided or solved. The design phase should determine system inputs, outputs, process alternatives, etc., which are important for building the new system. The analysis and design phases can be divided into several sub-stages and carried out in several steps. An implementation phase can be carried out using various procedures based upon the system elements that have been prepared in the design phase.

CIM analysis and design are very complex tasks; therefore, modelling methods should be developed and adopted to contribute to solving the complexities of these systems. Manufacturing organisations need modelling methodologies and techniques to deal with the different stages and aspects of implementing new manufacturing strategies. Modelling methods are required due to several factors such as increasing analysis and design requirements, the growth of industrial organisation size and complexity, the need to consolidate an organisation's future, the advent of new technology and strategies, and the increasing need for the development of integrated manufacturing systems.

4.3. Complexity of CIM Modelling

Modelling is the key to integrated manufacturing systems. However, the questions are how to select, develop and use modelling methodologies and techniques, and how to model, analyse and design CIM. The CIM modelling problem may refer to different CIM components and elements such as CAD, CAPP, CAM, CAPP, JIT, MRP, etc. Hence, it would be difficult to survey all these system models (Savolainen et al. 1995).

CIM modelling looks quite complex to analysts and designers because:

- The structuring and optimisation of CIM modelling requirements.
- Lack of understanding of CIM strategy.
- Different viewpoints about CIM objectives.
- Lack of proper modelling methods and techniques.
- Interaction between different CIM sub-systems such as information, decisional, and physical sub-systems.

4.4. Review of Modelling Methodologies and Techniques Applicable to CIM

Many modelling methodologies, techniques and tools have been used for the analysis and design of CIM systems. Some of these methods originated from fields outside system analysis e.g. Entity Relationship diagrams (ER), Petri nets and mathematical programming models. Others have been specifically developed for system analysis and modelling such as Integrated Computer Aided Manufacturing (I-CAM) techniques (Brandimate and Cantamessa 1995). These modelling methods have different characteristics which are appropriate for systems analysis and design. On these other hand, the modelling methods have some drawbacks.

During the review of previous work, many modelling methodologies and techniques have been identified. For example, Two-Stage Entity Relationships (TSER) (Hsu et al. 1995), Petri Net (PN) approaches (Desrochers and Al-Jaar 1995), Object-Oriented Methodologies (OOM) (Gaafar and Bedworth 1994), MERISE (Rochfeld and Tardieu 1983), Input/Output Analysis (IOA) (Pandya 1995), Entity Relationship Diagram (ERD) (Planche 1992) and GRAI Integrated Methodology (GIM) (Doumeingts et al. 1995b). Some of these modelling methods are still under development, completely new, or an integration of two or more methods. The modelling methodologies and techniques which are selected for this research are SSADM, IDEF methods (IDEF0, IDEF1x, IDEF3, IDEF4), SADT, OOM, GRAI and PN. Other methods are briefly described in this chapter including IOA, GIM and MERISE. Appendix-B also reviews simulation modelling methods relevant to CIM systems.

The reasons for the selection of these modelling methods are:

- The modelling methods have graphical components. It is generally agreed that graphical representation of systems is much more comprehensive than other representations (Chodari, 1997).
- The modelling methods show the hierarchical structure of complex systems and adopt the decomposition approach.
- The modelling methods adopt the partition hierarchy concept which is useful for manufacturing system analysis and design.
- The methods are flexible and provide a conceptual model to represent a general organisational view.

- The modelling methods selected represent a comprehensive sample of modelling objectives i.e. they include data, decision, physical, process, dynamic, static, and information aspects of the systems.
- The majority of these modelling methods are widely used for modelling, analysing and designing manufacturing systems.

4.4.1 SSADM (Structured System Analysis and Design Method)

SSADM is the UK government's standard method for carrying out systems analysis and design. This method was developed by CCTA (Central Computer and Telecommunications Agency) in the early 1980s (Anon 1994). Down et al. (1988), Eva (1992), and Weaver (1993) provide a more detailed description of SSADM. The latest version of this methodology, Version 4, has seven stages (numbered from 0 to 6) within five modules. Figure 4.3 illustrates a general structure of SSADM. This structure is derived from the references listed above which have described this methodology.

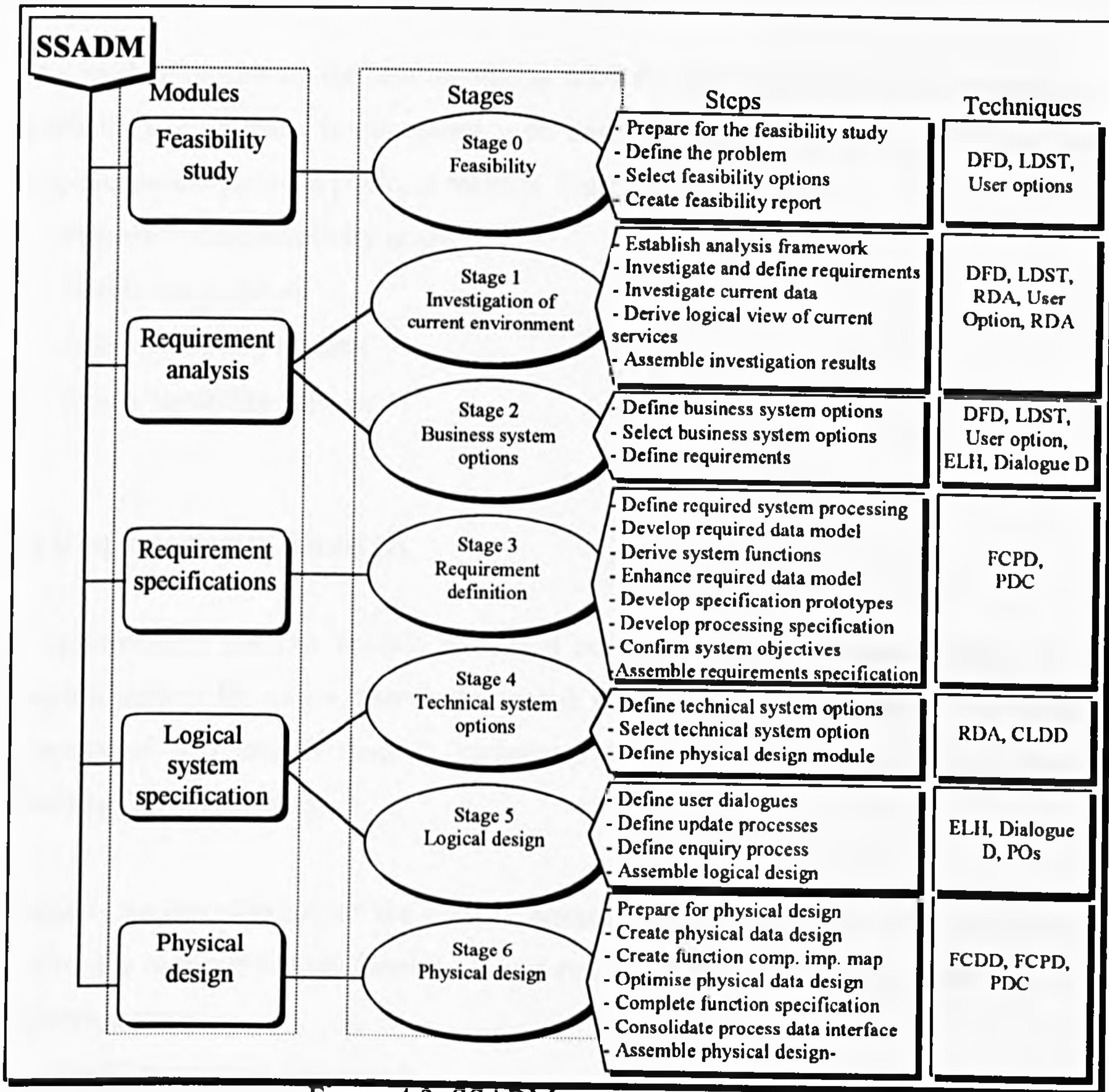


Figure 4.3. SSADM common structure.

4.4.1.1 SSADM Modules

SSADM has five modules as shown in Figure 4.3:

1. Feasibility study.
2. Requirement analysis.
3. Requirements specification.
4. Logical system specification.
5. Physical design.

These modules cover the system life-cycle from feasibility study to design. The following sections give brief descriptions of the SSADM modules.

a) Feasibility Study

This module represents the first module of SSADM and consists of one stage (stage 0-feasibility). This stage is concerned with ensuring that the project, which has been proposed in the planning phase, is feasible. Stage-0 has four steps:

- Prepare for the feasibility study.
- Define the problem.
- Select feasibility options.
- Create feasibility support.

b) Requirements Analysis

A requirements analysis module is carried out to enable a full understanding of the requirements of the new system and establish the direction of the project. This module consists of two stages: stage-1 (investigation of the current system) and stage-2 (business system options).

Stage-1, an investigation of the current system, gives more details of the work done during the feasibility study (module 1) and repeats much of that work. Stage-1 has the following steps:

- Establish analysis framework.
- Investigate and define requirements.
- Investigate current processing.
- Investigate current data.
- Derive logical view of current services.
- Assemble investigation results.

Stage-2, business system options, is carried out to determine the functionality of the new system and compare different design options. Based upon specific requirements, a set of options are selected and presented to management so that one can be selected. This stage has the following steps:

- Define system business options.
- Select business system options.
- Define requirements.

c) Requirements Specification

This module is used to identify the full requirement specifications and provide an obvious procedure for the system design stage, based upon the business option selected in stage-2. The requirement specification module consists of one stage (stage-3 - Definition of requirements which has the following steps:

- Define required system processing.
- Develop required data model.
- Derive system functions.
- Enhance required data model.
- Develop specification prototypes.
- Develop processing specification.
- Confirm system objectives.
- Assemble requirements specification.

d) Logical System Specification

This module is used to define the environment in which the system will operate and develop a logical specification for the system being modelled. It consists of two stages: stage-4 - Technical system options and stage 5 - logical design. These two stages are carried out in parallel.

Stage-4 determines the different configurations of system environment in terms of software and hardware, system strategy and functionality. It mainly concentrates on the technical options. This stage has the following steps:

- Define technical system options.
- Select technical system options.
- Define physical design module.

Stage-5 is carried out to create the logical aspects needed in stage-4. It defines system dialogue and update processes. This stage has the following steps:

- Define user dialogue.
- Define update processes.
- Define enquiry process.

- Assemble logical design.

e) Physical Design

This module is the last module in SSADM. It is carried out to translate the logical specifications into physical data design and programme specifications. This model consists of one stage (stage-6 - physical design). This stage has the following steps:

- Prepare for physical design.
- Create physical data design.
- Create function component implementation map.
- Optimise physical data design.
- Complete functional specification.

4.4.1.2 SSADM Techniques

Downs et al. (1988) described the system analysis and design techniques used within SSADM, and also presented a narrative outline case study to demonstrate the use of these techniques. That study involved the techniques: Data Flow Diagrams (DFD), Logical Data Structuring Technique (LDST), User options, Entity Life Histories (ELH), Dialogue design, Relational Data Analysis (RDA), Composite Logical Data Design (CLDD), Process Outlines (POs), First Cut Data Design (FCDD), First Cut Program Design (FCPD) and Physical Design Control (PDC). Figure 4.3 illustrates these techniques within their related SSADM stages. In the following sections, some of the techniques widely used in SSADM projects will be described.

a) Data Flow Diagrams (DFD)

A DFD is an information system technique which is used to show data flow around a system. It is very simple and uses understandable graphical symbols. DFD modelling components are process, data flow, data store and external entity (Hsu 1994). Figure 4.4 illustrates the graphical symbols of DFD components and demonstrates them in an example.

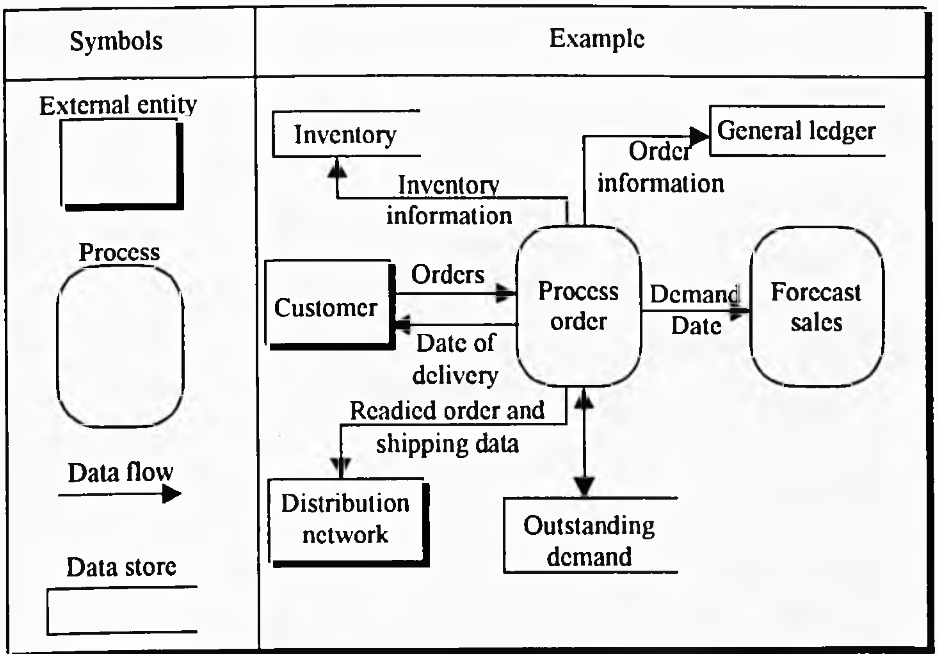


Figure 4.4. Graphical symbols and an example of DFD Technique.

The DFD shows the relationships between system components. The highest level of DFD can be decomposed into several levels to describe the basic processing units. This technique is used within stages 0, 1 and 2 in SSADM. Downs et al. (1988) reported the following objectives of a DFD:

- It graphically documents the system boundaries.
- It illustrates the flow of data between the system and its environment.
- It provides a hierarchical functional decomposition of the system.
- It documents the intra-system information movements.
- It supports communication.

b) Logical Data Structure Technique (LDS)

A LDS is an entity modelling technique used to provide a logical representation of the data requirements of the system being modelled. The main objectives of this technique are: to identify system activities, to represent the relationships between data and to identify data requirements. The LDS model can be carried out in several steps. The first step is to define system entities. Then, the LDS grid can be constructed listing all the identified system entities. This grid is a two dimensional matrix that illustrates the relationships between system entities. Following this, the LDS grid is converted into an

LDS model. Finally, the LDS model can be validated against the DFD. Figure 4.5 illustrates a LDS model.

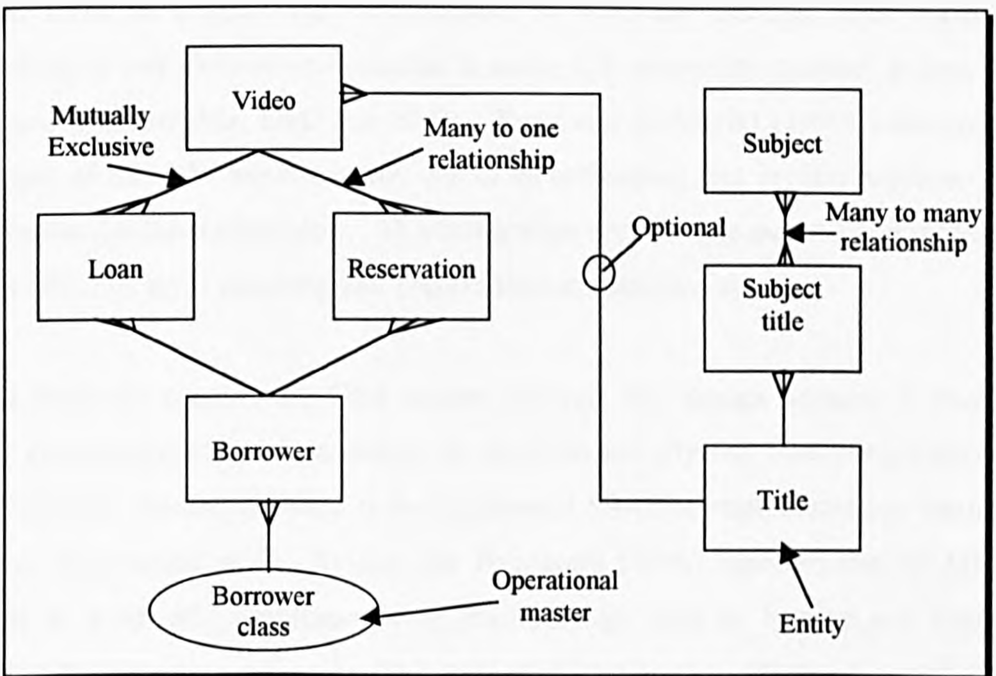


Figure 4.5. Logical Data Structuring (Gane 1979).

c) Entity Life Histories (ELH)

The main objectives of ELH are to validate DFD models, help to provide better understanding of system entities and clarify event interactions. The ELH model can be constructed using system entities identified in LDS and DFD models. Figure 4.6 illustrates the general structure of the ELH model. The diagram reads from left to right and shows the system that will be modified in some way to create an occurrence of the entity (Downs et al. 1900).

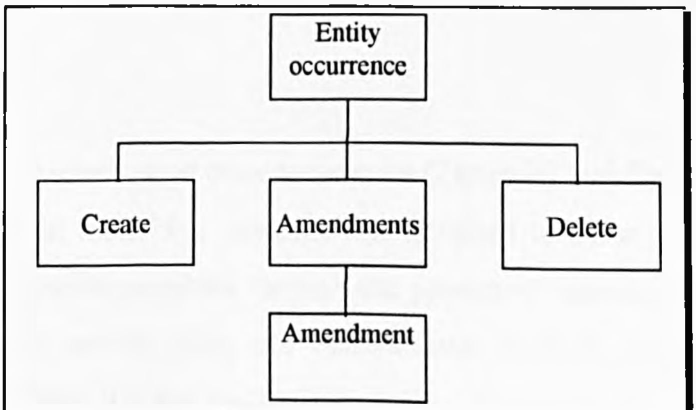


Figure 4.6. Entity Life History (Downs et al. 1988).

4.4.1.3 Discussion of SSADM

SSADM is an effective modelling methodology which uses a structured approach and graphical tools to support the development of software systems. This modelling methodology is well defined and adopted in many UK university courses. It uses three techniques, entity models, DFD and ELHs. Wyatt and Al-Maliki (1990) indicated that the strength of SSADM lies not in any one of its techniques, but in their combined use, as recommend by the methodology. This integration between the method and techniques provides effective error checking and consolidates model consistency.

SSADM does not support the CIM system analysis and design because it does not consider system time scales. In addition, the decision and physical modelling aspects are not well defined. Further problem is that successful SSADM implementation requires a high level of personal skills. Avison and Fitzgerald (1996) reported that SSADM is classified as a specific problem-solving methodology, that is, it does not focus on identifying the systems required by the organisation but begins with the assumption that a specific problem is to be addressed.

4.4.2 IDEF Methods

During the 1970s, the US air force programme for ICAM (Integrated Computer Aided Manufacturing) sought to increase manufacturing productivity using computer technologies. The ICAM programme developed a series of modelling methods known as IDEF (ICAM Definition) methods. These modelling methods are used to perform modelling activities in support of manufacturing system integration. The original IDEF methods were developed to enhance the communications between system levels and components and to illustrate how system activities were integrated or related to each other.

The original IDEF methods used three techniques (Zgorzelki and Zgorzelsa 1994):

- IDEF0 (functional modelling method) was designed to allow an expansion of the description of system activities through the process of activity decomposition and categorisation of activity data and relationships in terms of ICOM (inputs (I), controls (C), outputs (O) and mechanisms (M)).

- IDEF1 (information modelling method) was designed to allow the modelling of the information that an organisation deems important to accomplish its objectives.
- IDEF2 (Dynamic modelling method) was design to allow the modelling of the time-variety behavioural characteristics of the system activities. This modelling technique is not widely used and was replaced by modern simulation approaches (Zgorzelki and Zgorzelsa 1994).

IDEF0 and IDEF1 (usually with its last extension becoming IDEF1X) are widely used in many applications. Other IDEF methods have been developed such as IDEF3 (process flow and object state description capture method), IDEF4 (object-oriented design method) and IDEF5 (ontology description capture method). Table 4.1 illustrates the state of development of these techniques.

The following sections provide a more detailed description of the IDEF0, IDEF1X, IDEF3 and IDEF4 methods. The reason for the selection of these techniques is that they have demonstrated their usefulness as effective tools for functional, data and process modelling.

Methods	Perspective
1. IDEF0	Function Modelling
2. IDEF1	Information Modelling
3. IDEF1X	Semantic Modelling
4. IDEF2	System Dynamic Modelling
5. IDEF3	Process Description Capture
6. IDEF4	Object State Description Capture
7. IDEF5	Ontology Description Capture
8. IDEF6	Design Rational Capture
9. IDEF7	Information System Audit Method
10. IDEF8	Human-System Interaction Modelling
11. IDEF9	Business Constraint Driven Design
12. IDEF10	Implementation Architecture Modelling
13. IDEF11	Information Artefact Modelling
14. IDEF12	Organisation Modelling
15. IDEF13	3-Schema Mapping
16. IDEF 14	Network Design

Table 4.1. The IDEF family of Methods (Zgorzelski and Zgorzelsa 1994)

4.4.2.1 IDEF0 Method

a) General

IDEF0 is based upon the Structured Analysis and Design Technique (SADT), a graphical approach to system description, developed by Ross in 1970s (Gay 1993). The main objectives of IDEF0 is to perform system analysis and design, produce reference documentation to help in the development of the existing system, communicate different manufacturing entities during the analysis phase, present a better understanding of system, and present a graphical function representation for the organisation. An IDEF0 model consists of a hierarchy of diagrams, text and glossary. The diagram mainly based upon two graphical components: boxes and arrows, all cross-referenced to each other (Kusiak et al. 1994). The box represents a system function that can be defined as an activity, process or transformation. The arrows in the diagram represent data and function relationships. Figure 4.7 illustrates the basic IDEF0 concept.

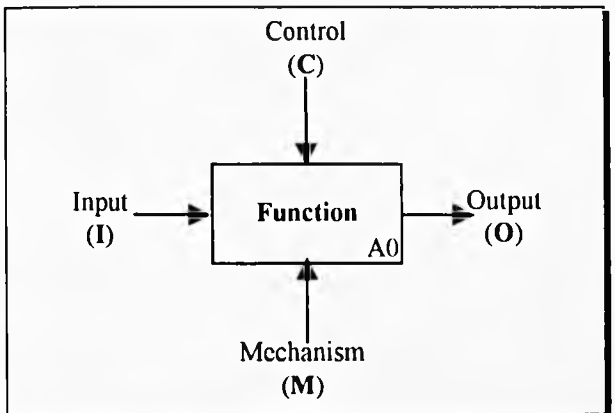


Figure 4.7. Basic IDEF0 concept.

As illustrated in Figure 4.7, arrows entering the left side of function box are inputs (I), arrows entering the top of the box are controls (C), arrows leaving the right side of the box are outputs (O) and arrows entering the bottom side of the box are mechanisms (M). IDEF0 model construction is based upon several design rules that define how the model components are used. Each box in the IDEF model should involve a function name and number.

b) IDEF0 Decomposition

IDEF0 boxes and arrows are combined in a diagram that represents a higher-level function (Arabshahi and Barton 1991). One of the most important features of the IDEF method is the hierarchy, as the top-level is decomposed into its basic sub-activities and elements. A model starts by presenting the whole system as a single function (a box with its arrow interfaces). This box is called the top box of the model and labelled A0. The top box can be decomposed into more child-diagrams until the system is described at the necessary level. The top-level diagram provides the most general or abstract description of the system being modelled. The series of child-diagrams provide more detail of the system. This feature restricts the amount of information that may be contained on the model on a single level. Figure 4.8 illustrates the IDEF0 model structure. The model diagrams provide a hierarchy of information that can be summarised in an IDEF0 node tree as illustrated in Figure 4.9. The node tree provides the relationships between all diagram levels.

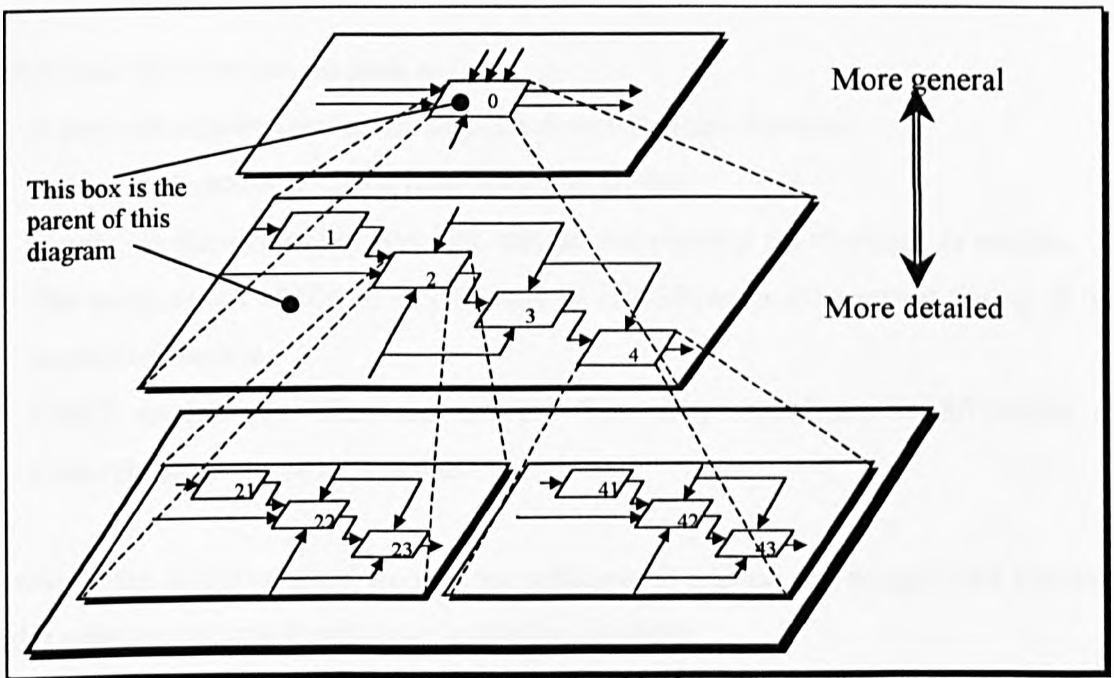


Figure 4.8. IDEF0 hierarchical structure.

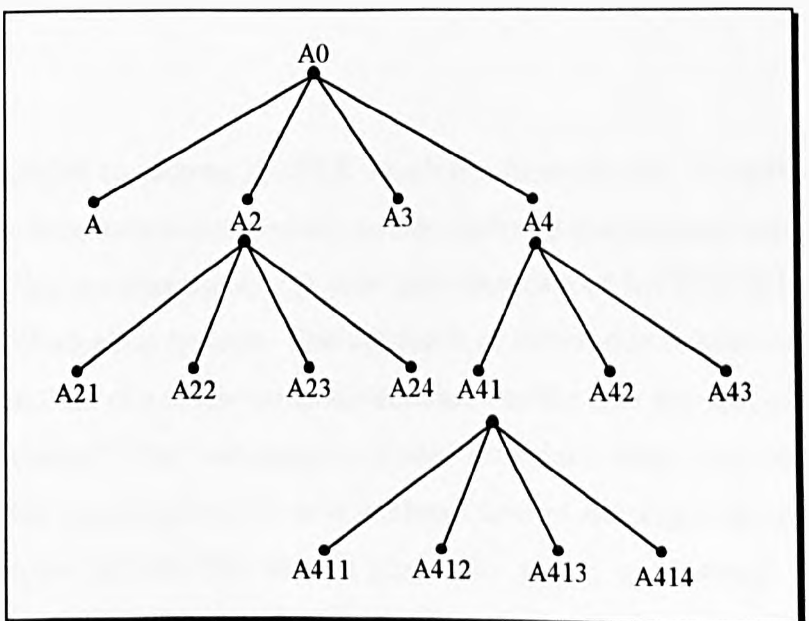


Figure 4.9. An IDEF node tree.

c) Discussion of IDEF0

IDEF0 is a functional/structural modelling method that is useful in defining the scope of a system functional analysis. Its model is presented in a hierarchical structure to provide more details about activities performed at different levels. This modelling method is simple to use and understand. It describes system activities by their ICOMs. The top-down analysis approach is usually more appropriate for IDEF0 than bottom-up construction.

IDEF0 has some limitations such as:

- It does not address time scales associated with systems functions.
- It does not consider decision flow within its models.
- It does not distinguish between information and physical flows within its models.
- The static nature of IDEF0 models may be considered as the greatest failing of the modelling method.
- IDEF0 models are often too concise. This may contribute to difficulties of comprehension for model readers.

However, the IDEF0 method alone is not sufficient to analyse and design CIM systems, and it must be integrated with other modelling methods.

4.4.2.2 IDEF1X Method

a) General

IDEF1 was extended to become IDEF1X which is a semantic data modelling technique. It is used to produce information models which represent the structure and semantics of information within an organisation. A principal objective of IDEF1X is to support the integration of information systems. This approach of integration focuses on the capture, management, and use of a single semantic definition of the data resource referred to as a "Conceptual Schema". The "conceptual schema" provides a single integrated definition of the data within an enterprise which is unbiased toward any single application of data and is independent of how the data is physically stored or accessed. The primary objective of this conceptual schema is to provide a consistent definition of the meanings and interrelationship of data which can be used to integrate, share, and manage the integrity of data.

Each IDEF1X model must be accompanied by a statement of purpose (describing why the model was produced), a statement of scope (describing the general area covered by the model), and a description of any conventions that the authors have used during its construction. Author conventions must not violate any of the rules governing model syntax or semantics.

The components of an IDEF1X model are entities, relationships and attributes. An entity represents a set of real or abstract things (people, objects, places, events, ideas, combinations of things, etc.) An entity is represented as a box, as shown in Figure 4.10.

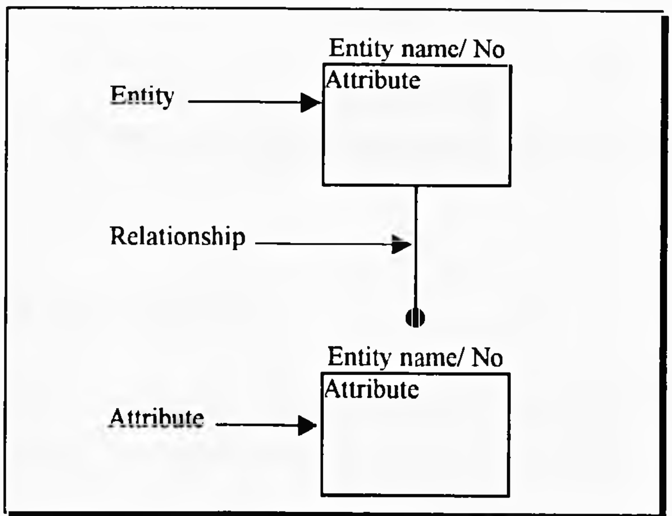


Figure 4.10. Basic components of IDEF1X model.

Each entity is assigned a label which is placed above the box. The relationships between entities are represented by lines with labels indicating the type of relationship. Each attribute is identified by a unique name expressed as a noun phrase which describes the characteristic represented by the attribute. Attributes can be defined by entering their names in a list inside the associated entity box.

b) Entity Type

An entity is a uniquely identified object of interest to the system about which information is collected. In IDEF1X, an entity can be "identifier-independent" or simply "independent". It is "Identifier-independent" if each instance of the entity can be uniquely identified without determining its relationship to another entity. It is "identifier-dependent" or simply "dependent" if the unique identification of an instance of the entity depends upon its relationship to another entity. Figure 4.11 illustrates identifier dependent and independent entity classes.

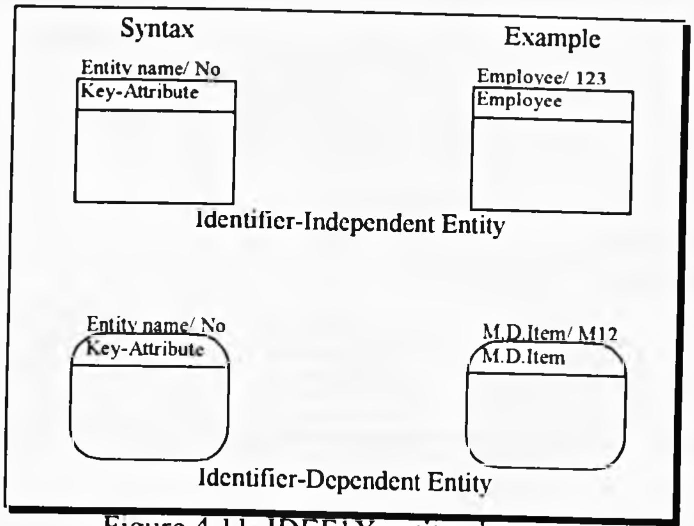


Figure 4.11. IDEF1X entity classes.

c) Relationship and Attributes

In an IDEF1X model, connection relationships are used to represent associations between various entities. Two types of specific relationship can be defined: connection relationship and categorisation relationship as shown in Figure 4.12.

Within an IDEF1X model, attributes are associated with specific entities. An "attribute" represents a type of characteristic or property associated with a set of real or abstract things (people, objects, places, events, ideas, combinations of things, etc.). An entity must have an attribute or combination of attributes whose values uniquely identify every instance of the entity. These attributes form the "primary-key" of the entity. Figure 4.12 also illustrates attributes in an IDEF1X model. More details of the method can be found in Kusiak et al. (1997).

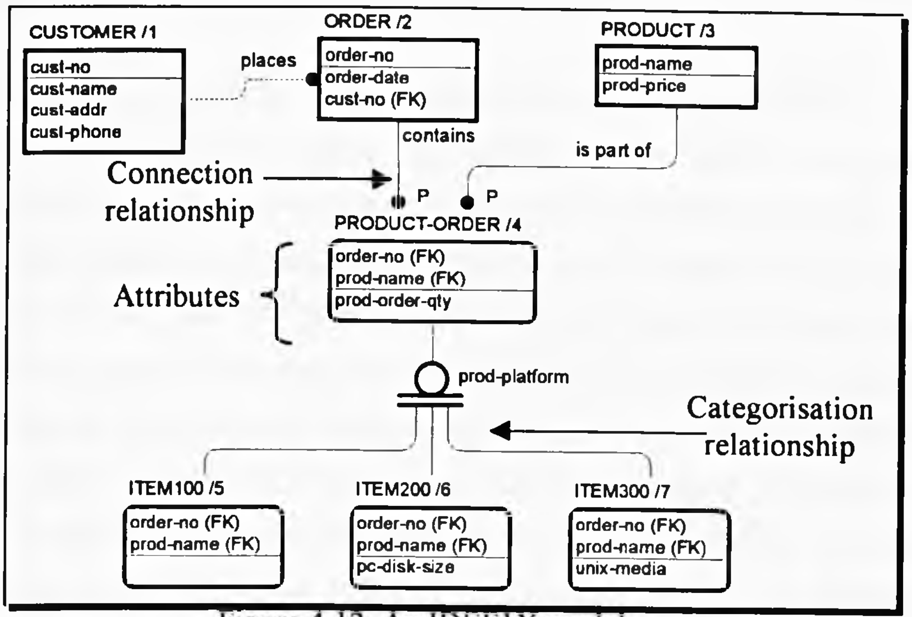


Figure 4.12. An IDEF1X model.

d) Discussion of IDEF1X

IDEF1X is conceptually similar to the Entity Relationships (ER) method, but it is different graphically, and more complicated semantically, thus making it more difficult to use than ER (Chadha et al. 1995). IDEF1X models are often used informally to describe the physical database structure.

Pandya (1995) identified some limitations of IDEF1X including the following:

- It lacks support for composite entity types; hence it requires attributes to be single value of simple data types such as strings and numbers.
- Domain constraints describe the semantics associated with entity type. Other constraints cannot be expressed between entity types.
- Entity attributes are used to identify instances of entity types. This requires an attribute value to be assigned before an instance of entity type can exist.

IDEF1X is suitable for modelling information systems, but as CIM comprises other systems such as decision, physical and control systems. IDEF1X cannot be used alone for system modelling.

4.4.2.3 IDEF3 Method

a) General

The IDEF3 Process Description Capture Method was created specifically to capture descriptions of sequences of activities. The primary goal of IDEF3 is to provide a structured method by which a domain expert can express knowledge about the operation of a particular system or organisation. IDEF3 is used to assist those engaged in capturing and analysing the vital processes of existing or proposed systems. Guidelines and simple-to-use graphical language structures aid users in successfully capturing and organising process information for multiple downstream uses. IDEF3's unique design includes the ability to capture and structure descriptions of how a system works from multiple viewpoints. This enables users to capture information conveyed by knowledgeable experts about the behaviour of a system, rather than directing user activity toward constructing engineering models to approximate system behaviour. This feature is among the central characteristics distinguishing IDEF3 from alternative offerings. As an integral member of the IDEF family of methods, IDEF3 works well in independent applications or in concert with other IDEF methods to identify and develop the vital business processes.

b) IDEF3 Process Descriptions

The basic elements of the IDEF3 description language are shown in Figure 4.13. This figure displays alternative symbol conventions for first-order relations. There are two basic components of the IDEF3 process description language: the process flow description and the object state transition network description. These two components are cross-referenced to construct IDEF3 diagrams (Mayer et al. 1995).

The IDEF3 process flow description is represented by the graphical elements that comprise process schematics and include Unit of Behaviour (UOB) boxes, links and junctions. A UOB represents an activity occurring in the process e.g. assemble parts, perform inspection or evaluate proposal. The relationships between UOBs are represented by three types of links, precedence links, relational links and object flow links. A precedence link is used to express simple temporal precedence between UOBs. A relational link is used to highlight the existence of a relationship between two or more

UOBs. An object flow link is used to provide a mechanism for capturing object related constraints between UOBs and carry the same temporal semantics as a precedence link. Junctions are used to model the logic branching within a process. Figure 4.13 illustrates different classes of junctions and an example of an IDEF3 process flow diagram is illustrated in Figure 4.14.

Object state transition network (OSTN) diagrams are used in IDEF3 to model object state changes relative to the process flow description. The basic components of OSTN diagrams are nodes (circles) and arcs. In IDEF3 models, each object may have a corresponding OSTN diagram. Nodes in the diagram represent different states of the object and arcs represents possible transitions that the object can make between model states, as illustrated in Figure 4.13. Figure 4.15 illustrates an example of an OSTN diagram.

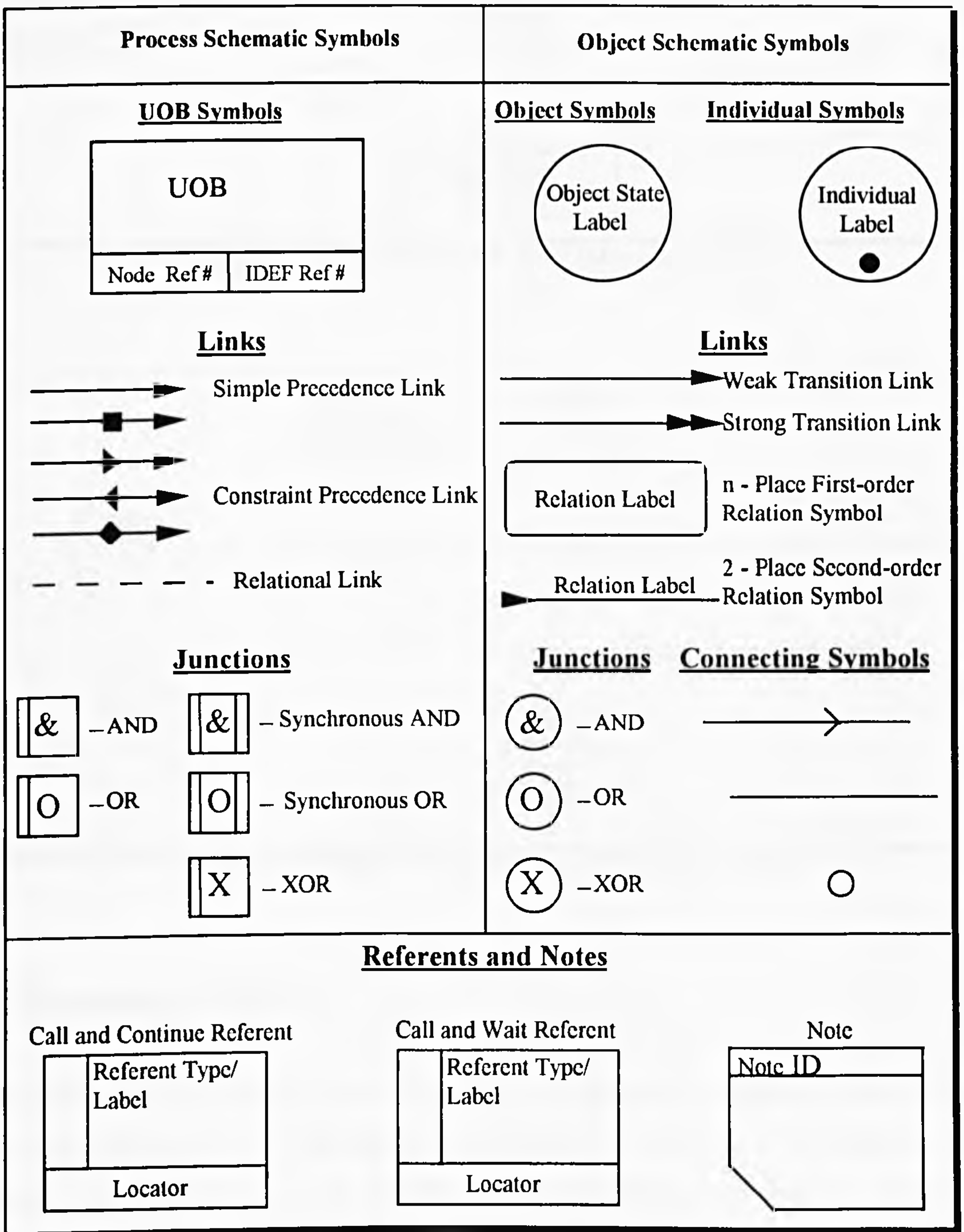


Figure 4.13. Symbols Used for IDEF3 Process Description (Mayer et al. 1995)

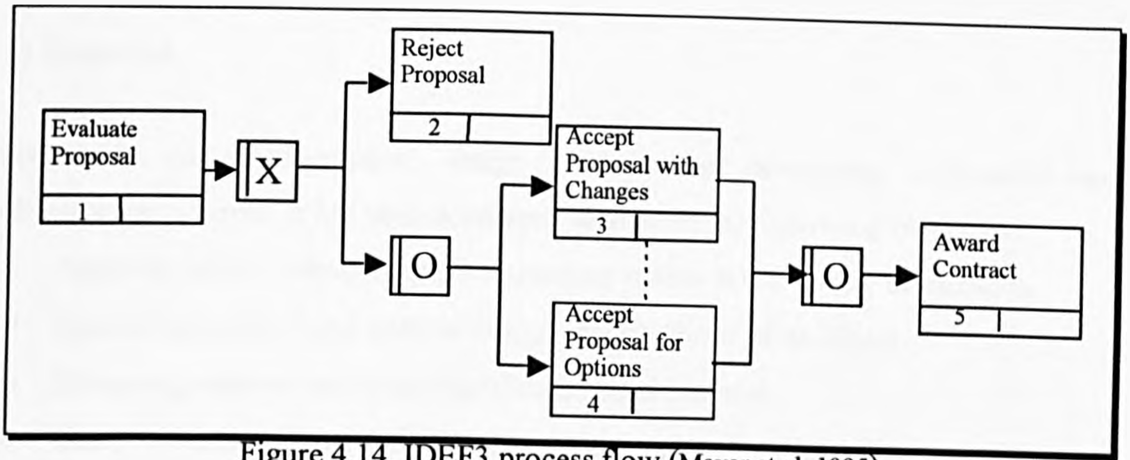


Figure 4.14. IDEF3 process flow (Mayer et al. 1995).

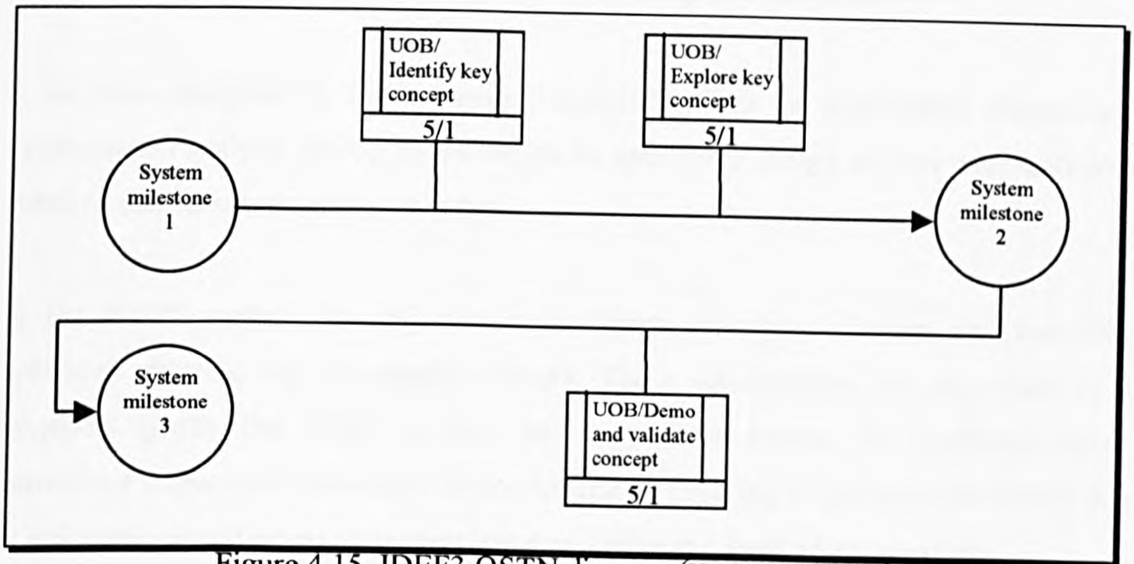


Figure 4.15. IDEF3 OSTN diagram (Kusiak et al. 1994).

c) Discussion on IDEF3

The IDEF3 method focuses on the abstraction and capture of knowledge about a given real-world system. It is a relatively new method in the analysis of manufacturing and design systems (Kusiak et al. 1994). In IDEF3 models many factors should be considered when describing what a complex system does, such as; What does a process require to perform its function? What objects participate in the process? What are the precedence and causality relationships between processes and events within the environment? (KBSI 1997). However, this method is difficult to use and understand and must be integrated with other IDEF modelling methods to represent complex manufacturing systems.

4.4.2.4 IDEF4 Method

a) General

IDEF4 is an object-oriented design method for developing component-based client/server systems. It has been developed to achieve the following objectives:

- Applying object-oriented design techniques within IDEF family of methods.
- Separating external and internal design specifications of an object.
- Designing systems which can interface to other systems.
- Using and updating the design during system use and maintenance.
- Reusing design objects in other system designs.
- Specifying object-oriented, distributed computing environments.

It has been designed to support smooth transition from the application domain and requirements analysis models to the design by specifying design objects with sufficient detail to enable source code generation.

In the IDEF4 method, the object-oriented design activity is divided into two sub-activities: discrete and manageable chunks. These sub-activities are supported by a graphical syntax. But IDEF4 is more than a graphical syntax. The graphical syntax provides a convenient framework for navigating an evolving object-oriented design that is ultimately specified on class invariant data sheets and method set contracts.

In the IDEF4 model, no single diagram shows all the information contained in the IDEF4 design model, thus limiting confusion and allowing rapid inspection of the desired information. Carefully designed overlap between diagram types serves to ensure compatibility between the different sub-models. The IDEF4 method allows the designer to easily make trade-offs between class composition, class inheritance, functional decomposition, and polymorphism in a design.

In general, an IDEF4 model is composed of two sub-models, the class sub-model and the method sub-model. These two sub-models are connected through dispatch mapping, as illustrated in Figure 4.16. All the information represented in a design model is captured by these two structures. Owing to the size of the class and method sub-models, the model designer never sees these structures in their entirety. Hence, the designer makes use of the collection of smaller diagrams and data sheets that effectively capture the information represented in both class and method sub-models.

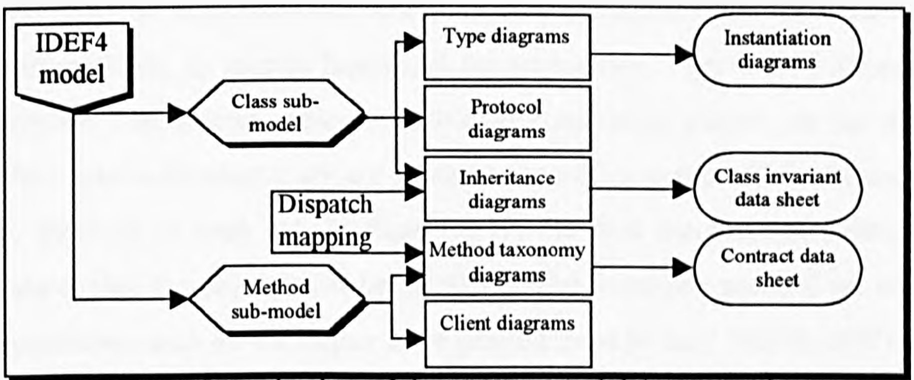


Figure 4.16 Organisation of the IDEF4 Model (KBSI 1995)

b) IDEF4 Class Sub-model

The class sub-model consists of a number of diagram types including inheritance diagrams to specify class inheritance relations, type diagrams to specify class composition, protocol diagrams to specify method invocation protocols and instantiation diagrams to describe object instantiation scenarios which assist the designer in validating the design. This class sub-model shows class inheritance and class composition structure. Figures 4.17 and 4.18 illustrate examples for inheritance diagrams and protocol diagrams.

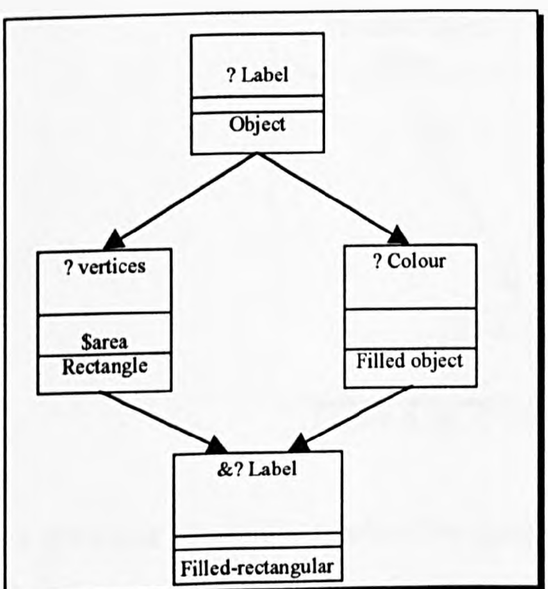


Figure 4.17. Inheritance Diagram (KBSI 1997)

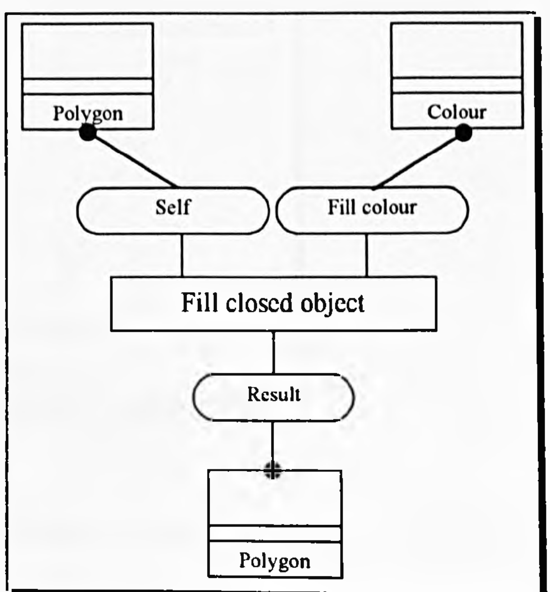


Figure 4.18. Protocol Diagram (KBSI 1997)

c) The IDEF4 Method Sub-model

The method sub-model consists of two diagram types: method taxonomy diagrams that classify method types by behaviour similarity, and client diagrams that illustrate clients and suppliers of methods, to specify functional decomposition. Figure 4.19 illustrates a taxonomy diagram. The arrows indicate additional constraints placed on the method sets. The method sets in the taxonomy are grouped according to the additional contracts placed on the methods in each set. In Figure 4.19, the first method set, Print, has a contract that states that the object must be printable. The Print-text method set contract would have constraints such as 'the object to be printed must be text' (KBSI 1997).

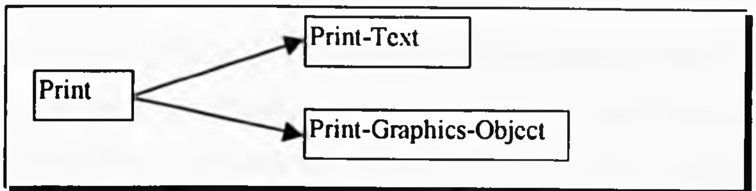


Figure 4.19. Method Taxonomy Diagram (KBSI 1997)

Figure 4.20 illustrates a client diagram. The Double-headed arrows point from the routine (called to the calling routine). In Figure 4.20, the Redisplay routine attached to the class Re-displayable-object calls the Erase routine of the Erasable-object class and the Draw routine on the Drawable-object.

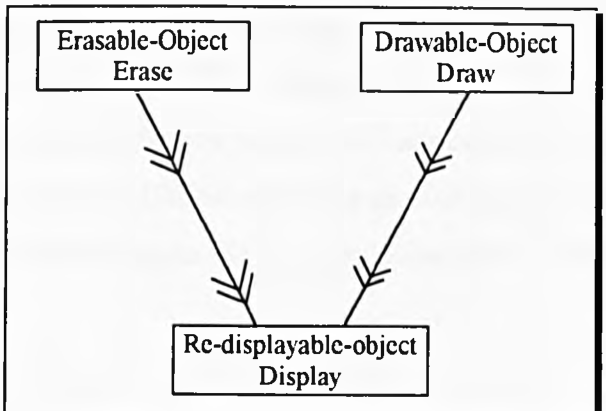


Figure 4.20. Client Diagram (KBSI 1997)

As IDEF4 is not only a graphical language, additional information about the inheritance diagrams, method taxonomy diagrams and type diagrams are presented in detailed data sheets.

Class-invariant data sheets are related to inheritance diagrams and specify constraints that apply to every instance of a particular class of objects. In the method, there is one class-invariant data sheet for each class e.g. the constraint, 'Every triangle has three sides', is a class-invariant constraint on the class Triangle (KBSI 1997).

Contract data sheets are related to the method sets in method taxonomy diagrams and specify contracts that the implemented methods must satisfy. In the IDEF4 model, there is one contract data sheet for each method set.

d) Discussion of IDEF4

Wu (1994) reported that the most direct development in Object-Oriented (OO) design in manufacturing was IDEF4, as it provided a comprehensive set of tools and procedures to help design and develop OO software systems. He also found that the issues related to system analysis were not specifically addressed.

The specialised vocabulary that has evolved around the OO method is one of the greatest barriers to object technology (KBSI 1995). There is a great deal of confusion centred on the use of different terminologies by different object-oriented languages. It is imperative to define IDEF4's object-oriented terminology before proceeding.

However, IDEF4 is difficult to understand and depends upon system class definitions. Integration of IDEF4 and other IDEF methods requires high accuracy in selecting system activities and defining classes, objects and attributes. For example, users of the IDEF1X cardinality notation in IDEF4 should be careful not to confuse the semantics of object-oriented modelling with semantic data modelling (KBSI 1995).

4.4.3 SADT Approach

The SADT approach was developed in the early 1970s by D. Ross and SoftTech, Inc. It is a system analysis and design method which uses a number of graphical and textual tools including activity diagrams, data diagrams, node lists and data dictionaries to represent the structure of the system being modelled (Pandya 1995). The SADT provides a set of a disciplined approach to model complex physical and information systems. It must be noted that IDEF0 is a sub-set of SADT. The SADT model construction is based upon seven concepts namely understanding via model building, top-down decomposition, dual aspects of system, functional modelling system versus implementation modelling, graphic format of model representation, support of disciplined teamwork, and all decisions and comments in written form (Ross 1985).

The SADT model is based upon two main structures: activity structure and data structure. These two structures are associated with two graphical tools: actigrams and datagrams which deal with system activities and data aspects respectively.

4.4.3.1 SADT Model Structure

The SADT model structure is represented by a diagram language (graphical and textual tools). It starts by representing the whole system in its context diagram (called top diagram) as one box. The top diagram is then decomposed into a number of child-diagrams to give more detailed modelling. These diagrams involve activity and data nodes. The nodes are related directly to the parent node in the higher diagram. The diagram contains at most six nodes; hence a model box or node can be decomposed into at most six nodes at a lower level. The aim of this hierarchical structure is to describe the activity or data nodes or boxes in more detail until a full system has been described. Figure 4.21 illustrates the SADT model hierarchy. The numbering of lower model diagrams are related to the parent node reference in the upper level diagram. Two types of numbering methods are used in the SADT model, which are related to both actigram and datagrams nodes. The reference of the actigrams begins with the letter 'A' and the reference of the datagrams begins with the letter 'D' as shown in Figure 4.21.

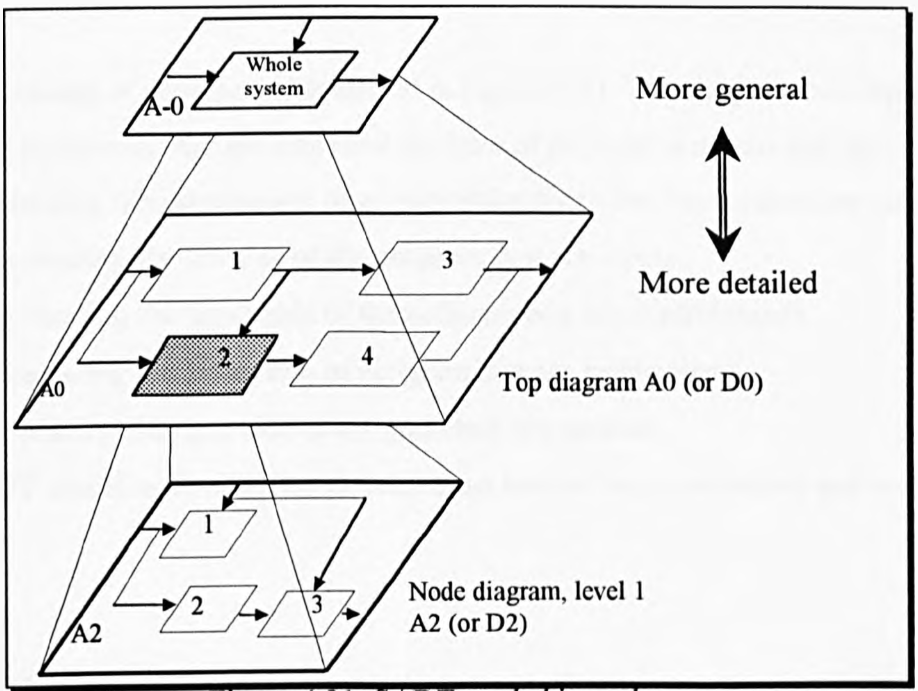


Figure 4.21. SADT mode hierarchy.

4.4.3.2 SADT Diagrams

In both actigrams and datagrams, the SADT model can be constructed using boxes and arrows as illustrated in Figure 4.22.

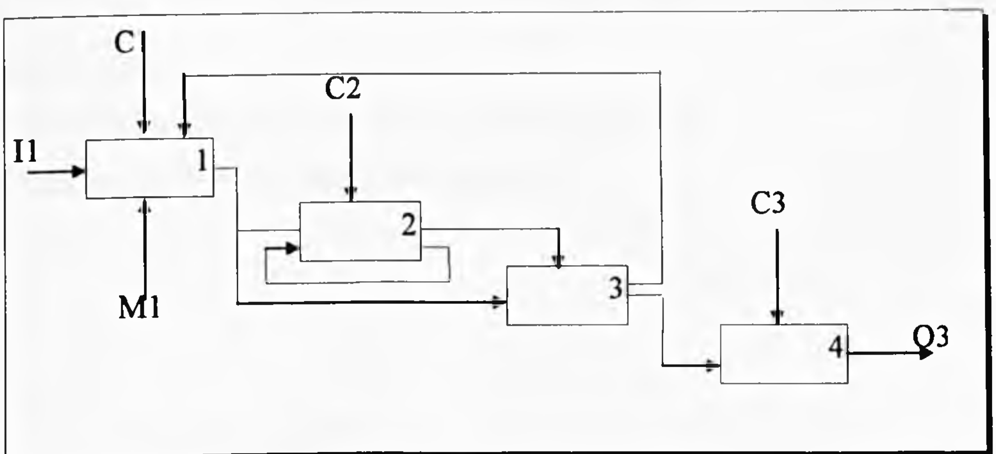


Figure 4.22. SADT diagram.

The main components of actigram and datagram are boxes and arrows. A box should contain a text label and number. Arrows represent the relationships between diagram boxes. SADT actigrams and datagrams are described in the following sections.

4.4.3.3. SADT Actigrams

The basic concept of actigram is illustrated in Figure 4.23. The actigram box represents the activity performed. Arrows represent the flow of physical elements and data between activities. The attachment of arrows and activity box has a particular meaning:

- Arrows entering the left side of the actigram box are inputs.
- Arrows entering the upper side of the actigram box are control inputs.
- Arrows entering the lower side of actigram box are mechanisms.
- Arrows leaving the right side of actigram box are outputs.

In the SADT model, each actigram activity must have at least one output and one control.

4.4.3.3. SADT Datagrams

SADT datagrams are used to model data elements of a system. Figure 4.23 illustrates the main concept of datagrams. The datagram consists of boxes and arrows which represent the data and activities respectively. The Box ICOM of arrows around the datagram box have a particular semantic:

- Input to the right side = an activity which creates or modifies the data.
- Control to the upper side = an activity which may affect the way the data can be created or used.
- Output from the right side = an activity which uses the data.
- Mechanism into the lower side = data support.

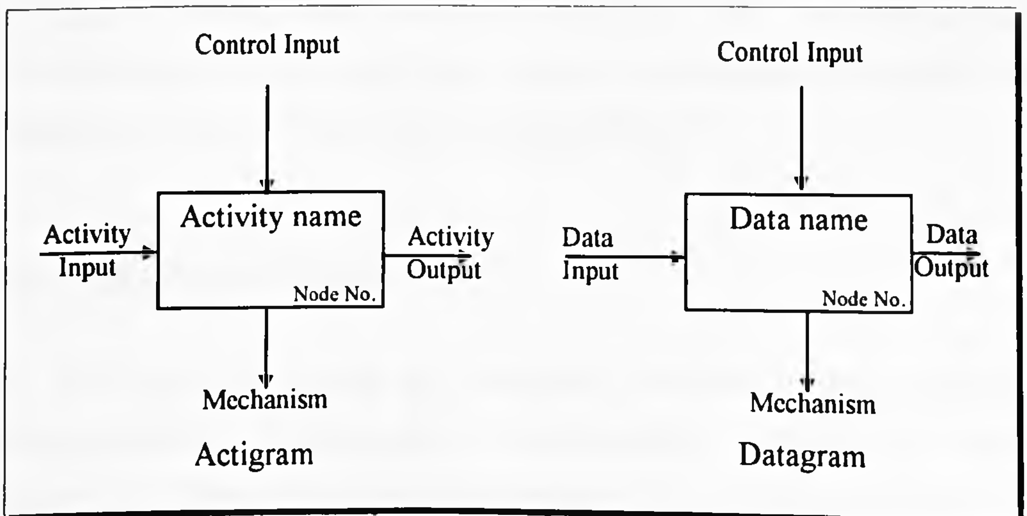


Figure 4.23. Basic concepts of actigram and datagram.

4.4.3.4 Discussion of SADT

SADT includes some good features such as the top-down decomposition approach and the ability to model both data and activities using simple graphical tools. Therefore, SADT is a good technique for system analysis and design.

However, This modelling method has some limitations including:

- Decision modelling is not included.
- System time scales are not considered.
- SADT models are static representations.
- Data modelling is not completely covered.

4.4.4 Object-Oriented Methodologies

Object-oriented methodologies request system components as objects (Gaafar and Bedworth 1994). An object-oriented model views the system as a collection of objects that contains both data and methods applied to data (Lefrancois and Montreuit 1994). Object-oriented (OO) methodologies have been used in recent years in analysis and design of manufacturing systems e.g. Wu (1994), Lenart and Nof (1997), Wuwongse (1997), Luo et al. (1997) and Kwon and Jie (1996).

Several OO analysis and design methodologies have been proposed such as OOA(Object-Oriented Analysis) (Coad and Yourdon 1991), BEBOOD (Petri-Net Based Object-Oriented Design method) (Chen and Lu 1997) and HOOMA (Hierarchical and Object-Oriented Manufacturing Systems Analysis) (Wu 1994). The major principle of all OO methodologies is to bridge the gap between system analysis and design, and to bring together the functional and data approaches (Wu 1994).

4.4.4.2 Discussion of OOM

OOMs have some advantages for developing structured analysis models for manufacturing systems including: ease of representation, abstraction, polymorphism, separation of modelling from design and implementation, supporting modularity (where classes can be modelled, design and implemented as stand alone elements), providing the vehicle to model both data and knowledge, allowing the concept of method to be extended to include rule-based, supporting integration through the sharing of common classes and simplifying the incorporation of changes and modifications (Lefrancois and Montreuil 1994, Gaafar and Bedworth 1994). OOM models provide good graphical techniques, and have a hierarchical decomposition from general levels to a more detailed description. Wu (1995) reported that OOMs provide an excellent approach to managing and expressing complex entities through data abstraction, encapsulation and inheritance.

OOMs have some limitation such as:

- Not being easy to use and learn; in addition OOMs do not have the ability to maintain a history of versions of the model (Chadha et al. 1991).
- Being classified as a specific problem-solving methodology, it does not focus on identifying the system required by the organisation but begins by assuming that a specific problem is being addressed.

4.4.5 GRAI Method

The GRAI method was developed by the GRAI laboratory at the University of Bordeaux-I in France in the 1970s. The GRAI method now has many industrial applications (Doumeingts et al 1995b). This method examines the structure of decision/activity centres and the flow of decisions and information between these centres.

The GRAI method is based upon three basic elements (Doumeingts et al 1995a):

- A conceptual reference model.
- A formalism associated with graphic tools.
- A structured approach allowing an efficient use of the method.

4.4.5.1 GRAI Reference Model

The conceptual reference model has been developed based on theories of complex systems, hierarchical system, and system control (Doumeingts et al 1993), as shown in Figure 4.24.

The conceptual model gives the basic ideas for designing a manufacturing system (Doumeingts et al 1992). The conceptual model structure of manufacturing systems is decomposed into three subsystems (Doumeingts et al 1995a):

1. Physical system, which includes the human resources; the manufacturing equipment; the material and tools; the physical processing which are all used to convert raw material into products.
2. Information system, which is used to transfer data between the elements of the system being modelled.
3. Decision system, which itself is decomposed into an upper system which is driven by periodic activities and an operating system which is event driven.

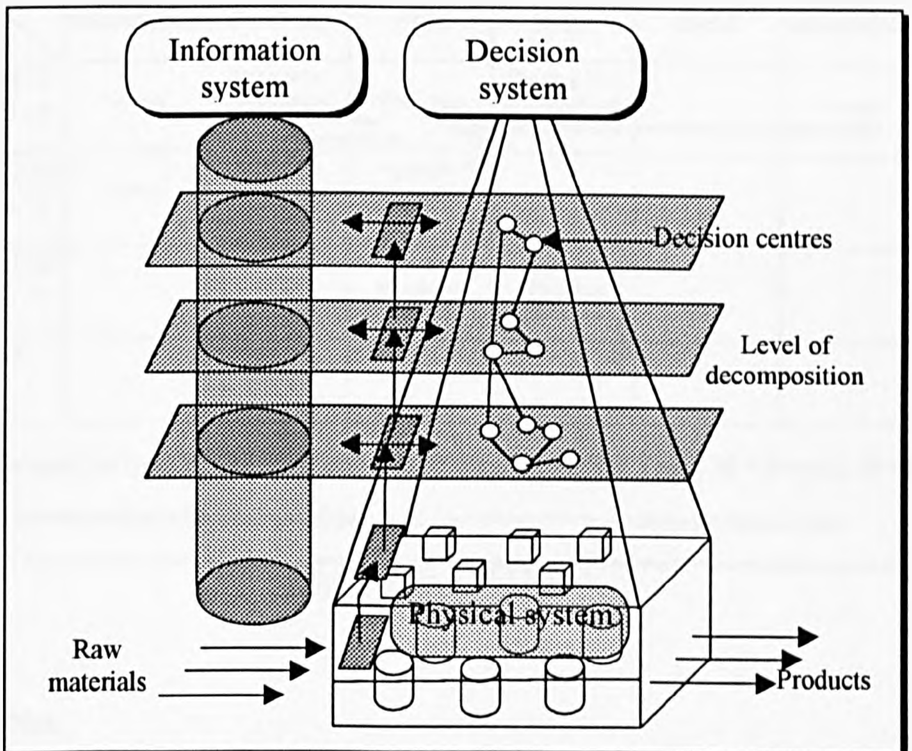


Figure 4.24. GRAI reference model (Doumeingts et al 1993).

4.4.5.2 GRAI Formalisms

The GRAI formalism concentrates on the decision subsystem and consists of GRAI grids (to show the organisation decision making centres) and GRAI nets (to describe the detail of activities in a decision centre) (Chen et al, 1990). The GRAI formalism can be associated with other available methods such as IDEF0 to model the physical system, and MERISE to model the data system (Doumeingts et al. 1995) (Doumeingts et al. 1993).

4.4.5.2.1 GRAI Graphical Tools

I. GRAI Grid

The GRAI grid is represented by a table of rows and columns, as shown in Figure 4.25, and it is constructed using a top-down analysis approach. The columns of the grid represent the function and the rows contain the decision time scales (Wu, 1992).

The relationship between decision centres is represented on the grid by a simple arrow (an information link) and a double arrow (a decision link) (Chen et al., 1990

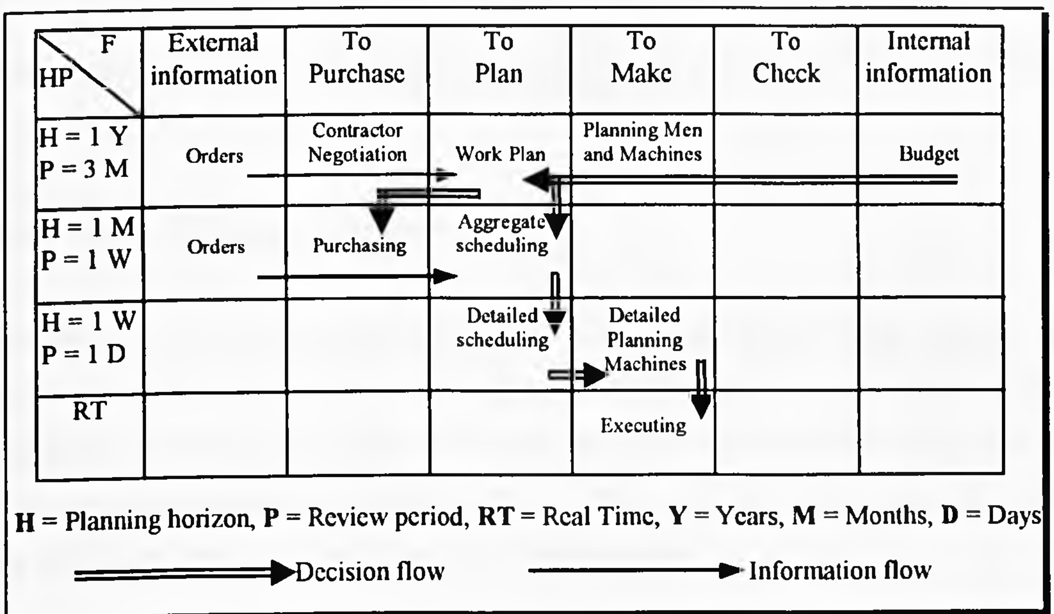


Figure 4.25. GRAI grid.

II. GRAI Net

The GRAI net describes the structure of the various activities in each of the decision centres identified in the GRAI grid and is constructed using a bottom-up approach (Chen et al, 1990). The activities are the fundamental elements in the net. Each activity has an initial and final status which requires a support of information, and produces results. An activity result can connect to a resource or input to another activity (Doumeingts et al 1995a). Figure 4.26 illustrates a sample GRAI net.

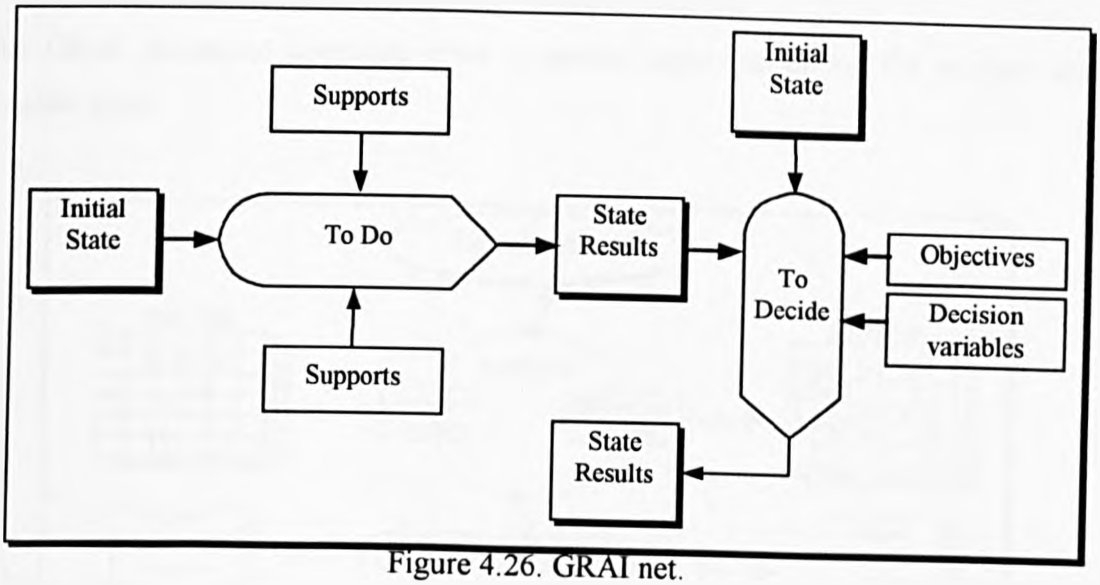


Figure 4.26. GRAI net.

4.4.5.3 GRAI Structured Approach

Doumeingts et al. (1995a) reported that the application of the GRAI method must follow set procedures, as illustrated in Figure 4.27. The construction of a GRAI model requires: a synthesis group, composed of the future users, and analysts/designers with expertise in GRAI techniques. As illustrated in Figure 4.27, the GRAI method involves two main phases: the analysis phase and the design phase.

In the analysis phase, the current system is considered and the necessary data are collected to construct system models. Top-down and bottom-up approaches are used in the analysis phase. In the top-down approach, GRAI grids, constructed to illustrate system decision centres are decomposed into several hierarchical grid models. In the bottom-up analysis, GRAI nets are used to describe decision centres in detail. This helps in the analysis of decisions made by decision centres and the variables and objectives used to carry out decisions.

In the design phase, the inconsistencies identified during the analysis phase are addressed. This phase can be carried out in two steps:

1. The construction of a frame using GRAI grids to model the proposed structure of the new system.

2. The construction of the decisional frame for each decision centre using GRAI nets to present more details of the basic activities carried out.

The GRAI structured approach gives a general specification of the system under consideration.

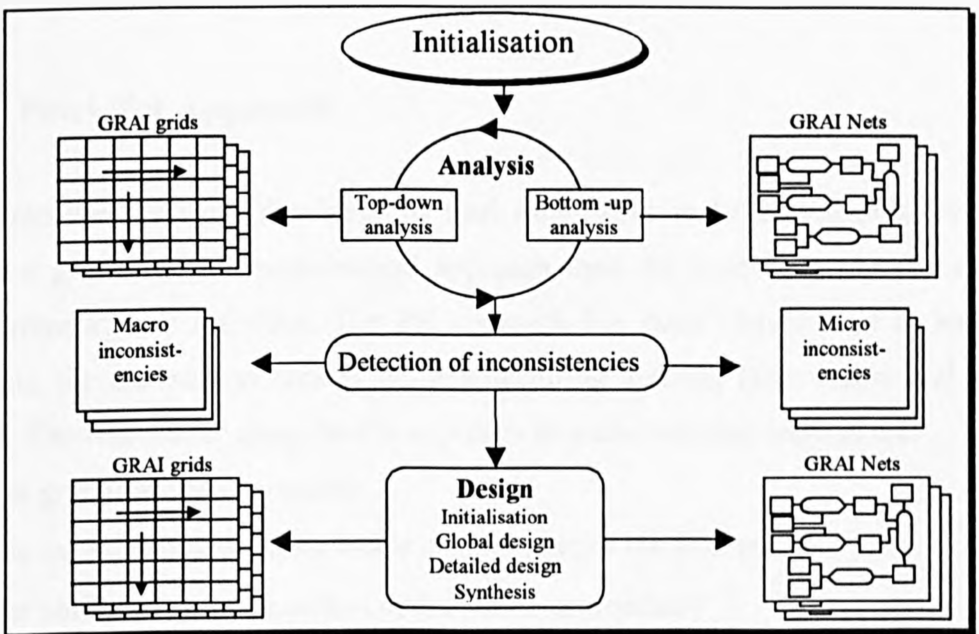


Figure 4.27. GRAI structured approach (Doumeingts et al. 1992).

4.4.5.4 Discussion of GRAI Method

The GRAI method comprises good techniques and tools for modelling manufacturing systems (Chodari 1997). It generates a conceptual model that gives a generic view of an organisation. It provides a top-down decomposition approach using the GRAI grid and bottom-up design approach using GRAI nets. The GRAI method is the only modelling method discussed in this chapter which considers decision flow, addresses system time scales within its models, and offers good graphic interaction. Therefore, this modelling method is suitable for the analysis and design of manufacturing systems.

The GRAI method has some limitations such as:

- The rigid rules of GRAI grid and net construction.
- Modelling with GRAI net is not easy to learn and requires much practice (Czernik and Quint 1992).
- The information and physical flows are not well modelled within the GRAI method.
- Identifying planning horizons and periods is difficult.

- GRAI is a static modelling method, not suitable for modelling the dynamic behaviour of information and control systems (Harhalakis et al. 1995).

However, the strength of the GRAI method is its ability to focus on the system time scales and decision aspects.

4.4.6 Petri Net Approach

The Petri Net (PN) was developed by Carl Adam Petri in 1992 (Valvanis, 1990). The PN is a graphical and mathematical approach used for modelling asynchronous and concurrent system activities. The PN approach has been widely used in modelling, analysis, simulation and control of manufacturing systems (Desrochers and Al-Jaar, 1995). The reasons for using the PN approach in manufacturing systems are:

- The graphical representations.
- The mathematical analysis tool is useful to verify the system.
- The ability to generate control codes (some approaches).
- PN models can be used to implement real-time control systems.
- PN models represent a hierarchical modelling tool.

4.4.6.1 PN Concept

Figure 4.28 illustrates a PN example. The basic components of a PN model are two types of nodes: places and transitions. The PN nodes are connected by direct arcs. Formally, the PN is defined as the four-tuple PN = {P, T, I, O}.

Where: P = {p1, p2, ..., pn}.

T = {t1, t2, ..., tn}.

I = Input function.

O = Output function.

Input and output functions are related to model places and transistors. Hence, an input place is directed to a transition. A transition is directed to output places.

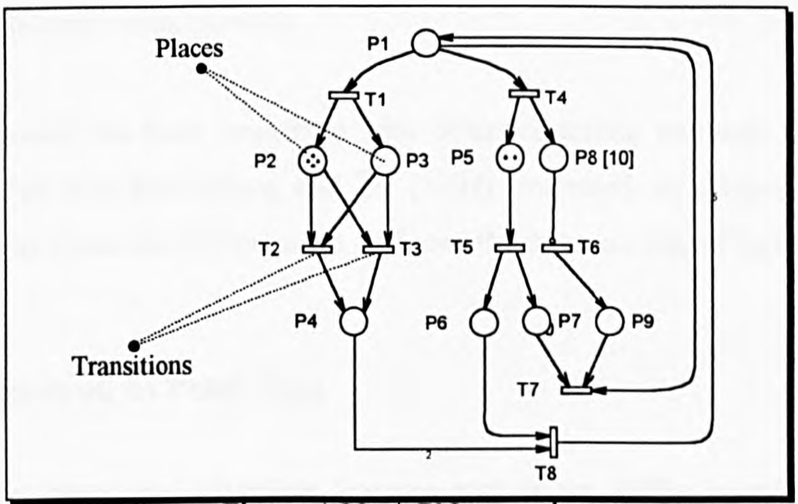


Figure 4.28. A PN example.

A model transition is enabled when all its input places are marked by tokens from each one of its input places by placing a token in each one of its output places. This basic token movement is used for describing and analysing the flow of information and control in the system being considered. The most important feature of PN is the ability to model the dynamical behaviour of a system by firing model transitions. The meaning of token movement is the challenging system state.

It should be noted that there are various extensions of the PN approach including Timed Petri Nets (TPN), Stochastic Timed Petri Nets (STPN), Generalised Stochastic Petri Nets (GSPN) and predicate/transition nets.

4.4.6.2 Application of PN in Manufacturing Systems

In the last few years PN approaches have been widely used for manufacturing applications. Desrochers and Al-Jaar (1995) presented a book titled "Applications of Petri Nets in Manufacturing Systems". The book illustrated that there are many aspects of manufacturing systems which can be modelled using PN approaches. The flexibility of the PN concept enables the analyst to form the suitable analysis and control models for the system being considered. D'Souza and Khator (1994) presented a survey paper of PN applications in control and modelling automated manufacturing systems. It was found that PNs are being increasingly used to model advanced manufacturing systems for analysis and performance evaluation. D'Souza and Khator (1994) indicated that this field still needs more research work.

The PN approach has been integrated with other modelling methods to increase its capabilities. For example, Cheng and Lu (1997) presented an integrated modelling methodology in which the PN approach performs the dynamic side of its models.

4.4.6.3 Discussion of Petri Nets

PN approaches have good modelling features such as the ability to represent systems graphically, the ability to provide a complete qualitative analysis and the ability to link directly structured properties. PNs can also describe a system model in a hierarchical structure.

Valvanis (1990) and Pandya (1995) reported some limitations to PN including:

- In a PN model, there is only one class of place used to present the conditions that exist in the system. System analysis and design require more than one type of places.
- Only one class of token is used to represent information or control flows;
- At any transitions of multiple inputs and outputs, there is no indication to illustrate the flow of tokens.
- A general description of PN models is not available.
- Model diagrams become cluttered when complex systems are modelled.
- General computerised tools are not available to support PN applications.

PN models are very difficult to build and implement. Therefore, PN is unable to model CIM systems unless supported by coded subroutines and integrated with other effective modelling methods.

4.4.7 Other Modelling Methods

This section presents other modelling methods that have been (or can be) used in manufacturing applications. These methods are not widely used but they present good modelling specifications and can be used for specific industrial cases, or integrated with other methods to develop new powerful modelling methodologies. The modelling methods and techniques selected are Input/Output Analysis (IOA), MERISE and GRAI Integrated Methodology (GIM).

IOA is an analysis method used to generate model component requirements to solve problems (Pandya 1995). The method procedure starts by identifying system requirements. Then outputs of the model are defined, taking into account the system requirements identified. Following this, system inputs are configured based upon system requirements and the outputs identified. The main components of the IOA model are the inputs and outputs. Hence, the IOA model connects the organisation sub-systems based upon their inputs and outputs. The inputs of one sub-system can be connected into the outputs of another sub-system. This method is very simple and gives an obvious representation of an organisation's sub-systems. On the other hand, this method has some limitations such as misinterpretation, sub-system details not being included, and the complexity of creating feedback or parallel activities within the model (Pandya 1995, Wu 1992).

MERISE is a modelling method used for the analysis and design of information systems based upon the PN concept. It is composed of three levels; conceptual, logical and physical. A MERISE model involves static and dynamic diagram models. The basis of the modelling method essentially lies in its three cycles namely the decision cycle, the life cycle and the abstraction cycle, which cover data and process elements with equal emphasis (Avison and Fitzgerald 1996). MERISE provides graphical support tools and has been used in many applications. Chodari (1997) reported that this method is not suitable for analysing and designing manufacturing systems due to its weakness in supporting decision-making systems. Botta et al. (1997) reported that although the approach provides a good structure and optimisation of data and different abstraction levels are well separated but it is not easy to use and there is no good integration between the data model and functional model.

The GIM is an integrated methodology developed to support the system analysis and design phases. It is composed of three components framework, method formalisms and structured approach. GIM adopts three modelling methods in an integrated manner. The GRAI, MERISE and IDEF0 methods are adopted to support different phases of manufacturing systems. In the GIM model, the GRAI method is used to model decision sub-systems, MERISE is used to model information sub-systems and IDEF0 is used to model physical sub-systems. GIM lacks active integration between its methods; hence, it is not more than a theoretical representation for this integration. This methodology lacks a suitable computerised tool to support the integration of method elements and it does not consider dynamic aspects of manufacturing systems.

4.5. Assessment of Modelling Methods

There are two main reasons for comparing modelling methods, an academic reason and a practical reason (Avison and Fitzgerald 1996). In the academic field, modelling methods are compared in order to understand their characteristics such as tools, techniques, objectives and mechanisms. In practice, modelling method are compared to select a suitable method or technique for a specific application based upon specific requirements. However, these two reasons are related to each other. Academic studies are carried out to support modelling methods that are used in real applications and many academic studies have originated from real applications (Avison and Fitzgerald 1996).

In general, the modelling methodologies and techniques can be compared and evaluated based upon several requirements. The identification of modelling requirements is different from one perspective to another. Therefore, several sets of modelling requirements have been addressed by researchers and practitioners. Chadha et al. (1991) examined a number of modelling tools using the following list of requirements that an 'ideal' modelling method should meet. They suggested a modelling method should be:

- ⇨ Able to express different levels of abstraction.
- ⇨ Able to decompose from a high level to low level.
- ⇨ Easy to learn, use and understand.
- ⇨ Able to incorporate changes to real systems with a reasonable effort.
- ⇨ Able to maintain a history of changes and versions.
- ⇨ Rich in manufacturing/material handling language.
- ⇨ Able to incorporate manufacturing and information constraints.
- ⇨ Able to describe the resources needed to manufacture and support a product.
- ⇨ Able to describe the resources needed for an information system.
- ⇨ Able to describe the movement and quantities of materials in manufacturing systems.
- ⇨ Able to describe the movement and quantities of flow of information in the system.

- ⇨ Able to describe movable resources.
- ⇨ Able to model exceptional and unexpected events.
- ⇨ Able to manage the information of exceptional and unexpected events.
- ⇨ Able to describe sequences of data transactions and data operations and their interactions and relationships.
- ⇨ Able to support a product description.
- ⇨ Able to support data dictionary.
- ⇨ Able to handle products/materials.
- ⇨ Able to handle data.
- ⇨ Able to describe data relationships.
- ⇨ Able to handle multiple type of products/materials.
- ⇨ Able to handle multiple type of data.
- ⇨ Able to verify and test the model.
- ⇨ Able to implement as a CASE tool.
- ⇨ Able to incorporate manufacturing quality and safety issues.
- ⇨ Able to incorporate information security and integrity issues.

Using the above list of requirements, Chadha et al. (1991) compared a number of modelling methods including IDEF0, DFD, SAMM (Systematic Activity Modelling Method), IDEF2, IDEF3, ER/ERD, IDEF1X, NIAM (Nijssen's Information Analysis Modelling), OO and dependency diagrams, as illustrated in Table 4.2. The authors concluded that none of the modelling methods was comprehensive and none well developed for use in manufacturing design environments.

Although the comparison was based upon the requirements of the information systems in manufacturing. It gives good guidelines for evaluating modelling methods.

Modelling methods			Requirements											
			Level of abstraction	Hierarchy	Ease of use	Flexible	Version control	Constraints	Exceptional event	Sequences & interactions	Flows and quantities	Resource requirements	Relationships & aggregates	Verifiable/ Testable
	Process/flow model	IDEF0		X			X		X	X	X		-	
		DFD		X	X					X			-	
		SAMM		X					X	X	X		-	
		IDEF2							X	X	X		-	X
		IDEF3		X			X		X				-	
	Data model	ER/ERD	X	X	X				-				X	
		IDEF1X	X		X				-				X	
		NIAM		x	X		X		-				X	
		OO	X		X				-				X	
		Dependen-cy diagram							-				X	X

Table 4.2. Modelling method requirements matrix (Chadha et al. 1991).

Brandimarte and Cantamessa (1995) presented a survey of various modelling methods used within CIM systems. The following questions were used in their survey:

Q1. What is your particular field of interest in the context of CIM?

Q2. What do you use such language/ formalism for?

Q3. What may this language / formalism model?

Q4. If you have to communicate with this language / formalism, which people do you feel confident will understand you with ease?

Q5. At what point(s) of the CIM system life cycle is this language / formalism useful?

Q6. Do you think this language clips or deforms the object?

Q7. Do you think this language introduces a bias in the model?

Q8. Is there any software tool for supporting the use of the language / formalism? If so, which? Does it work well?

Q9. Please give a short list of references describing the language and its applications within the CIM domain.

Brandimarte and Cantamessa (1995) used their questionnaire to compare several modelling methods. Figure 4.29 illustrates six modelling methods selected from that study.

IDEF0	ERD	DFD
Q1. Virtually all CIM modelling areas and many others where IDEF0 has become a popular mean for manufacturing. Q2. Describing functions, selecting software, validating. Q3. Processes, activities and their behaviour with their relationship with data. Q4. CIM system developers belonging to different "cultures", and qualified end-users. Q5. Requirement definition and design. Q6. Time scale of activities, economic and organisational aspects of the system are left out. Q7. IDEF0 promotes hierarchical control systems. Q8. There are a number of such tools.	Q1. Data modelling. Q2. Validating and implementing databases. Q3. Data connected with CIM systems, business activities and products. Q4. CIM system developers and data base engineers. Q5. Implementation and operation. Q6. The MLF does not clip the object; the problem is rather than it tends to promote redundancy in complex systems. Q7. The MLF promotes a tabular view of the world. But tables are very well suited for some problems. Q8. Many editors are also interfaceable to DBMS.	Q1. Software modelling. Q2. Modelling of functions and data. Q3. The CIM system, or a business function. Q4. CIM developers. Software analysts. Q5. Analysis, design. Q6. DFDs only describe data being transformed. Q7. Not known. Q8. Graphic editor support structured DFD and some CASE tools are interfaceable with them.
GRAI grids	*GRAI nets*	IDEF1/IDEF1X
Q1. Enterprise modelling area. Q2. Describing, validating. Q3. The CIM system and business functions. Q4. CIM system developer. Q5. Analysis, design. Q6. Not known. Q7. Not known. Q8. Not known.	Q1. Enterprise modelling area. Q2. Describing, validating. Q3. Business functions. Q4. CIM system developer. Q5. Analysis, design. Q6. Not known. Q7. Not known. Q8. Not known.	Q1. Data modelling area. Q2. Validating and implementing databases. Q3. Data connected with CIM systems, business activities and products. Q4. CIM system developers. Q5. Requirement definition and design. Q6. As in ER diagrams. Q7. Not known. Q8. There is some.

Figure 4.29. A survey findings of modelling methods (Brandimarte and Cantamessa 1995).

The author's comparison gave an idea of the disparity of knowledge of modelling tools among CIM experts. The survey has highlighted the need for a deeper study of modelling methods used in modelling CIM.

Another study presented by Pandya (1995) compared various modelling methodologies and techniques. This comparison was based upon the relation to the timing horizons of the business processes and the conventional planning and control levels. Table 4.3 shows the results of the study. The study compared modelling methods based on the business and planning and control requirements in manufacturing which are important for modelling organisational functions in CIM systems.

Methodology/ tools	Applications in manufacturing/ Business processes				
	A	B	C	D	E
SSADM	***	***	**	*	*
SADT	*	**	**	*	*
IDEFO	*	***	***	***	**
IDEF1X	*	**	***	***	***
GRAI grid	**	***	***	**	*
GRAI nets	**	***	***	**	*
Neural nets	*	*	*	***	*
PN	*	**	*	**	*
IOA	**	**	***	***	**
Jackson's	*	*	*	*	***
Warnier-Orr	*	*	*	**	***

Key: *** most suitable
** may be used
* not recommended

A- Traditional corporate-level planning and control (Business processes with planning horizons of>= month, e.g. technology acquisition, forecasting, marketing functions, long-term planning).

B- Traditional factory-level planning and control (business processes with planning horizons of 1 week to 1 year e.g. purchasing function production function).

C- Traditional shop-level planning and control (Business processes with planning horizon with one day to one month e.g. tools management, inventory control, schedules, maintenance, quality control).

D- Traditional cell-level planning and control (Business processes with planning horizons of 1 day ti 2 weeks, e.g. short term scheduling (dynamic), process monitoring, unscheduled maintenance).

E- Development of data for manufacturing/business process.

Table 4.3. Suitability of modelling tools and methodology in manufacturing management and business processes (Pandya 1995).

Pandya (1995) concluded that no modelling tool or methodology gave adequate results and reported that a combination of modelling tools must be used to model a complete business environment.

4.5.1 Framework for comparing the CIM Modelling Methods

Avison and Fitzgerald (1996) reported that comparing modelling methods is a very difficult task and the results of any such work are likely to be criticised. They referred to the different viewpoints of modelling methods such as the views of analysts, designers, users, researchers, etc.

Before starting a comparison and evaluation of any modelling method, some suitable requirements should be established and used in a framework for comparing modelling methods. Identifying these requirements is different from one perspective/ organisation/ person to another.

The framework suggested in this research for comparing and evaluating modelling methodologies and techniques is composed of five elements: Modelling objectives, inputs, practice, models and outputs. The reasons for presenting a framework for comparing modelling methods are:

- There are no agreed general frameworks or procedures that can be used for comparing modelling methodologies and techniques.
- The comparison of modelling methods is based upon the modelling applications.
- The importance of modelling method factors is different from one model builder/practitioner/user to another.

Figure 4.30 illustrates the framework developed and its basic factors. Every element involves a set of factors. Ideally, any modelling method is developed or selected to meet various requirements. The requirements modelling method can be formulated based upon several factors such as those shown in Figure 4.30.

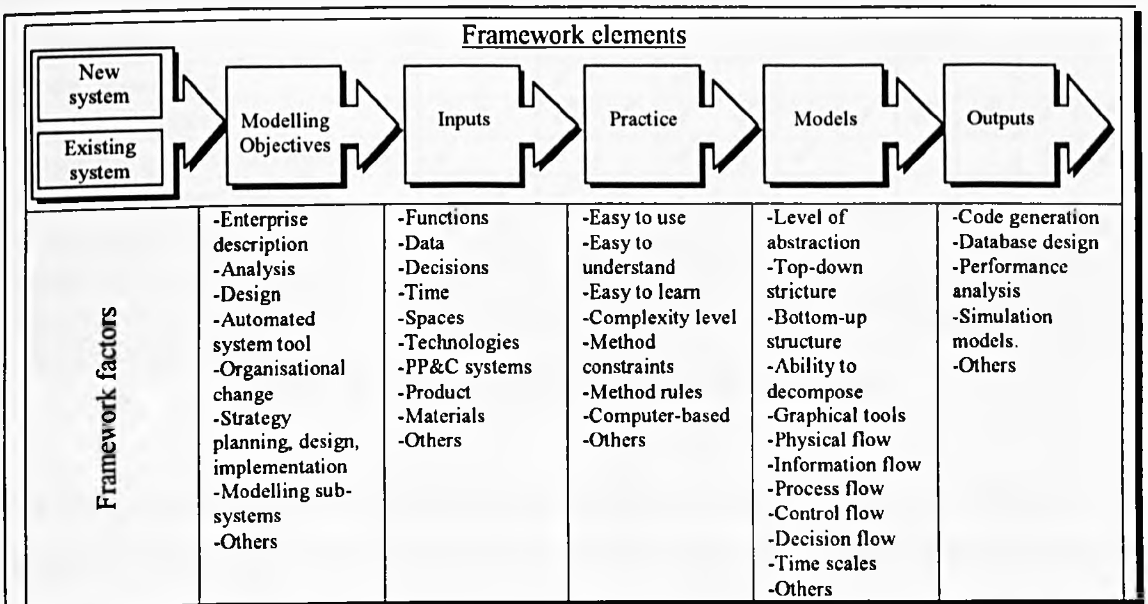


Figure 4.30. Framework for comparing modelling methods.

Using a set of modelling requirements, the methods selected in this chapter are compared and evaluated, as illustrated in Table 4.4. The factors used in this comparison are those which have importance in computer integrated manufacturing applications.

Modelling requirements	Modelling methods											
	SSADM	IDEF0	IDEF1X	IDEF3	IDEF4	SADT	OOM	GRAI	PN	IOA	MERISE	GIM
Enterprise modelling		✓			✓	✓	✓	✓			✓	✓
Ability to express different levels of abstractions	✓				✓	✓	✓	✓			✓	✓
Top-down structure	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Bottom-up structure	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓
Easy to use, learn, understand		✓				✓		✓		✓	✓	✓
Ability to decompose from high level to low level	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Modelling information flow	✓	✓	✓	✓		✓	✓		✓		✓	✓
Modelling decision flow								✓	✓			✓
Modelling process flow				✓		✓				✓		✓
Modelling physical flow		✓		✓		✓						✓
Modelling control flow		✓					✓		✓		✓	
Simulation				✓					✓			
Checking consistency	✓	✓	✓	✓	✓		✓		✓			
Time scales				✓				✓	✓			✓
Code generation			✓		✓							
Graphical tools	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Describing data relationships	✓		✓		✓	✓	✓				✓	✓
Computer-based method	✓	✓	✓	✓	✓							
Conceptual modelling		✓			✓	✓	✓	✓		✓	✓	✓
Functional modelling		✓		✓	✓	✓	✓			✓	✓	✓
Structural modelling	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Conflict detection				✓						✓		

Table 4.4. Comparison of CIM modelling method

The comparisons of CIM modelling methods indicates that no single modelling method meets all modelling requirements of manufacturing system. SSADM does not support the analysis and design of manufacturing systems. It was developed for software engineering and it does not consider some important manufacturing factors such as decision flow, time scales and dynamic modelling.

IDEF0 is a good functional/structured modelling method and is easy to learn, understand and use. It has some limitation such as lacking decision modelling, time scales and simulation aspects. However, IDEF0 may be used to model functional aspects of manufacturing systems or can be integrated into another modelling methodology. The strength of IDEF1X is apparent in information modelling; hence it can be used for analysis and design of information sub-systems. This modelling method does not support other manufacturing aspects such as physical and decisional systems. IDEF3 is designed to capture the knowledge of the area expert concerning the operation of a particular process. It is a good method for process description. It is difficult to use and to learn. IDEF4 is an OOM. These methods are dependent on the development requirements. Most of the exiting OOMs support information systems but do not support process and decision modelling. In addition, most OOMs are specifically for problem solving and require professional skills.

SADT is a good method to model functional and information aspects but it does not consider decision control and system time aspects. This method lacks a computer-based method and describes systems statically. Hence it is not a suitable modelling tool for effective analysis and design of CIM systems.

GRAI is a generic modelling method of manufacturing systems and has good graphical tools. This method is good for modelling decision flow based upon horizons and review periods. The GRAI method does not support information and physical systems. In addition, it has no meaningful rules for constructing its grids and nets. It also describes the static nature of manufacturing systems and does not consider any dynamic behaviour.

IOA can be used to give general descriptions of complex systems. A computer-based method is not available. This method supports the system design phase but is not very well known. Several important requirements such as decision modelling, simulation, time scales, and model consistency can not be achieved by the IOA.

The PN approach is very difficult to learn and use. PN is good for modelling control flow but it does not provide an adequate description for information and decision flows. In addition, PNs lack a general computerised tool and have limited graphical elements.

MERISE has limited ability to model CIM systems because it was developed to support information systems only.

GIM is composed of GRAI, MERISE and IDEF0; hence it is the most suitable method for the analysis and design of manufacturing systems. Unfortunately, this methodology is no more than a toolbox as it lacks true integration between the elements and data sharing is not available. GIM needs computerised tools to achieve the conflict detection and model consistency of its models. In addition, this methodology does not support dynamic aspects of manufacturing systems.

Most existing modelling methods can only support particular aspects of CIM systems. Limitations and problems of current CIM modelling methodologies and techniques have been addressed by many researchers and authors. For example, Brandimarte and Cantamessa (1995) reported that the current modelling methods do not pay enough attention to many important aspects of CIM systems which need deep integration of many components and elements. Chadha et al. (1991) mentioned that the existing modelling tools and approaches do not satisfy all the requirements of the complex manufacturing systems. Aguiar and Weston (1995) compared a number of modelling methods and concluded two important points. The first is that no single modelling method provides a complete support for decisions along the integration manufacturing enterprise life cycle. The second is that there are a number of gaps such as a lack of a good formalism which must be filled. It is clear that there is a need for new modelling methods to support the analysis and design of CIM systems.

4.6. Conclusion

This chapter has focused on the modelling methodologies and techniques applicable to CIM systems. Several modelling methods were selected including SSADM, IDEF0, IDEF1X, IDEF3, IDEF4, SADT, OOM, GRAI, PN, GIM, MERISE and IOA for this study. These modelling methods have been discussed and compared according to a number of established requirements. Several important points are concluded including:

- The term 'modelling' means different things to different people and the understanding of the modelling concept is very important during the analysis and design of complex systems.
- Modelling plays an important role for analysing and designing complex manufacturing system such as CIM systems.
- Before starting a comparison or evaluation of modelling methods some requirements should be established according to modelling objectives, inputs, practice, models, and outputs because there is no formal guideline for comparing and evaluating modelling methods.

- Many authors have agreed on the need for an integrated modelling method for the analysis and design of manufacturing systems and confirmed that no single modelling method exists to support different aspects of a complex system (the physical, decisional, information and the dynamic aspects). It has been found that most existing modelling methods have been developed to support only particular aspects of a manufacturing organisation.
- The only guarantee to successfully analysing and designing CIM systems is to use a modelling methodology which involves and mobilises all the people concerned, and which takes into account function, information, decision, organisation resources, as well as economic, social and human aspects (Doumeingts et al. 1995).
- To solve the CIM modelling problems, it is evident that the need for an integrated method exists. This integrated method can be created by selecting potentially cognate groupings of modelling methods and techniques to seek a means of extending and unifying them to support different phases of CIM systems analysis and design creating software tools that support CIM systems (Aguiar and Weston 1995).
- There is a need to develop software tool to support CIM system analysis and design.
- Simulation models need to be integrated into static models of manufacturing systems (conceptual and structural models). This integration would provide a clear picture of modelling domains in manufacturing systems and support decision activity centres at every level of manufacturing management.
- The integration of static and dynamic modelling methods to produce a method for CIM system analysis and design is discussed in the next chapter.

CHAPTER-5

DEVELOPMENT OF AN INTEGRATED MODELLING METHOD FOR CIM SYSTEMS ANALYSIS AND DESIGN

5.1. Introduction

It was concluded in the last chapters that there was a need for an integrated modelling method for the analysis and design of CIM systems. This chapter addresses the need for developing a modelling method which integrates different modelling aspects. Modelling CIM systems is very difficult due to the complex relationships between different components and sub-systems, and the shortcomings of modelling methodologies and techniques currently available. In this chapter, an integrated modelling method is proposed. This integrated method combines a number of existing modelling tools and employs them for modelling different system domains in the CIM environment. The method developed can be applied through a number of steps based upon different levels of abstraction in the organisation. This chapter also discusses these steps and illustrates the coupling methods between the tools selected. A tool to support the method developed is also presented in this chapter.

5.2. Need for An Integrated Modelling Method

While recognising the potential benefits of a fully integrated manufacturing system, few organisations have achieved CIM implementation. Reasons include the lack of a clearly defined overall CIM strategy and effective methodologies and techniques for modelling and measuring specific implementations against the strategy. Modelling CIM systems is very complex due to the multitude of simultaneous activities carried out. These include design and development, manufacturing, distribution and marketing, and involve a wide variety of physical, decision and information relationships. Rapidly changing technologies and customer preferences necessitate frequent changes in the products manufactured and the strategies and facilities required by the organisation. Consequently, the models representing the CIM systems tend be long and complex. These models should be continuously evolving to represent the static and dynamic aspects of the manufacturing systems.

Decision, information and physical sub-systems represent the major components of a manufacturing system (Doumeingts et al. 1995b). These sub-systems need to be modelled efficiently to solve system analysis and design complexities. It is clear that one of the most important objectives of an organisation is to achieve quick response capability, flexibility and integration. To achieve these, the three sub-systems of the manufacturing systems should ensure the following:

- All main components of CIM should have access to integrated databases.
- The different flows of manufacturing sub-systems (decision, information and physical flows) are finely co-ordinated.
- The various functions involved in the working of the organisation are defined.
- The decisions and information needs of the function are effectively modelled.
- A dynamic interaction between system activities exists.
- All activities, data and resources of an organisation are correctly related to each other.

In Chapter-4, modelling methods which have been used for analysing and designing different aspects of CIM systems were identified. It was concluded that no single modelling method or technique could be used to model, analyse and design a complex manufacturing system completely, or indeed, model a significant number of components of these complex systems. Most existing modelling methods are no more than static graphical representations and are not well defined. Those modelling methods are open to misinterpretation and inconsistencies. Modelling needs a method which is simple and able to support different levels of abstraction.

The CIM analysts and designers need to model the basic manufacturing operations as well as management decision and information systems to produce an integration framework for the organisation. According to Colquhoun et al. (1993), most authors agree that no single method can model functions, information, decisions and dynamic behaviour of the system. It is surprising that the interfacing and integration between existing modelling techniques such as IDEF0 and dynamic modelling has not received more attention. Gunasekaran et al. (1994) reported that there was a need to study carefully the development of CIM apart from simply automating the information systems and process control. This can be carried out by considering the CIM concept at each area of manufacturing to achieve the integration of various functional areas based upon integrated modelling methodologies. This is also evident from the comparison of modelling methods, as illustrated in Chapter-4. This combination of modelling approaches brought together in a CIM application offers many advantages.

5.3. Selecting Components of A modelling Method

The decision, information and physical sub-systems involve a set of activities and entities that are related to each other and form the complete system. Consequently, many researchers suggest that manufacturing systems need an integrated modelling method that can model the three sub-systems and simulate their dynamic aspects. The nature of information and material flows influence decision making in the whole organisation and enhance the design parameters of the CIM system (Gunasekaran et al. 1994).

In this work, an integrated modelling method is configured and called GI-SIM (GRAI/IDEF-Simulation). This method is composed of the following components:

1. GRAI grid.
2. IDEF0
3. IDEF1X
4. SIMAN (ARENA)

These components are adopted from existing modelling methods and developed to meet the needs of CIM system modelling. The principle of this integrated method is to apply the most suitable tools to the particular problem within CIM systems, combine the strengths and eliminate the weakness of existing methods and tools.

The reasons for selecting the GRAI grid in GI-SIM are:

1. It relates to the analysis and design of decision systems, rather than the information and physical systems.
2. It has the ability to model within time based analysis (Wainwright 1993).
3. It has the ability to analyse the implications of "top-down" decisions.
4. It has the ability to give a generic view of an organisation.
5. It provides a good graphical representation.

IDEF0/1X are selected in GI-SIM for the following reasons:

1. They have demonstrated their usefulness as simple and effective communication tools, which encourage user involvement and co-operation with system builder (Maji 1988).
2. No other modelling methodology can provide the same functional analysis capability (Colquhoun et al. 1993).
3. They have the ability to model information and physical systems.
4. They have the ability to decompose from a high level to more details.
5. They offer the opportunity for enhancement, integration with each other and integration with other modelling tools (Colquhoun et al. 1993).
6. IDEF1X can be easily translated into a relational database system.

The reasons for the selection of SIMAN/ARENA in GI-SIM are:

1. It has the ability to model the dynamic aspects of manufacturing systems
2. The ARENA package was readily available.
3. It has the ability to represent performance measures.
4. It has the Ability to support decision making variables.
5. It has the ability to close the gap between conceptual/structural and simulation modelling.

5.4. GI-SIM Framework

A good modelling method should include conceptual/structural and system relationships and classify their modelling objectives (decision, information and material flows). It should be able to handle complex systems and provide formal guidelines for method application. In modelling, it is important to differentiate between conceptual/structural, generative and evaluative models. The conceptual/ structural model is used to present a global view of the organisation and define the basic concepts, system sub-activities and the relationships between system functions and activities. The generative model is used to satisfy objectives using an optimal solution technique. The evaluative model is used to evaluate a set of decisions and provide the user with performance measures using simulation techniques. It is anticipated that the decomposition of general conceptual models into structural and dynamic views will be helpful when modelling complex manufacturing systems.

The GI-SIM modelling method has been developed to capture the characteristics of a manufacturing system completely. GI-SIM provides an integrated set of four modelling tools (GRAI grid, IDEF0, IDEF1X and ARENA) which have previously been used in existing different modelling methods. GI-SIM employs the strengths of each to include conceptual/functional and dynamic modelling concepts and provide a powerful tool.

Figure 5.1 illustrates the relationships between the method components. It provides the main purpose of the modelling concept as a formal method for conceptual, functional and analytical modelling. This is to facilitate modelling procedures, based upon user requirements related to different sub-systems, and demonstrate the integration between the GI-SIM components for different levels of system abstractions. A further feature of the GI-SIM common architecture is illustrating the importance of the effective transfer of the flow of any sub-system between different levels of abstractions and their relevant specification domains. It demonstrates that compatibility between modelling tools is very important to achieve adequate linking and integration.

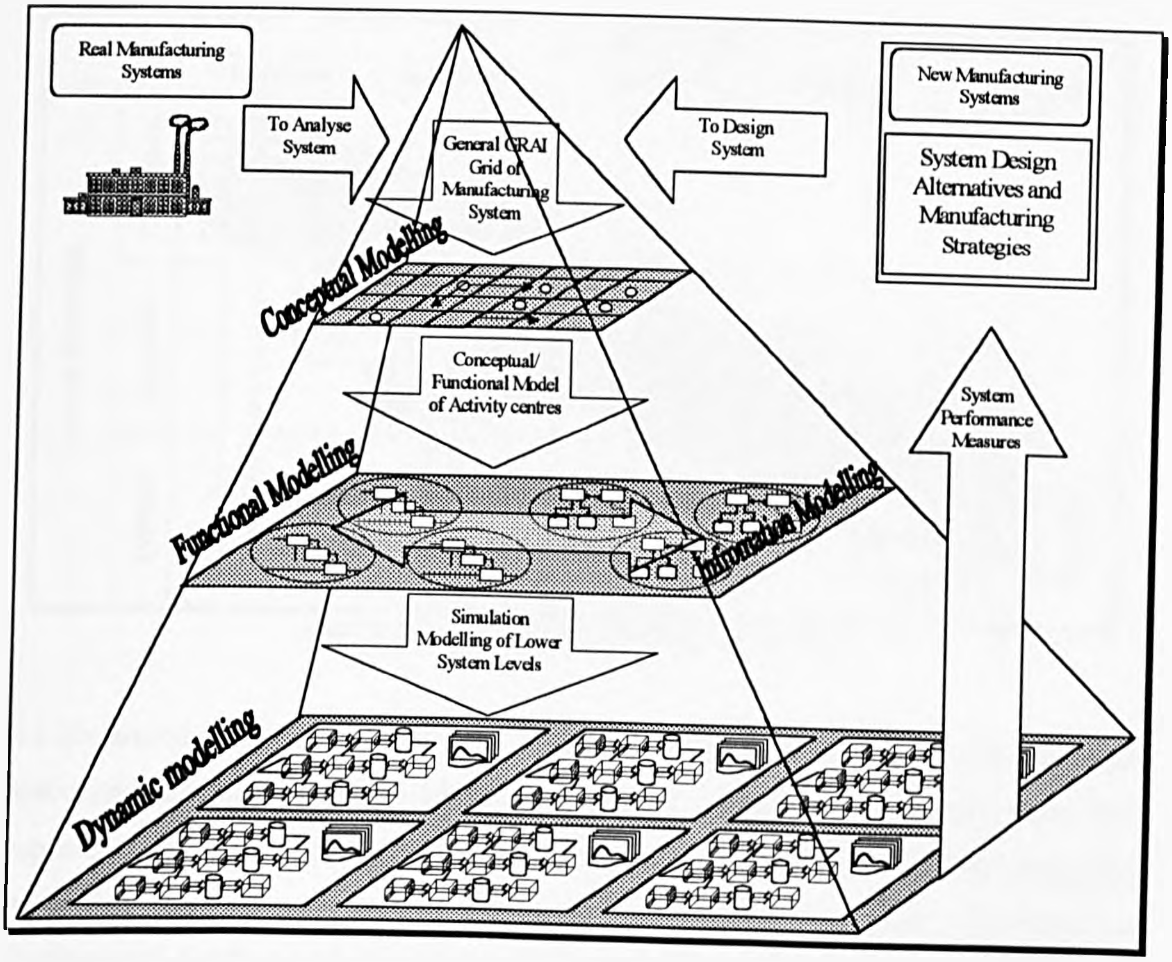


Figure 5.1. The GI-SIM general structure.

Figure 5.2 illustrates levels of abstraction, namely; conceptual, structural and detailed. These levels can be considered within five system modelling domains:

- Decisional
- Functional.
- Information.
- Physical.
- Dynamic.

These modelling domains are closely related to each other; hence, the classification of modelling domains in some manufacturing application would be very difficult. For example, taking a decision need inputs (information, physical, etc.) because any decision should have objectives and variables. This decision can also be implemented functionally, based upon its inputs, and measured dynamically, based upon its timed outputs.

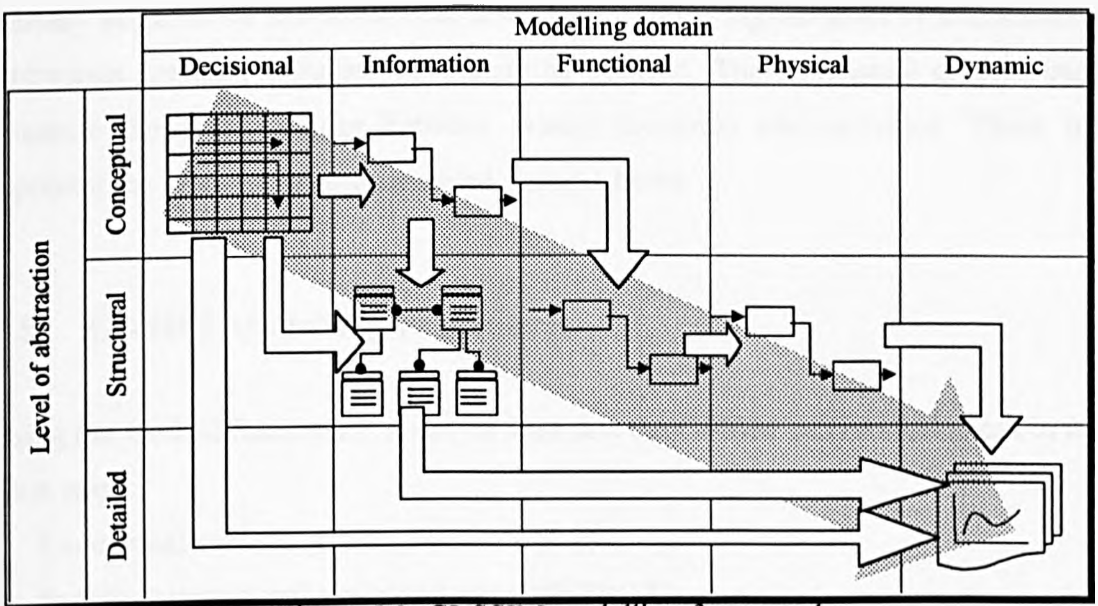


Figure 5.2. GI-SSIM modelling framework.

As illustrated in Figure 5.2, GI-SIM covers the basic levels of abstraction and their associated modelling domains within an industrial organisation. The conceptual level represents the general concept of an organisation and can be modelled by conceptual modelling methods such as the GI-SIM grid. The conceptual model represents the fundamental functions which apply within the system. In manufacturing systems, the most important modelling domain for the conceptual level is the decisional domain. The other aspects of the system can be used to support the decision domain in system modelling. In some cases conceptual models can represent the physical views. The structural level represents the main structure of the system activities in several levels based upon specific relationships, identified at the conceptual level. This level is used to model the static relationships between system functions. At the conceptual level, these functions generally correspond closely to the objects in the real-world system. At a structural level of modelling, the type of dependency that links system functions is represented by various relationship forms. More details about these relationships can be modelled in three modelling domains (information, functional and physical domains) using IDEF0/1X tools. At a detailed level, the connection between events and time variables via dynamic modelling is carried out. Therefore, the detailed level represents the actual implementation of system activities and their dynamic behaviour. In the GI-SIM framework, dynamic modelling using SIMAN/ARENA is used as the method to describe the detailed level of system activities.

This context of modelling is vital to provide the foundation for systems integration. The primary objective of this framework is to capture, at the highest level of abstraction the interaction between complex manufacturing systems. The conceptual context should illustrate the primary links between system functions and activities. These links represent the working or recommended systems flows.

5.5. GI-SIM Modelling Procedures

Using the method framework, it can be seen that the GI-SIM can be carried out in three main steps:

1. Conceptual modelling using the GI-SIM grid;
2. Functional/structural modelling using IDEF0/1X;
3. Simulation modelling using SIMAN/ARENA;

5.5.1 Conceptual Modelling - Step 1

When analysing and designing a manufacturing system one of the fundamental tasks is to define the general view of an organisation. This can be achieved during the first step of the GI-SIM method. A global structure of a manufacturing system can be developed using a single level of a modified GRAI grid to illustrate the main functions, decision centres and activity centres. The relationships between activity centres can be classified into three types of system flow: decisions, information and material. These system flows can be shown in the general grid using different arrow styles, as illustrated in Figure 5.3. The importance of the decision sub-system and time scales in manufacturing organisations is the main reason for adopting the GRAI grid in the GI-SIM method. This step defines system specifications that can be used in the subsequent modelling steps. These specifications involve decisions and activity centres, horizon/period times, activity inputs/outputs in terms of decisions, information and/or materials relationships. GI-SIM involves two types of decision links (vertical and horizontal decisions) depending on the hierarchical levels of decision sub-systems which are based upon the planning horizon and its review periods. In vertical decisions, the decision link source and destination can be found in the same manufacturing function, but the horizontal decision link connects two types of manufacturing functions.

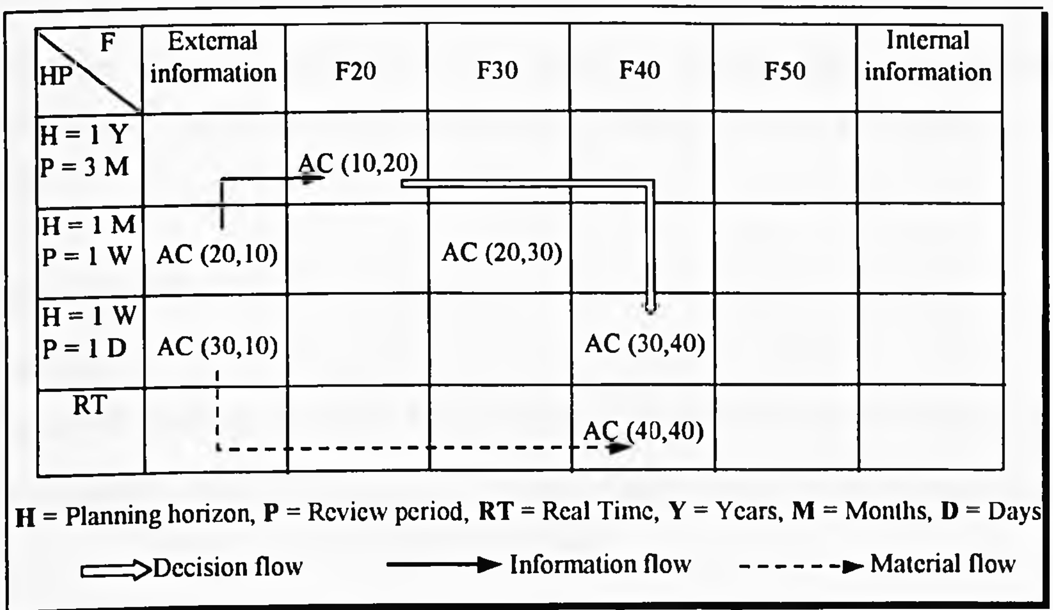


Figure 5.3. Representation of system flows.

The first step of this modelling method can be carried out by:

- Identifying the main functions of manufacturing systems (F10, F20, F30, etc.). These functions can be divided into two main categories; organisational and operational functions. The selection of GI-SIM grid functions is based upon the objective of the study.
- Identifying the decision/activity centres related to each function. These decision/activities can also be categorised into three main types; decisional, information and physical.
- Determining the planning horizons and review periods for each level based upon the activity centres defined and their activity cycles.
- Constructing the main relationships between grid cells (AC (level no, Function no)) in terms of decisions, information and materials.

It should be noted that the GI-SIM grid concentrates on decision modelling. Ultimately, decision modelling seeks basic principles to help the decision-maker to develop effective decisions, define decision variables or choose between several alternatives of system elements and policies. This is very complex because the development or adoption of a manufacturing strategy involves many decision variables and alternatives. Therefore, the purpose of conceptual modelling is to rapidly arrive at a well-structured level which conforms to a common architecture.

5.5.1.1 GI-SIM Time scale Formulation

To facilitate the computerisation of the method, all elements should be formulated mathematically. The grid horizons and periods at different levels of the GI-SIM grid are related.

Let:

The grid functions = $F_1, F_2, F_3, F_4, \ldots$

The grid levels = $L_1, L_2, L_3, L_4, \ldots$

The grid cell (activity centre) = $AC_{l,f}$. Where l is the level number and f is the function number. The constraint number of levels and functions can be represented as:

$$\text{Max}\{l, f\} \le \{\text{Maxl}, \text{Maxf}\} \text{ and}$$

$$\text{Min}\{l, f\} \le \{\text{Minl}, \text{Minf}\}.$$

Where:

Minl and Maxl are the minimum and maximum number of levels involved in the grid, and Minf and Maxf are the minimum and maximum number of functions involved in the grid.

Planning horizons = $H_1, H_2, H_3, H_4, \ldots$ for levels $L_1, L_2, L_3, L_4, \ldots$ respectively.

Review periods = $P_{11}, P_{12}, P_{13}, P_{14}, \ldots P_{1n}$ for planning horizon H_1.

Hence;

The review period P_{ij} is the *jth* period of horizon *i*.

Then;

$$H_1 = \sum_{j=1}^{n_1} P_{1j} \text{ for } L_1 \tag{1}$$

and

$$H_i = \sum_{j=1}^{n_i} P_{ij} \text{ for } L_i. \tag{2}$$

$$\text{Number of periods for } L_i = np_i = \frac{H_i}{P_i} \tag{3}$$

If L_h is the last level in the GI-SIM grid then:

$$H_{h-1} = \sum_{j=1}^{n_{h-1}} P_{(h-1)} \text{ and } H_{h-2} = \sum_{j=1}^{n_{h-2}} P_{(h-2)} . \quad (4)$$

Hence;

$$H_{h-2} = k_{(h-1,h-2)} * \sum_{j=1}^{n_{h-1}} P_{(h-1)} \quad (5)$$

Where $k_{(h-1,h-2)} = \frac{H_{h-2}}{H_{h-1}}$

If $np_l = \frac{H_l}{P_l}$ then the relationship between H_l and H_{h-1} can be represented by:

$$H_l = \left[k_{(h-1,h-2)} \times k_{(h-2,h-3)} \times \ldots\ldots \times k_{(2,1)}\right] \times \sum_{j=1}^{n_{h-1}} P_{(h-1)} \quad (6).$$

These formulations can be represented graphically, as illustrated in Figure 5.4. The figure shows three levels of horizons and their associated periods. Figure 5.4 is an example of hierarchical production planning which can be decomposed into three levels based upon the three types of manufacturing management, namely, strategic, tactical and operational.

To check that every level has a unique planning horizon, the following BASIC algorithm can be applied:

```
FOR i = 1 TO n-1
        FOR i'= 2 TO n
                IF Hi = Hi' THEN Li AND Li' HAVE THE EQUAL PLANNING
                HORIZONS.
                RE-CONSTRUCT GI-SIM GRID
        NEXT i'
NEXT i
```

The hierarchical system in manufacturing uses decreasing planning horizons and periods, this can be formulated as:

$$H_1 > H_2 > H_3 > H_4 > \ldots\ldots$$

For every level, it should be noted that: $H_i > P_i$

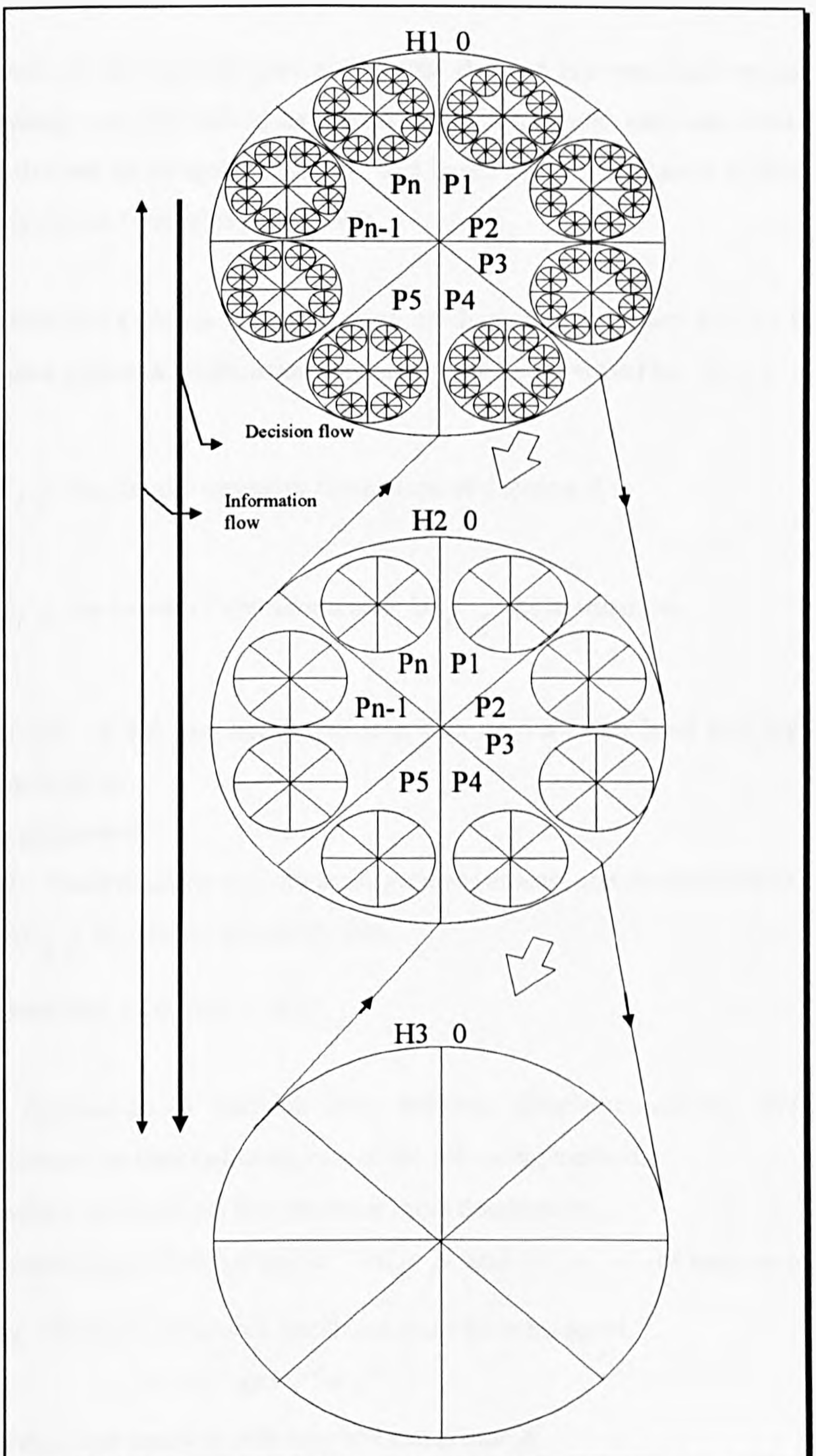


Figure 5.4. Decomposition of system activity horizons and periods.

5.5.1.2 Decision flow formulation

At each level of the GI-SIM grid and within defined horizons and review periods, decision strategy can be defined as a sequence of decisions, each one referring to an interval equivalent to an updating period and based upon information collected during the sampling period (Banerjee et al. 1994).

Every decision has a source and destination, as illustrated in Figure 5.3. As formulated in the previous section a decision/activity centre can be identified by $AC_{l,f}$.

Hence ;

$AC_{l,f}$ may be the source or destination of decision *d*.

Let:

$AC_{l,f}$ the source of decision *d* and $AC_{l',f'}$ its destination.

Then:

The rule: "a decision frame should not go from a lower level to a higher level" can be formulated as:

For decision *d*: $l' - l \geq 0$

And the rule: "each decision activity must generate at least one decision frame".

If $AC_{l,f}$ is a decision activity then:

At least one {*d* source = (*l*,*f*)}.

To avoid duplication of decision links between (Decision/Activity) D/A centres, decision links can be checked using one of the following methods:

1. If more than one decision link have the same destination;

$AC_{l,f}$ is destination of both *d* and *d'*. $AC_{l',f'}$ and $AC_{l'',f''}$ are sources of *d* and *d'* respectively. Then; the following constraint must be considered,

$$l' \neq l'' \text{ and } f' \neq f''.$$

2. If more than one decision link have the same source;

$AC_{l,f}$ is the source of both *d* and *d'*. $AC_{l',f'}$ and $AC_{l'',f''}$ are destinations of *d* and *d'* respectively. Then; the following constraint must be considered,

$$l' \neq l'' \text{ or } f' \neq f''.$$

This can be extended for more than two decision links.

5.5.1.3 Activity Formulation

A theory of activity formulation can be derived from the system flows during a specific planning horizon and review period. The activity formulation is very important to develop system utilisation based upon considerations of dynamic data exchange between different levels of conceptual modelling. This contributes also to reducing the substantial gap between theory and practice in hierarchical production planning. Figure 5.5 illustrates the hierarchical relationships between system time scales. Figure 5.6 illustrates the relationships between level time scales and activity cycles.

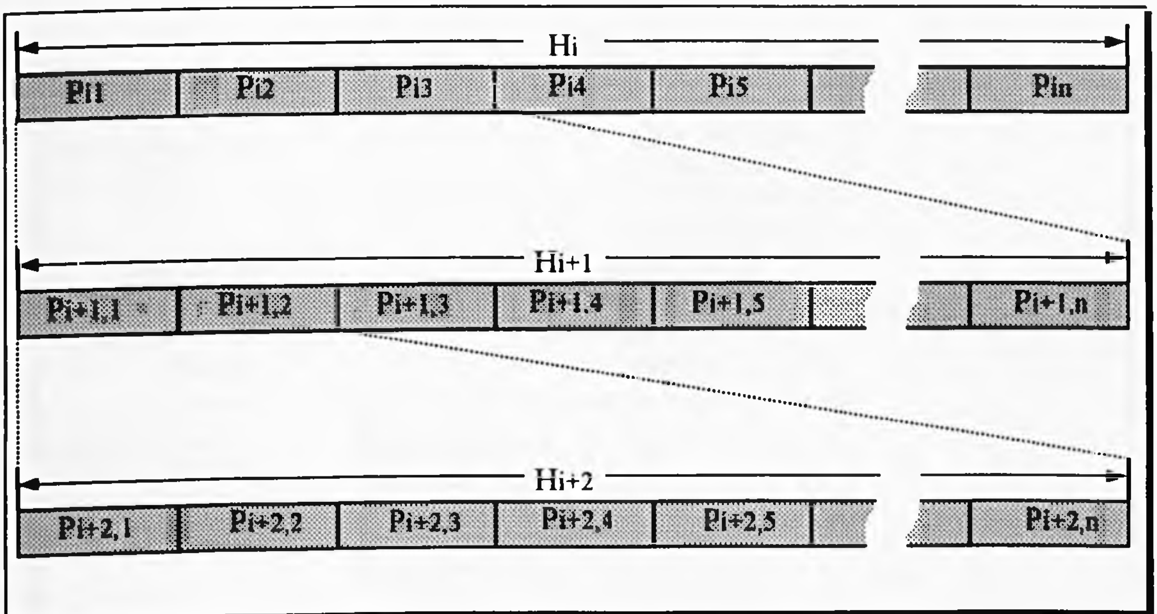


Figure 5.5. Hierarchical representation of grid time scales.

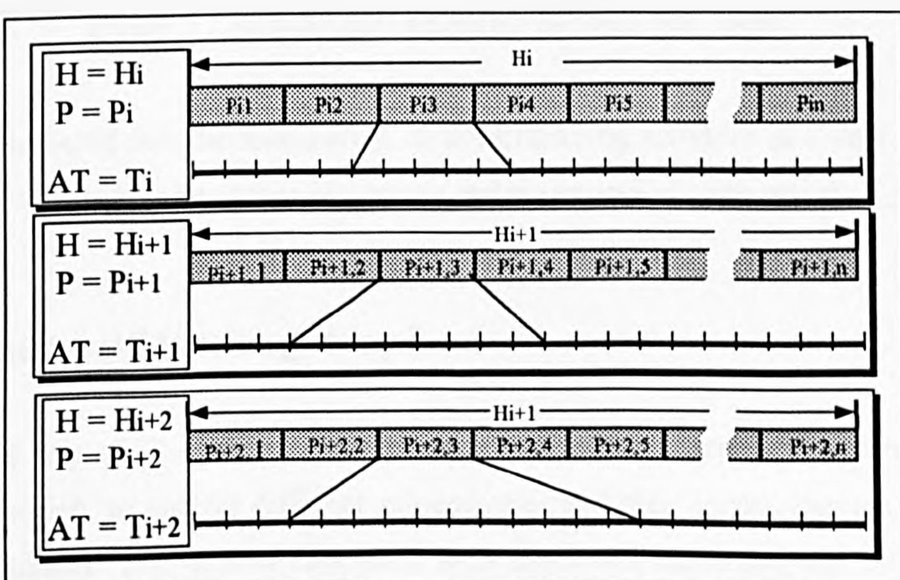


Figure 5.6. The relationships between level time scales and activity cycles.

As shown in Figure 5.6, Ti = activity time. For each manufacturing activity,

$$Ti \leq Pi,$$

Let:

A D/A centre can be decomposed into several child-activities ($A_{1,}\ A_{2,}\ A_{3,}\ A_{14} \ldots A_{m,}$),

and every child-activity dedicated to complete jobs ($J_{1,}\ J_{2,}\ J_{3,}\ J_{14} \ldots J_{k}$).

Using these assumptions, Figure 5.7 can be derived.

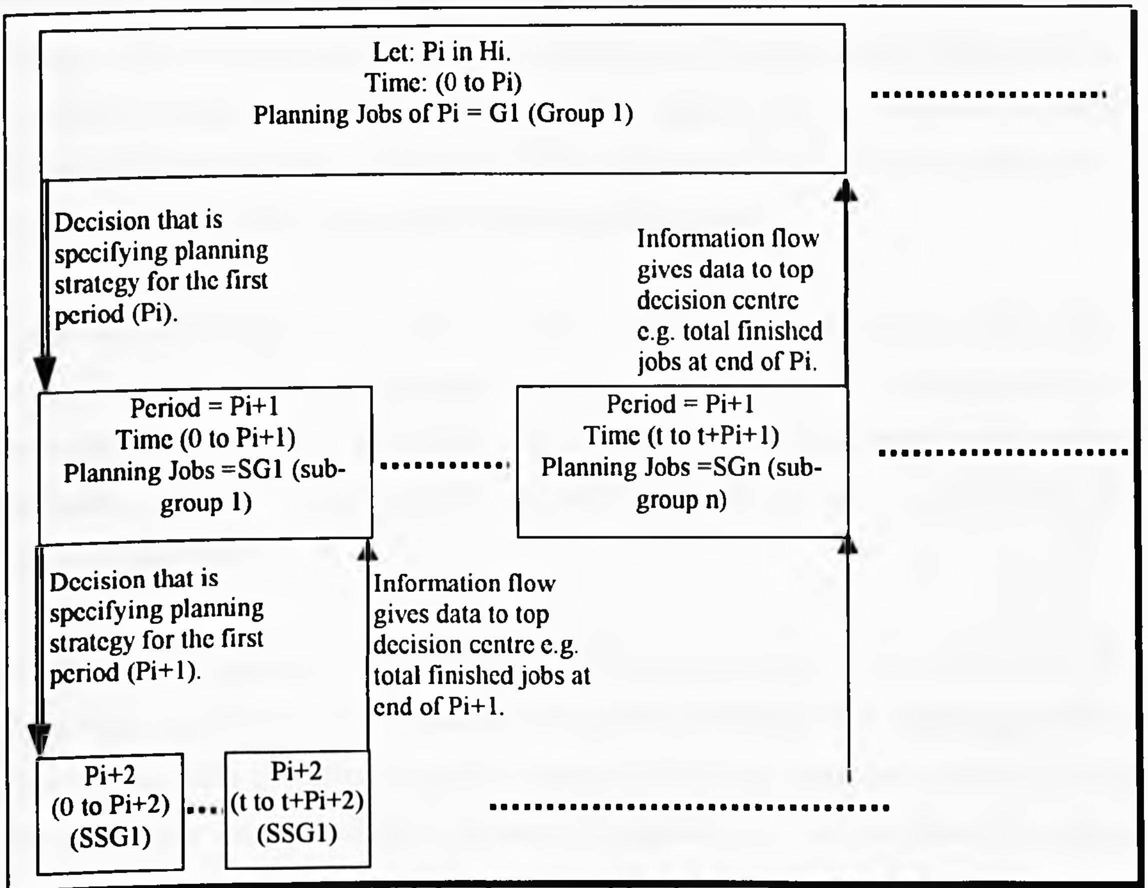


Figure 5.7.Activity decomposition between grid levels.

It should be noted that the formulation of manufacturing activities is a very complex task due to the random behaviour of systems and the variety of applications.

5.5.2 Structural Modelling - Step 2

The second step of GI-SIM is the construction of IDEF0/1X models for every activity centre identified, to analyse different sub-activities and their inputs, outputs, controls and mechanisms. This step is concerned with functional modelling and information modelling. In functional modelling, the model builder describes what the system does.

This is a very difficult task particularly in the system design phase because of the complexity of generating system activities and sub-activities. The top activity of every IDEF0 model represents the general activity centre to which jobs relate. The IDEF0 model of every activity centre can be decomposed into more detailed diagrams until the activity centre is described in the necessary level of detail. Inputs and outputs of the IDEF0 model are classified according to the inputs and outputs of the related activity centre, as shown in Figure 5.8. Because a conceptual model shows only important information and physical flows between D/A centres, more details about system flows appear at the structural and detailed modelling levels. The complete IDEF0 model is a hierarchy of decagrams derived from the decomposition of the decision or activity centre obtained from the GI-SIM grid. The decomposition feature of this method can be completed using both top-down and bottom-up approaches.

Selecting IDEF0 functions is very important, particularly for decision centres, because these functions involve basic elements and variables used for decision making. In manufacturing systems, decisions require effective representation and powerful modelling methods because decisional mistakes lead to large organisational and technical problems.

IDEF0 models illustrate how information, decisions and material are used by each D/A centre and how they are exchanged between system functions. The models generated in this step establish characteristics which are required in the subsequent modelling steps. This helps the model builder to localise functionality as well as identify important elements in the GI-SIM model, such as information, decisions and material movements, and system operations, as shown in Figure 5.8.

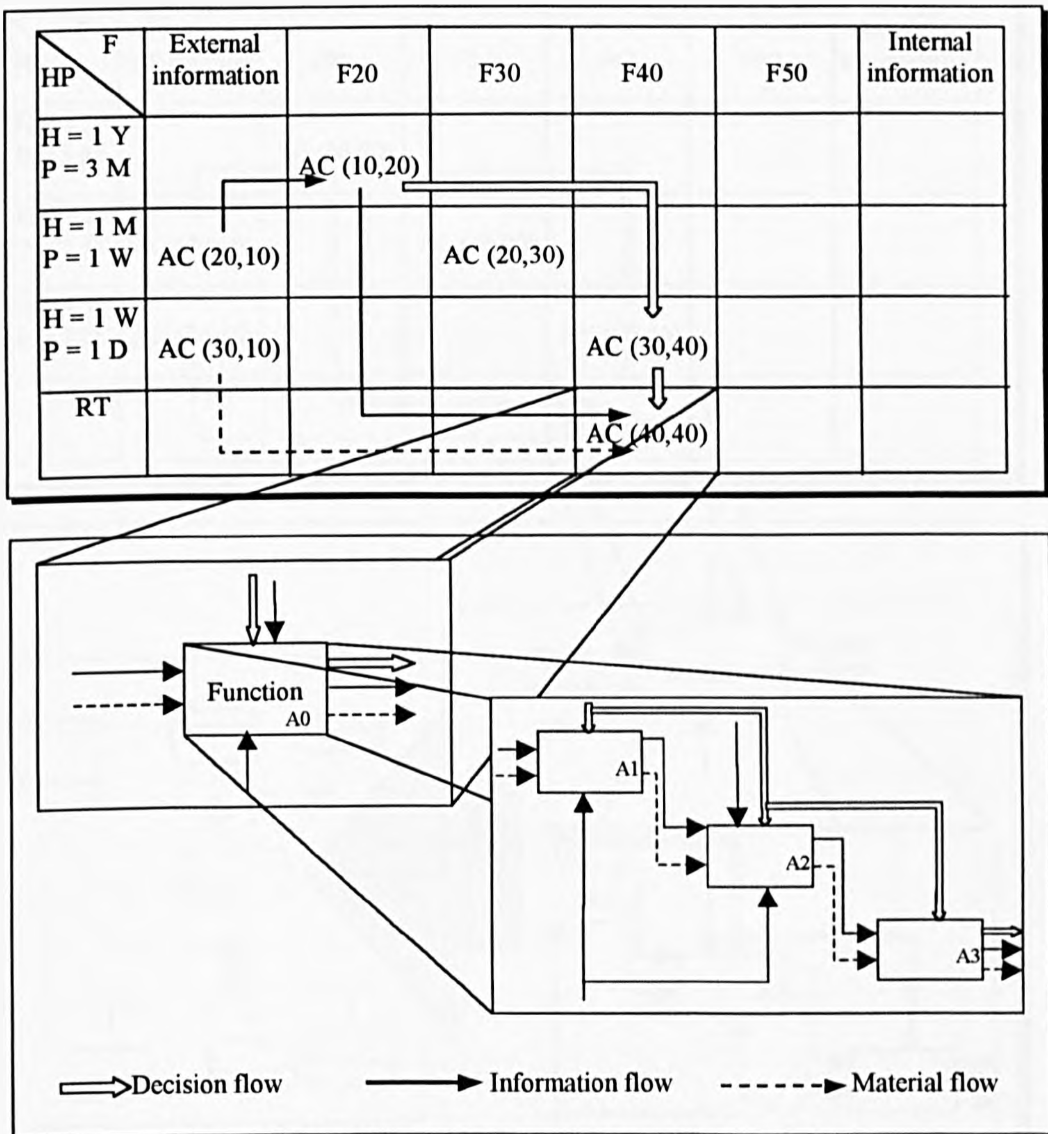


Figure 5.8 GRAI grid and IDEF0 coupling in GI-SIM

IDEF1X models are constructed using both conceptual and functional modelling results to model the information system in terms of entities and relationships. The IDEF1X model is generated using information flows at both conceptual and structural levels to explore the relevant entities and attributes related to a specific information flow. For example, in GI-SIM the information flow 'customer_order' can be found. This can be considered as an input for the 'order_processing' activity, because the IDEF0 model uses the general flows of information; hence the flow (customer_order) will be modelled using IDEF1X and its related system entities. The 'customer_order' entity has several attributes including 'order_number', 'customer_number', 'customer_address', 'contact_name'. These attributes can be found only in IDEF1X models. Figure 5.9 illustrates the modelling of information flow using IDEF1X.

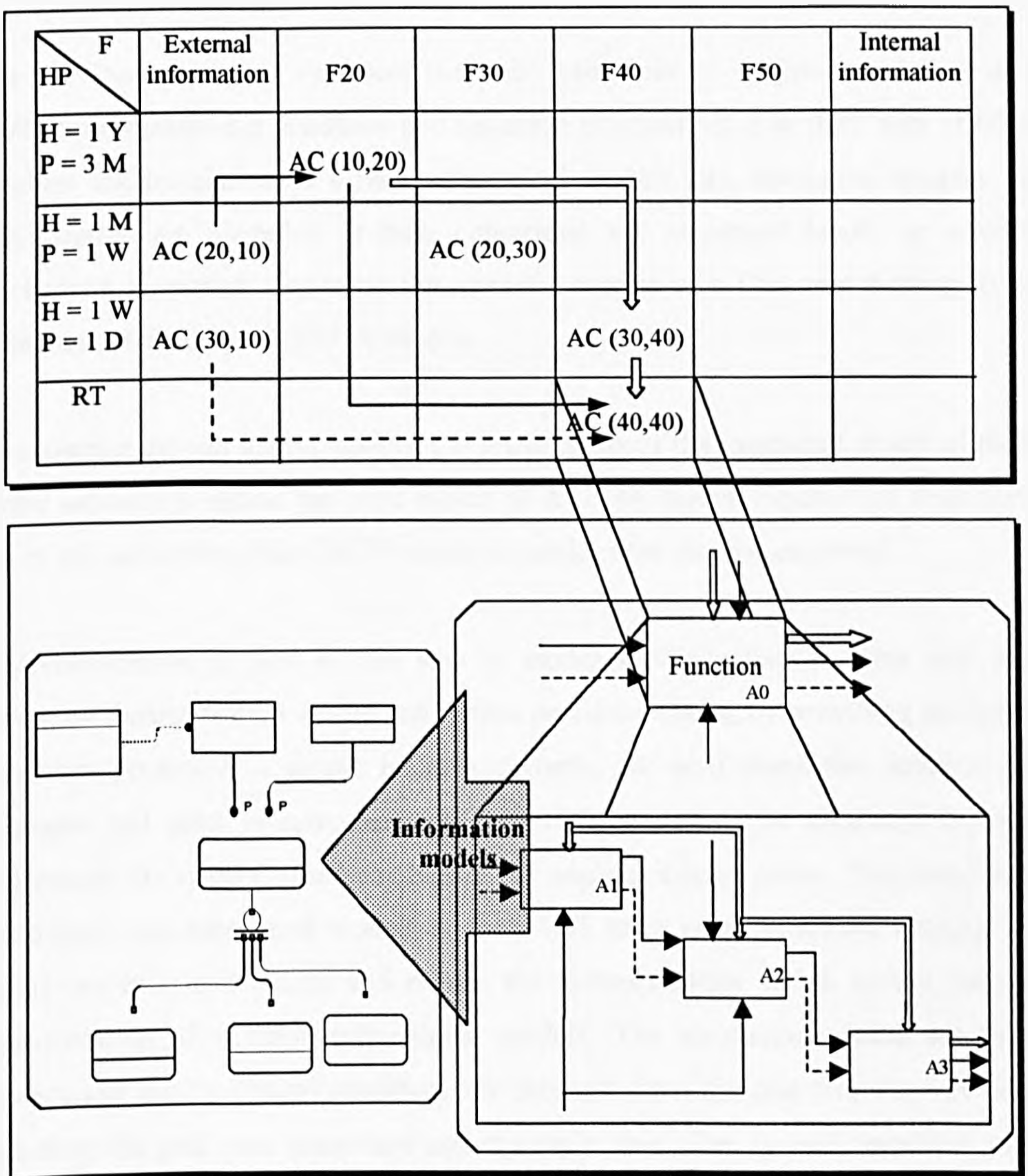


Figure 5.9. Information models coupling in GI-SIM

IDEF1X can be used to formulate a relational database because it describes the data structure at each level of functional modelling. It provides knowledge about the entity classes required by D/A centre, the relationships between them and the features which differentiate the unique elements amongst them. This assists the user to provide the essential structures of data domains. The database system generated using IDEF1X models can be accessed by different components requiring data. The main problem of this type of database is that it needs a logical model which is very different from the conceptual model. These modelling domains are needed to define the basic system specifications which will be described in the detailed level and based upon the activities dynamic behaviour.

5.5.3 Dynamic Modelling - Step 3

The previous steps only represent the static behaviour of a system and they do not explicitly represent the condition and sequence of activities. The third step of GI-SIM involves the translation of functional/physical models into simulation models. Since D/A centres are modelled at both conceptual and structural levels, an additional mechanism is needed to identify the dynamic aspects of a D/A centre using its basic elements obtained by IDEF0/1X models.

To construct the simulation models, the lower levels of the functional model of the D/A centre are used to define the basic blocks of ARENA model. Figure 5.10 illustrates the use of sub-activities of the IDEF0 model to produce the simulation model.

SIMAN/ARENA is used in this step to model system activities. This step is also important during system design and assists decision-making by providing performance measures, presented in simple tables and charts, for each alternative solution. Many strategies and tasks in manufacturing organisations need to be simulated in order to understand the system behaviour before the implementation phase. The integration of simulation and conceptual modelling tools will solve many problems relating to the system analysis and design and reduce the inconsistencies which occurs during the representation of conceptual/functional models. The simulation results are used to provide and justify system specifications obtained from the first two steps of GI-SIM including the grid time scales and activity cycle time. The dynamic model is used to evaluate system specifications in the analysis phase or define new decision/activity variables in the design phase. Figure 5.11 illustrates the GI-SIM mechanism.

Simulation of manufacturing activities requires information such as details of process sequence and resource variables for the process. Most of these requirements will be typically contained in the previous modelling steps i.e. provided by different domains modelled by the grid and IDEF0/1X models. Constructing a simulation model for any D/A centre is only one part of a complete project. Once the model is built, the model is run and outputs are collected. By analysing these outputs several performance measures can be used to support different decision tasks. In the design phase, decision making can be taken based upon several modifications which can be measured statistically. This will be helpful for achieving organisation goals.

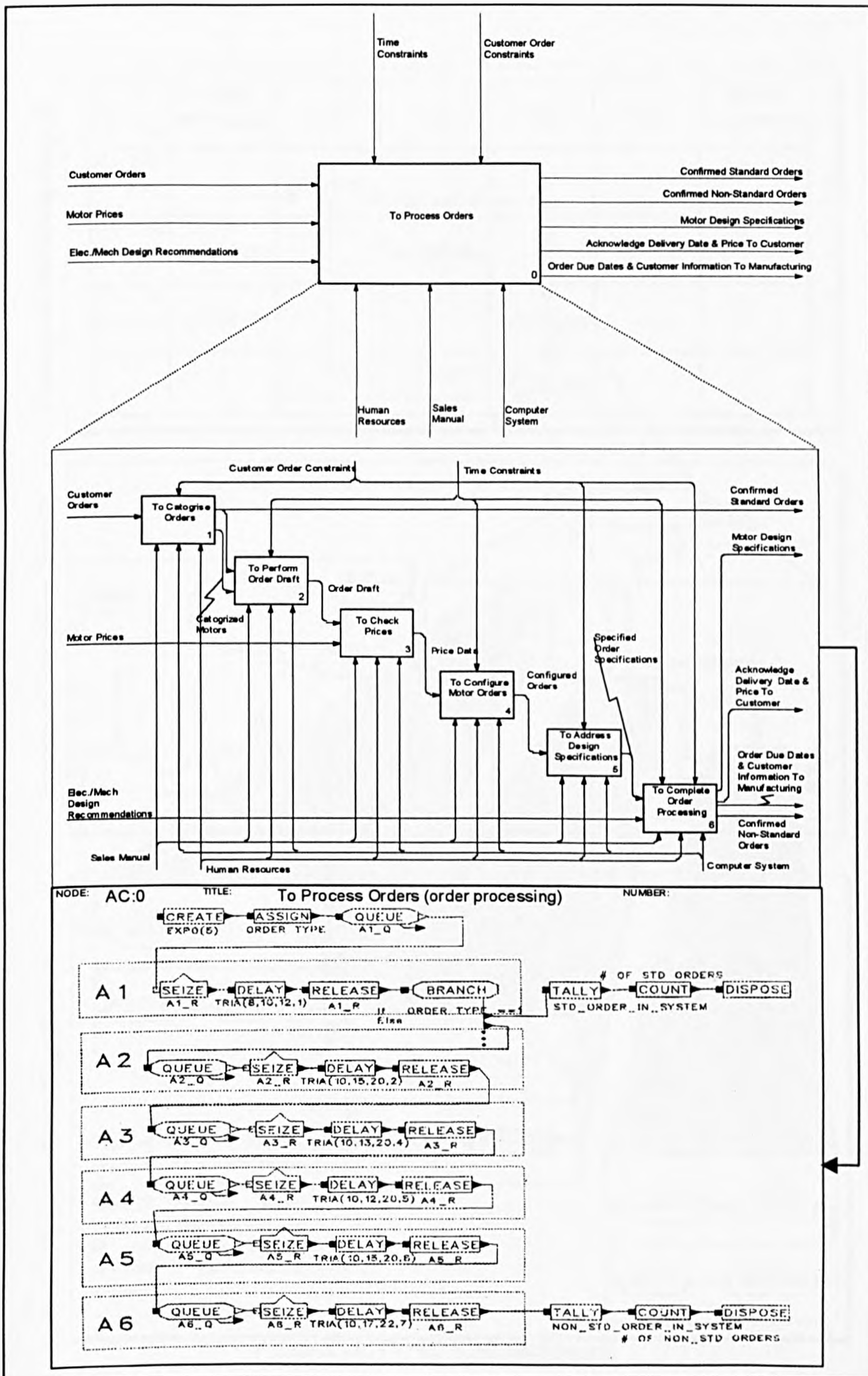


Figure 5.10. The use of IDEF0 model to construct the simulation model.

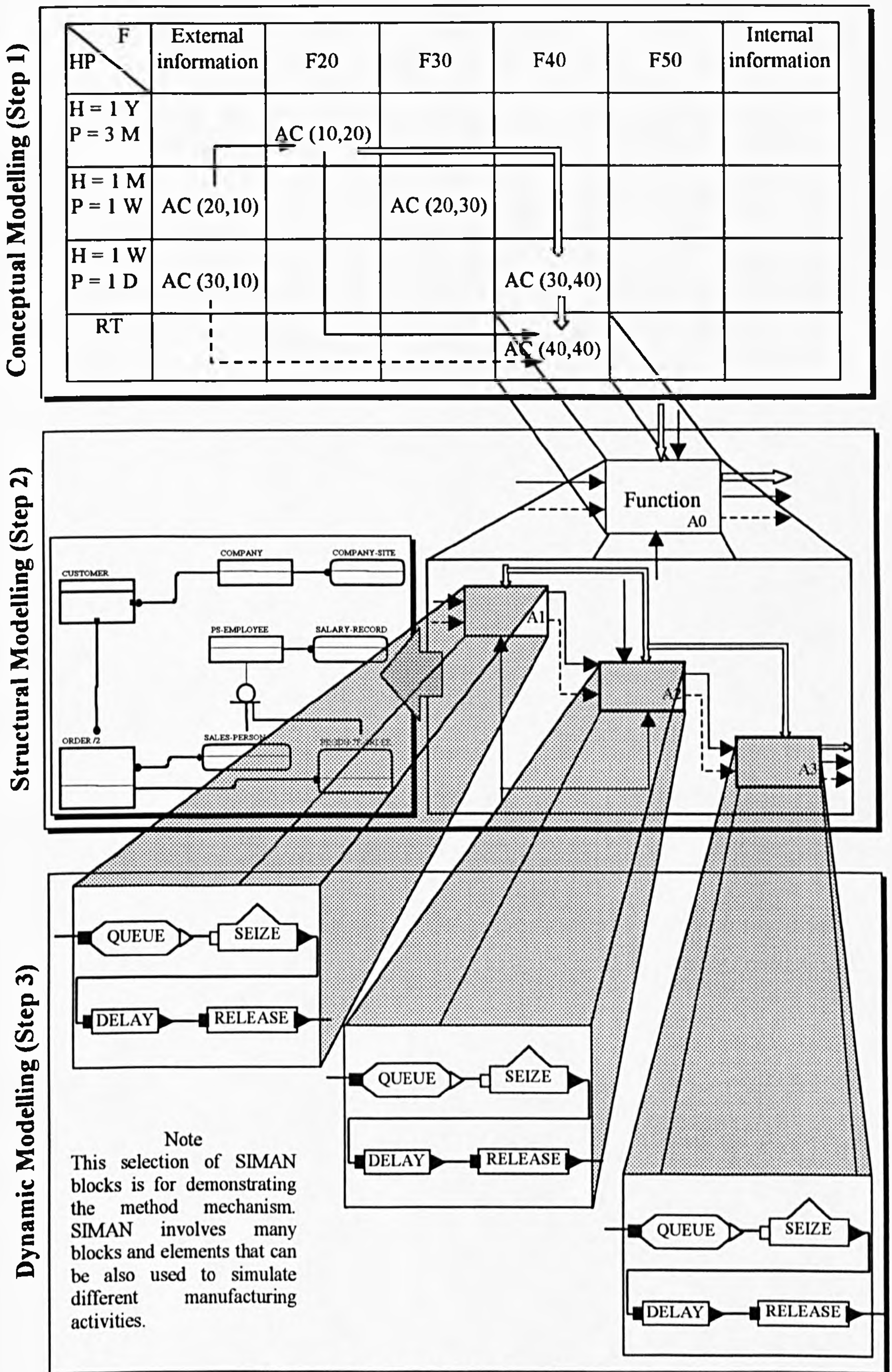


Figure 5.11. The GI-SIM mechanism.

5.6. Computer-Based Method

The difficulties involved in creating a software-based method have long been recognised (Budgen 1994). Computerised tools have been developed, using a visual programming language, to support the GI-SIM method and to demonstrate the linkage between its modelling tools (the grid, IDEF0/1X and SIMAN tools). The computerised tools developed contain several user interfaces which aid the user. These interfaces include:

1. The initial interface.
2. The set-up interface.
3. The retrieving interface.
4. The drawing interface.
5. The activity interface.
6. The horizon/period interface.
7. The function interface.
8. The editing interface.
9. The rule reference interface.
10. The analysis (checking rules) interface.

Appendix-C presents selected computer codes used for constructing these interfaces. Figure 5.11 shows a flowchart of the GI-SIM computerised tools

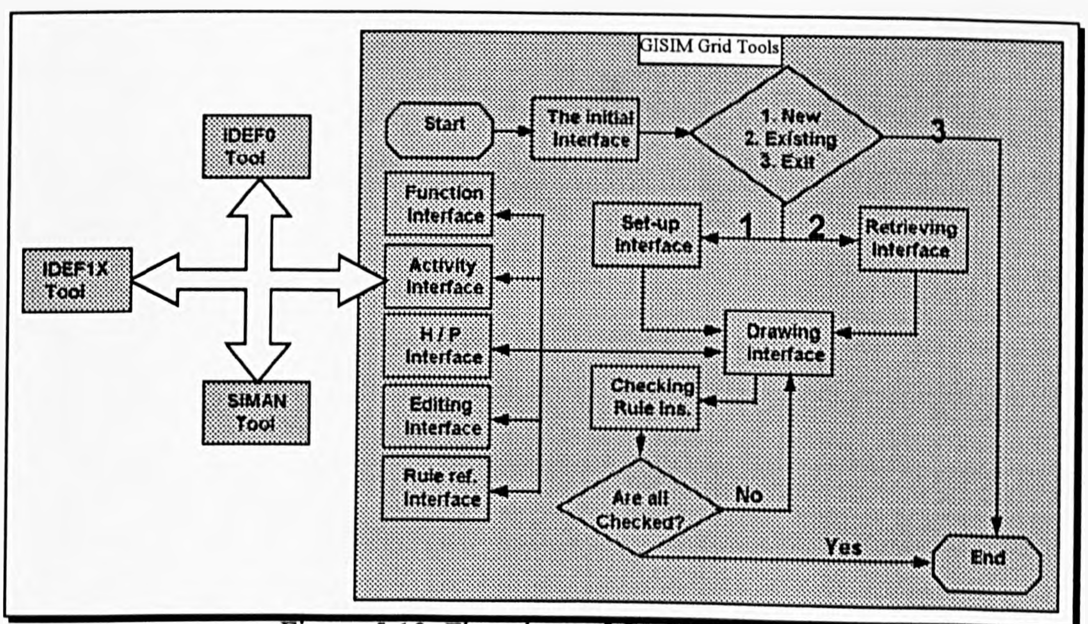


Figure 5.12. Flowchart of GI-SIM tools.

5.6.1 The Initial Interface

The initial interface operates at the start of program implementation and requires the user to determine the project type (new or existing project). The interface initiates the starting procedures for a new project, retrieves procedures for an existing project, or aborts access to the tool. Figure 5.12 shows the initial interface.

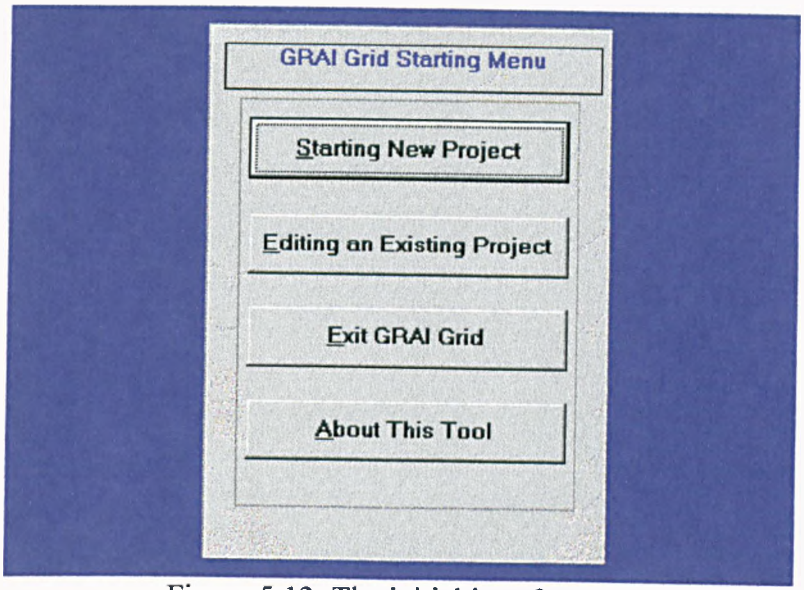


Figure 5.13. The initial interface.

5.6.2 The set-up Interface

The set-up interface is preceded by the new project procedures, which are initiated when a new project is selected. The running of the subsequent interface depends on the initial inputs to the set-up interface. The inputs relating to this interface produce details of the number of functions (columns of the grid), sub-functions (sub-columns of the grid), and levels (rows of the grid). Figure 5.13 shows the set-up interface.

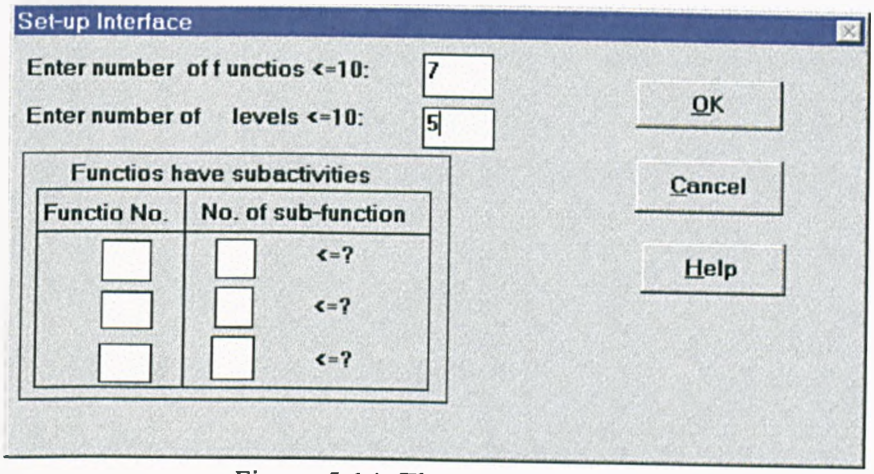


Figure 5.14. The set-up interface.

5.6.3 The Retrieving Interface

The retrieving interface is designed using a common dialogue control, which is available in Windows for facilitating common features of programming such as file saving and retrieving, printing and colour facilities, in addition to special user subroutines. This interface is used to restore the existing project and convert text into graphical elements on the drawing interface. This interface is shown in Figure 5.14.

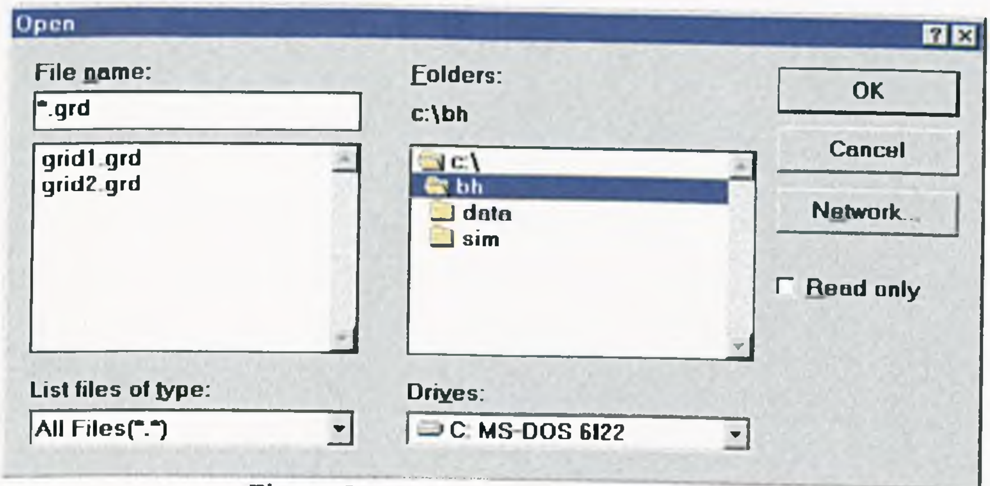


Figure 5.15. The retrieving interface.

5.6.4 The Drawing Interface

After specifying the basic requirements of a new project using the set-up interface, or retrieving an existing project using the retrieving interface, the grid can be generated using the drawing interface. It is designed according to GRAI method procedures and rules (GRAI-1991 - cited by Wainwirght 1993). The table is designed as specified by the set-up interface. All elements in the drawing interface are integrated to enable the user to carry out and check the project easily. Figure 5.16 shows the drawing interface.

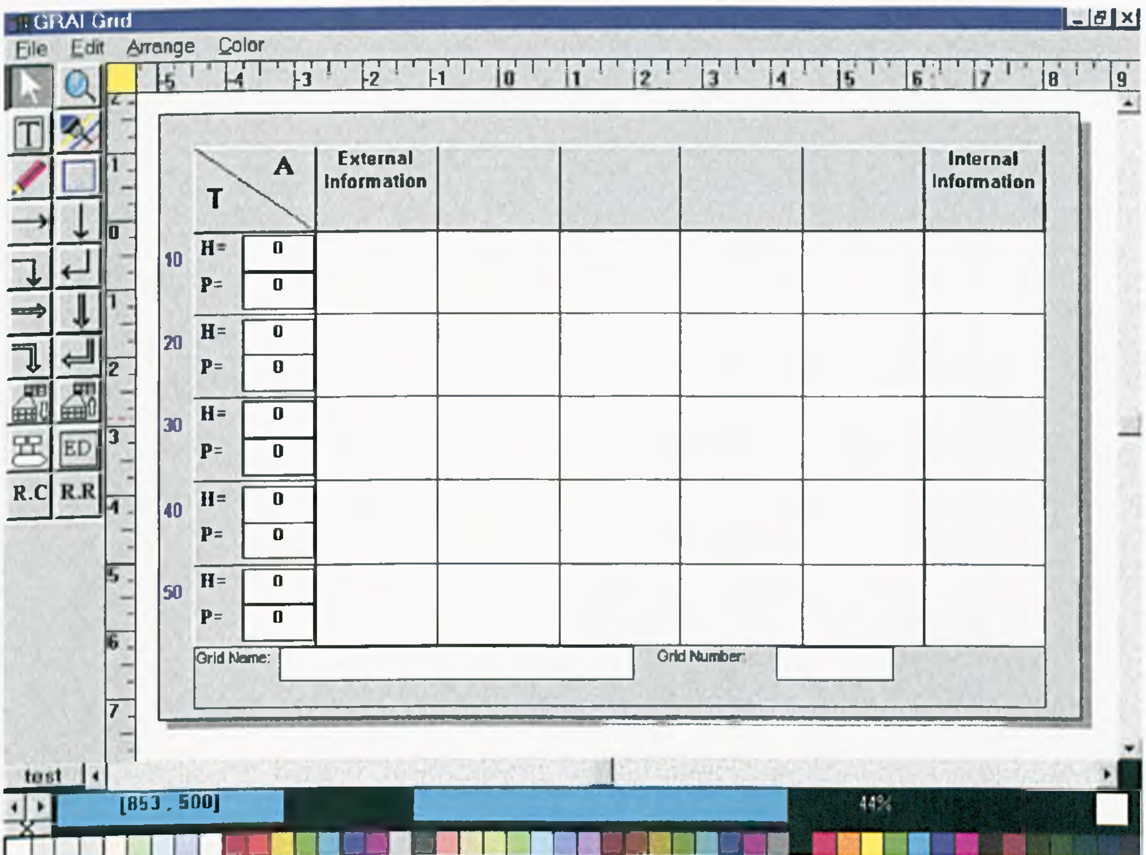


Figure 5.16. The Drawing interface.

5.6.5 The Activity Interface

The activity interface is used to enter and modify activity names, activity types (information, physical, decisional) and activity description. A simple linking procedure with the IDEF0/1X and SIMAN tools is programmed through this interface, as shown in Figure 5.16.

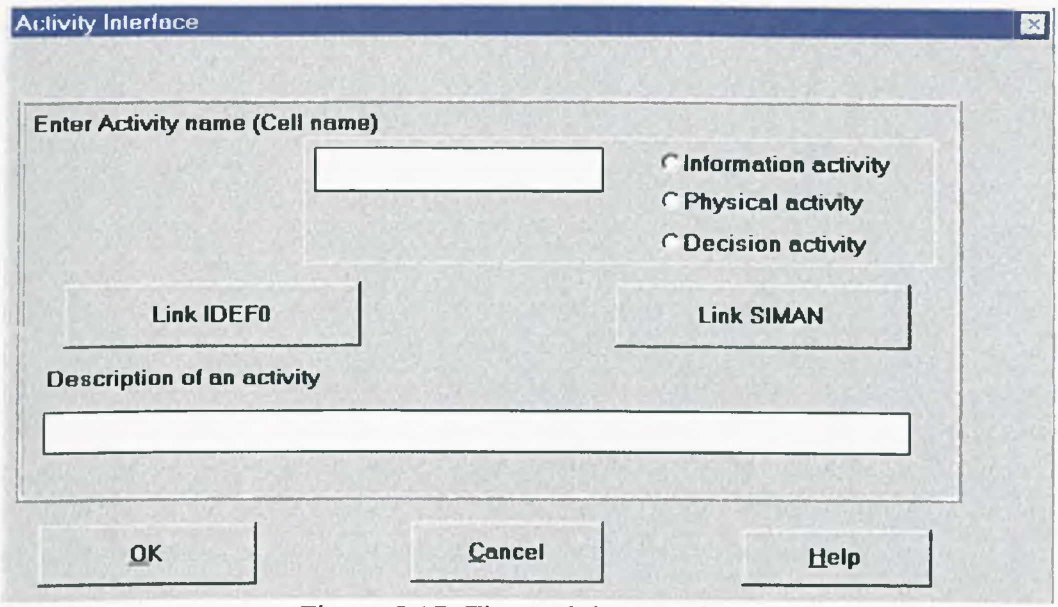


Figure 5.17. The Activity Interface.

5.6.5 The Horizon/Period Interface

The horizon/period interface contains two types of text data and option facilities which enable the user to enter or modify the horizons, review periods and the associated time units (year, month, week etc.), which are basic elements in the GI-SIM grid. Figure 5.17 shows the horizons/periods interface

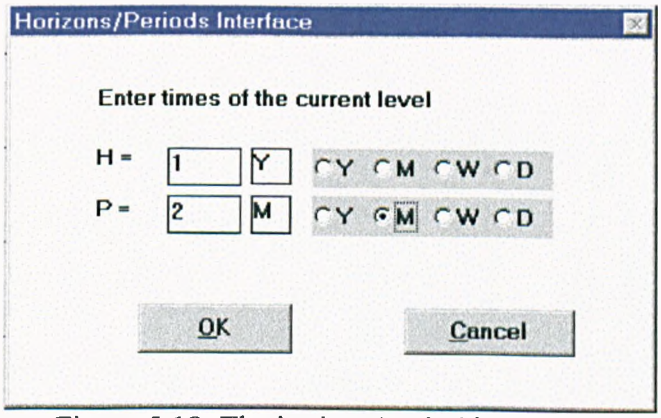


Figure 5.18. The horizon/period interface.

5.6.6 The Function Interface

The function interface is used to produce or modify the function and sub-function names (column titles). It runs the associated subroutine, which transfers the new function names to their labels in the grid table. Figure 5.18 shows the function interface.

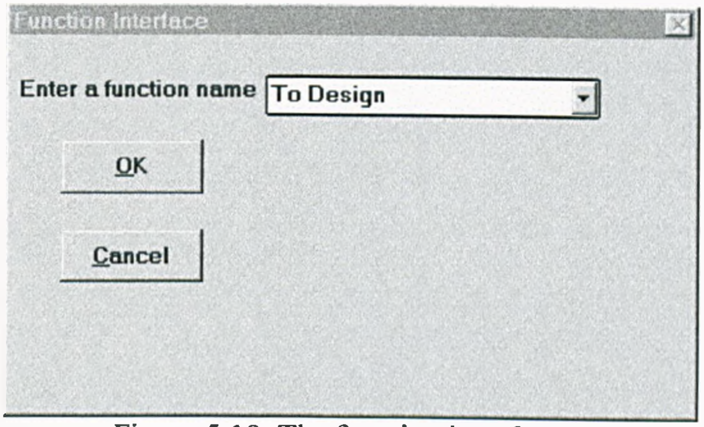


Figure 5.19. The function interface.

This interface involves a number of predefined manufacturing functions such as To Design, To Manufacture, To Deliver, etc. which can be selected from a list constructed on this interface, as shown in Figure 5.18.

5.6.6 The Editing Interface

The computerised tools must enable the user to insert new features or delete existing elements relating to the current work. The editing interface is used to perform such tasks as editing and making changes relating to the GI-SIM grid. The interface is capable of deleting or inserting any function, sub-function or level. Figure 5.19 shows the editing interface.

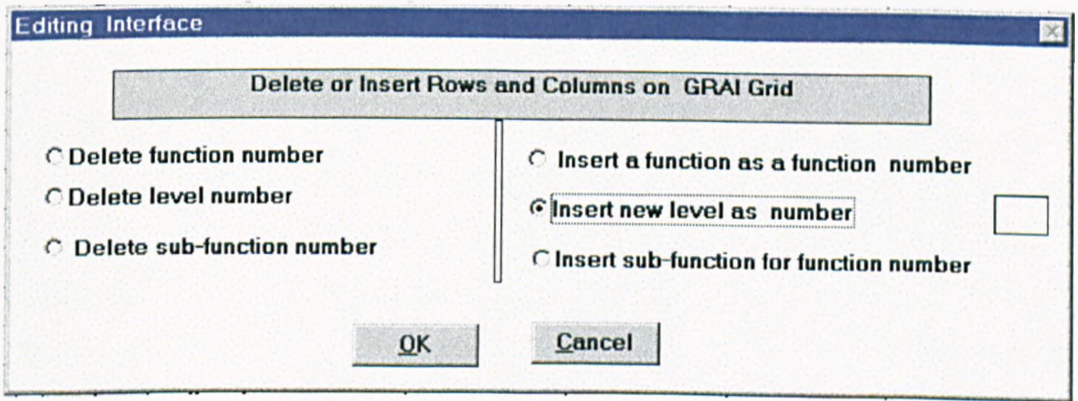


Figure 5.20. The editing Interface.

5.6.7 The Rule Reference Interface

The rule reference interface acts as a small database inside the GI-SIM computerised tool. This database contains the construction grid rules, which have been identified by previous researchers (GRAI-1991 cited by Wainwright 1993). The user can read the rules via the interface and gain an understanding of the construction of the grid model during the design and analysis phases. Figure 6.20 shows the rule reference interface.

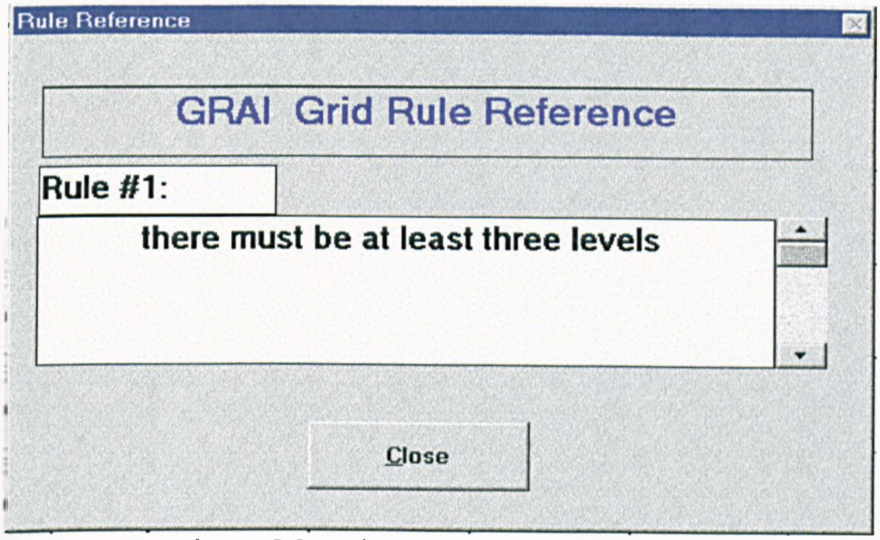


Figure 5.21. The rule reference interface.

5.6.8 The Analysis Interface

The analysis interface represents the intelligent aspect of the tool. The construction of the grid model depends upon several rules which are defined in the rule reference interface. The analysis interface is used to verify the construction of the grid model. This will identify any mistakes made during the building and design stages according to the rules defined. Several messages and marks notify the user of any irregular factors in the model and assist the user in correcting as appropriate. The simple design of this interface enables users to check all the rules either together or individually. Figure 5.21 shows the analysis interface.

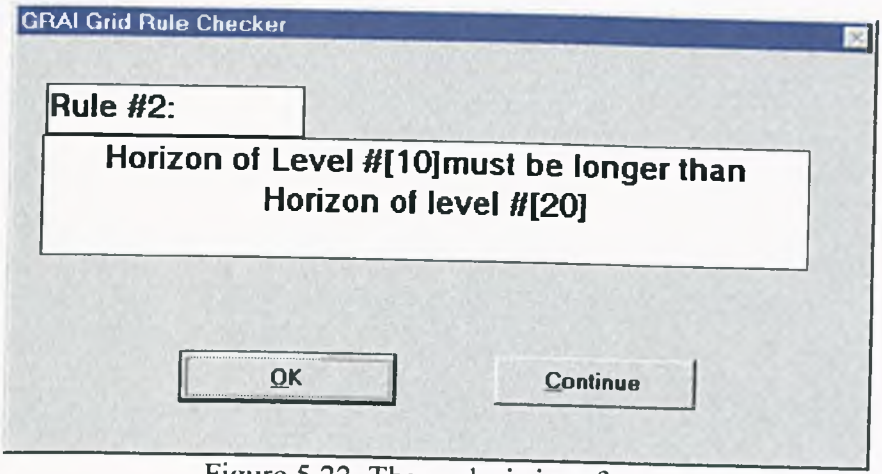


Figure 5.22. The analysis interface.

5.7. Conclusion

Considering the complexity of CIM systems, the diverse nature of modelling requirements, and the existing methods available for modelling CIM, it is believed that it is essential to develop an integrated modelling method to achieve effective and efficient analysis and design for different system domains. This chapter introduces an integrated modelling method (GI-SIM) which has the capability to analyse and design complex manufacturing systems. It presents a global view of the organisation in its grid, and describes the different activity centres using the IDEF0/1X modelling techniques. In this method, the lowest level of IDEF0 models can be translated into simulation tools. These features make the GI-SIM method a powerful tool for analysing and designing the dynamic aspects of CIM systems.

GI-SIM is simple to implement and to learn, as discussed in this chapter. When compared with other modelling methods used for system analysis and design, GI-SIM has distinct advantages. GI-SIM is flexible and combines three important modelling concepts (conceptual, functional/structural and simulation) to describe the manufacturing system from its global view to its detailed specifications, and represents different modelling domains (functional, decisional, information, physical and dynamic aspects) of manufacturing systems.

Computerised tools supporting the GI-SIM method have been presented to develop the method and increase its capabilities. The object linking method has been used to enhance the various GI-SIM components (the GRAI grid, IDEF0/1X and SIMAN tools). This connection can be programmed through an activity interface constructed in the GI-SIM grid.

The goal of this work was to present an integrated modelling method incorporating the main modelling characteristics such as model conception, functionality and dynamic aspects; hence, GI-SIM can support manufacturing systems analysis and design phases. By using this method, important benefits are derived, including:

- Concise graphical expression of manufacturing system activity centres and the decision flows between them. This makes it easier to understand the general manufacturing strategies and the relationships between defined organisational functions;
- Structured functional expression of the decision centres defined in the first step, which provide a basic understanding of a system being modelled;
- Related data expression of information resources using IDEF1X. This can be used to build relational database systems for different components of CIM systems;
- Simulation of sub-activity boxes designed in the method to develop modelling the real dynamic aspects of system sub-activities;
- The use of linking tools (the grid, IDEF0 and SIMAN tools) facilitates user access and data exchange between the activity centres and functional/simulation models.

The GI-SIM modelling method has been developed for the analysis and design of manufacturing systems. A case study and evaluation of the modelling method developed are discussed in the following chapters.

CHAPTER-6

AN EVALUATION OF GI-SIM FOR THE ANALYSIS OF MANUFACTURING SYSTEMS

6.1. Introduction

This chapter presents an analysis of manufacturing systems using a case study company at Brook Hansen Motors (Appendix-D), using the GI-SIM modelling method. Different functions of the manufacturing systems are defined and decomposed into their main D/A centres, and then into sub-activities which represent their basic elements. The main objectives of this chapter are to validate the modelling method (GI-SIM) presented in chapter-5 and to analyse the manufacturing systems of Brook Hansen Motors. A detailed description of Brook Hansen Motors is presented in Appendix-D. The main findings of this study are given in the last section of this chapter.

6.2. Introduction to The Enterprise Analysis Phase

The analysis phase of modelling is concerned with developing a global view of the organisation and gives appropriate levels of abstraction. This phase aims to understand how an existing manufacturing system works. A modelling method used for the analysis phase should be selected or developed to contain a common structure of abstraction levels and give an accurate description of the industrial enterprise.

One of most serious problems facing the analyst is the generation of modelling entities from real-world systems and abstraction of the related functions from their complicated departments. Another difficulty is the classification of these functions and representing the relationships between their different activities while, at the same time, considering the dynamic aspects of system flows. Two approaches have been used to carry out system analysis, namely, top-down and bottom-up. Top-down analysis is carried out starting from the top level of the manufacturing system and going downwards to lower levels of manufacturing functions. This approach is powerful enough to get an overall understanding of the manufacturing system structure. Bottom-up analysis is carried out starting from the basic functions and going upwards to top functions. This approach is used widely in the design phase.

6.3. Application of the GI-SIM Method To Brook Hansen Manufacturing Systems

This study is concentrated on the Huddersfield site where Brook Hansen Ltd. has its headquarters. The analysis is implemented in three phases according to the GI-SIM method, namely, conceptual, functional/structural and detailed, as presented in chapter-5. The analysis is performed on the basis of meetings and interviews involving managers, decision makers and supervisors.

6.3.1 Construction GI-SIM Grid

The GI-SIM grid is constructed in one level as shown in Figure 6.1. The grid illustrates the current system flows through the company. The relationship of D/A centres between manufacturing functions and their respective horizons and review periods are illustrated in Figure 6.1.

6.3.1.1 Identification of System Functions

The initial stage of the analysis is concerned with selection of operational manufacturing system functions performed within Make-To-Order (MTO) and Make-To-Stock (MTS) production. These functions are:

- To Process Orders.

- To Design.
- To Plan.
- To Manufacture.
    - To Make.
    - To Assemble.
- To Purchase.
- To Store.
- To Distribute.

These functions play an important role in the operational level where most of manufacturing system problems and complexities occur. GI-SIM presents a general view of the company activity centres showing decisions, information and material flows between system functions. Most of these functions are still traditional although some have adopted new technologies.

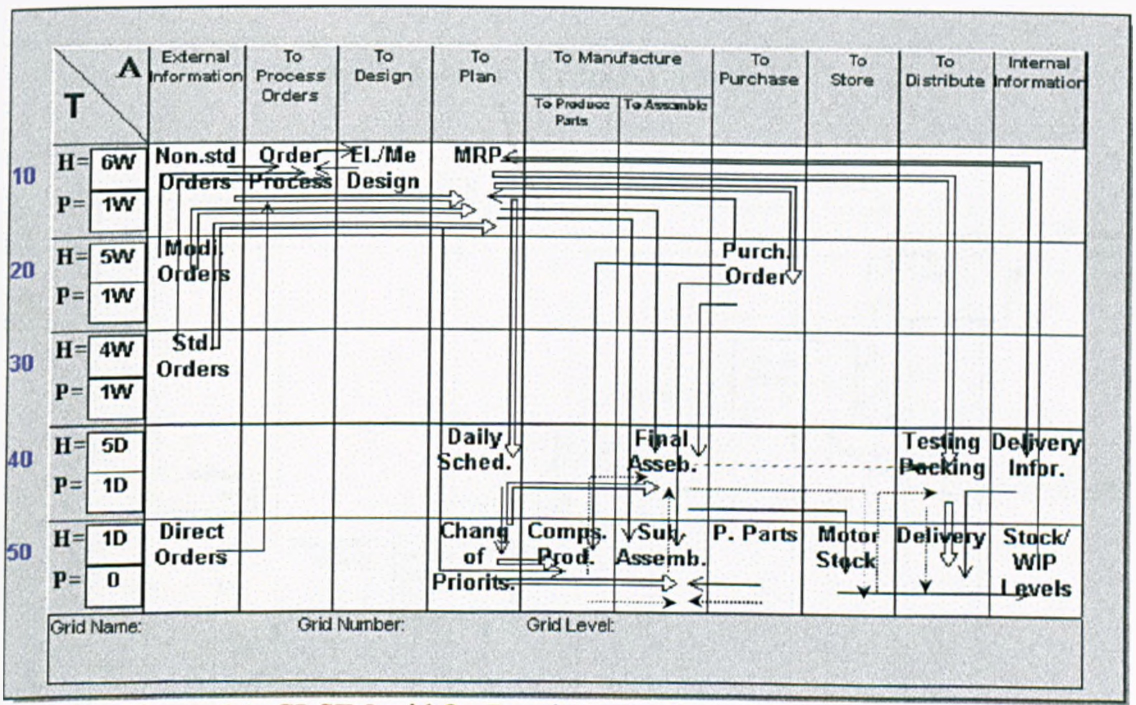


Figure 6.1. GI-SIM grid for Brook Hansen's manufacturing systems.

As illustrated by the GI-SIM grid in Figure 6.1, Table 6.1 shows different D/A centres and their associated horizons and periods for every manufacturing function.

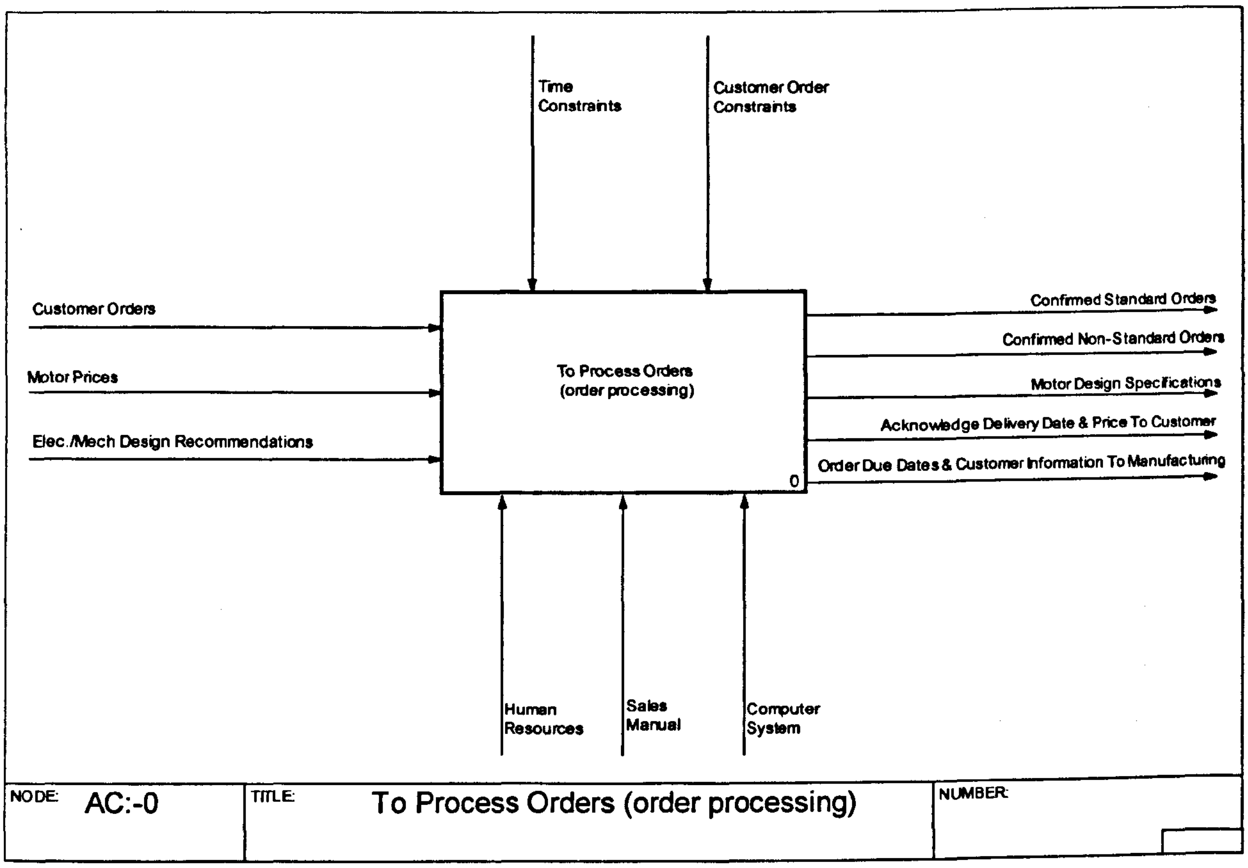


Figure 6.2. Order Processing D/A centre.

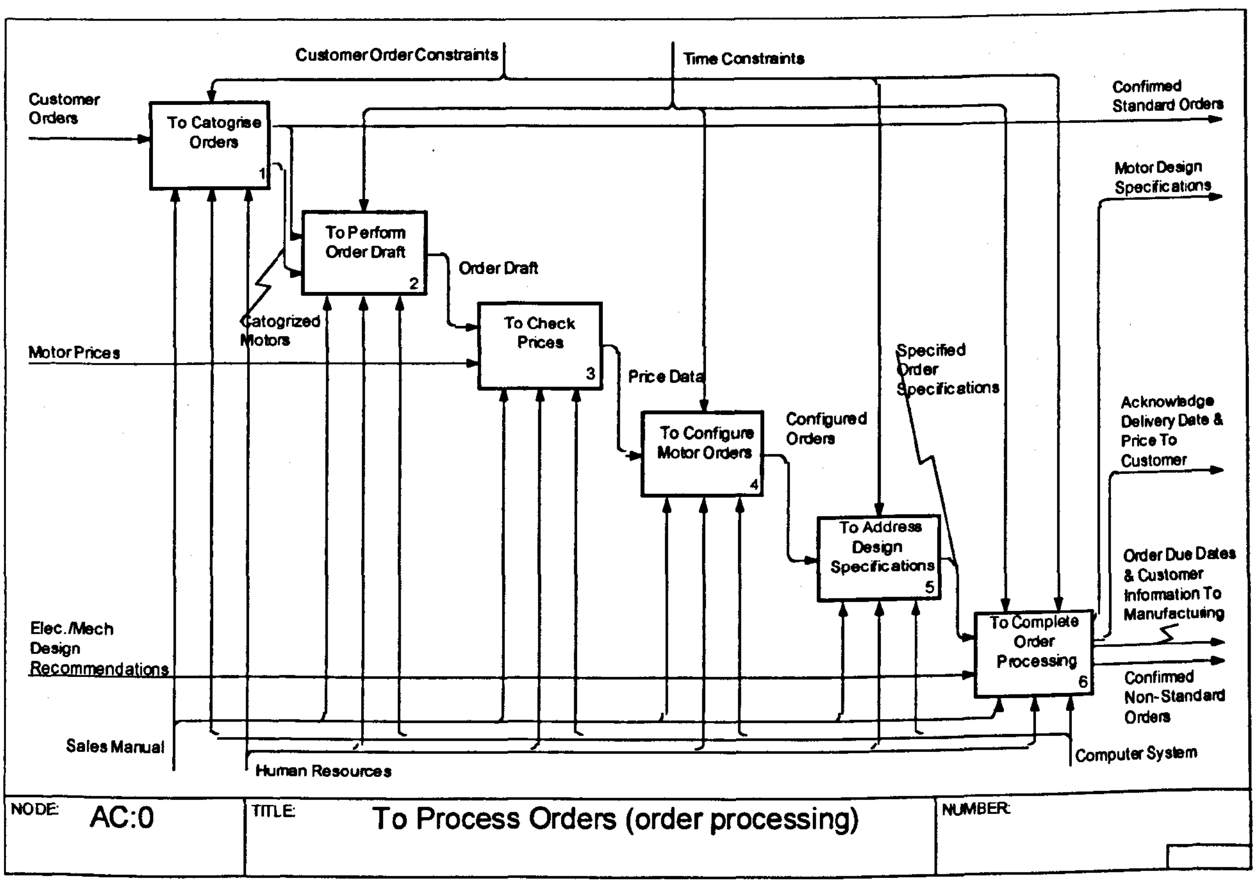


Figure 6.3. Sub-activities of order processing D/C centre.

System function	Sub-function	D/A centre	Horizon	Period
To Process Order	-	Order Processing	6 Weeks	1 Week
To Design	-	Elec./Mech. Design	6 Week	1 Week
To Plan	-	MRP Daily Schedule Change of Priority	6 Week 5 Days 1 Day	1 Week 1 Day RT
To manufacture	To Make To Assembly	Producing Components Shafts Rotors Die casting parts Sub-assemblies Rotor assembly Winding assembly Final Assembly	1 Day - - - 1 Day - - 5 Days	RT - - - RT - - 1 Day
To Purchase	-	Purchase Order Common parts	5 Weeks 1 Day	1 Week RT
To Store	-	Motor stock	1 Day	RT
To Distribute	-	Testing & packing Delivery	5 Days 1 Day	1 Day RT

Table 6.1. GI-SIM grid inputs.

To Process Orders

This function involves the documentation of incoming orders from customers directly or sales offices and agents. These orders include standard and non-standard motors. Order processing is the link between the customers and manufacturing department. Orders rules and configurations also can be defined by this function. The order processing function contains one D/A centre (Order Processing). This D/A centre carries out its tasks through four sub-activities:

- To categorise orders.
- To perform order drafts.
- To check and add prices.
- To configure orders.
- To address design specifications.
- To complete order processing.

Figures 6.3 and 6.4 illustrate the IDEF0 model of the order processing activity centre. The main inputs of the model are customer orders and motor prices. The main outputs of this activity are motor design specifications related to non-standard orders, defined standard orders, acknowledgements of delivery dates and prices for customers, and the order due dates and customer information for the manufacturing department. The order processing sub-activities are controlled mainly by time and customer order constraints. Computer systems and sales manuals are used to support order processing sub-activities. In this function, most of the order processing tasks and statistics are carried out manually.

Before constructing the simulation model for order processing activities, the motor orders for the last few years need to be considered for the following reasons:

- Analysis of motor orders over the last years identifies the characteristics of trends and changes in demand.
- Motor orders can be related to a specific probability distribution using SIMAN tools in order to determine order data parameters.

Figure 6.4 illustrates the motor orders for period (1990 to 1997). Three types of curves are shown; STK (Stock Motors) represents the standard motor orders; Non-STK (Non-Stock Motors) represents the non-standard motor orders; and TOTAL represents the total motor orders through a week.

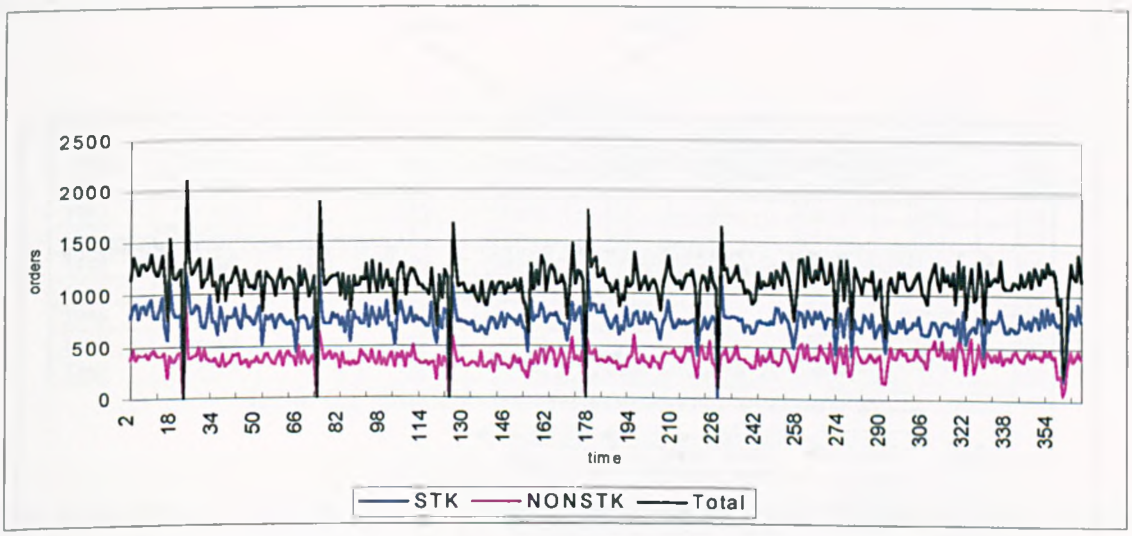


Figure 6.4. Motor orders during period (1990-1997).

Figure 6.5 shows a general comparison between customer orders over the last few years and indicates order trends and amounts per year.

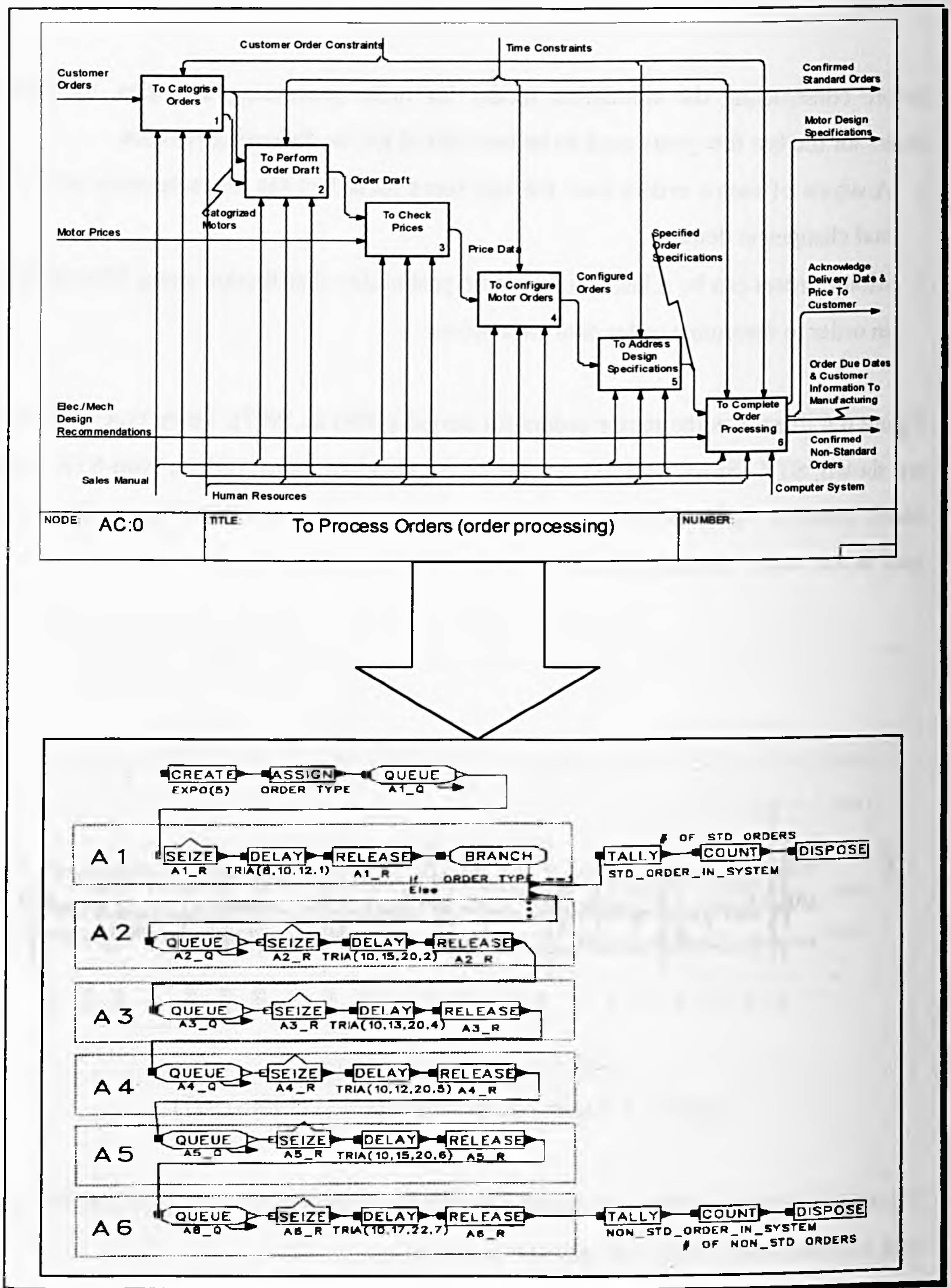


Figure 6.6. The IDEF0/ARENA models for order process D/A centre.

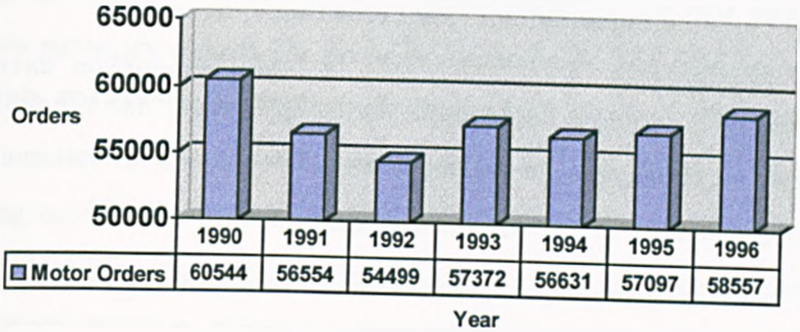


Figure 6.5. Motor orders (Total) (1990-1996)

It can be concluded from the Figures that the total motor orders during 1990 represent the highest number of orders during period 1990-1996. The reduction of motor orders continued over 1991 and 1992, but the growth of orders started again to increase again over the next three years (1994,1995 and 1996).

Table 6.2 illustrates the statistical analysis for the motor orders during the period 1990-1997. It should be noted that the year 1997 is considered in seven week periods. The table illustrates the probability distribution, mean values and standard deviations.

	STOCK			NON-STOCK			TOTAL		
YEAR	FPD	MEAN	STDD	FPD	MEAN	STDD	FPD	MEAN	STDD
1990	Normal	800	161	Normal	388	104	Normal	1190	245
1991	Normal	734	152	Normal	374	85	Normal	1109	222
1992	Normal	715	145	Normal	333	86	Normal	1048	218
1993	Normal	756	153	Normal	369	93	Normal	1124	228
1994	Normal	721	150	Normal	389	81	Normal	1110	206
1995	Normal	713	100	Normal	407	87	Normal	1120	162
1996	Normal	707	114	Normal	419	97	Normal	1126	180
1997	Normal	718	202	Normal	380	110	Normal	1098	309
Total	Normal	735	144	Normal	383	94	Normal	1117	214

Table 6.2. Statistical functions of customer orders.

The above figures indicate that motor orders are very varied over time; hence, it would be very difficult to predict customer demand using traditional forecasting methods. This problem should be considered from different perspectives such as market aspects, competition, product life cycle, etc. to integrate different information and support forecasting techniques.

Simulation modelling of motor orders is carried out using SIMAN /ARENA tools as discussed in Chapter 5. The translation of the basic sub-activities of the functional model into ARENA blocks is illustrated in Figure 6.6. SIMAN simulation and

Systems Modeling Corporation
Summary for Replication 1 of 4

Project: Order Processing — Run execution date : 2/12/1998
Analyst: A.m.A — Model revision date: 2/12/1998

Replication ended at time : 2400.0

TALLY VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Observations
NON_STD_ORDER_IN_SYSTE	646.10	.50263	73.003	1197.7	116
STD_ORDER_IN_SYSTEM	566.08	.58595	11.719	1161.3	123

DISCRETE-CHANGE VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Final Value
NR(A1_R)	1.0000	.00000	.00000	1.0000	1.0000
NR(A2_R)	.73937	.59372	.00000	1.0000	1.0000
NR(A3_R)	.70805	.64212	.00000	1.0000	1.0000
NR(A4_R)	.66809	.70484	.00000	1.0000	.00000
NR(A5_R)	.72192	.62064	.00000	1.0000	.00000
NR(A6_R)	.78980	.51590	.00000	1.0000	1.0000
NQ(A1_Q)	113.78	.61298	.00000	241.00	241.00
NQ(A2_Q)	.46962	1.7489	.00000	4.0000	.00000
NQ(A3_Q)	.05962	3.9714	.00000	1.0000	.00000
NQ(A4_Q)	.03446	5.2930	.00000	1.0000	.00000
NQ(A5_Q)	.07800	3.4381	.00000	1.0000	.00000
NQ(A6_Q)	.17128	2.1996	.00000	1.0000	.00000

COUNTERS

Identifier	Count	Limit
# OF STD ORDERS	123	Infinite
# OF NON_STD ORDERS	116	Infinite

Beginning execution of replication 2 of 4

Figure 6.7.Simulation output for order processing sub-activities .

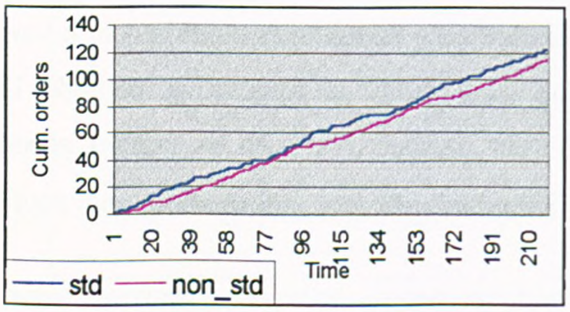


Figure 6.8. Number of orders (Cumulative)

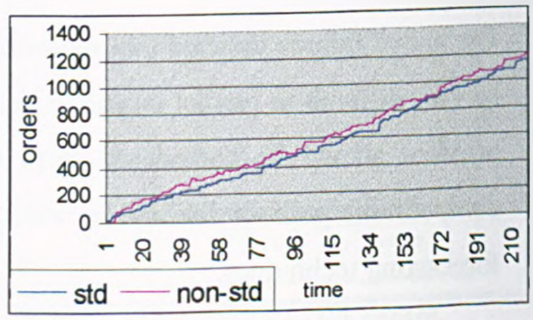


Figure 6.9. Time in system

experiment models relating to order processing sub-activities are presented in detail in Appendix E. Figure 6.7 illustrates the output report of the first simulation run. Other simulation summary reports are given in Appendix-F. The SIMAN report involves the information for the model replication categorised by type. The first category in the report summarises the observations recorded at any TALLY blocks in the order processing model. The output report contains two tally variables corresponding to the time in system for each of the two orders in the model. The report contains the average, coefficient of variation, minimum observation, maximum observation and number of observations generated during the replication. The second category of output involves discrete-change variables. These values are recorded automatically by DSTATS element in the experiment and include statistics on the length of queues and utilisation of order processing activities. The statistics consists of the average, coefficient of variation, minimum observation, maximum observation, and final value. The next category of the output report displays counter summary statistics and includes the current count and the count limit for two counters in order processing model. The counters show how many standard and non-standard motor orders have been completed by the order processing decision centre during this replication.

Figures 6.8 and 6.9 illustrate other forms of performance analysis related to the order process. The cumulative number of orders processed is illustrated in Figure 6.8 and the average time in system is illustrated in Figure 6.9 for both types of orders. Utilisation of order processing centre is based upon the following factors:

1. Arrival rate of customer orders.
2. Number of people doing these tasks.
3. Number of motors per order and their types.
4. Modification range for every non-standard order.

Comments on Order Processing D/A Centre

Analysis of the order processing activity centre indicates that there is a need to adopt advanced technology to assist in carrying out order processing tasks and provide real time information for other resources. This would help to reduce the costs of the order processing centre and eliminate the problem of order processing duplication. This problem generates other complexities in the manufacturing department because some

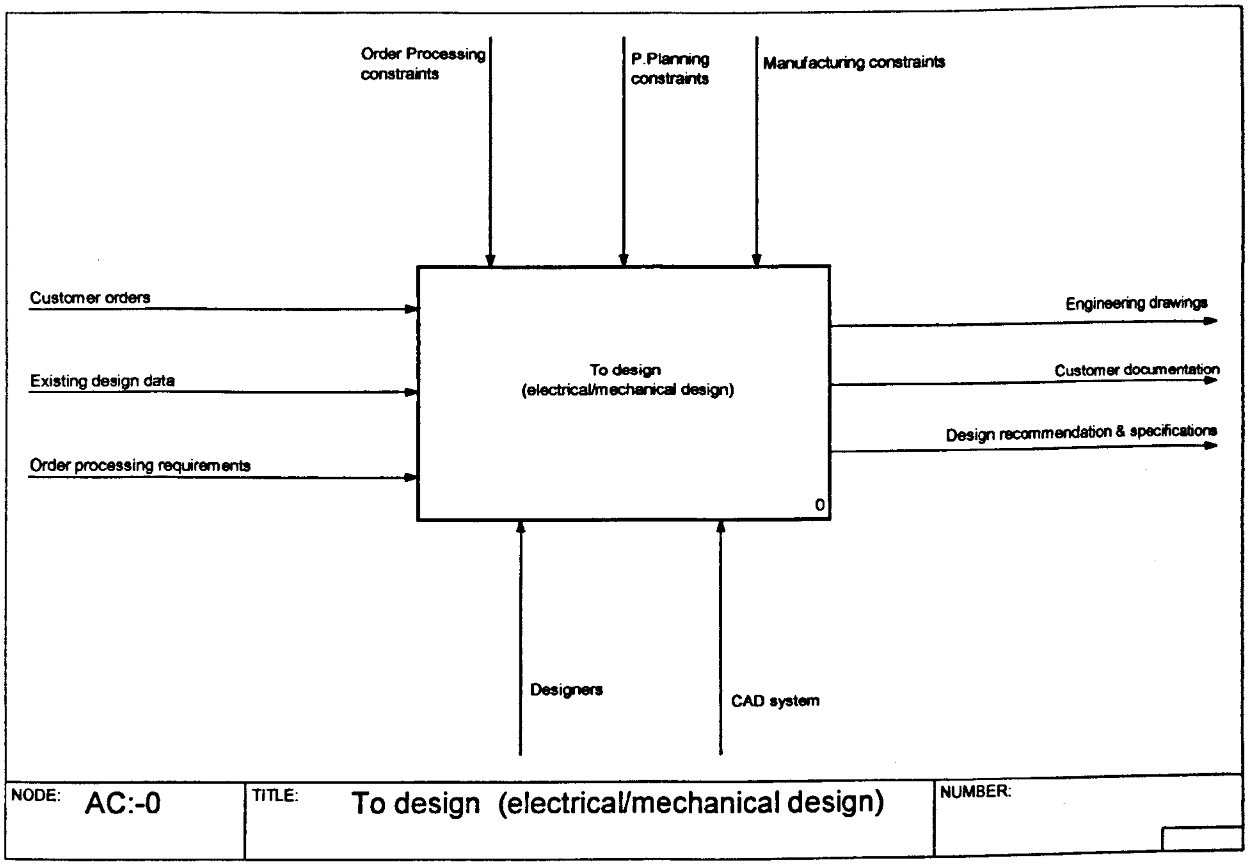


Figure 6.10. Elec./Mech. Design D/A centre.

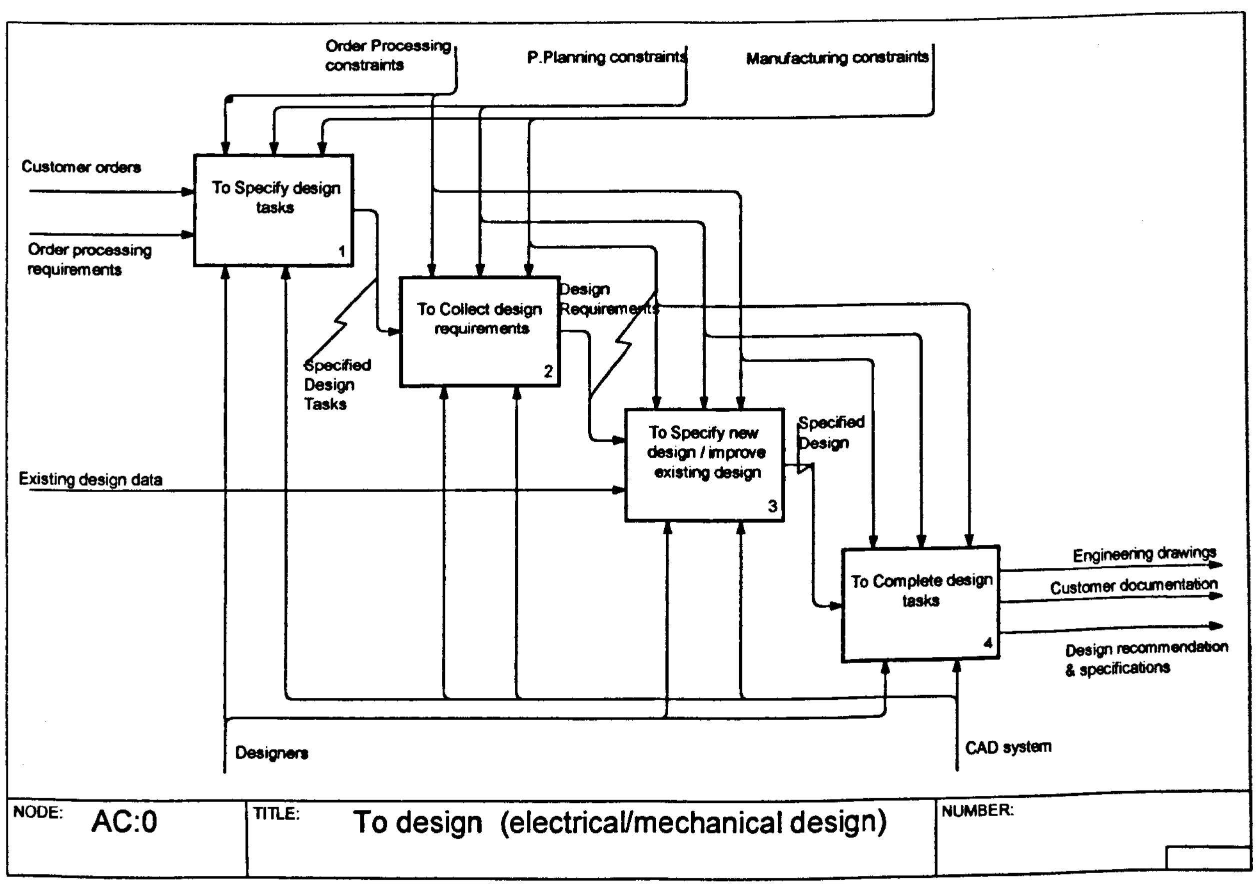


Figure 6.11. Sub-activities of electrical/mechanical design centre.

customer orders produced are based upon manual cards and others are based upon the MRP schedule.

Providing information more effectively to the order processing unit will increase the accuracy of predicting customer lead times, taking into account special item requirements. Sales manual and paper catalogues should be replaced by a system that provides a means of altering order requirements electronically. This system should integrate all order processing sources (sales branches, offices, etc.) to achieves several goals such as:

- Retraining and editing customer details using standard attributes.
- Providing customer order history to facilitate forecasting studies.
- Classifying customer orders based upon intelligent systems and central databases.
- Avoiding order duplications.
- Carrying out long-term and short-term planning.
- Reducing order processing review periods.
- Having obvious decision links between order processing D/C centres and other manufacturing activities.
- Modelling data flows and defining its entity attributes.

To Design

The function 'To design' carries out two tasks; electrical and mechanical design but is represented by one decision centre (Elect. /Mech. Design) in the GI-SIM grid as illustrated in Figure 6.2. Design D/A centre is decomposed into four sub-activities which represent the basic tasks and elements of this D/A centre. These sub-activities are:

- To specify design tasks.
- To collect design requirements.
- To specify new design/improve existing design.
- To complete design tasks.

Figures 6.10 and 6.11 illustrate IDEF0 models for the design D/A centre. The model categorises the design activity inputs into three types, namely, customer orders, order processing requirements and existing design data. The model outputs are engineering drawings, customer documentation and design specifications. The design function is supported by electrical/mechanical designers and Computer Aided Design (CAD) systems for both 2D and 3D. Three types of constraints are illustrated by the model: order processing decisions, production planning and manufacturing constraints.

Comments on Elect./Mech. Design

The analysis study illustrates that the design department has several problems which are summarised in Table 6.3. These are categorised into three types, integration, data, and operational problems.

Problem Category	Problem Description
Integration	- Lack of integration with the other strongly related departments such as manufacturing systems, processing and production planning. - Lack the automatic transfer of new part details to systems. - Lack the automatic transfer of purchase requisitions to the related departments. - Lack product routing generation facilities.
Data	- Lack the intelligent facilities for transfer design data to other format. - Lack of integrated database to review and update design data - Lack of techniques for parts grouping and group technology - Lack the accessing to stock information during process changing
Operating	- Lack of provision accurate information for times scales needed by other departments - Lack the ability to deal with BOM easily. - Lack the proper construction of BOM for new or non-standard components. - Lack of new technologies which can assist in design, engineering analysis and testing such as finite element systems and simulation modelling.

Table 6.3. Obstacles to design functions

It has been found that the design department needs a long planning horizon and review period, particularly for detailed design. This means that the sequencing of design operations requires more modifications and computer support to increase utilisation of this function. The design function receives more and more customer specification requirements related to motor components; hence, using an effective solution to this problem will increase activity performance.

To Plan

'To Plan' is based upon the MRP system, as discussed in Appendix-D. The GI-SIM grid (Figure 6.1.) illustrates three D/A centres for this function. These D/A centres are: MRP, Daily schedule and Change of priorities. As illustrated in the grid, the Daily

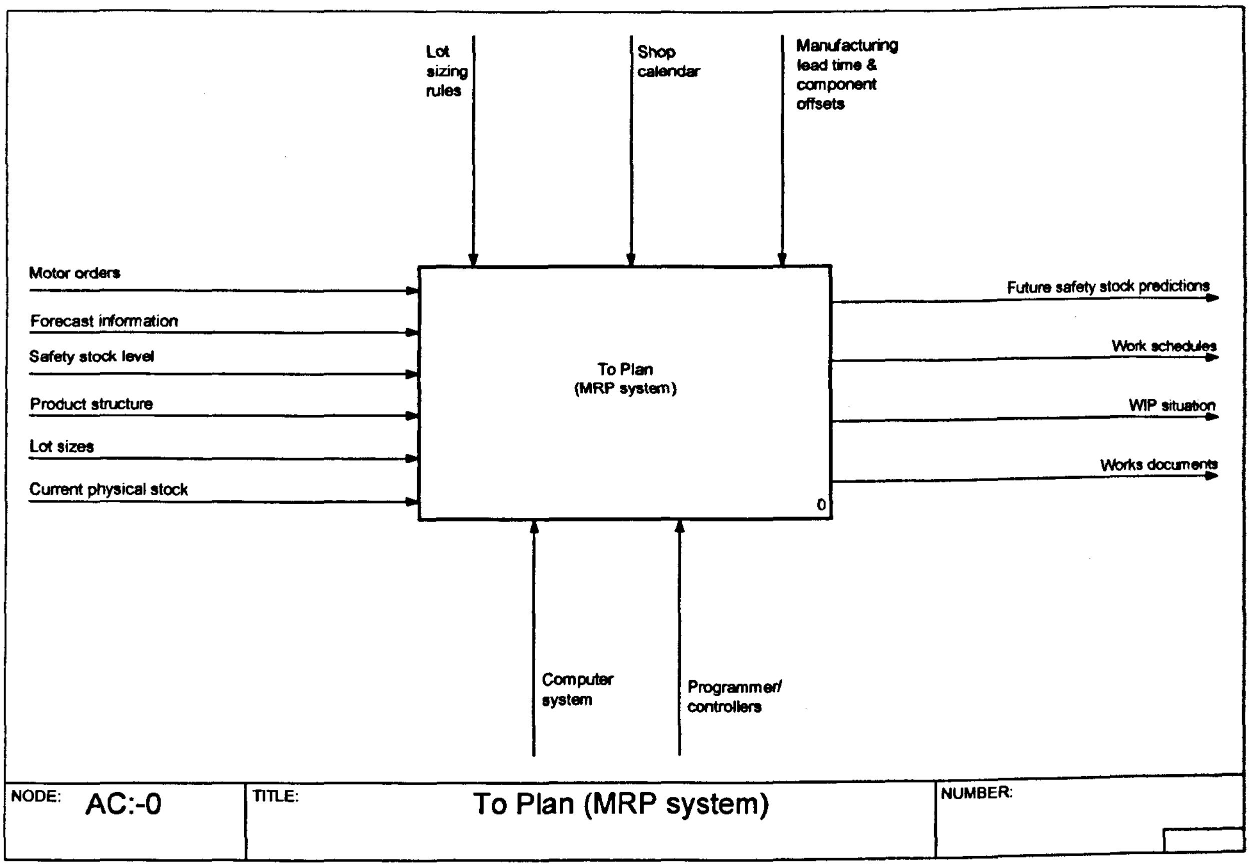


Figure 6.12. MRP D/A centre.

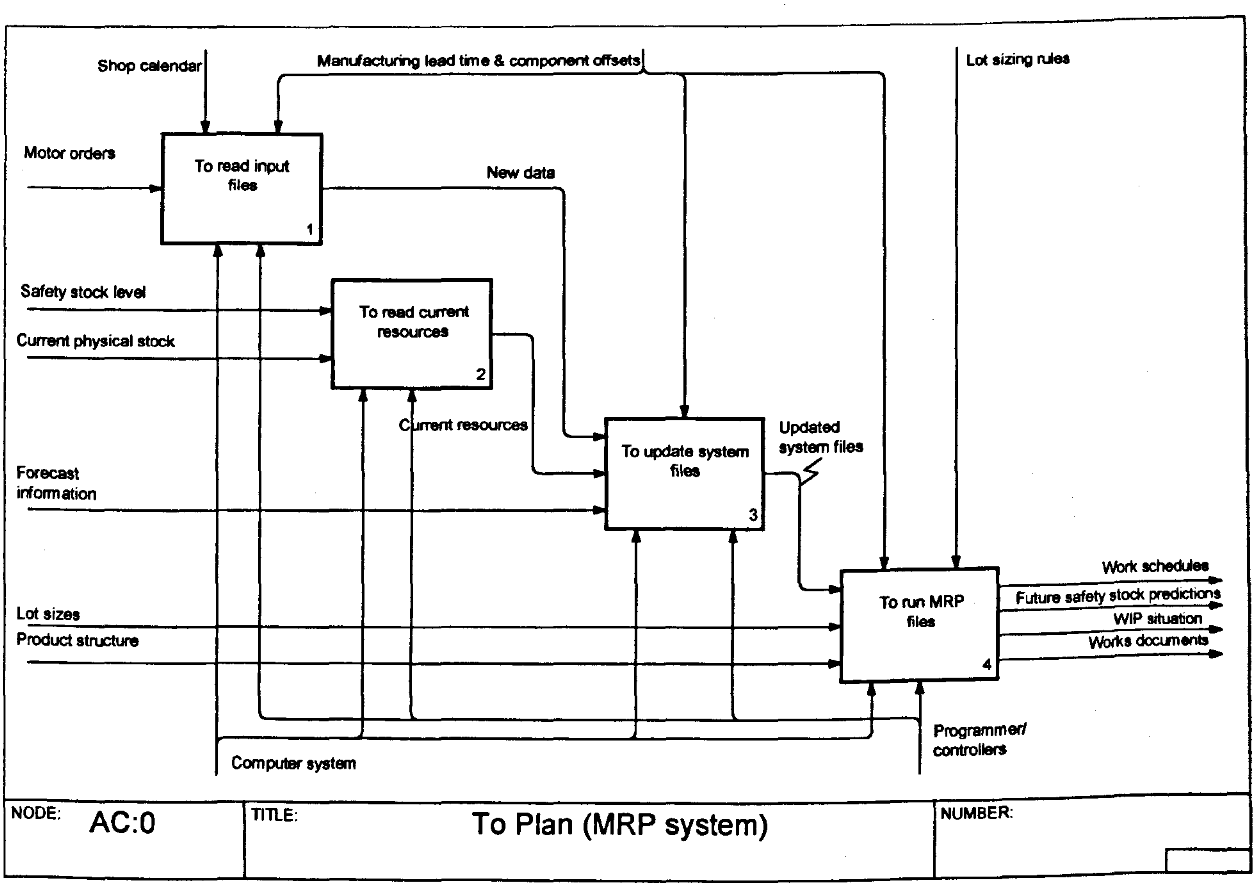


Figure 6.13. MRP sub-activities.

schedule centre is mostly controlled by MRP centres orders, a change of priority is authorised by manufacturing supervisors or production controllers. MRP provides a weekly report and has a planning horizon of 5-6 weeks. This D/A centre receives motors orders from the order processing D/A centre and provides other manufacturing functions with several type of information, as mentioned in Appendix-D. Daily schedule D/A centre can be considered as a result of MRP system, because the scheduling system is generally a part of the MRP system for MTS production.

MRP D/A centre can be decomposed into four sub-activities:

- To read input files.
- To read current resources.
- To update system files.
- To run MRP system.

As shown by the IDEF0 models in Figures 6.12 and 6.13, the MRP model inputs are motor orders, safety stock level, current physical stock level, forecast information, lot sizes and product structures. The outputs are work schedules, future safety stock schedules, WIP situations and works documents. The MRP activity centre is controlled by the shop calendar, lot sizing rules, manufacturing lead times and component offsets, and supported by computer systems, programmers and controllers.

Daily schedule D/A centre can be broken down into four sub-activities:

- To check production plan.
- To compute components due date.
- To synchronise production flows.
- To produce daily schedule.

Figure 6.14 and 6.15 show the IDEF0 model for this D/A centre. Producing the daily schedule requires the general work schedule produced by the MRP system and the other inputs of MTO production. This D/A centre is controlled by capacity planning and time constrains, and supported by MRP computer systems. The daily schedule D/A centre has a review period for one day and can be applied for one week (5 days).

The 'change of priorities' D/A centre usually reschedules the output of the daily schedule D/A centre manually based upon several factors such as manufacturing

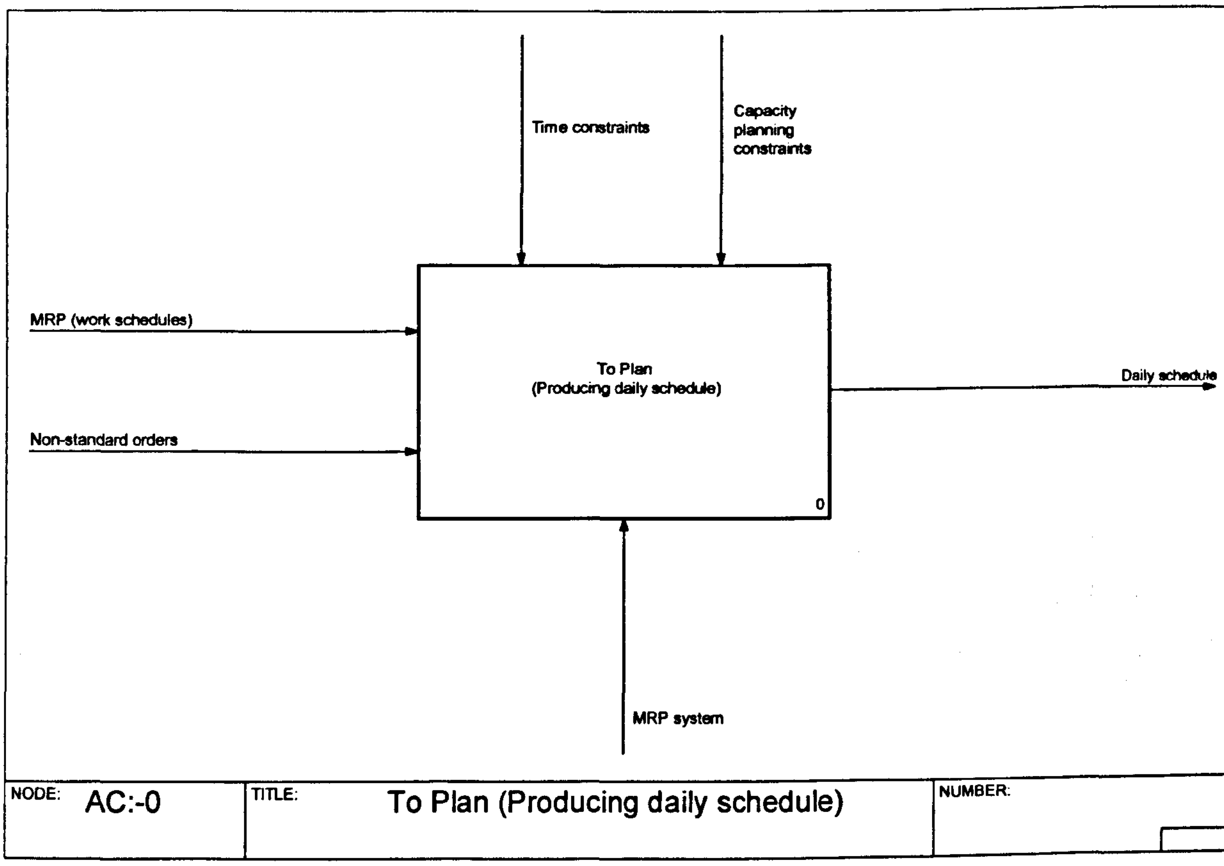


Figure 6.14. Daily schedule D/A centre.

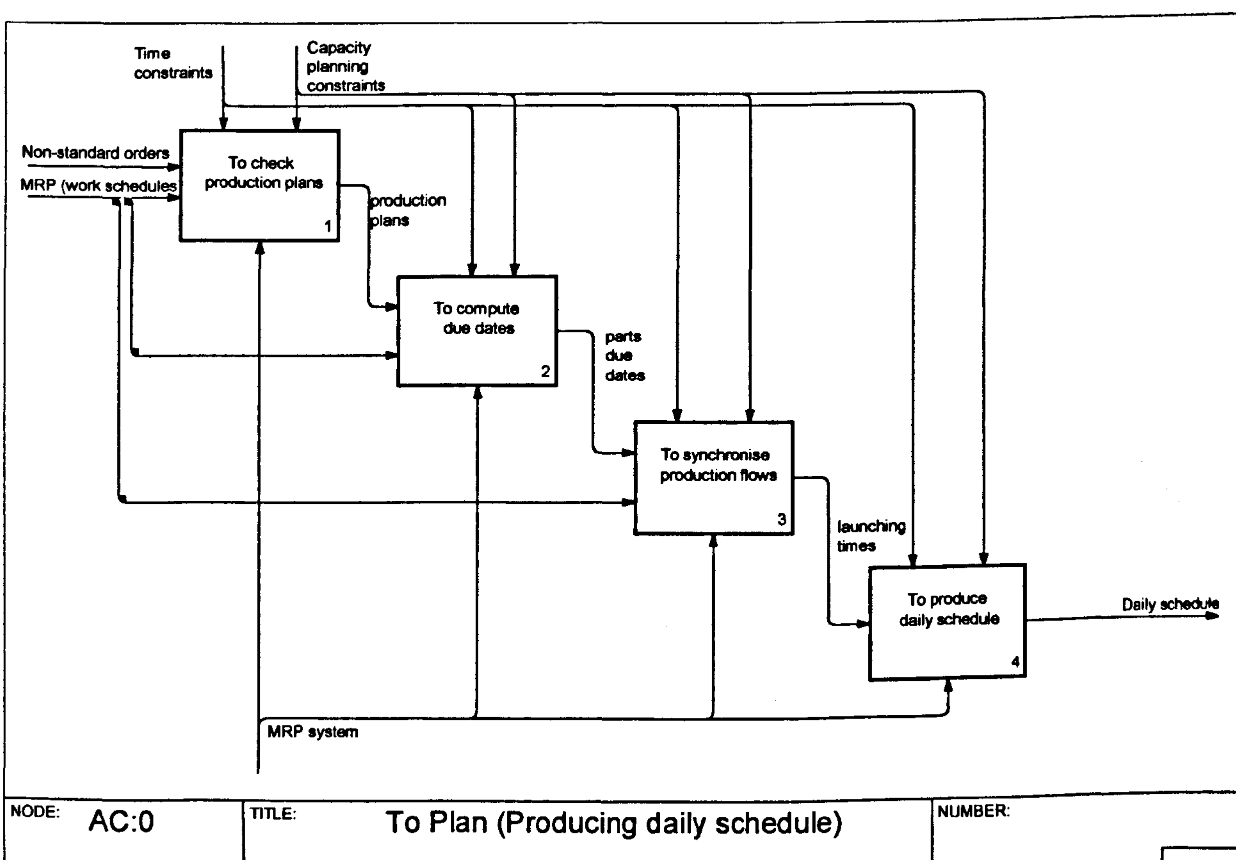


Figure 6.15. Sub-activities of daily schedule D/A centre.

constraints (set-ups, order similarities, breakdowns, etc.), manual orders, WIP levels, and so on. This D/A centre appears at the last level in the GI-SIM grid because its planning horizon is one day and its period is Real Time (RT). Figures 6.16 and 6.17 illustrate the IDEF0 models for the 'change of priority' D/A centre.

Comments on 'To Plan' Function

Analysis of the 'To Plan' centre indicates that there is a need to formulate and consolidate the new production planning function to involve all production planning activities. The absence of this important function affects the decision flow and the integration of manufacturing systems. It has been found that the MRP system is very weak and has several drawbacks. The MRP system is a cornerstone in production planning function and it should be capable of handling the production planning and control tasks efficiently. The current system has the following problems and barriers:

⇨ MRP system is incapable of handling all types of motors.

⇨ MRP system is incapable of providing a scheduling system for other manufacturing strategies such as JIT and Kanban systems.

⇨ The current system is very closely tailored to the needs of the area for which it is intended. For example, the screen details for cast iron machining are significantly different from those for the production of rotor assemblies, windings, etc.

⇨ Absence the integration between MRP and manufacturing control systems.

⇨ The system is incapable of applying different types of control by product or manufacturing area. For example, Re-order point, Kanban.

⇨ MRP system does not allow utilisation of supplier stock control systems, for example, bar coding on some purchased items.

⇨ The system is incapable of managing manufacturing of MTS, MTO, stock modifications, repairs, spares and motor interiors.

⇨ Incapability of applying forecasting operations based upon marketing information and order history.

⇨ It is incapable of calculating Average Weekly Demand (AWD) based upon more accurate information and allowing it to be used as a calculated forecast. AWD is now calculated by modifying the old AWD with the present actual demand according to a smoothing factor.

For example, if the smoothing factor is 0.1 then the new:

$$\text{AWD} = 0.1 \times \text{new demand} + 0.9 \times \text{old AWD}.$$

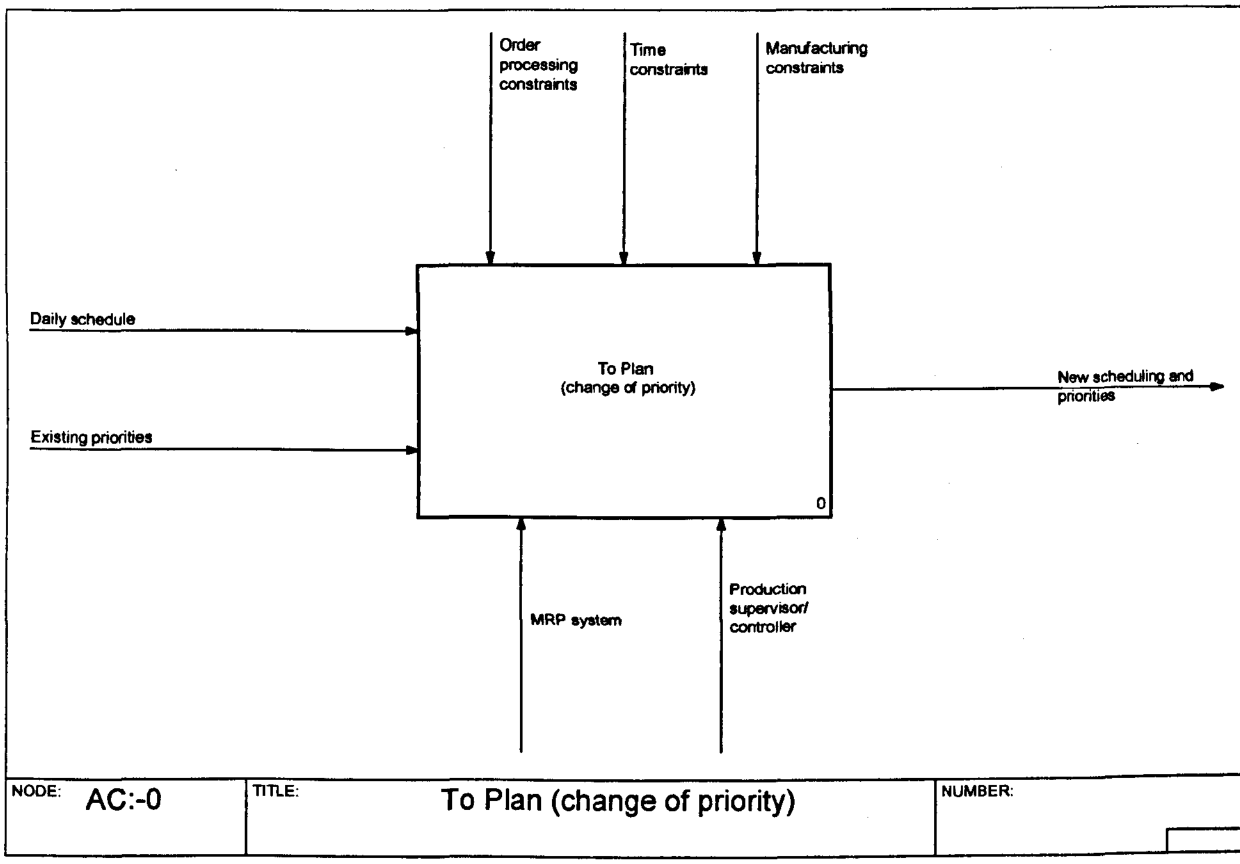


Figure 6.16. Change of priorities D/A centre.

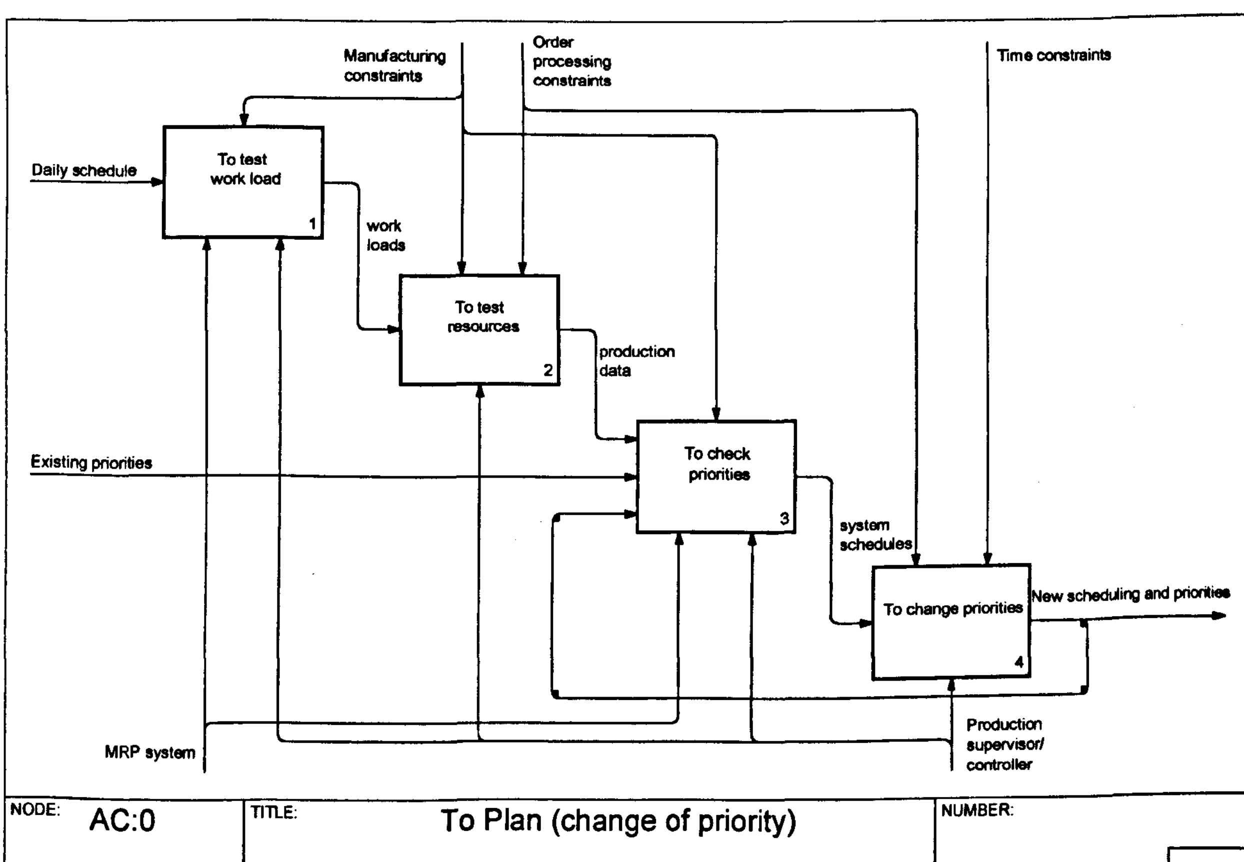


Figure 6.17. Sub-activities of change of priorities D/A centre.

- ⇨ It is incapable of applying various lot sizing rules such as make one-for-one, minimum lot size, multiples of lot size, etc.
- ⇨ It is incapable of handling fixed safety stocks. The current method used is based upon the standard deviation of the last 12 weeks independent demand.
- ⇨ It is incapable of determining scrap percent and re-order points by part.
- ⇨ Current system involves several units of measures such as Kilogram (KG), Ton (TN) and Meter (MT).
- ⇨ It is unable to hold windings specification details.
- ⇨ Details of wagon routes and times are ignored in the current production system;
- ⇨ Adjustment of manufacturing requirement dates can not be done automatically.
- ⇨ Lacking of data support of part specifications and parts matching.
- ⇨ The MRP scheduling system is based upon weak rules, so the scheduling is one of the biggest problems in the production system because:
  - The system could not allow scheduling rule definition and control at a macro level.
  - Dealing with the current scheduling system is complicated.
  - It is incapable of providing real time updates to other application modules.
  - It is incapable of containing the real time production and order changing; hence, the change of priority is applied.
  - It is incapable of scheduling and controlling other manufacturing units such as hand wound stator cores.

'To Plan' function is the backbone of any manufacturing organisation. This function should be concerned with long-term and short-term planning activities.

To Manufacture

In this case study, this function is divided into two sub-functions, 'To Produce Parts' and 'To Assemble', as illustrated in the GI-SIM grid in Figure 6.1. To understand this important function, the main manufacturing procedures are outlined below:

- Motor orders are taken from standard and non-standard motors as described in the order processing function. Stock availability of standard motors can be checked at this point.

- Delivery dates for both standard and non-standard motors are defined at the order entry stage based upon different stages.
- Special component requirements are identified at this stage and requisitions placed to manufacturing or purchasing.
- During an overnight MRP run, standard motor requirements are placed against stock, taking into account warehouse stocks, safety stocks, AWD etc. to produce motor launch requirements.
- Winding and assembly tickets are printed in advance during daily runs for production up to date determined by the ticket time fence.
- The resulting launch requirement for motors and components is presented in a variety of formats and sequences based upon the manufacturing area. These include on-line screens, reports and tickets.
- In due course a launch decision is recorded, by keyed input or via bar coded input. This results in the issue being recorded, non-Kanban components being allocated and, if the issue point is the defined point of usage for any components, the down dating of component stocks.
- For some standard components, batch cards are printed at issue time.
- Bar coded or keyed WIP movement transactions are recorded as items move between tracking zones. These transactions also include down dating component stocks at the point of usage and actioning any unrecorded earlier transactions.
- Store items are taken from line stock or from stores as required and booked out of stores at the point of issue from the store. Line stocks are not recorded.
- A daily stores run takes place prior to MRP, which incorporates a report control system for printing of daily, weekly or monthly reports. Using this system the user decides on the frequency and number of copies of the reports. Weekly reports can also be specified to arrive on a particular day of the week.
- All store transactions are on-line, the system having standard facilities for raising and passing GRN, issuing work etc. A variety of user defined reports are produced such as recommended re-order action, shortage reports and outstanding orders.
- When standard motors pass the final inspection they are passed to the stock motor warehouse for booking in as described in warehouse and distribution section.
- When non-standard motors pass the final inspection, they are booked through final inspection as a WIP transaction and forwarded to distribution for despatch as described before.

Figure 6.18 illustrates the common process flow for electric motor production and associated departments. Figure 6.19 illustrates average WIP transactions per day for the Huddersfield manufacturing site.

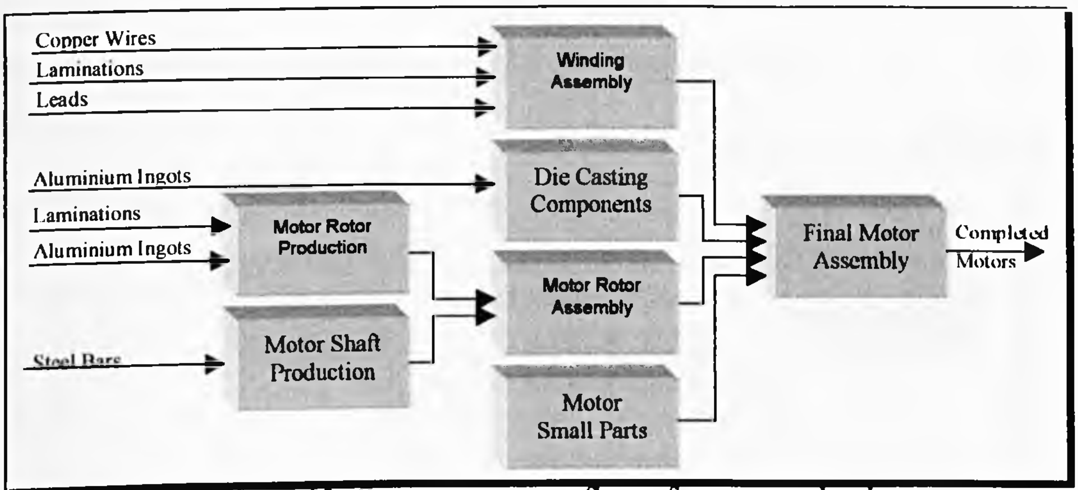


Figure 6.18. Common process flow of motor production.

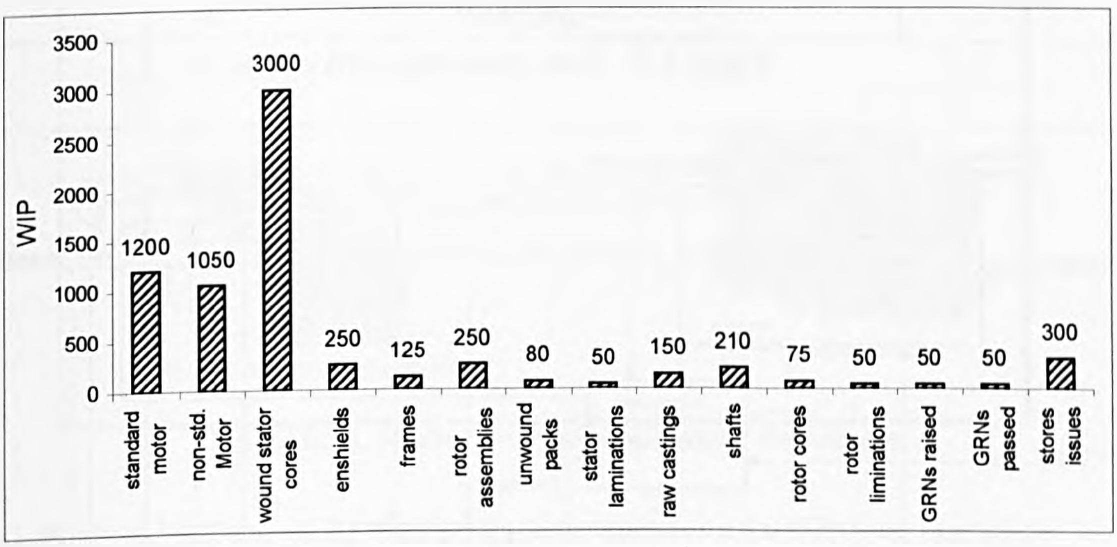


Figure 6.19. Average WIP transactions per day for Huddersfield site.

To Produce Parts

Function 'To Produce Parts' involves one D/A centre (components production). This D/A centre represents manufacturing departments that produce motor components (Rotor production, shaft production and die-casting production).

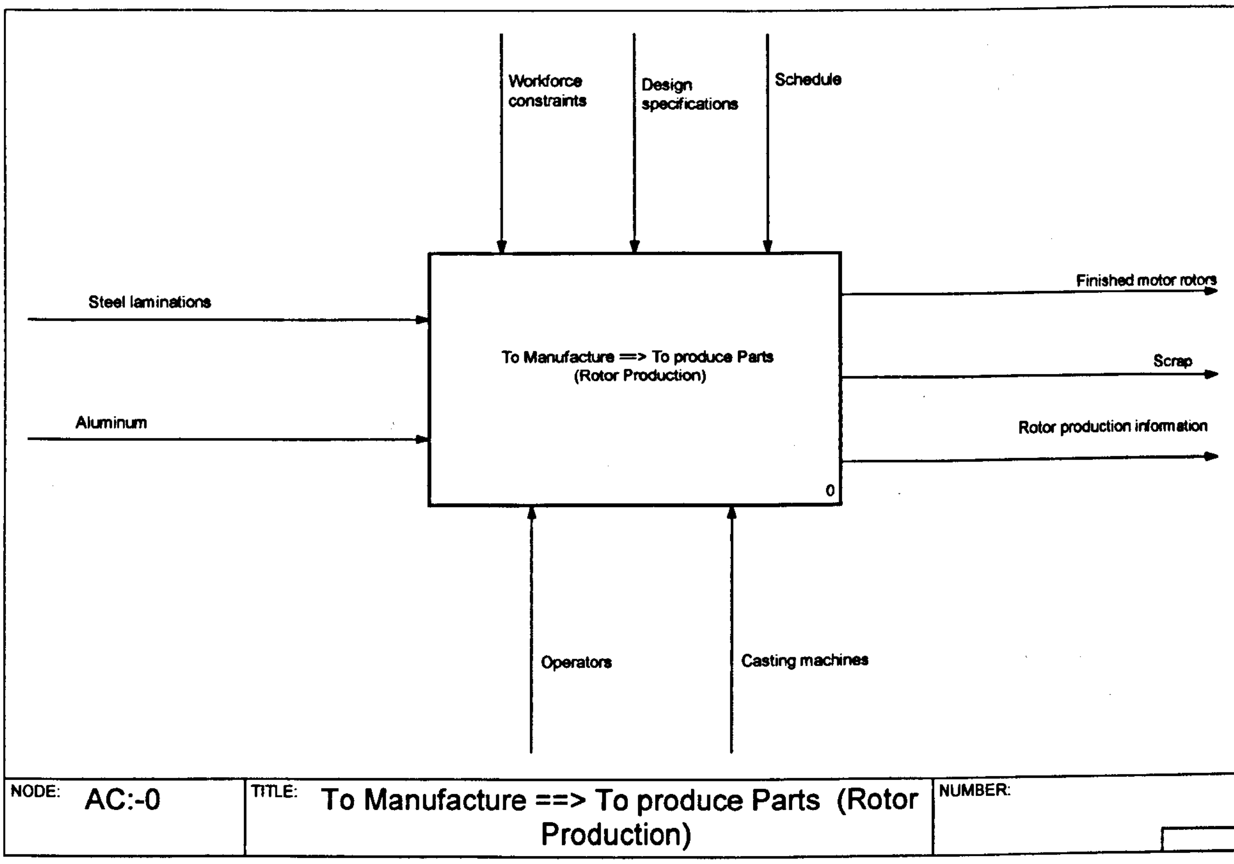


Figure 6.21. Rotor production D/A centre.

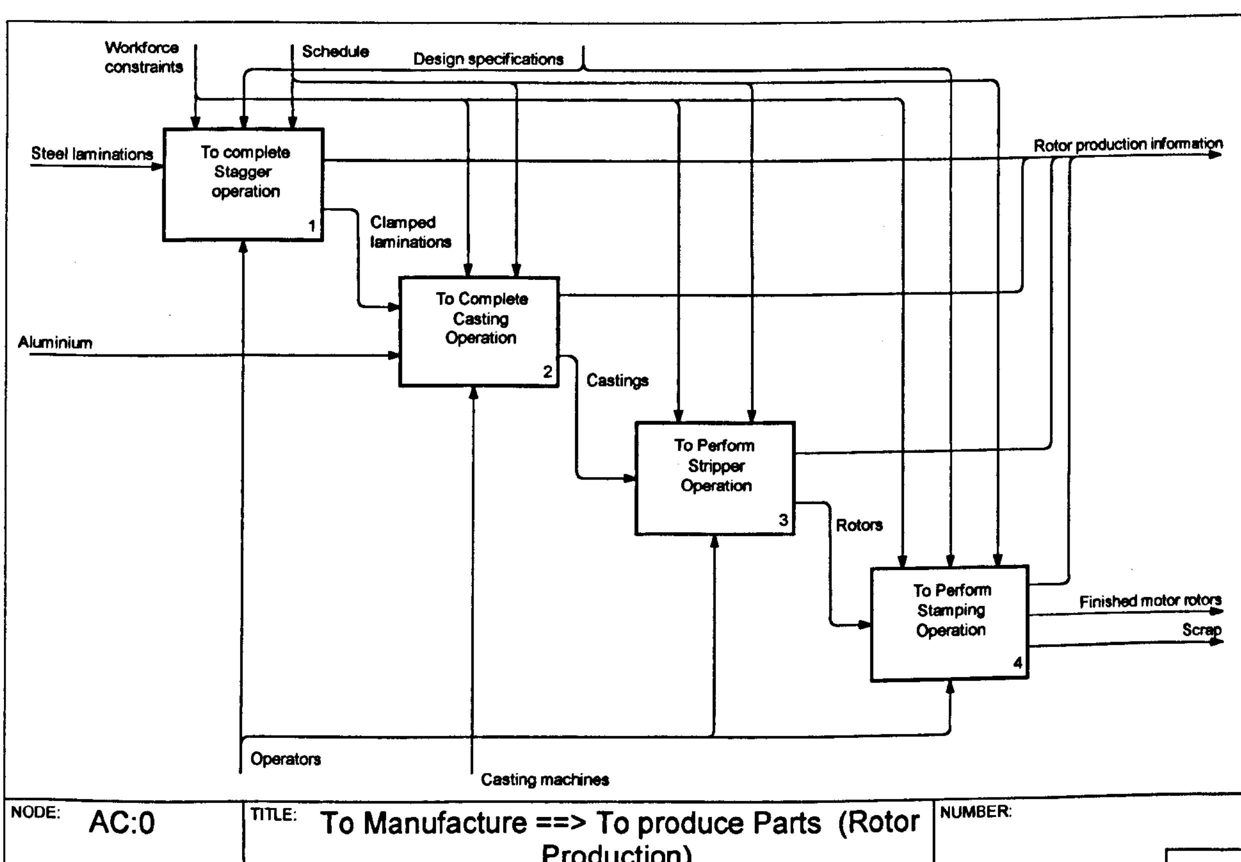


Figure 6.22. Sub-activities of rotor production D/A centre.

Rotor Production

All motor rotor types are produced in the rotor production location at the Huddersfield site. This D/A centre feeds the rotor assembly department with rotors 160/180 and 132, and supplies assembly lines of motors 100, 112 in their production cells. Figure 6.20 shows the general manufacturing processes for producing rotors.

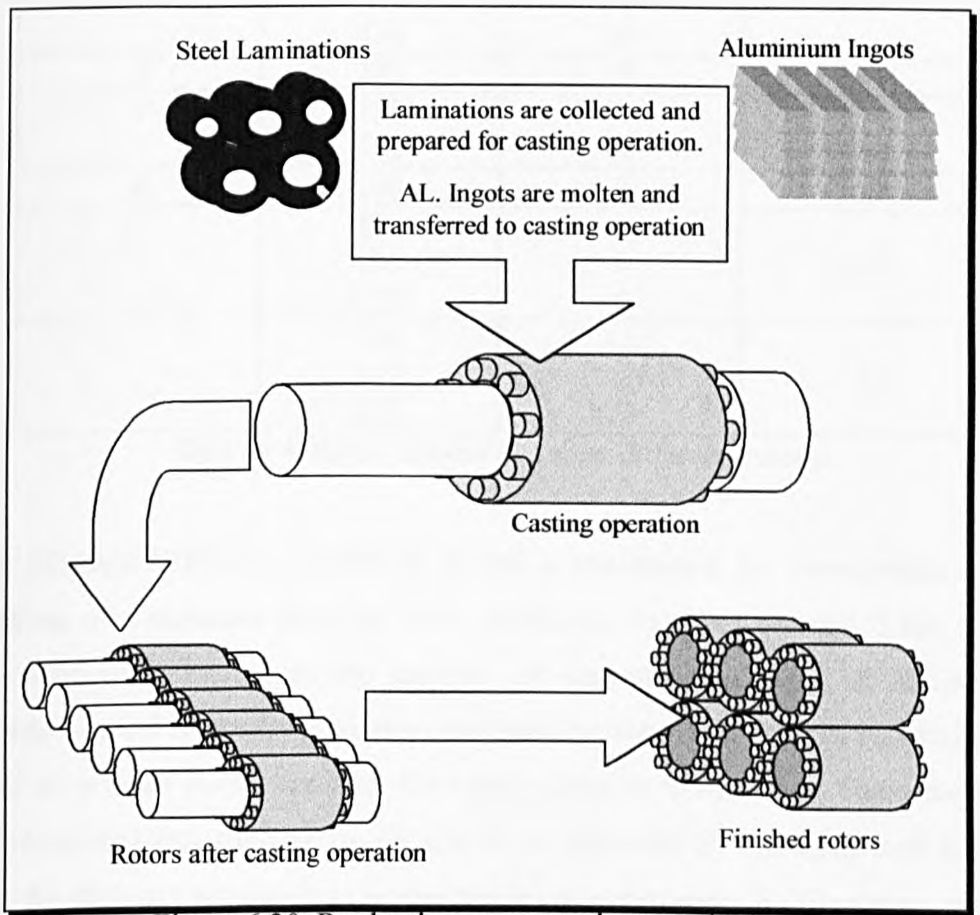


Figure 6.20. Production processes in rotor department.

As illustrated in Figure 6.20, rotor production depends on the following operations:

- Stagger operation.
- Casting operation.
- Stripper operation.
- Stamping operation.

IDEF0 models have been developed for the rotor production activity as illustrated in Figures 6.21 and 6.22. The model represents activity controls by schedule, workforce constraints and design specifications. The mechanisms are operators and casting machines. The main inputs of this activity are aluminium and steel laminations, and the outputs are rotor production information, finished motor rotors and scrap.

Table 6.4 illustrates rotor production stations and their capacities based upon motor size.

Station No.	Parts Produced (Frame size)	Production Rate (Unit/Hour)	Working Hours a day
1	100 112	28 28	7.55
2	132	18	16.8
3	132 160	20 10	16.8
4	160	7	16.8
5	160 180 C225	6 6 6	7.55
6	100 112 132	43 43 21	7.55

Table 6.4. Rotor stations and their different outputs.

Using SIMAN/ARENA a simulation model is constructed for rotor production. The modelling of a complete shop for rotor production has been attempted but there are some restrictions related to the capacity of educational version of ARENA. The simulation model of the large systems has been broken down into six small simulation models to provide output statistics for every particular workstation. These models and their associated experiments are illustrated in Appendix E. An integrated simulation model for these six workstations is also presented in Appendix E. Simulation results are summarised in Table 6.5. These results are produced from one simulation run based upon data collected from the rotor production department. Figures E-1 to E-6 (Appendix-F) give summary reports for rotor casting stations and Figures 6.23-25 illustrate different statistical measures of these stations.

Station No.	Type of Production	Simulation output unit/week	Run Time (min/week)	Utilisation %	Batch Size		
					Min	Avg.	Max
1	100 112	588 533	2265	99	16	34	55
2	132	1495	5040	99	11	29	48
3	132 160	599 541	5040	99	1	19	38
4	160	569	5040	99	11	29	49
5	160 180 C225	52 96 78	2265	99	3	19	40
6	100 112 132	280 96 567	2265	99	62	79	100

Table 6.5. Simulation output for rotor production.

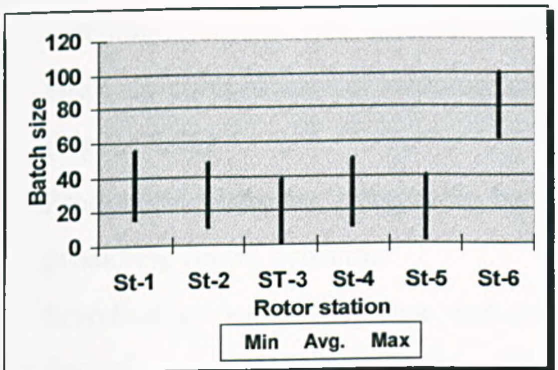


Figure 6.23. Rotor batches range

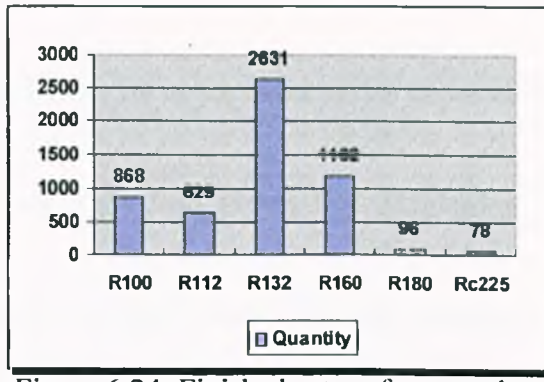


Figure 6.24. Finished rotors for a week.

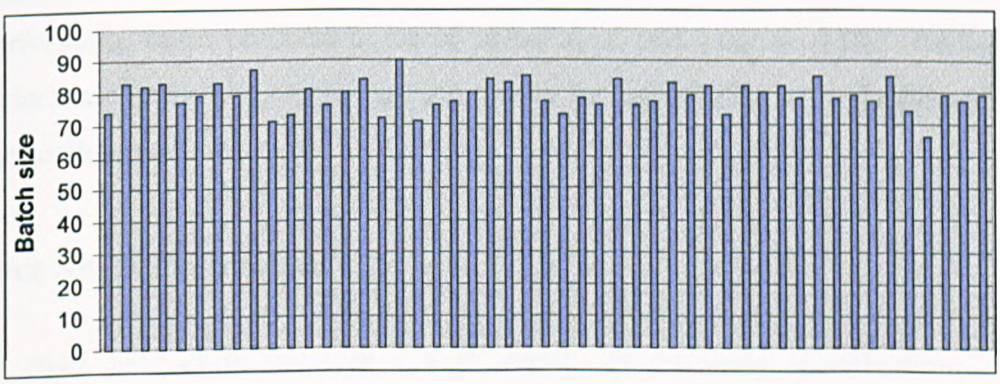


Figure 6.25. Segment of generation batch size in simulation model.

Comments on Rotor Production

Analysis of rotor production gives the following points:

- Rotor production is based upon updated schedules generated by the MRP system. This causes problems in the selection of motor batches and keeps them permanently high. Changing of priorities is based upon conventional factors but requires sophisticated computer programs that take into account several internal and external factors.

- Rotor production workstations are still very conventional manufacturing stations. Installing new production technologies would give more accuracy and increase production rate.
- Table 6.5 illustrates that rotor stations are fully utilised and operated manually.
- Scrapped rotors cannot be reworked because reworking facilities do not exist.
- The layout of the rotor production deportment would be not appropriate for using new manufacturing strategies such as JIT and Kanban systems.
- Rotor production needs to be fully integrated with shaft production and winding assembly.
- High variation of sizes of customer orders effects production rates in this department (Figure 6.25).
- Production plans are changeable because of some rush orders and difficulties in predicting future demands.
- Selection of stations batches and estimation of time events are also performed depending on planner experience without using any production technique or philosophy such as group technology methods or cellular manufacturing techniques.
- Delaying customer orders are probable because of a lack of computation in performing rotor production plans, scheduling and control. MRP feedback is generated weekly and has several limitations such as lacking batch details and daily production rates.

Motors Shaft Production

Motor shaft production involves a high variety of customer specifications. These specifications include material type, machining specifications and design properties. Hence, five production lines are used for producing motor shafts at the Huddersfield manufacturing site. These five production lines are:

1. Shaft integrated production unit.
2. An automated line installed near the integrated production unit (as illustrated in Appendix-D).
3. Shaft production unit for cell-100.
4. Shaft production unit for cell-112.
5. Special shaft production shop (manually).

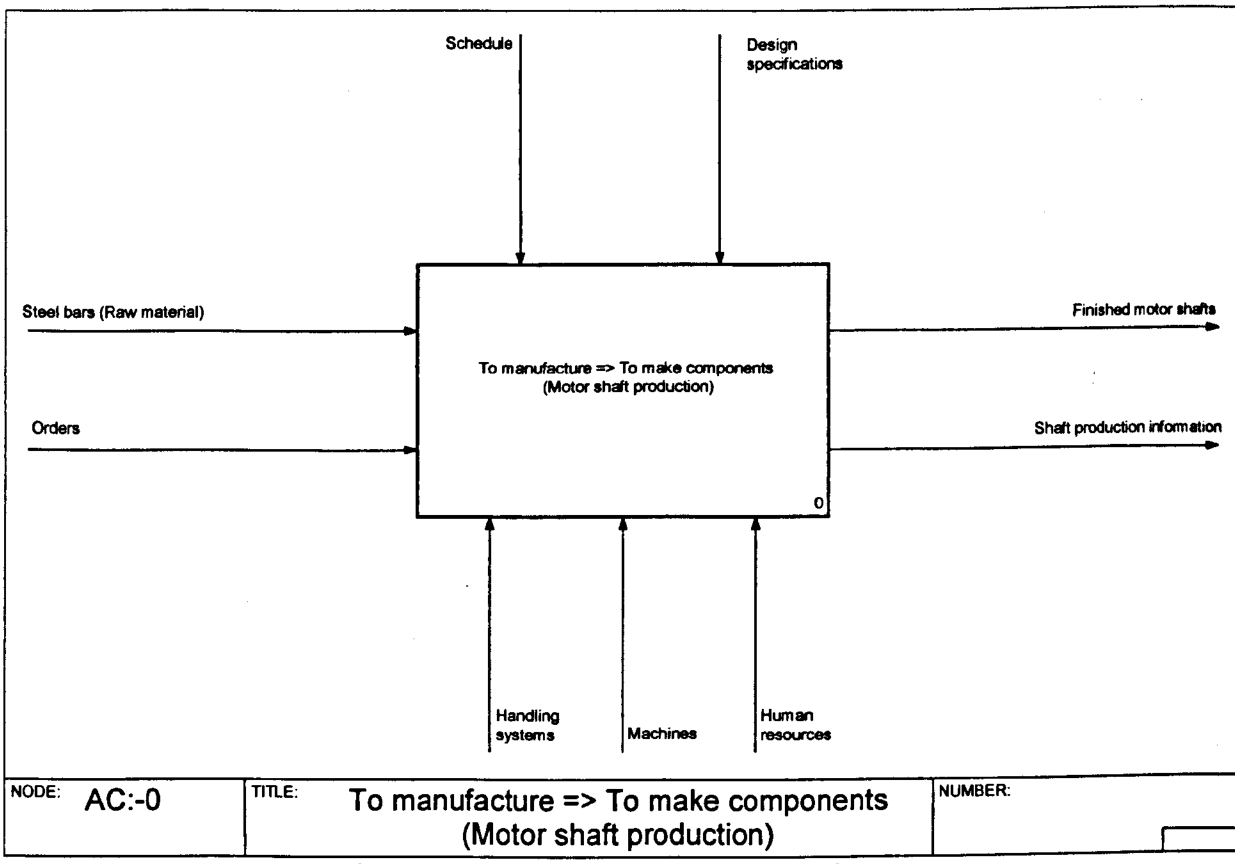


Figure 6.26. Motor shaft production D/A centre.

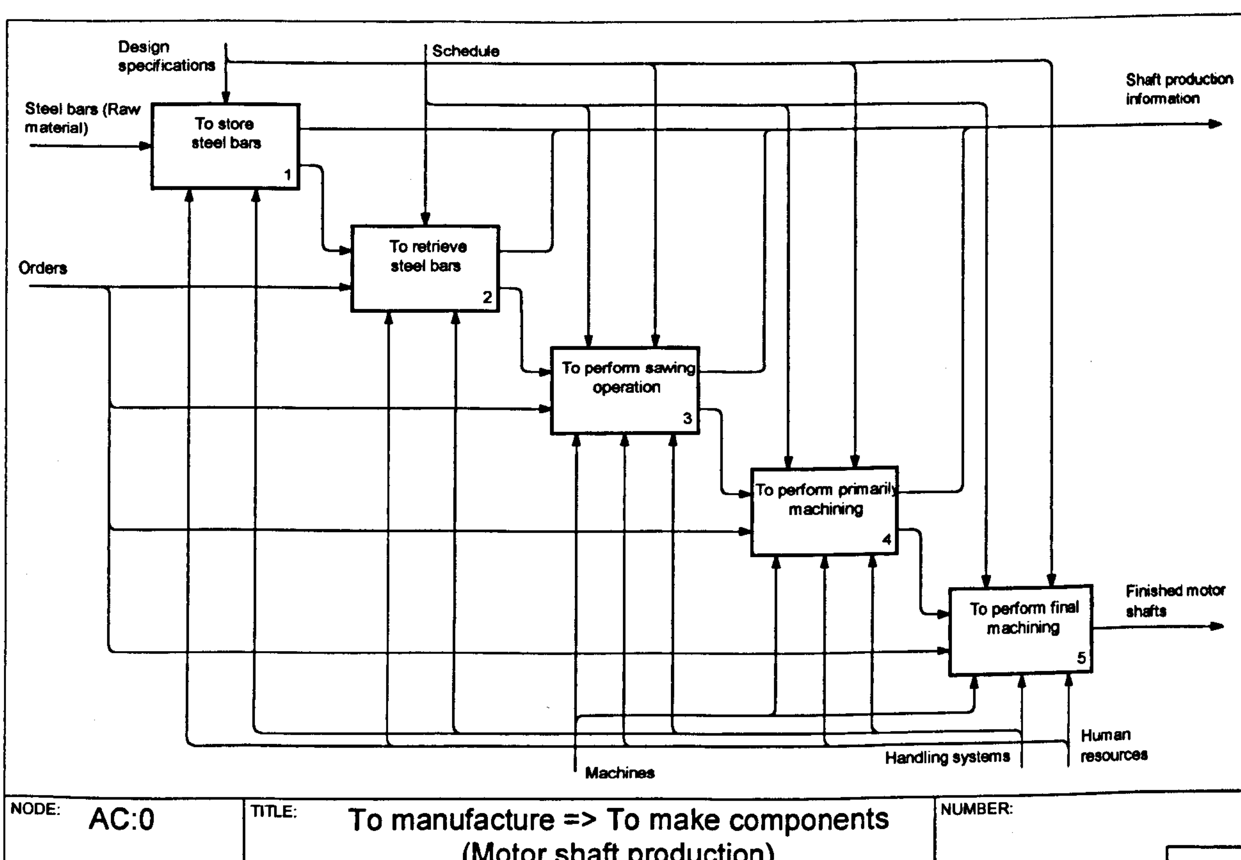


Figure 6.27. Sub-activities of rotor production D/A centre.

In general, this D/A centre can be modelled functionally, as illustrated in Figures 6.26 and 6.27. These IDEF0 models illustrate the basic manufacturing operations used to produce motor shafts. The top activity is decomposed into five sub-activities:

- To store steel bars.
- To retrieve steel bars.
- To perform sawing operation.
- To perform primarily machining.
- To perform final machining.

Shaft production operations are shown in Figure 6.28.

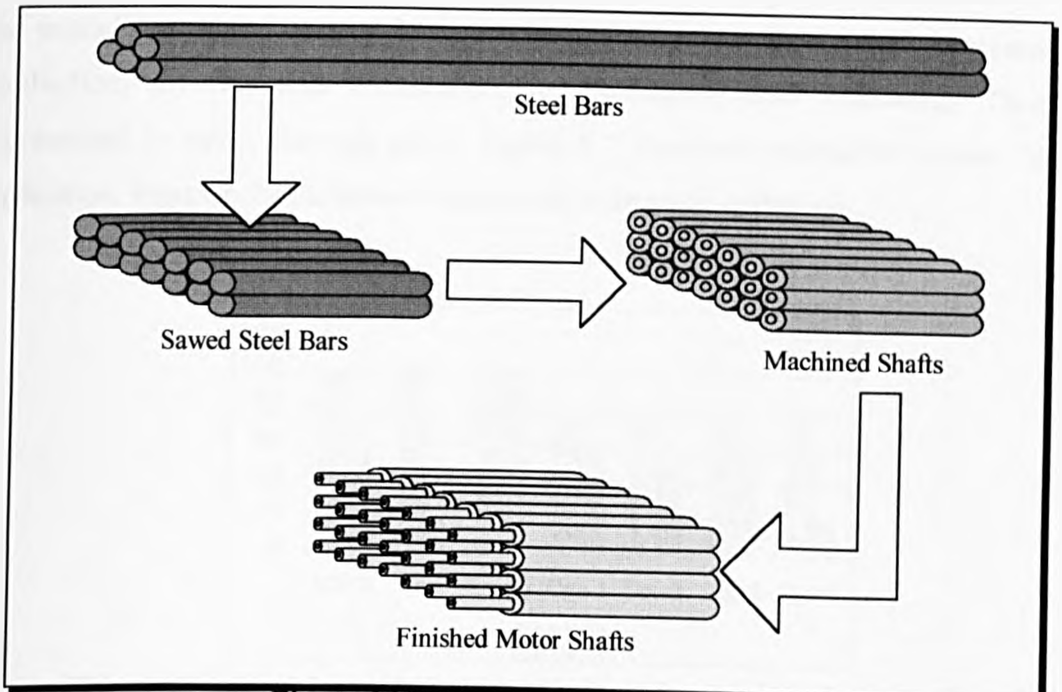


Figure 6.28. Shaft production operations.

The classifications of manufacturing processes are different from one shaft production line to another; hence, the development of functional models would be different. To avoid these changes in functional/physical models, table 6.6 illustrates the model sub-functions and their associated manufacturing process for the first four shaft production lines. The last one will be ignored in this study because it uses very conventional manufacturing methods and is used to produce very special types of motor shafts in small batch sizes.

No	Sub-activity	Manufacturing operations			
		Line 1	Line 2	Line 3	Line 4
AC1	To store bars	Storing bars	Storing bars	Storing bars	Storing bars
AC2	To retrieve bars	Retrieving bars	Retrieving bars	Retrieving bars	Retrieving bars
AC3	To saw	Sawing operation	Sawing operation	Sawing operation	Sawing operation
AC4	To perform primarily machining	Facing, Drilling, Centring Tapping.	Turning, Milling, Tapping, Screwing, Drilling.	Turning, Milling, Tapping, Screwing, Drilling.	Turning, Milling, Tapping, Screwing, Drilling.
AC5	To perform final machining	Turning, Milling, Drilling, Grinding.	Grinding.	Grinding.	Grinding.

Table 6.6. Classification of shaft operations.

Four simulation models are constructed for shaft production lines. The simulation model and experiments are presented in Appendix-E. Production line-1 (shaft integrated unit production) involves four workstations for performing final machining. These are represented by cell-1 through cell-4. Figure F-7 illustrates simulation results for one replication. Figure 6.29 illustrates station availability and utilisation.

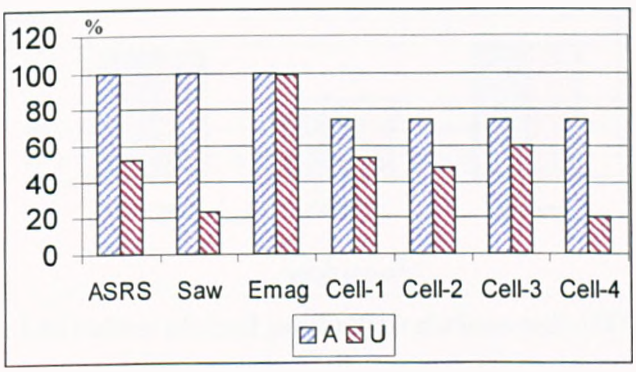


Figure 6.29. Shaft integrated production unit (availability and utilisation)

It is clear from Figure 6.29 that the EMAG machine represents the bottleneck stations in the production line. For this reason the EMAG machine works 20 hour each day. As illustrated by the simulation report, cell-1, cell2 and cell-3 produce 424, 379 and 241 motor shafts/week respectively, using input data attributes. WIP level is approximately 200 units for this shaft production line. Other analysis results are illustrated in Figure F-7.

Shaft production line-2 is a new line for producing shafts for motors size (132). This production line is composed of two main workstations. The first one is an automated machine that carries out five different operations, namely, turning, milling, tapping, screwing and drilling, and the second is used to perform grinding operations. Figure F-8 illustrates the simulation report for this production line. The report shows that utilisation is:

OKUMA_LT_15_M utilisation = 97%

GRINDING utilisation = 55%

OPERATOR utilisation = 72%

The total output of this production line is approximately 870 motor shafts per week. Because the first part of this line is working automatically, the WIP level is very low.

Shaft production lines 3 and 4 are similar. Line-3 is used to produce cell-100 shafts and line-4 is used to produce cel-112 shafts. Simulation results are illustrated in Figures F-9 and F-10. SIMAN models and experiments for shaft production are presented in Appendix-E. Figure 6.30 illustrates the utilisation of machines and operators for line-3 and line-4. Simulation reports are presented in Appendix-F.

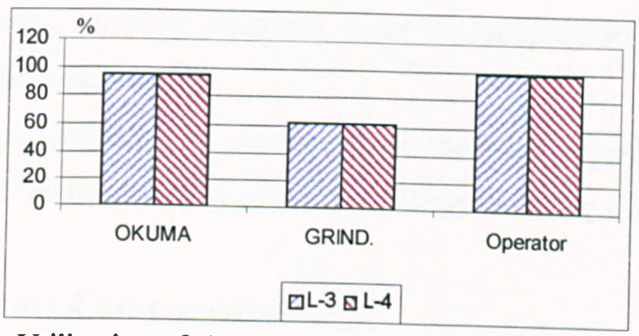


Figure 6.30. Utilisation of shaft production stations cell-100 and cel-112

Simulation results indicate about 690 shafts can be produced from cell-100 and cell-112.

Comments on Motors Shaft Production

Many varieties of customer specifications are found in motor shafts. These specifications are related to length of shaft, machining, materials and designs. The MRP system is the main resource for shaft production and other special orders. Hundreds of shaft types are placed to shaft production from order processing through the MRP system. The related design diagrams are sent directly to the manufacturing department from the design department. The analysis of shaft production is very difficult because of the huge variety of customer orders and complexity of performing perfect scheduling for these order quantities. These lead to increasing production costs through increasing machine set-ups, overtime, order delay and WIP levels. This study indicates several important points related to shaft production lines, including:

- Grouping customer orders based upon design and manufacturing features is very important in shaft production to reduce set-up times and lead times. The existing method does not adopt any grouping or clustering techniques such as Group Technology to combine motor orders.
- Formulation of capacity planning is performed based upon quantities of orders not scheduling techniques and known resource capacities.
- Using MRP production for shaft production should be restricted to MRP parts and other equipment should be produced using other manufacturing techniques such as JIT and Kanbans.
- WIP is high for standard motors.
- Breakdowns of sawing tools specially in the automated lines (Line-2, Line-3 and Line-4) in OKUMA machines that perform several machining operations automatically using computer programs, cause the stopping of the other operations performed on the same machine.
- Writing machine programs by production planners and operators wasting time. These programs can be generated from the CAD system using CAPP methods.

Die Casting Motors Components

Motor components such as frame, drive end-shields, non-drive end-shields, flanges, terminal boxes and bearing caps are manufactured in the foundry department, as discussed in Appendix-D. The GI-SIM grid presents these activities under 'To Manufacture' function. This D/A centre has the same modelling factors as rotor and shaft production. Die-casting manufacturing operations can be represented by the following activities:

- To melt Aluminium ingots.
- To handle molten material.
- To perform casting operation.
- To collect/Inspect casting components.

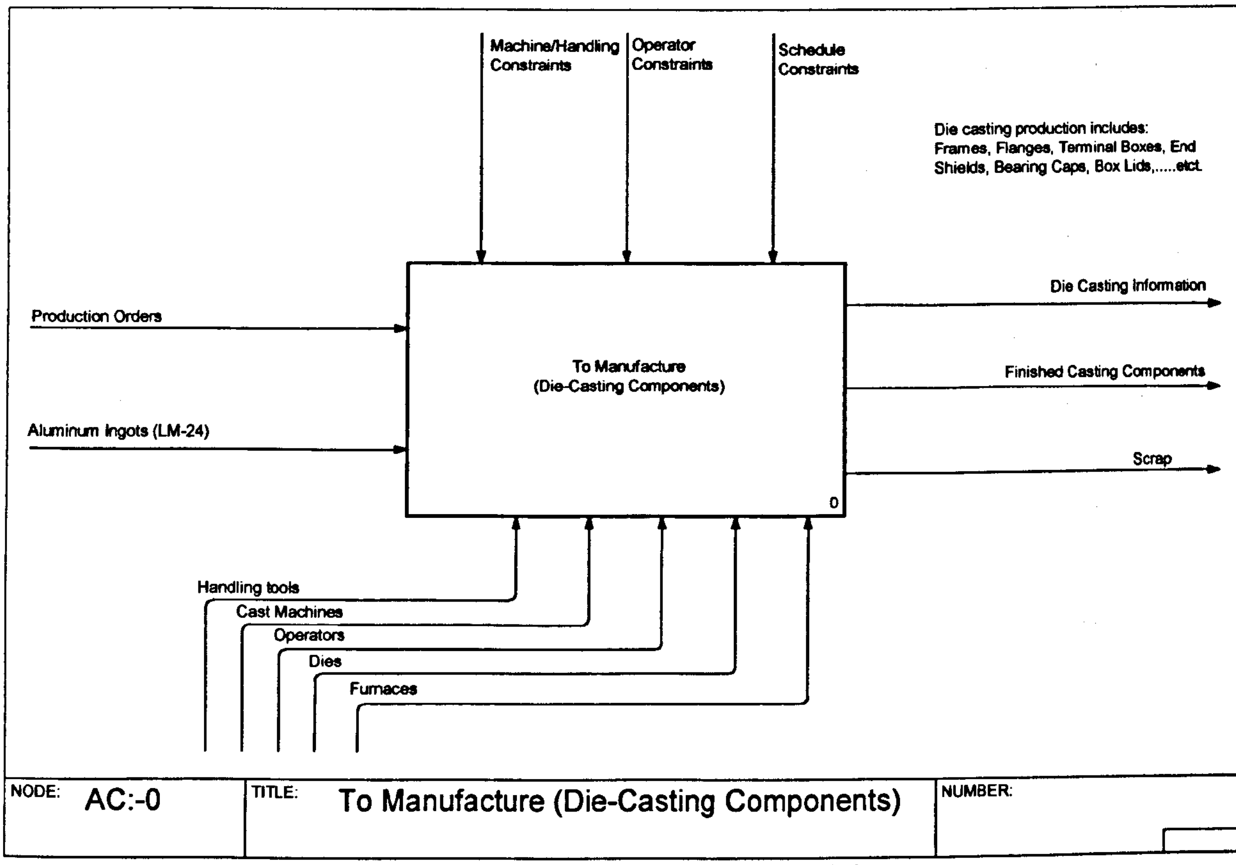
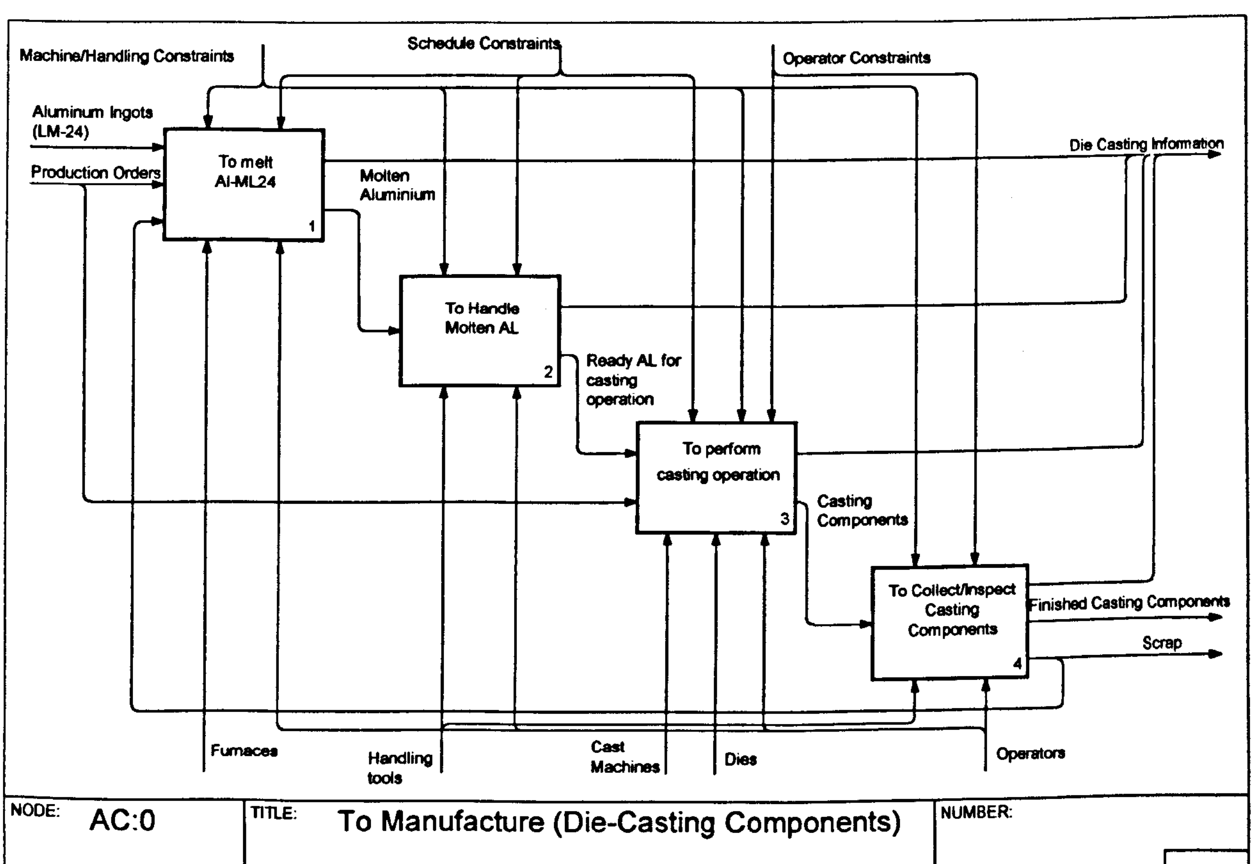


Figure 6.31. Die-casting production activity centre



9.32. Die-casting operations.

Figures 6.31 and 6.32 illustrate IDEF0 models for die-casting production. The main inputs are orders and aluminium ingots and the outputs are casting information, finished casting components and scrap. Operations of this activity centre are controlled by operator, scheduling and machines constraints, and supported by operators, casting machines, handling tools and electrical furnaces. There are several types of casting machines: IDRA500, IDRA560, CAST MASTER500, CAST MASTER600, TRIULZI750-1, TRIULZI750-2, TRIULZI480-1, TRIULZI480-2, TRIULZI750-1, TRIULZI800, TRIULZI950, WOTAN400-1, TRIULZI630, WOTAN400-2, WOTAN700 and IDRA1200. These machines can produce more than one component, as discussed in Appendix-D. The current production system used in die-casting is mixed by MRP and is similar to Kanban. Die-casting machine set-ups take a long time and due to the variety of customer orders, machine utilisation is low. Figure 6.37 illustrates the average number of die-casting machines used for fourteen weeks. The litters D, L and N in Figure 6.33 indicates shift type Day, Link and Night respectively.

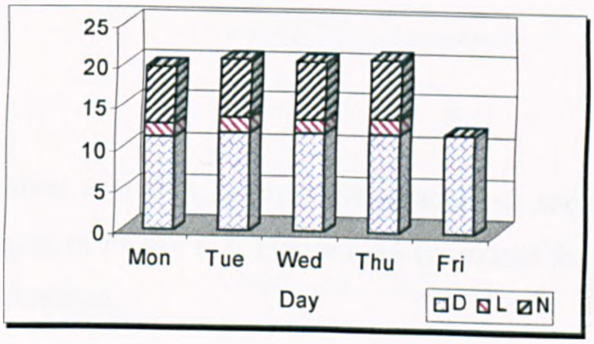


Figure 6.33. Die-casting machines availability.

Simulation models of die-casting production would be very complicated for the following reasons:

- There are no specific production plans which can be used for specific periods of time;
- No scheduling system is used for this production. Manual scheduling and conventional planning methods are used;
- Every machine can be used to produce different components.

Comments of Die-casting Production

The foundry department is one of the most complex departments at Brook Hansen as it feeds motor production facilities at both Huddersfield and Honley. Its performance is estimated to be about 65% based upon the history of production over several weeks. Analysing die-casting production gives the following points:

- The department layout needs to be re-arranged to minimise molten aluminium movements between casting stations.
- There are high levels of WIP in the casting department.
- Scheduling casting operations is completed manually and several problems are associated with this method such as low machine utilisation and delayed orders.
- Die handling and installation takes a long time. This reduces utilisation and makes scheduling more difficult.
- Capacity planning modelling is implemented based upon order sizes. This makes using the Kanban system very difficult because Kanban has restrictions regarding number of containers and their capacities.
- Design time for new dies takes a long time. This increase lead times and design and manufacturing costs.
- Casting operations have high scrap rate.

To Assemble

This sub-function involves two D/A centres 'sub-assembles' and 'final assembly', as illustrated by GI-SIM grid in Figure 6.1. Figure 6.34 illustrates the general architecture of 'To Assemble' sub-function.

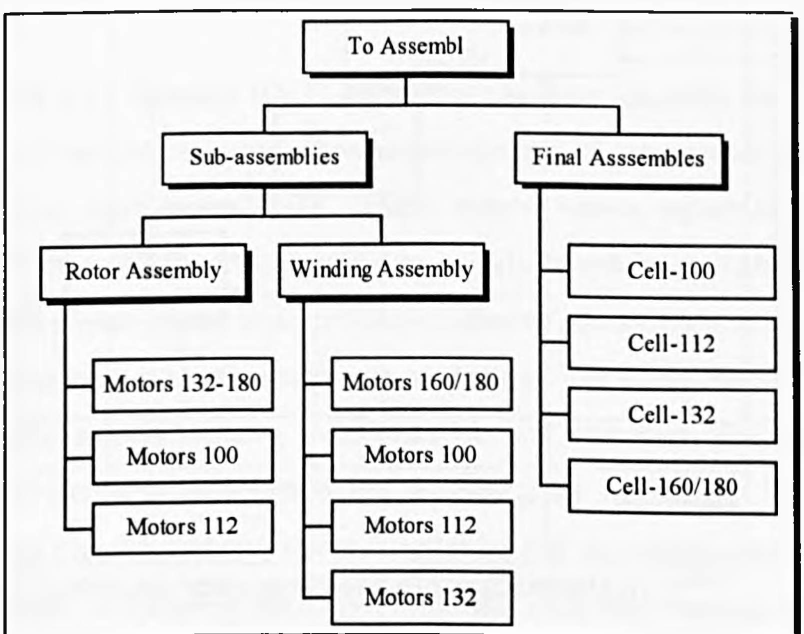


Figure 6.34. 'To Assemble' sub-function.

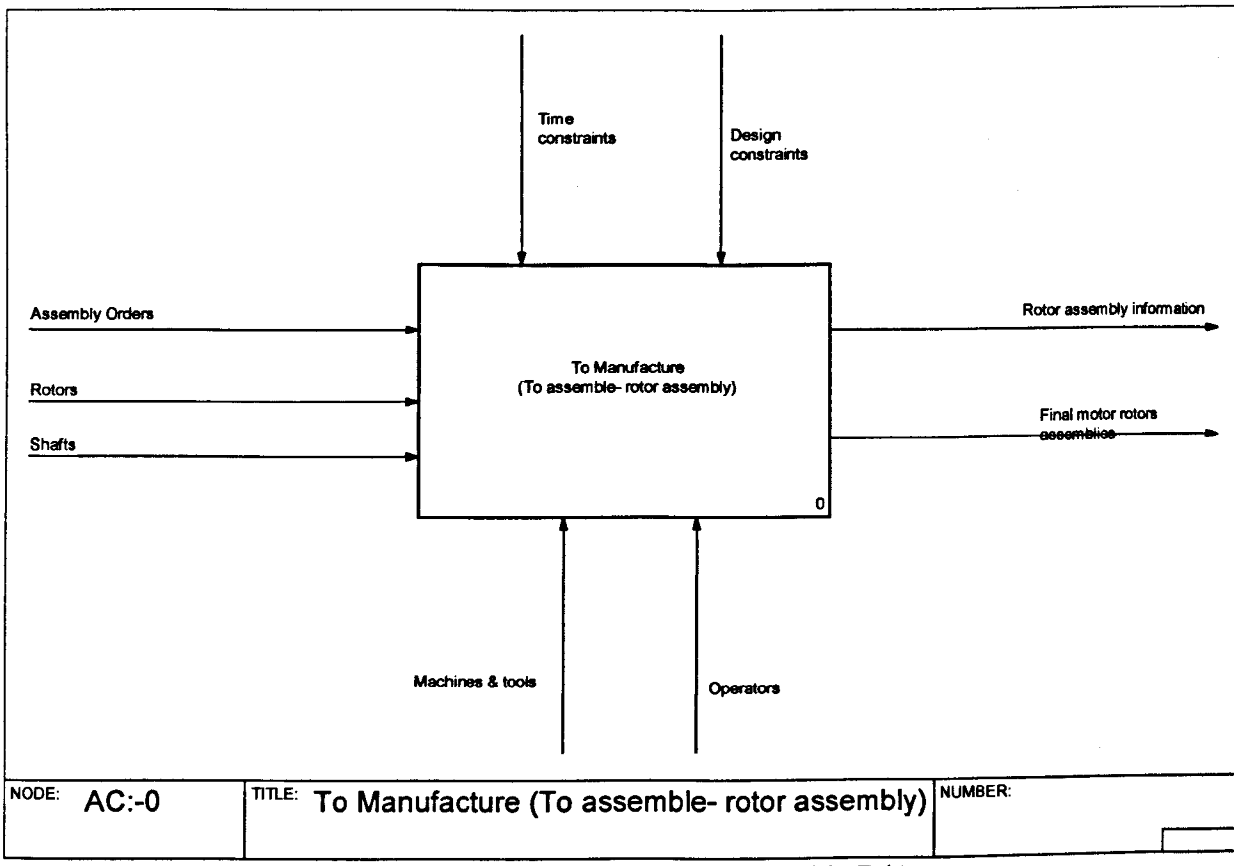


Figure 6.36. Top activity of Rotor assembly D/A centre.

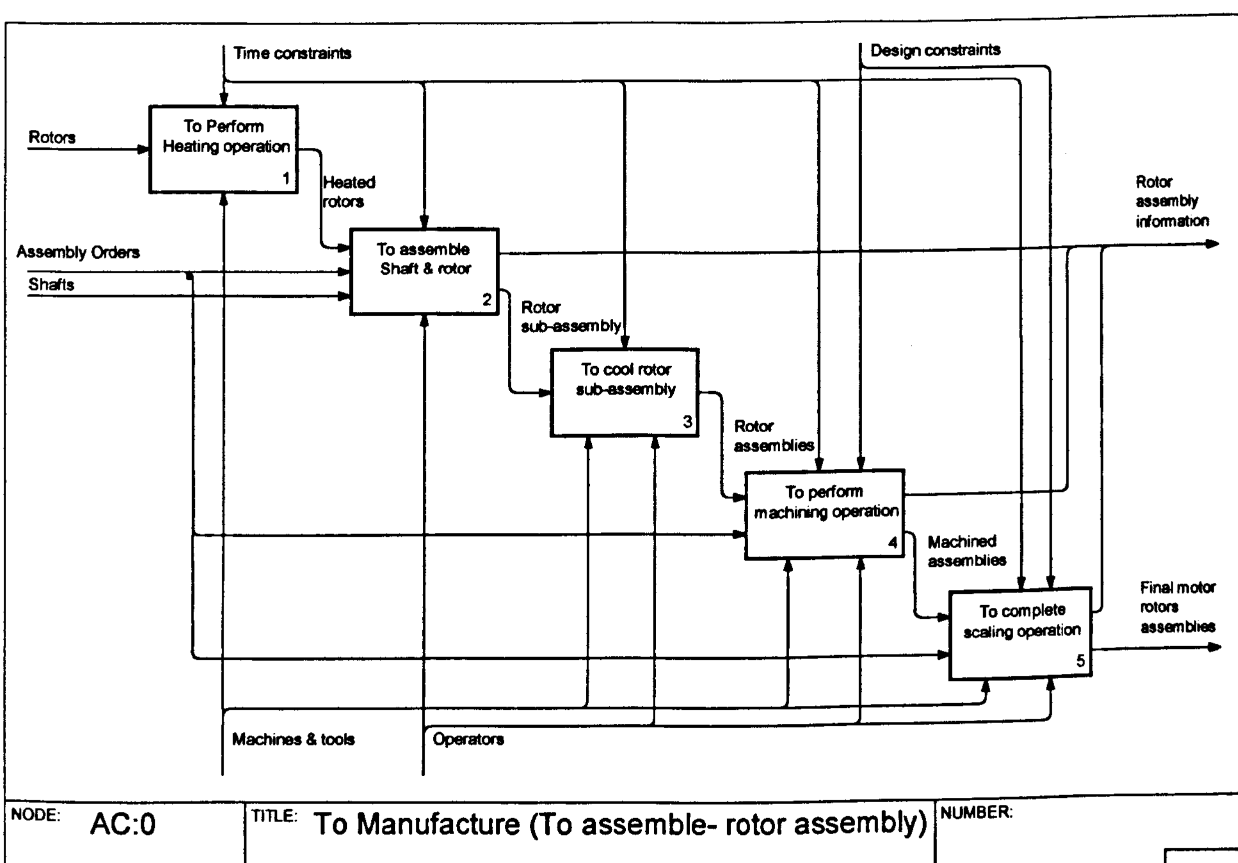


Figure 6.37. Sub-activities of rotor assembly D/A centre.

Sub-assembly D/A centre involves two types of sub-assemblies 'rotors sub-assemblies' and 'windings sub-assemblies'. These two centres appear at the last level of the GI-SIM grid with planning horizon for one day and real time review period.

Rotor Assemblies

There are three locations where motor rotors are assembled. The first one is located at the rotor assembly department near the shaft production. This assembly line feeds the final assembles of motors 132, 160 and 180. The second rotor assembly line is located near cell-100 and it is used to assemble motors 100 only. The third rotor assembly line belongs to motors 112 and is located near that manufacturing cell.

Rotor assembly activity can be broken down into five sub-activities as illustrated in Figure 6.35.

- To assemble motor rotors
  - To perform heating operation
  - To assemble shaft & rotor
  - To cool sub-assembly
  - To perform machining operations
  - To complete scaling operations

Figure 6.35. Sub-activities of rotor assembly D/A centre.

Figures 6.36 and 6.37 illustrate IDEF0 models of the rotor assembly D/A centre. The top activity of the model represents the general concept of motor rotor assembly. The model shows four main inputs: MRP orders, special orders, rotors and shafts. The operations of rotor assembly are controlled by a daily schedule, provided by the MRP system and rescheduled by the rotor production planner. In addition to this, the design specifications represent other constraints on production. The model developed indicates two types of mechanisms, namely, machines/tools and operators. The outputs of this model are rotor assembly information and finished rotor assemblies. The model top activity has been decomposed into five sub-activities that are responsible for producing final rotor assembly and sending the relevant information to the planning centre.

Sub-activity AC1 represents heating operations for rotors to facilitate fitting the shaft which is represented by sub-activity AC2 in the IDEF0 model. Sub-activity AC2 transfers its outputs (rotor assembles) to the next sub-activity AC3 to cool the sub-assemblies. Machining operations are required for rotor assemblies; this can be done by sub-activity AC4. Final machining and balancing are carried out by sub-activity AC5 which produces the final rotor assemblies. Figure 6.38 illustrates the rotor assembly drawing and assembly chart.

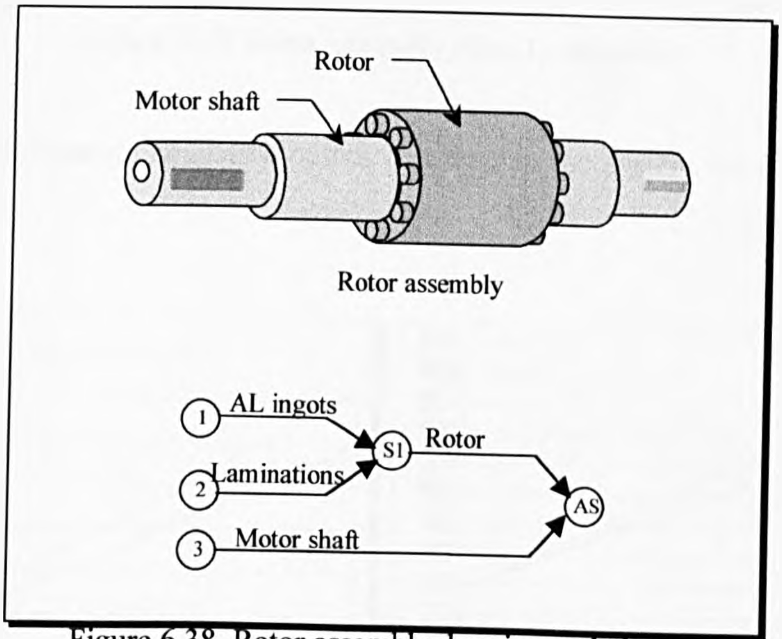


Figure 6.38. Rotor assembly drawing and chart.

In the third phase of the GI-SIM analysis procedure, three simulation models are constructed for the rotor assembly lines. Complete simulation models and experiments are given in Appendix-E.

The rotor assembly line that feeds cell-132 and cell-160/180 combines two lines for both small and large motors. Figure F-11 (Appendix-F) presents a summary report for this assembly line. This assembly line works for approximately 47.75 hours per week. Figure 6.39 shows the utilisation of rotor assembly stations. It is very clear that low utilisation is one of the rotor assembly problems.

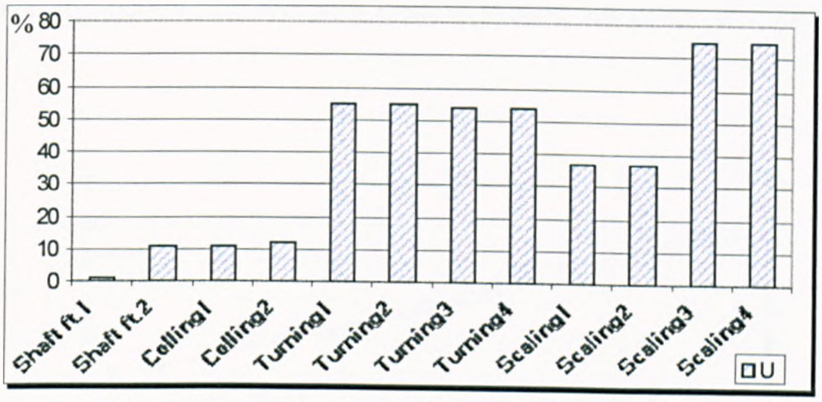


Figure 6.39. Rotor assembly (line-1) utilisation.

Figures 6.40 illustrates cumulative output and time in the system for rotor assembly line-1.

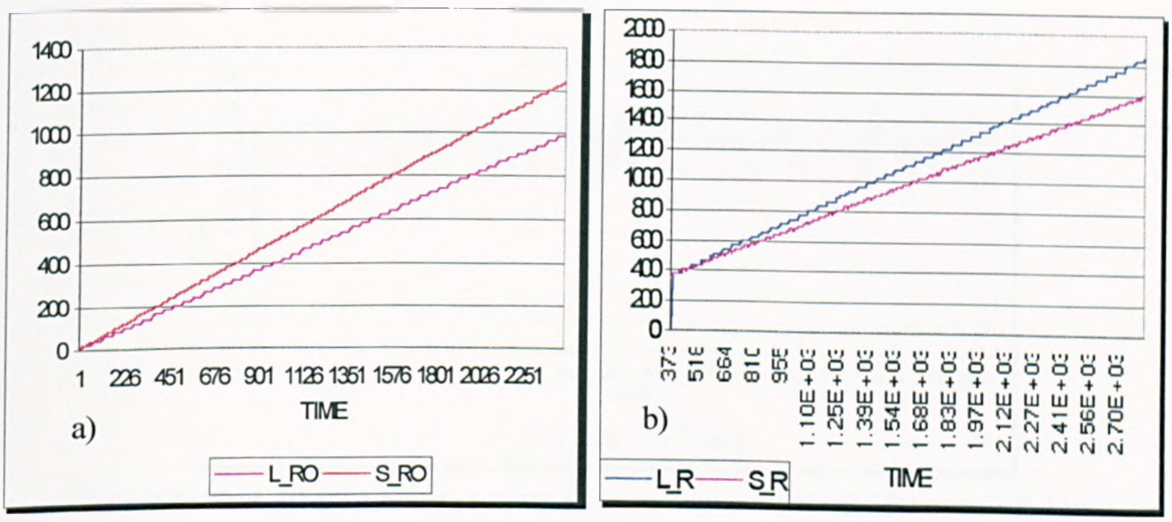


Figure 6.40. a) Cumulative production output and b) Cumulative time in system for rotor assemblies (assembly line-1)

Figure 6.40 (b) illustrates the WIP situation for one week of production. This is a high level of WIP because of the need for rotor assembly cooling using traditional methods (room temperature) or air fan coolers.

Rotor assembly lines 2 and 3 are used to feed final motor assemblies at manufacturing cells 100 and 112 respectively. Simulation models and experiments for these two lines are illustrated in Appendix-E. The run time is 47.75 hours. Figures F-12 and F-13 (Appendix-F) illustrate the simulation output for cell-100 and cell-112 rotor assembly lines.

The cumulative production rate and jobs time in system are given in Figures 6.41 and 6.42.

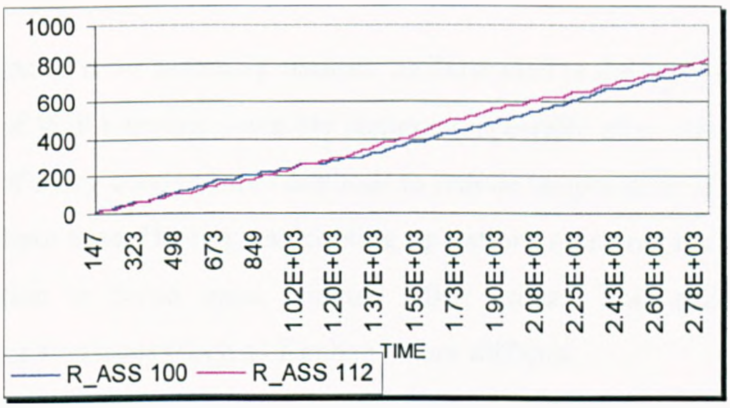


Figure 6.41. Cumulative production output for rotor assembly Cell-100 and Cell-112.

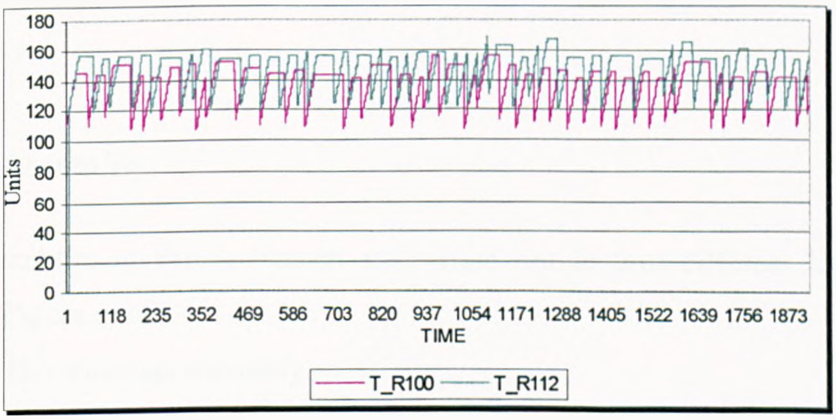


Figure 6.42. Average time-in-system for rotor assembly Cell-100 and Cell-112

Utilisation of these two rotor assembly lines is illustrated in Figure 6.43.

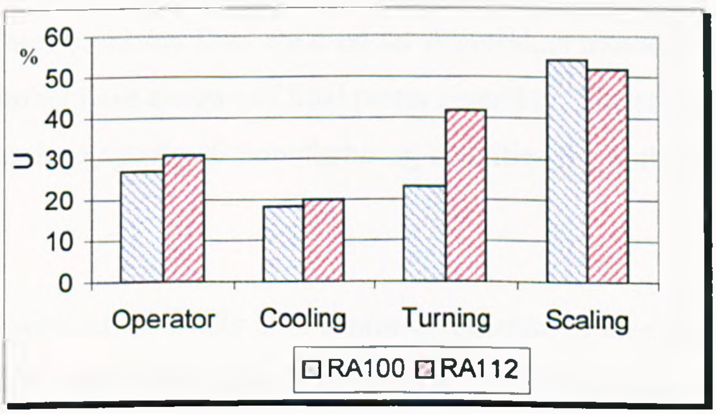


Figure 6.43. Utilisation of rotor assembly lines for cells 100 & 112.

Comments on Motor Rotor Assembly Lines

The rotor assembly operations lack advanced technologies and operate under traditional manufacturing methods. The analysis of these assembly lines gives the following points:

- Low utilisation of rotor assembly stations, as illustrated in the analysis figures.
- High levels of WIP between assembly stations (especially after water-cooling). This is the result of using conventional methods to reduce temperature of sub-assemblies.
- Long throughput time. Heating and cooling operations represent the bottlenecks.
- The production is based upon updated MRP orders. This makes using other manufacturing strategies (such as Kanban) more difficult.
- Batch selection is based upon the production card and unit number attached to the component. This method increases cycle times and effects on some urgent customer orders.
- Using traditional manufacturing systems in rotor assemblies also reduces accuracy and quality.

Windings Assembly

Winding assemblies at Brook Hansen are carried out in four different locations, as illustrated in Figure 6.34:

1. Cell-160/180 windings assembly.
2. Cell-100 windings assembly.
3. Cell-112 windings assembly.
4. Cell-132 winding assembly.

Most outputs of these assembly lines are used for Aluminium motors. It should be noted that winding assembly lines are part of final motor assembly. The reason for considering them here is to analyse details of manufacturing activities for both windings and final assembles.

In this analysis a winding assembly D/A centre is regarded as an element of the motor sub-assemblies D/A centre with planning horizon of one day and real time review period, as shown by the first phase of GI-SIM analysis in Figure 6.1. In the second phase, IDEF0 models are constructed for this D/A centre based upon sequences of

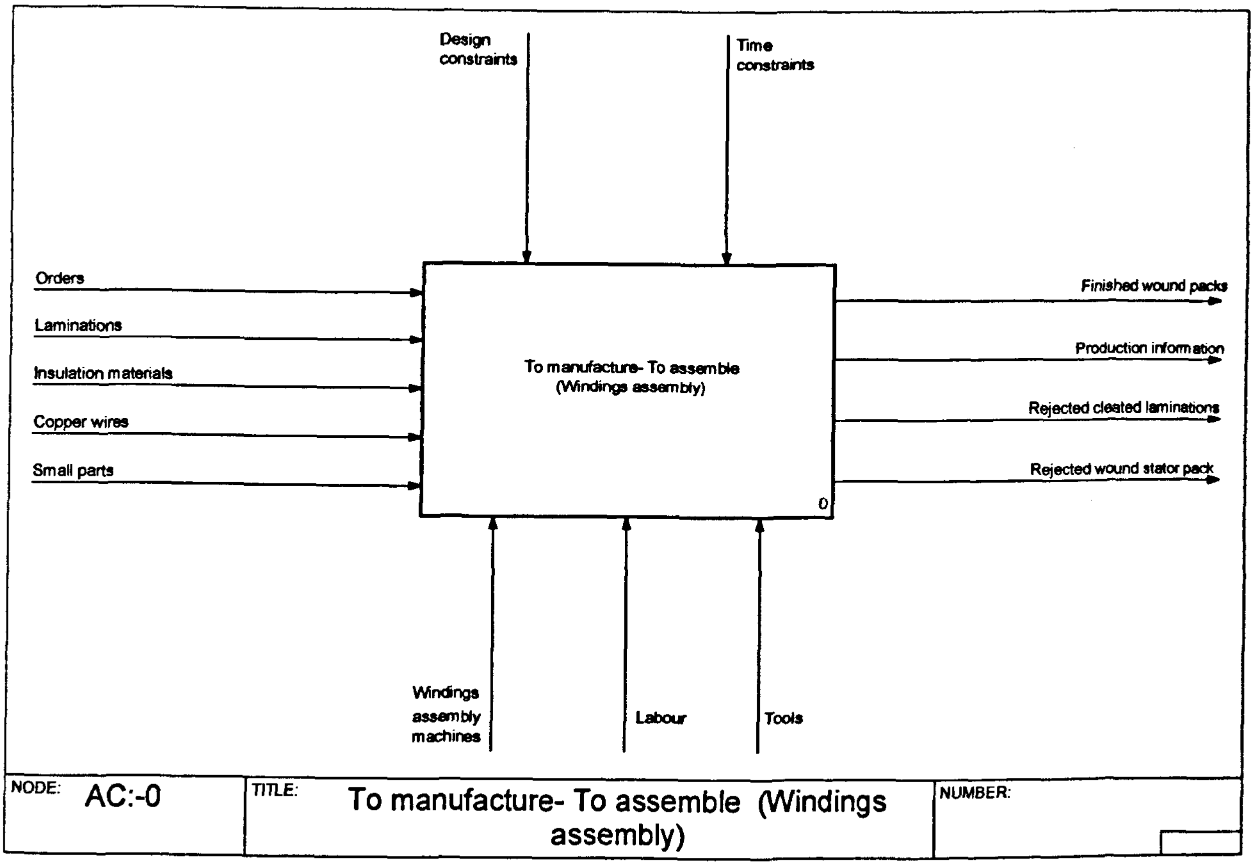


Figure 6.45. Windings assembly D/A centre.

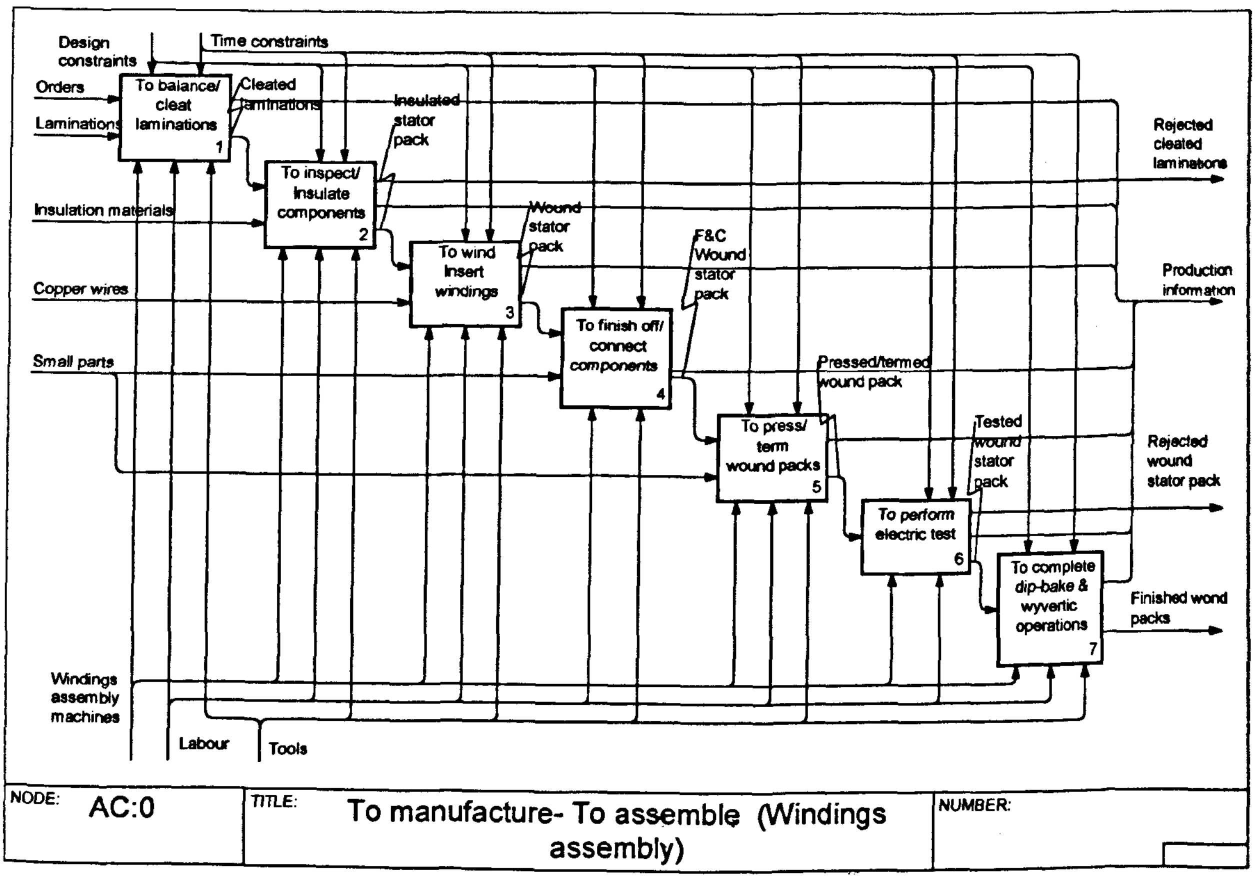


Figure 6.46. Child-activities of motor windings assembly.

system flows between production sub-activities. Figure 6.44 illustrates child-activities of this D/A centre.

To assemble windings

- To balance and cleat laminations
- To inspect and insulate components
- To wind and insert
- To finish off and connect
- To press and term
- To perform electric test
- To perform dip-bake and wyvertic operations

Figure 6.44. Windings assembly sub-activities

Using the windings assembly sub-activities and IDEF0 tool, a structural model is constructed for the D/A centre, as illustrated in Figures 6.45 and 6.46. The IDEF0 model summarises the different relationships between sub-activities of winding assembly. Sub-activity-AC1 represents collecting steel laminations and balancing them using an electronic scale based upon order specifications. The cleating operation is also involved in sub-activity-AC1. The output of this activity is the input of Sub-activity AC2 which represents inspecting and insulating cleated laminations. Rejected components are returned to the steel lamination store and the accepted components are delivered to the insulating machine then to the subsequent operations which are represented by Sub-activity AC3. Sub-activity-AC3 represents the operations of winding, inserting and pressing copper wires into the stator pack. Following this, the finishing and connecting operations are completed. These two operations are represented by Sub-activity AC4 in the IDEF0 model. Sub-activity AC4 delivers its output to its subsequent sub-activity-AC5 which represents pressing the wound pack and completing the terminal operations. Before performing dip and bake operations, components are tested electrically. Electrical testing is represented by Sub-activity AC6 in the model. Finally, sub-activity-AC7 represents the dip-bake and wyvertic operations. The model inputs are orders, laminations, insulation materials, copper wires and small parts. The outputs are: the finished wound stator pack, production information and the rejected components. This D/A centre is supported by assembly labours, machines and tools, and controlled by time constraints and design specifications.

Many types of wound pack can be produced based upon customer specifications. These specifications include number of poles, wire specifications, core length, insulation material and treatment features.

In the third phase of the GI-SIM modelling method, simulation models are constructed for the winding assembly lines. Simulation models and experiments are given in Appendix-E. Figure F-14 (Appendix-F) illustrates the simulation output for the winding assembly line of cell-160/180. There are three performance measures which are considered in this analysis, namely, utilisation, time-in-system and output rate. Figure 6.47 illustrates the utilisation of the winding assembly stations based upon a particular simulation run for cell-160/180.

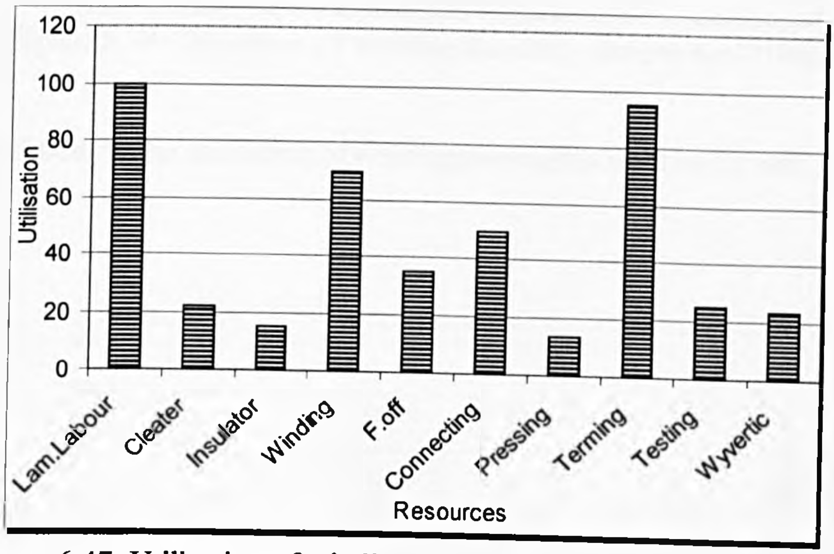


Figure 6.47. Utilisation of windings assembly stations (cell-160/180)

Figures 6.48 illustrates jobs time-in-system and production rate for this assembly line using simulation statistics results.

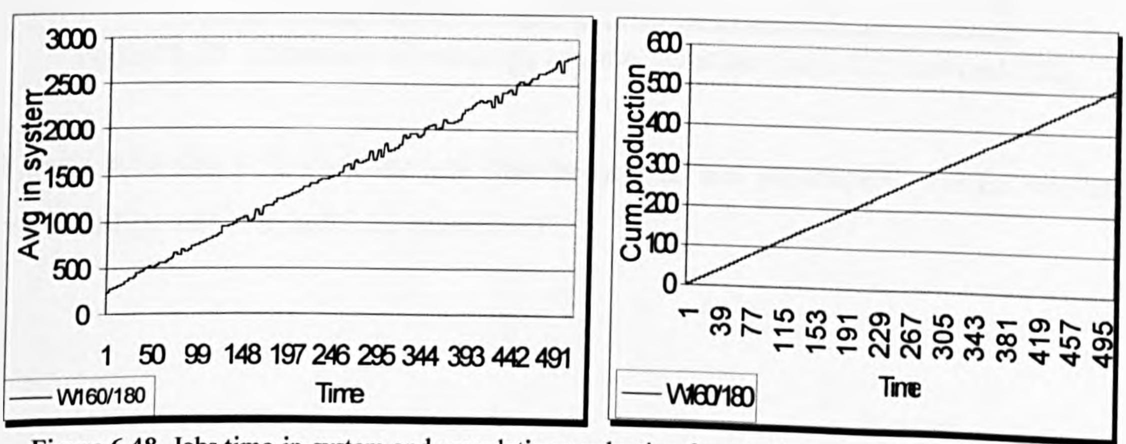


Figure 6.48. Jobs time-in-system and cumulative production for windings assembly (cell-160/180).

Figure F-15 (Appendix-F) illustrates the summary report for winding assembly (cell-100). This report is the output of one of the simulation runs related to this assembly line. Utilisation of this assembly line is given in Figure 6.49.

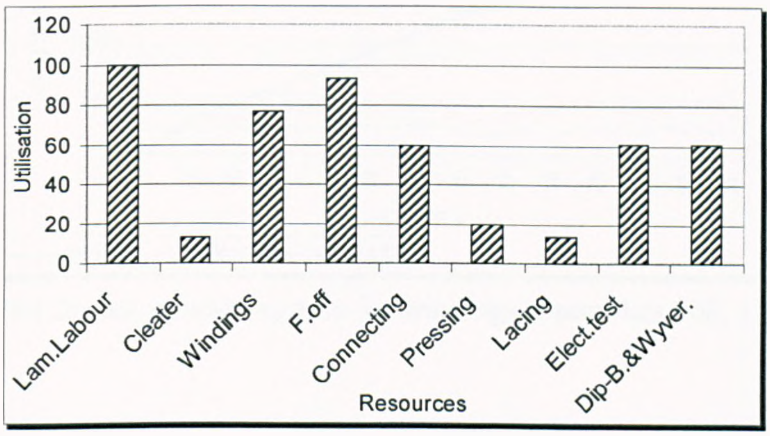


Figure 6.49. Utilisation of winding assembly stations (cell-100).

Figure 6.50 illustrates the utilisation of windings assembly stations for cell-112 and cell-132.

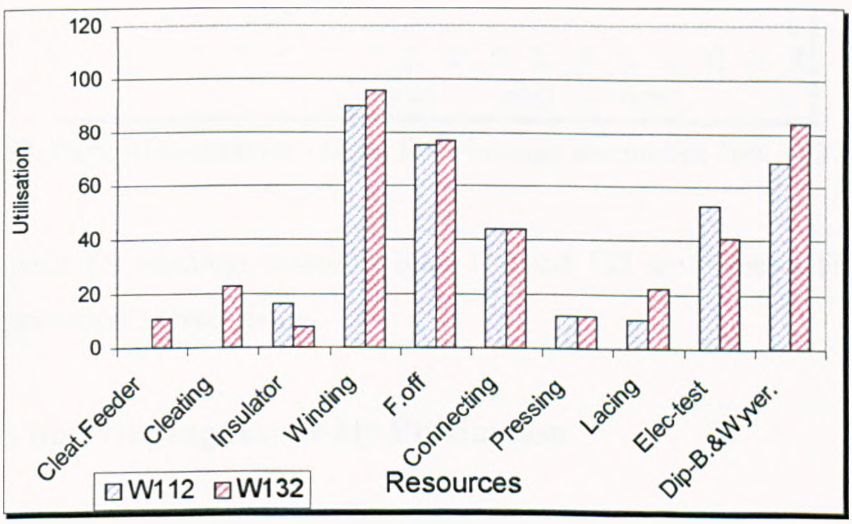


Figure 6.50. Utilisation of windings assembly stations (cell-112 and cell-132)

Figures 6.51 and 6.52 illustrate jobs time-in-systems and production rates for windings produced by cell-100, cell-112 and cell-132.

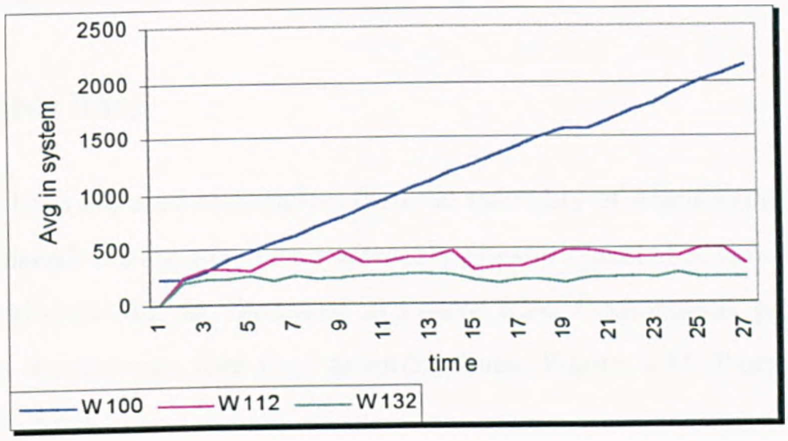


Figure 6.51. Plot for unit time-in-system for windings assemblies 100, 112 and 132.

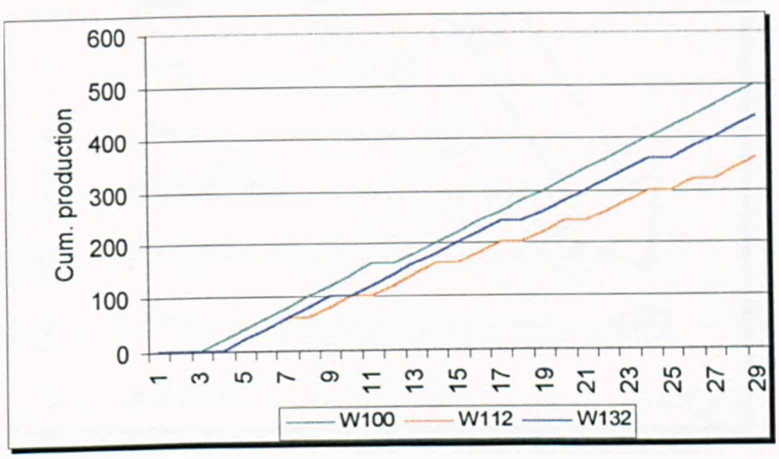


Figure 6.52. Plots of cumulative output for windings assemblies 100, 112 and 132.

Summary reports for windings assembly lines 112 and 132 are given in Figures F-16 and F-17 (Appendix-F) respectively.

Comments on Winding Assembly Production

Winding assembly lines receive a wide variety of customer specifications. Therefore, production planning and scheduling is very complex. The analysis indicates several points on the assembly of motor windings. These include low utilisation, high WIP and difficulties of scheduling. It has been found that although there are bottlenecks in these assembly lines. The bottleneck problem is moving from one station to another in the assembly line. This problem arises from the many changeovers and from stations that are not fully utilised. Another problem for these assembly lines is related to handling systems. Material handling systems of the winding assemblies are conveyor systems which have failed segments in many locations. This problem increases WIP levels, lead time and decreases utilisation and production rates.

Final Assembly lines

Four assembly lines are used to complete the final assembly of Aluminium motors at the Huddersfield manufacturing site. These assembly lines are located in cell-100, cell-112, cell-132 and cell-160/180, as illustrated in Figure 6.34. Components production and sub-assemblies departments feed final assembly lines. Figure 6.53 illustrates the final motor assembly chart.

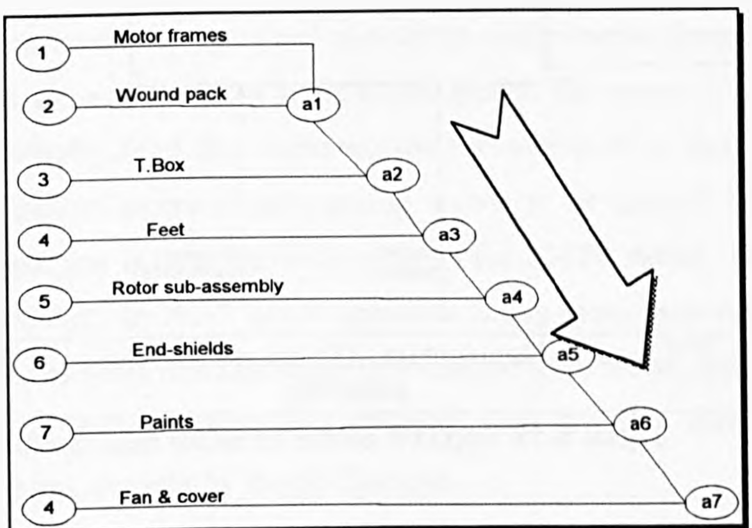


Figure 6.53. Assembly chart for motor final assembly.

Appendix-D gives more details of the assembly cells and their layout. To start the second phase of analysis for this activity centre, the basic sub-activities should be identified. Final assembly sub-activities are slightly different from one cell to another. In general, Figure 6.54 shows the child-activities of a final assembly D/A centre.

To complete final assembly

- To assemble frame & Wound pack
- To perform machining operations
- To combine T.box & feet
- To fit rotors & motor ends
- To perform elect. test
- To perform painting operations
- To assemble fan and cover

Figure 6.54. Sub-activities of motor final assembly.

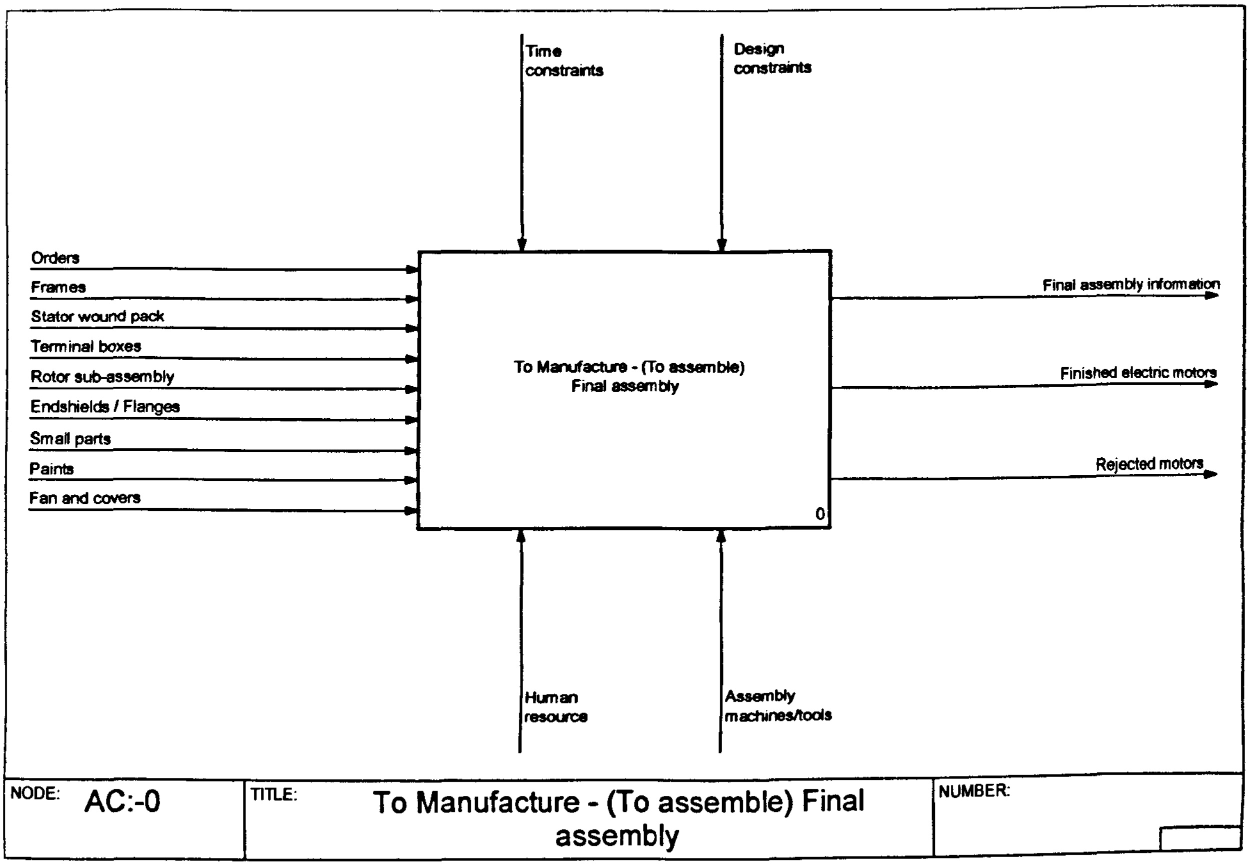


Figure 6.55. Top D/A centre for motor final assembly.

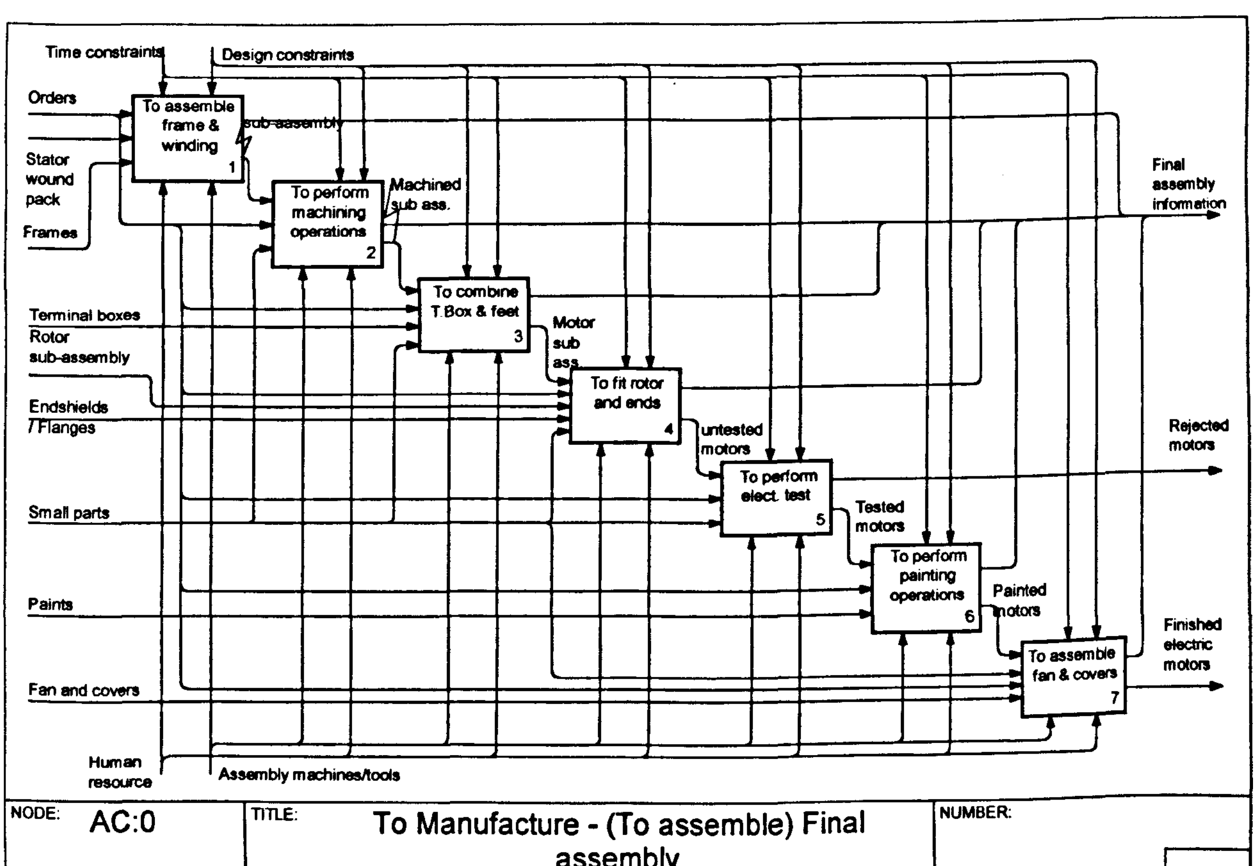


Figure 6.56. Sub-activities of final assembly D/A centre.

The IDEF0 model for final assembly is constructed using D/A centre sub-activities, as shown in Figures 6.55 and 6.56. Motor final assembly D/A centres receives decisions, information and material from other D/A centres, as illustrated in GI-SIM Figure 6.1. Production planning and control of final assembly launch assembly operations are based upon MRP orders after changing their priorities. Sub-activity-AC-1 is the first child-activity in this production line. It represents fitting stator wound packs into motor frames. Hence, it is fed by windings from the windings assembly line and motor frames from the die-casting department. The output of this D/A centre is the input for the subsequent sub-activity-AC-2 (machining operations). Following this, sub-activity-AC-3 represents combining terminal boxes and motor feet. Then, the sub-assembly is moved to another process for fitting rotors and end-shields and/or motor flanges. This process is represented by sub-activity AC-4 in the IDEF0 model. The output of this sub-activity is used by sub-activity AC-5 that represents the performing of an electrical test. After this operation, motors access to the painting station to be painted with appropriate colours. This operation is represented by AC-6 in the IDEF0 model. This sub-activity feeds the final sub-activity AC-7 which represents fitting motor fans and covers. These operations of the assembly line feed other D/A centres in the model such as motor stock and delivery D/A centres. Information obtained from this D/A centre is linked to relevant D/A centres, as given by the GI-SIM grid.

The third phase of modelling is to construct dynamic models for the motor assembly lines. Simulation modelling for electric motors final assemblies is divided into four models according to current assembly lines. SIMAN models and experiments are given in Appendix-E. Simulation modelling is implemented for one week. Figures F-18 to F-21 (Appendix-F) illustrate summary reports for final assembly lines of cell-100, cell-112, cell-132 and cell-160/180 respectively. The assembly line of cell-160/180 involves both aluminium and cast Iron motors. Most of the assembly operations depend upon human resources, hence, it would be very difficult to measure system performance. Triangular distribution is used for time estimated of assembly stations. This distribution returns a value between Min and Max with the values tending to be centred around Mode (most likely value). The triangular distribution is used because the exact form of the distribution is not known. In addition, this distribution is easier to use and explain.

Activities of final assembly lines are analysed in terms of various performance measures. Figure 6.57 illustrates the utilisation of assembly line stations for each motor type.

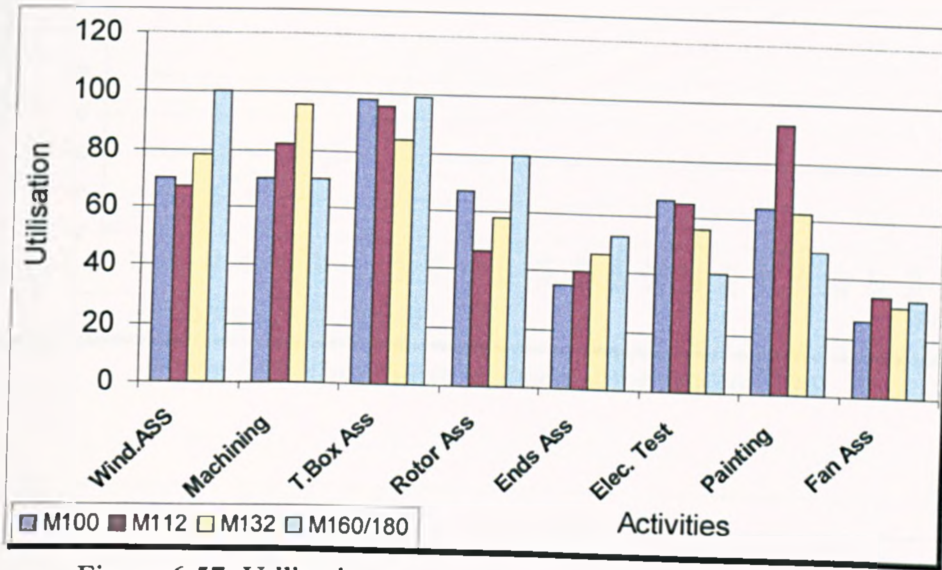


Figure 6.57. Utilisation analysis of motor final assembly lines.

Other statistical measures have been observed during the simulation run including production rate and cumulative time-in-system for all assembly lines. Figures 6.58 and 6.59 show cumulative production through five days of production for cells-100-112-132 and cell-160/180 respectively. Figures 6.60 and 6.61 illustrate the job time-in-system for all four assembly lines.

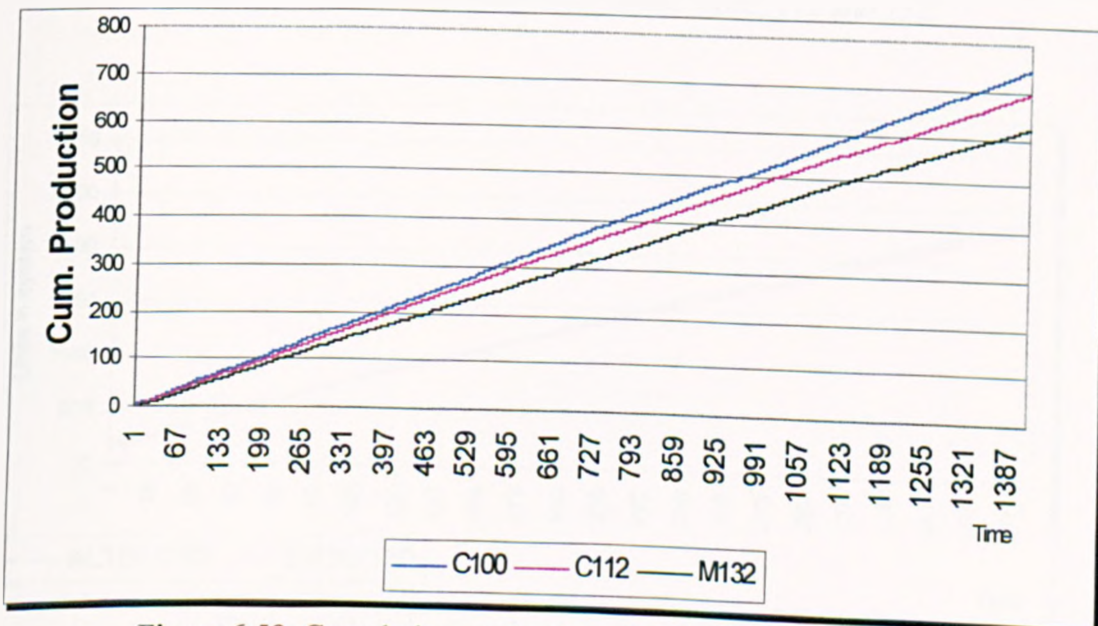


Figure 6.58. Cumulative production of cell-100, 112 and 132.

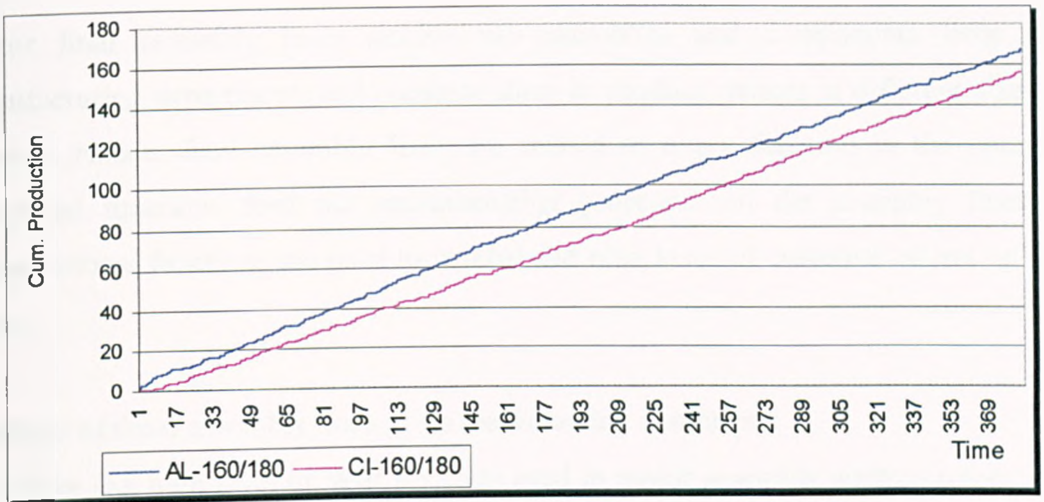


Figure 6.59. Cumulative production for cell-160/180.

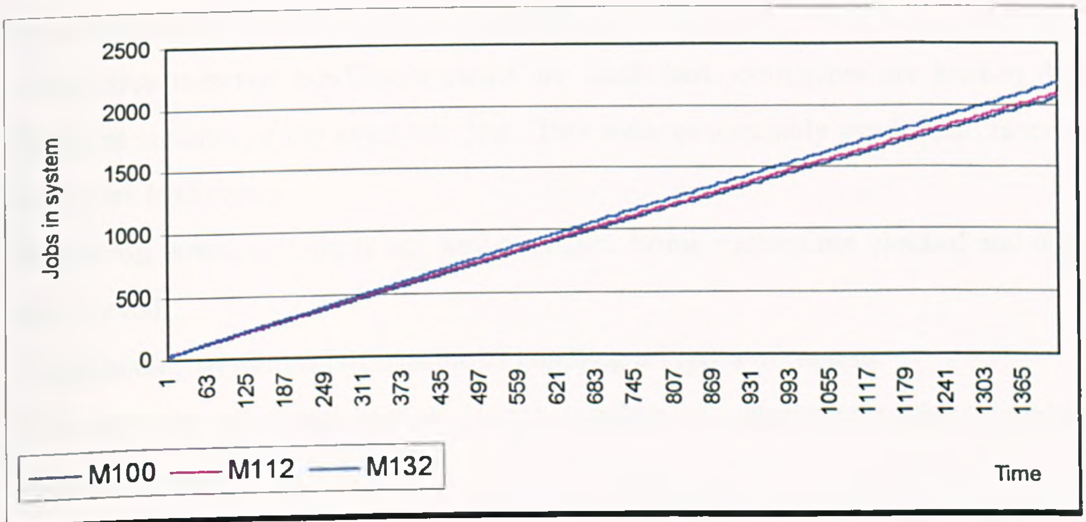


Figure 6.60. Jobs time-in-system for cells-100, 112 and 132.

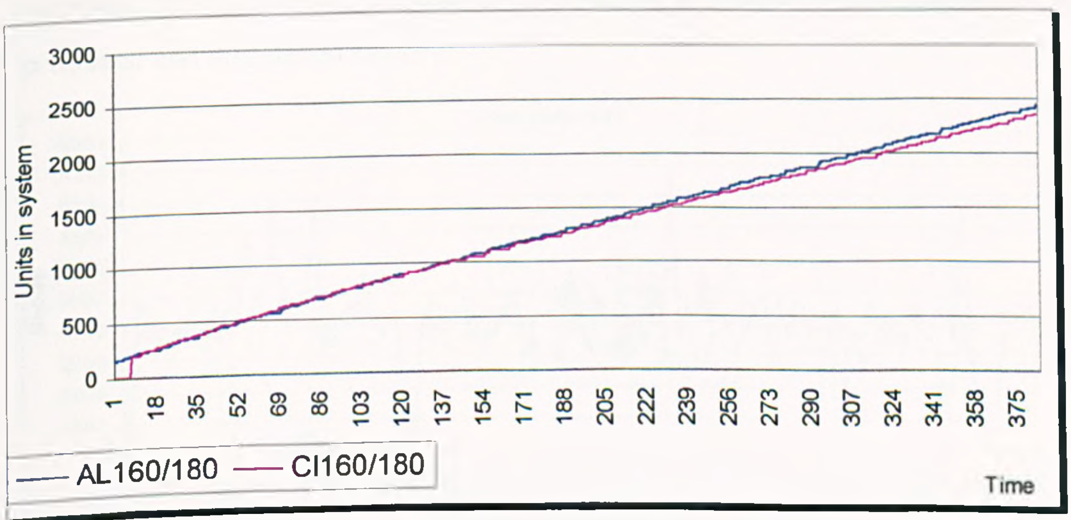


Figure 6.61. Jobs time-in-system for cell-160/180.

Comments on Motor Final Assembly Lines

Motor final assembly lines receive sub-assemblies and components from other manufacturing departments and combine them to produce motors in different sizes and powers. Hence, final assembly lines are related to every function in the company. Technical functions feed the manufacturing processes on the assembly lines and organisational functions are used to control and plan loads of customer orders on these lines.

Analysis of these assembly lines gives the following comments:

- There is a high level of WIP for parts used in motor assembly such as rotors, ends, flanges, terminal boxes, frames and stator wound packs.
- There is a low utilisation of assembly stations because of the high number of set-ups, bottlenecks and variations of order sizes.
- Ineffective material handling systems are used. Role conveyors are broken down between stations of the assembly line. This reduces assembly production rates and increases lead times.
- Balancing assembly lines is not well managed. Some stations are blocked and others are starved.
- The planning system is not capable of handling all types of motors.
- The assembly planning system is not capable of supporting various levels of capacity planning.
- The rate of rejected motors is high. Electric test sometimes fails all motors. This effects customer orders and planned production. Figure 6.62 illustrates motor intake numbers, production and despatch. It is evident that there are variations between produced and dispatched motors.

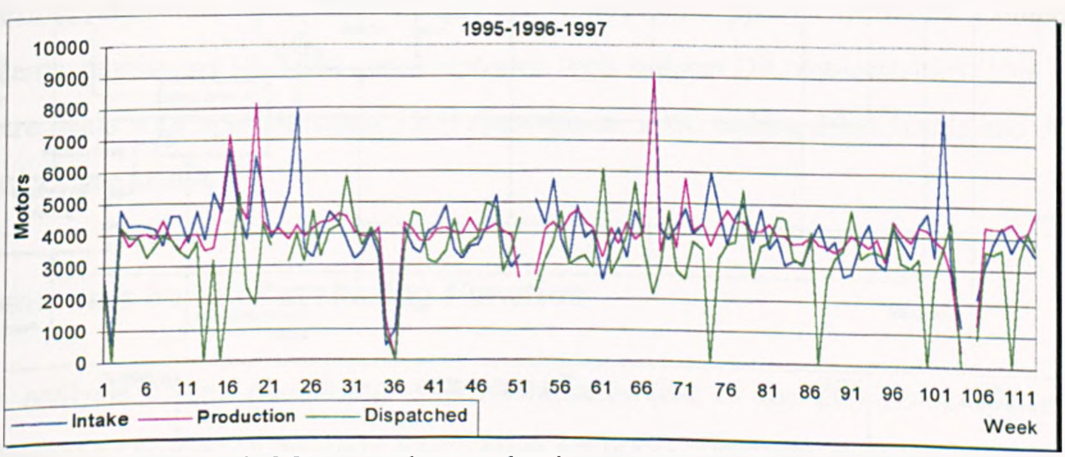


Figure 6.62. Motors order, production and dispatching variations.

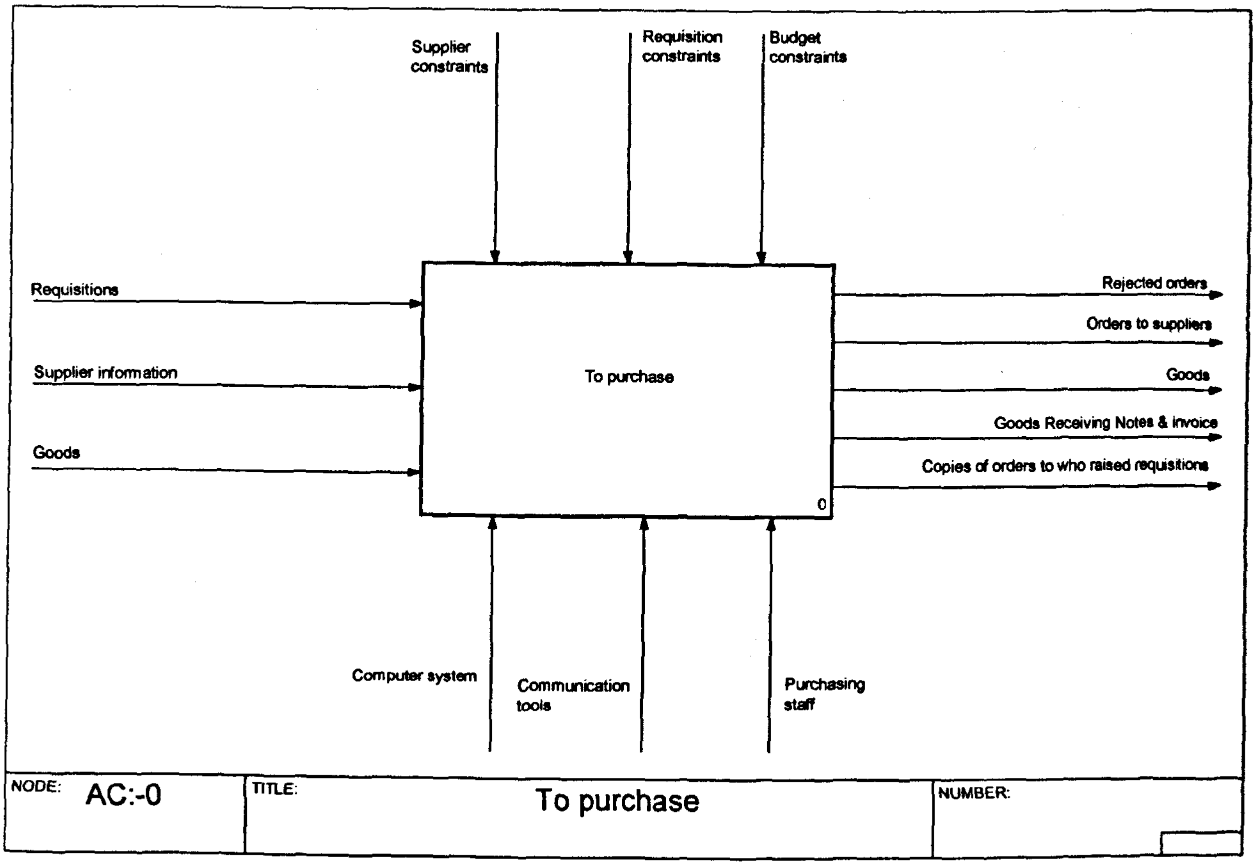


Figure 6.64. Top function of purchase D/A centre.

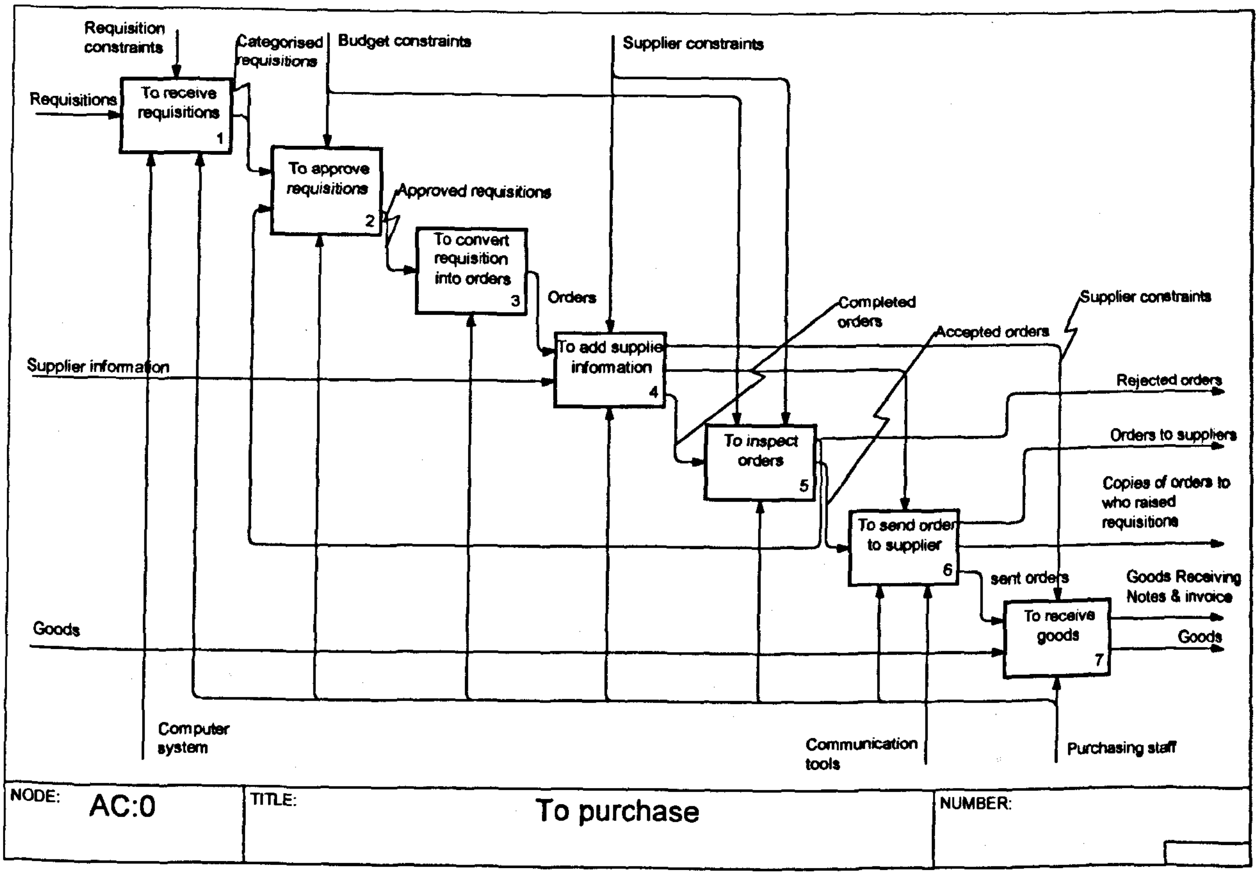


Figure 6.65. Sub-activities of purchase A/D centre.

To Purchase

This function involves two main D/A centres 'purchase orders' and 'common production parts'. The first D/A centre (purchase orders) has planning horizon for one week and review period for one day, when the 'common parts' D/A centre has horizon for one day and real time period, as illustrated in Figure 6.2.

The second step in D/A centre analysis is construct models for functions being considered. Constructing IDEF0 model for this D/A centre requires identification of basic activities related to purchasing operations. These activities are presented in Figure 6.63.

To purchase
- To receive requisitions
- To approve requisitions
- To convert requisition into orders
- To add supplier information
- To inspect orders
- To send orders to supplier
- To receive goods

Figure 6.63. Sub-activities of purchasing D/A centre.

Figures 6.64 and 6.65 illustrate IDEF0 model for the purchase D/A centre. This D/A centre receives three main inputs, namely, requisitions, supplier information and goods. The outputs are rejected orders, orders to suppliers, copies of orders to who raised orders, good receiving notes (GRN), invoices and goods. These outputs are the result of interacting sub-activities of purchasing D/A centre. The models illustrate three types of controls: requisition constraints, budget constraints and supplier constraints. Computer systems, purchasing staff and communication tools support D/C sub-activities. This D/A centre deals with approximately 1500 requisitions, 2000 orders, 3000 GRNs and 3000 invoices per month.

Comments on the Purchasing Function

The analysis of the purchasing activity indicates that of the purchasing system is incapable of producing accurate information on prices, products, suppliers and orders

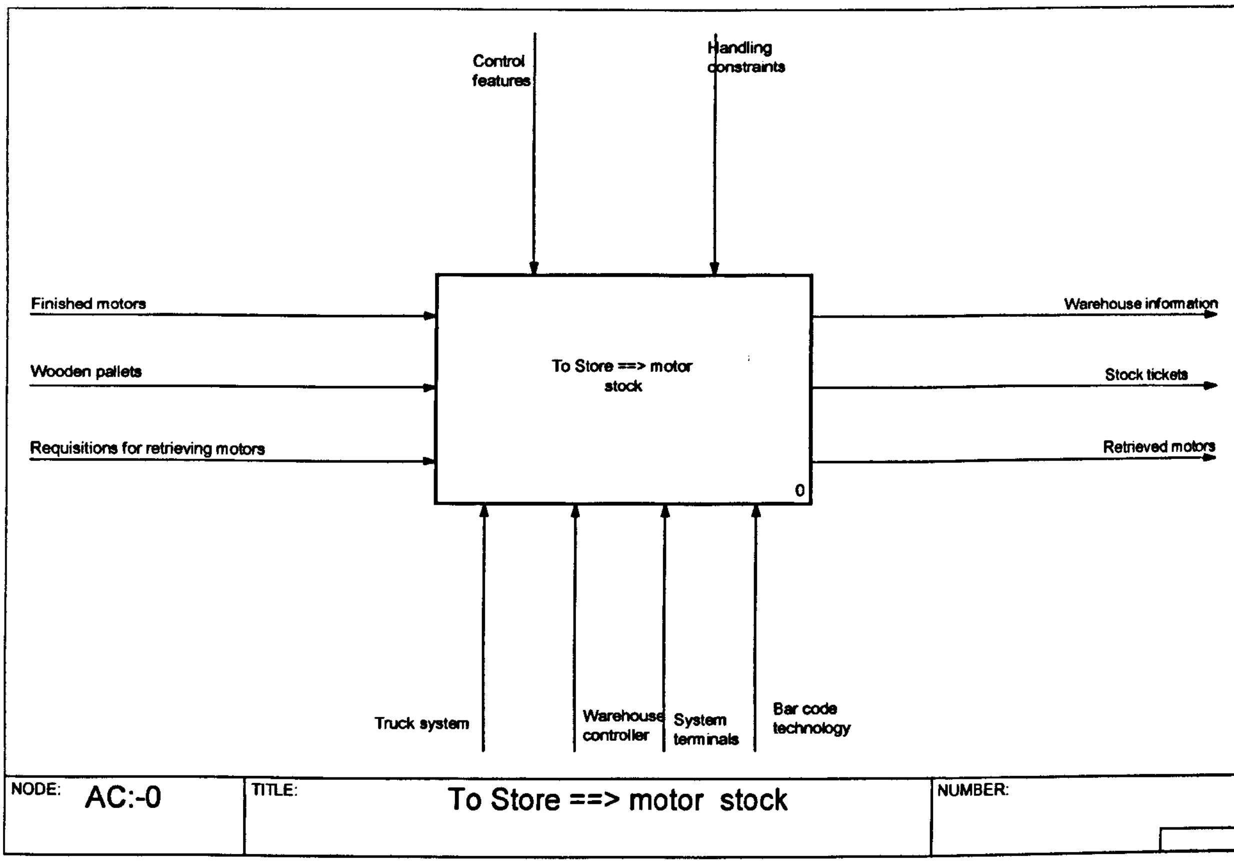


Figure 6.66. Top function of motor stock D/A centre.

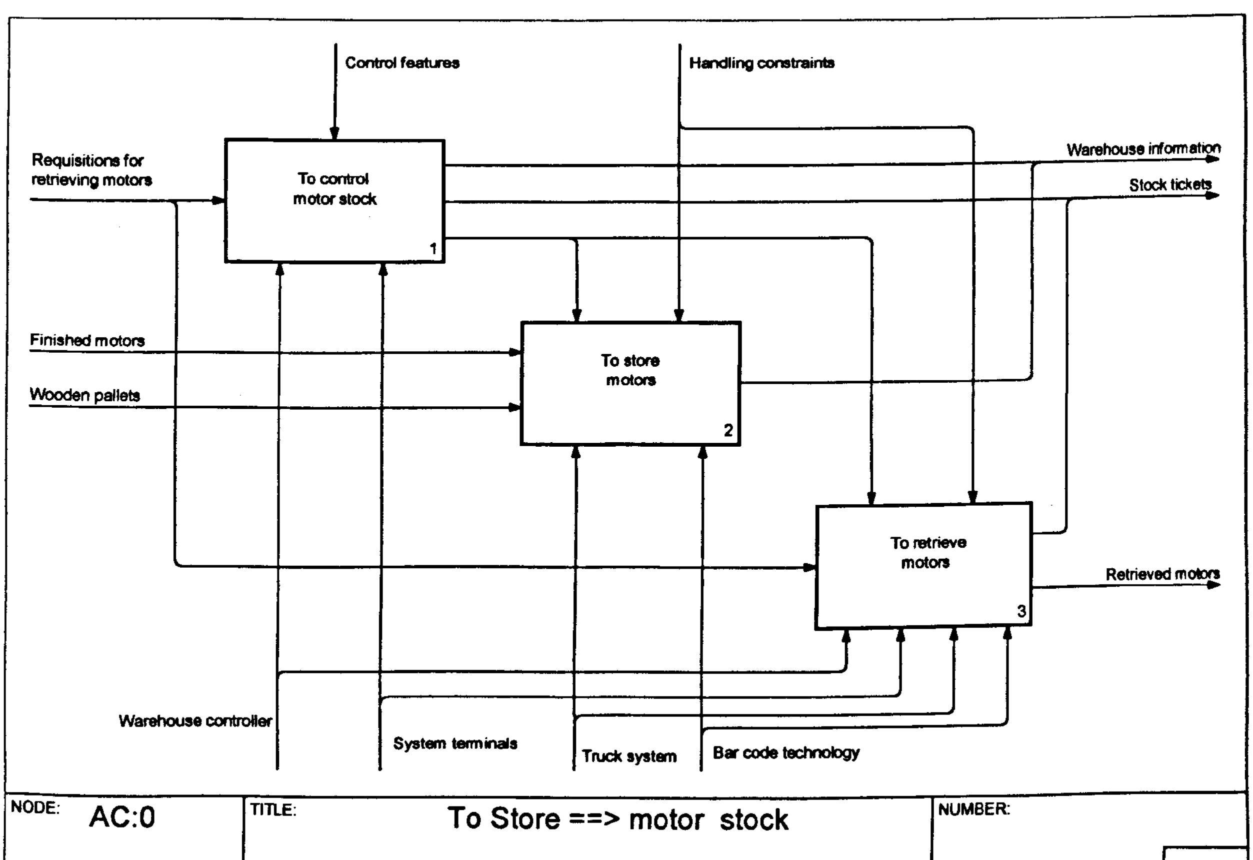


Figure 6.67. Child-activities of motor stock D.A centre.

across all sites to increase purchasing performance. Absence of integration with manufacturing systems and other related systems is another major problem for this D/A centre. The integration with other related systems also allows purchasing to provide a better stock management. The current purchasing system is also incapable of categorising requisitions based upon motor orders or sizes. This also creates problems in sorting approved requisitions by product groups or suppliers.

'To Store' Function

'To store' function involves one D/A centre (motor stock), as given by GI-SIM grid in Figure 6.1. Describing this D/A centre requires the identification of function sub-activities. Motor stock D/A centre can be decomposed into three sub-activities:

- To control warehouse.
- To stock motors.
- To retrieve motors.

Figures 6.66 an 6.67 illustrate functional model of motor stock D/A centre. Sub-activity AC-1 controls sub-activities AC-2 and AC-3. Storing motor operations are represented by sub-activity AC-2 in the model. The retrieving operations are represented by sub-activity AC-3 in the model. These sub-activities are related to each other in terms of inputs and controls. The inputs of the model are finished motors, pallets and requisition for retrieving motors. The outputs are stock tickets, warehouse information and retrieved motors. The model illustrates two types of controls (stock control features and picking rules) and mechanisms (human resource, bar code technology, truck systems, and system terminals).

Comments on 'To Sore' Function

The analysis of the 'To Store' function indicates several comments including:

- The motor stock system lacks the integration with other manufacturing system functions such as production systems.
- The conventional methods of classification are used in stock system. Hence, picking restriction exists because of different weights and sizes of motors.
- Shortages problems.

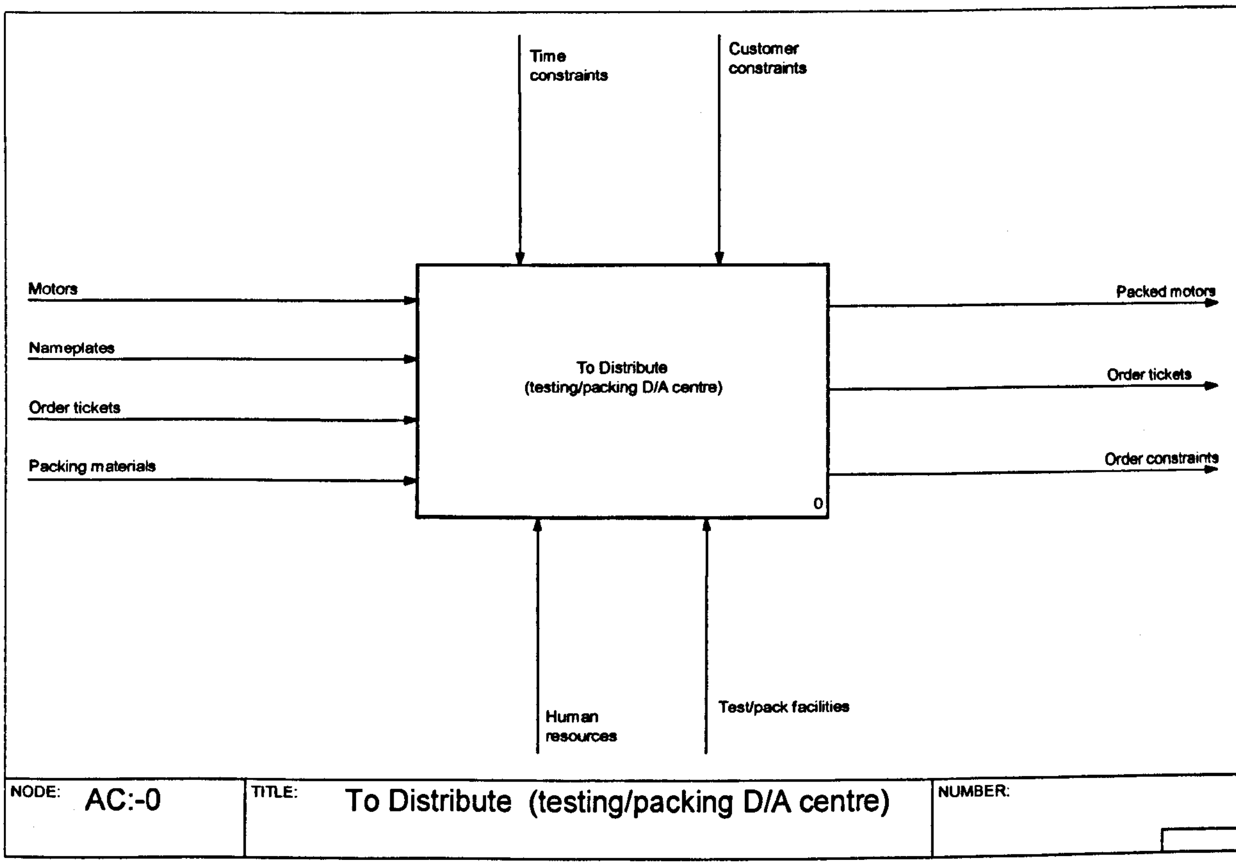


Figure 6.69. Testing/Packing D/A centre.

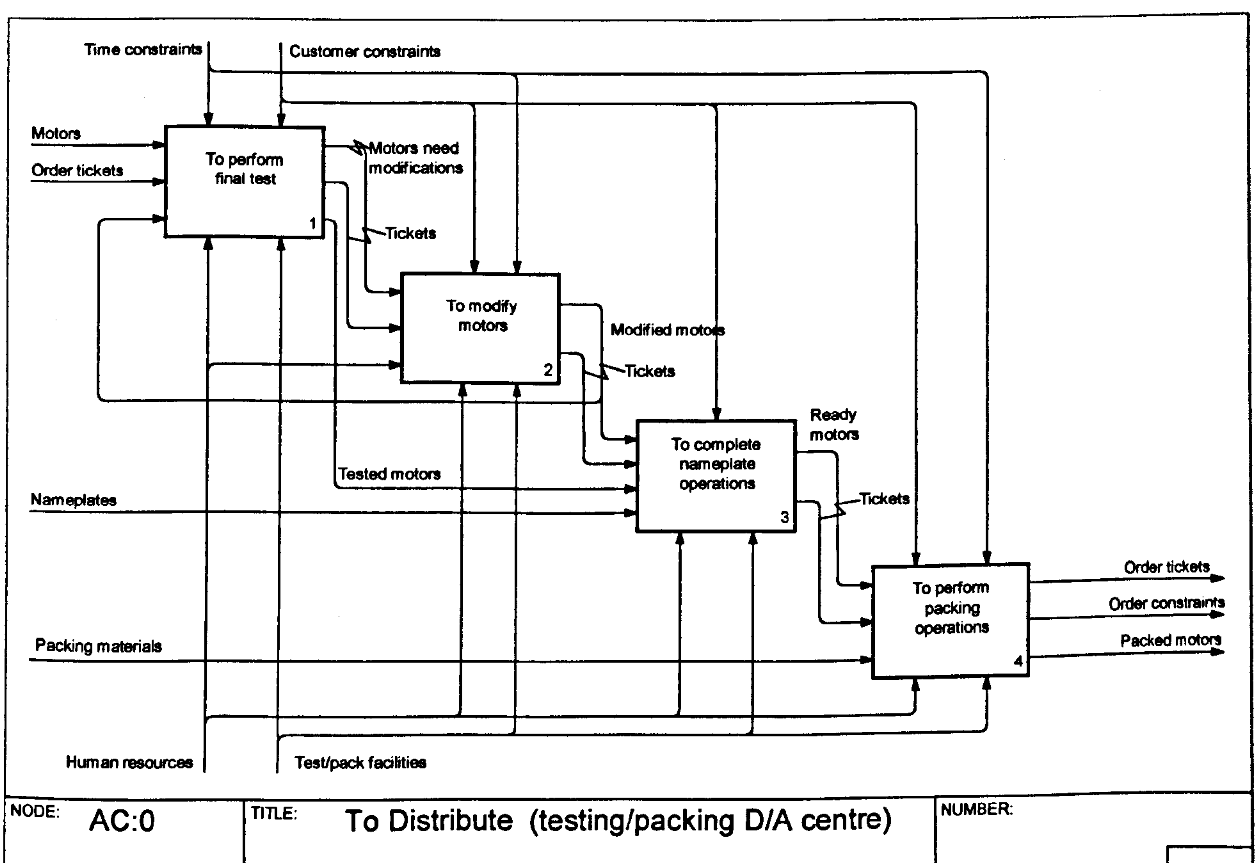


Figure 6.70. Sub-activities of testing/packing D/A centre.

- The current system is incapable of calculating the best picking route for the truck, being in mind the aisle the truck currently occupies.
- No sequencing rules are employed for retrieving motors such as FIFO.
- Control of pallets is not considered. This causes shortages in pallets.
- Updating despatching details should be started from stock system when order is retrieved from stock.
- Information of stock orders is not well maintained to be used in forecasting and future company plans.

To Distribute

The 'To Distribute' function involves two D/A centres testing/packing and delivery. The first D/A centres have planning horizon for one week and a review period for one day, when the second has a planning horizon for one day and a real time review period.

To complete the second phase of analysis for this function, it is necessary to identify basic sub-activities of these D/C centres. Figure 6.68 illustrates a decomposition of the 'To Distribute' function.

- To distribute
  - To test/pack
    - To perform final test
    - To modify motors
    - To complete nameplate operations
    - To perform packing operations
  - To Deliver
    - To control motor delivery
    - To prepare motor delivery
    - To update system information
    - To deliver customer orders

Figure 6.68. Basic sub-function of 'To Distribute' function.

Figures 6.69 and 6.70 illustrate the IDEF0 model for the testing/packing D/A centre. The model illustrates functional sequence of this D/A centre. Sub-activity AC-1

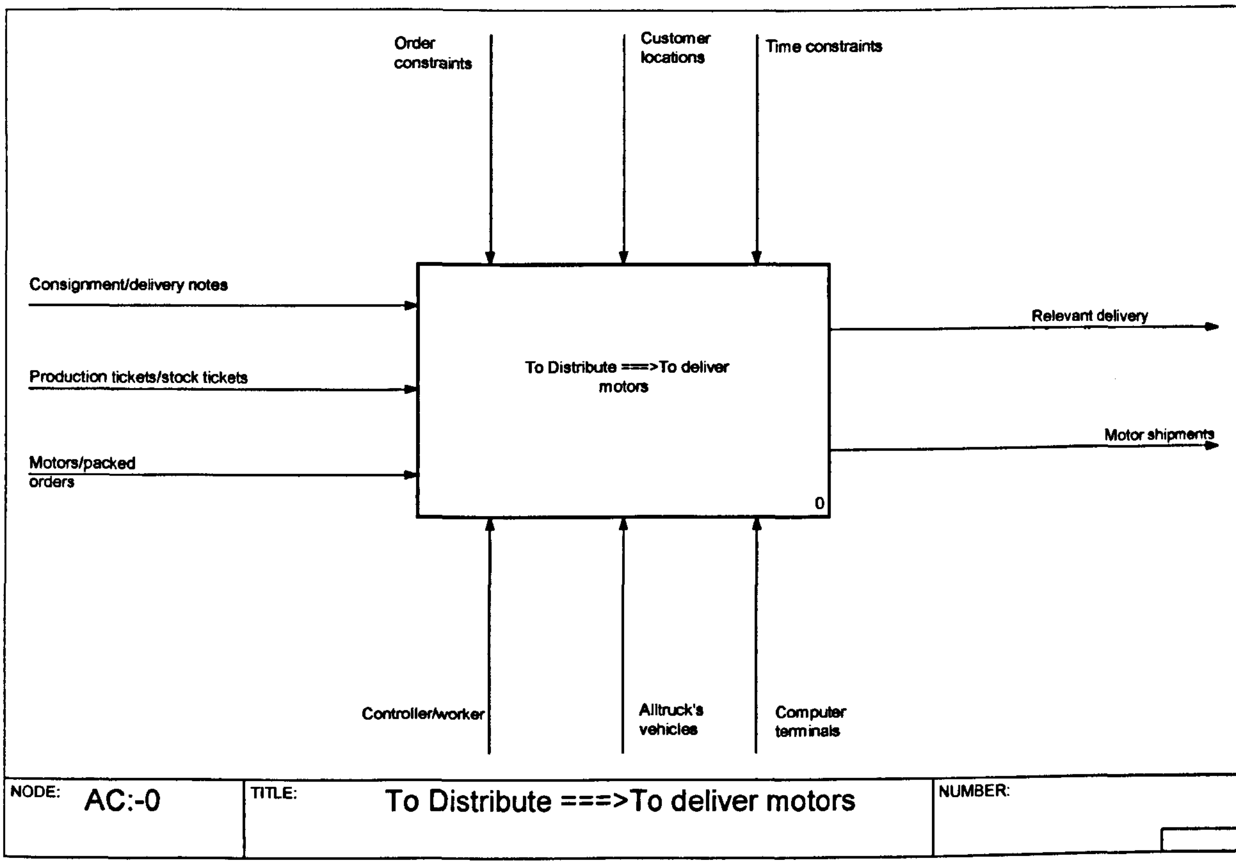


Figure 6.71. Delivery D/A centre.

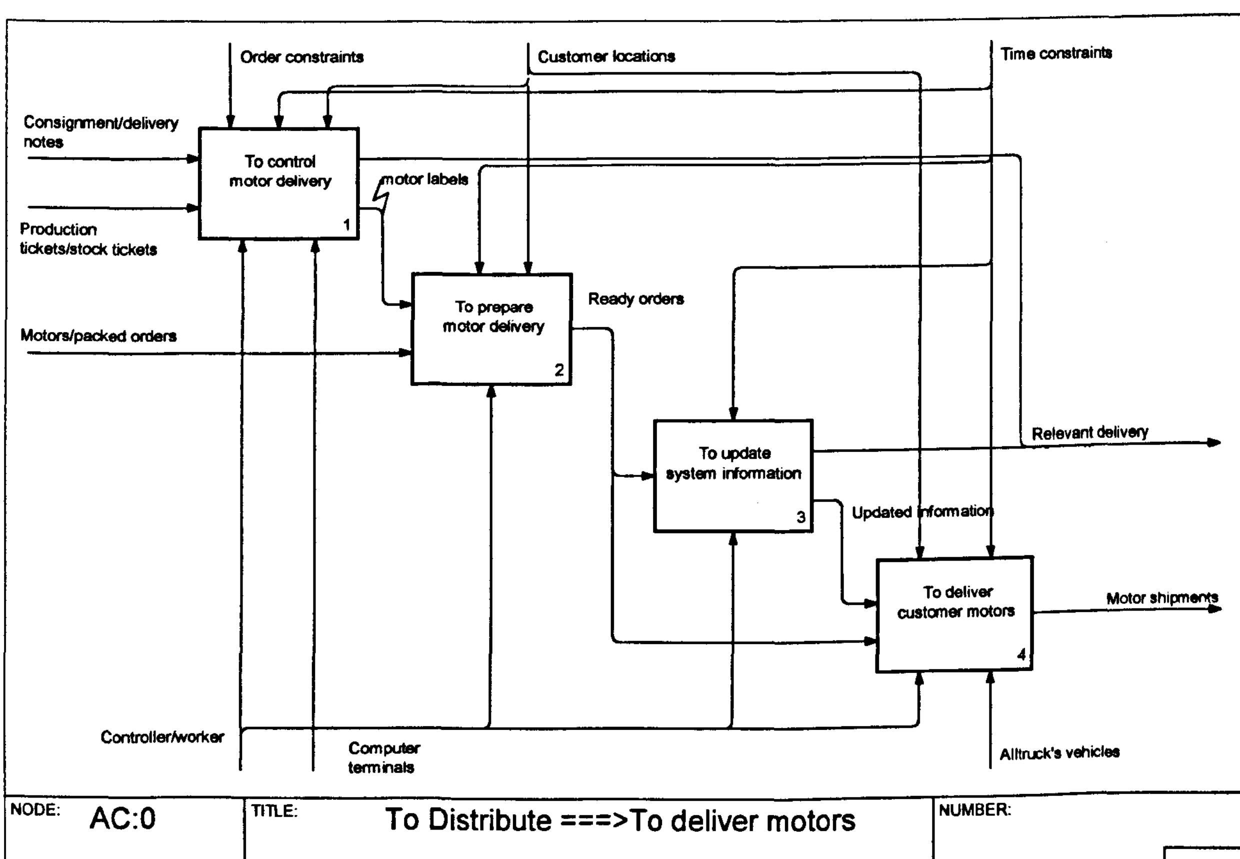


Figure 6.72. Sub-activities of deliver D/A centre.

represents final test operations which are carried out before delivery of motors. This sub-activity is followed by sub-activity AC-2 which represents modification operations. Some motors require testing after completing modifications. Hence, one output of sub-activity AC-2 is used by sub-activity AC-1. Following this, nameplate fitting operation is represented by sub-activity AC-3. Finally, sub-activity AC-4 represents packing operations for electric motors. In general, operations of testing/packing D/A centre are controlled by time and customer constraints, and supported by human resources and testing/packing facilities. The inputs used in this model are finished motors, nameplates, order tickets and packing materials. Outputs are packed motors, order tickets and order constraints.

Figures 6.71 and 6.72 show the IDEF0 model for the delivery D/A centre. The model represents delivery operations using four sub-activities. Controlling of delivery operations is represented by sub-activity AC-1; preparing delivery operations are modelled by sub-activity AC-2; operations of updating system are emulated by sub-activity AC-3; and final delivery operations are represented by sub-activity AC-4. Outputs of this D/A centre are the delivery information and motor shipments. The inputs are consignment/deliver notes, production tickets and motors. The main constraints of these tasks are customer locations and order constraints. The model illustrates three types of mechanisms (controller/operators, computer terminals and delivery vehicles).

Comments on 'To Distribute' Function

The 'To Distribute' function represents the connection point between the physical output of the manufacturing systems and customers. This study provides several points related to this function including:

- Systems used by this function cannot differentiate between customer orders for different packing methods. Neither can they identify customer packing method requirements.
- Complexities of controlling motor pallets.
- Problems of scheduling deliveries.
- Different customer requirements for packing methods and materials.
- Problems of different weights and dimensions of motors.
- Lack of proper integration with other manufacturing functions increases lead times of sub-activities of these functions.

6.4. An Evaluation of GI-SIM for The Analysis of Manufacturing Systems

In this chapter the manufacturing systems of Brook Hansen Motors have been analysed using the modelling method developed in this research (chapter-5). Through the use of GI-SIM in a major study undertaken in a large manufacturing company, it can be seen that the method is an effective analysis tool for examining and modelling complex manufacturing systems.

The research clearly demonstrates that GI-SIM provides supporting tools and procedures to support systems analysis. Its main contribution is its ability to provide an excellent vertical and horizontal integration. A vertical integration links levels of abstractions and a horizontal integration links modelling domains. These domains are configured based upon systems specifications and modelling objectives.

The GRAI method or IDEF0 cannot model adequately other aspects in the manufacturing environment because of their limited modelling structure. Figure 6.73 illustrates the GI-SIM method comparing it with the scope of GRAI and IDEF0.

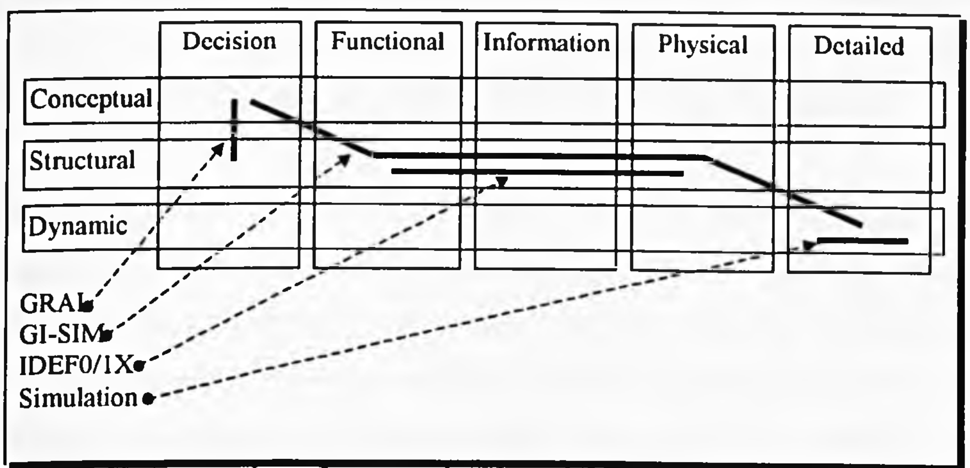


Figure 6.73. Integration of systems levels and domains in modelling methods.

In this research, interviews, observations and questionnaires were used to produce the detailed specifications of the existing systems. The method presents the global view of operational manufacturing systems using its grid showing the main functions of manufacturing. This step considers the time scales and different D/A centres derived from the basic functions of the company. Thirteen D/A centres are considered and modelled using suitable GI-SIM tools. These investigate the basic elements and child-activities of each centre using a top-down analysis approach. Simulation tool is used for physical D/A centres to obtain performance measures for dynamic aspects of the manufacturing system. Figure 6.74 illustrates the modelling objectives for various D/A centres considered.

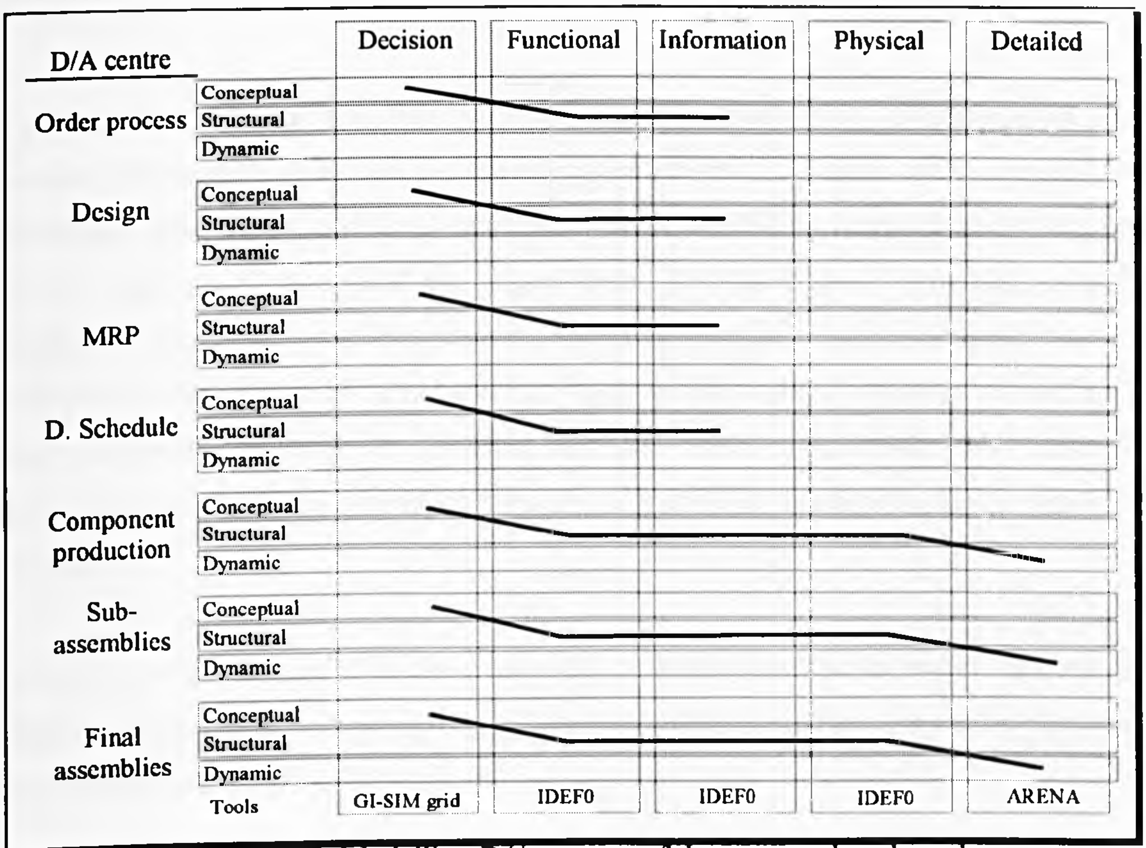


Figure 6.74. Modelling D/A centres of the case study selected.

The analysis objective for every D/A centre should be clear to provide relevant modelling results. The method used has formal guidelines for its three phases. It is simple to implement, as demonstrated in this study. The use of this method enables models to be understood by people at all levels of the organisation. The D/A centres are modelled and summarised in a common format. This gives solid ground for the next phase of the modelling studies which are design and implementation.

6.5. Discussion and Conclusion

This study was carried out to validate the modelling method developed and to identify the sources of complexities and the origins of the problems in the company selected. Manufacturing systems functions have been identified based upon operational concepts and sub-system flows through company facilities. This identification of operational functions is used to explore the basic elements and sub-activities related to every decision/activity centre. Most of the decision making problems should not refer to the decision flow or time aspects found in the top level of modelling, because these problems are related to one or more of the child-activities belonging to that decision centre.

Testing GI-SIM has proved that the flexibility and inconsistency of static modelling methods has a direct effect on the quality of the analysis. Dynamic systems cannot be measured using static modelling techniques. Static modelling methods have achieved good results in understanding organisation structures and providing simple representations of systems activities, but analysing dynamic aspects of these activities presents a clear picture of manufacturing function behaviour. Simulation modelling is very important for analysing physical systems. There is no doubt that statistical measures obtained from simulation models are helpful in developing decision-making procedures.

It can be concluded that GI-SIM is a powerful modelling method for system analysis. It supports most aspects of manufacturing systems and has a wide range of applications for detailed system analysis.

The analysis of manufacturing systems of Brook Hansen Motors offers some important findings on every manufacturing function. The following points summarise the main findings of this study:

- It was noted during the study that some departments were independent in their decisions, information and tasks (see GI-SIM grid-Figure 6.1). This independence caused several problems for system analysis studies and dispossessed roles and data of some important manufacturing functions (such as production planning function) in the other functions, as demonstrated by structural models.
- Lack of integration between system functions makes information systems very complex and useless in several D/A centres such as scheduling and manufacturing.
- Using conventional methods in selecting orders and grouping parts increases lead times and reduces function utilisation.
- High levels of WIP were evident, as illustrated by GI-SIM dynamic modelling.

- Keeping traditional manufacturing methods effects accuracy, quality and increases customer lead-times, as shown in Figures of simulation results.
- Scrap rates are high especially in final motor assemblies and die-casting department, as illustrated by GI-SIM during the analysis of physical systems.
- Planning and control manufacturing operations do not depend on new sophisticated methods.
- Trend of customer orders has not changed over the last few years.
- GI-SIM grid observes inconsistencies of decision sub-system, as shown in Figure 6.1.

Brook Hansen Motors should adopt a new manufacturing strategy and sophisticated integrated systems to achieve their plans and consolidate their future.

CHAPTER-7

AN EVALUATION OF GI-SIM FOR THE DESIGN OF CIM COMPONENTS

7.1. Introduction

This chapter describes the strategic configuration based upon CIM and the role of integration in achieving business and manufacturing goals. It defines the macro structure of CIM using the GI-SIM concept. The GI-SIM modelling method is used for the design of selected CIM activities. The study is concerned with operational CIM systems which still require more research work. The main objectives of this chapter are to evaluate and demonstrate the modelling method developed (GI-SIM) for the design of complex manufacturing systems, and to give guidelines for designing the operational specifications of CIM components which are relevant to company strategy.

7.2. Design phase of CIM

CIM has been widely recognised as a manufacturing strategy which can reduce costs and lead times, and increase manufacturing flexibility and quality. The benefits of CIM are discussed in chapters 2 and 3.

The problem of designing CIM is still a subject of conflict and it is not widely considered, especially when it relates to large manufacturing organisations. Exploiting the strength of CIM in competitiveness is based upon modelling methods and implementation mechanisms which should have characteristics compatible with CIM design requirements.

In the CIM design phase, the overall structure and operations of the manufacturing organisation must be evaluated and efficiently restructured. Chapter-6 has presented the analysis phase of manufacturing systems of Brook Hansen Motors and this chapter will try to identify opportunities for modernisation and automation of the most critical environments in the manufacturing systems. Proposal will be made to restructure the existing systems to achieve organisation goals.

This design framework of the CIM strategy selected is based upon a review of organisational needs (Chapter-2), modelling method considerations (Chapters 4 and 5) and results obtained from the analysis phase (Chapter-6). The formulation of CIM should also be based upon the identification and analysis of manufacturing system requirements from which decisions, data structure and functional interact and work. These supports of the design phase should be the results of analysing system functions in depth for both static and dynamic tasks.

The design phase is based upon a bottom-up analysis approach, starting from basic components in which, simple concepts are modelled first, and more complex concepts are built (at increasing levels of abstraction) (Berio et al. 1995). This approach to design is used to take full advantage of analysis results and considers the technical and problematic details. Gunasekaran et al. (1994) reported that because of the higher investment and design complexity of CIM, it becomes essential to improve the development aspects at an early stage of design, because the performance of the system depends upon the design as well as the operation of the system being considered.

Business and manufacturing goals must be identified before adopting CIM and the competitors must be known within the global market perspective. It is also important to know how good competitors are. A business plan of manufacturing organisation should be developed using different information sources i.e. analysis results, customers, competitors, etc. to achieve business goals. These objectives which must be specific and measurable are very important to consolidate the future of the organisation. Typical examples include reduced lead times and increased system flexibility, as discussed in Chapter-2. A lack of clear objectives about several aspects of manufacturing systems leads to difficult problems in introducing new strategies. Manufacturing objectives must be derived from the overall business plan, because the business plan represents the strategic direction of the organisation and aims to achieve planned business goals (Danzyger 1990). All other low level programs such as tactical and operational programs need to be restructured and considered in terms of their functional objectives and operations, because these two programs are the key to manufacturing competitiveness to meet the planned business goals and improve manufacturing activities, as illustrated in Figure 7.1.

Therefore, manufacturing objectives are used to develop a new manufacturing strategy for different organisational aspects such as product, facility, design, information, etc. All these things contribute to the attainment of manufacturing and business objectives. The plan of this strategy is derived from the manufacturing objectives. Hence, depending on the CIM concept, the manufacturing plan can be implemented by considering and integrating new production programs and technical manufacturing activities. The production programs are related to the organisational activities such as JIT, Kanban, OPT, etc. Technical activities are more concentrated on the operational level of manufacturing systems, including design and manufacturing operations. All these activities should work together to achieve manufacturing and business goals.

In the case study, it is very clear that manufacturing flexibility would be the key to deal successfully with the uncertainty of customer orders and motor specifications. The quick response for changing and developing manufacturing environment is facilitated by incorporating production planning programs and technical functions in the manufacturing systems to achieve system flexibility.

Chapter-2 gives more details about manufacturing flexibility and its classification. To achieve these flexibility aspects in Brook Hansen Motors, several manufacturing functions including production programs and the technical aspects can be automated and integrated based upon the powerful concept of CIM. Figure 7.1 illustrates the relationships between strategies and objectives.

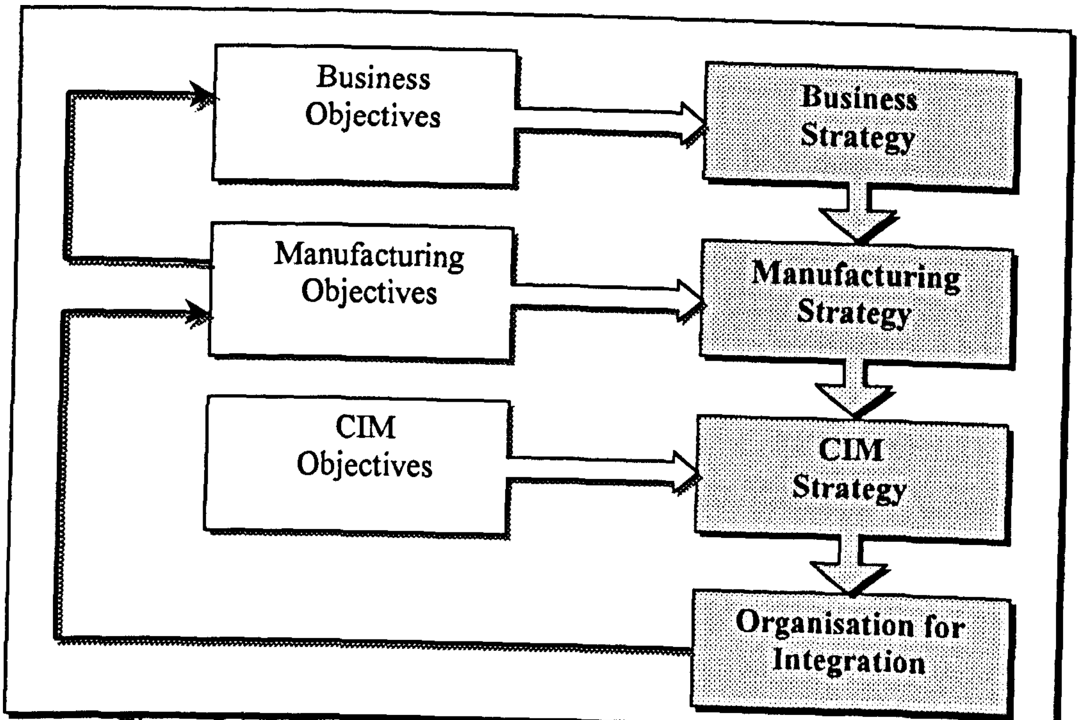


Figure 7.1. The relationships between strategies and objectives.

These objectives (business and manufacturing objectives) cannot be achieved within a day; they require to be considered and planned over time. Many questions were raised during the analysis phase when changing and developing exiting system. These questions have a direct effect on business and manufacturing objectives. In Brook Hansen several questions have been raised such as; Why are WIP levels high? Why are dispatched motors less than planned and taken in? Why is utilisation of production stations low? Why do some manufacturing operations require long and multiple set-ups? Why is capacity planning and scheduling systems not working effectively? Why are scrap rates high? Why is controlling manufacturing information systems still very difficult? etc.

Once the CIM has been selected as a manufacturing strategy for Brook Hansen Motors, the manufacturing strategy should be translated into specific strategies and subsequent activities based upon the hierarchical structure of the organisation in terms of expected decision, information, material and process flows. Specific strategies and activities are related to CIM basic regions (CAD, CAM, CAPP) (Hitomi 1996). These are considered as child-strategies which include basic elements and sub-activities that need to be tested and modelled before system implementation.

The computer activities of Brook Hansen Motors should be guided by a rather strong and well-structured CIM philosophy. Data should be processed and used in manufacturing functions in an efficient way. It should be noted that CIM strategy to Brook Hansen and any other manufacturing organisation is not a ready product, but a concept and strategy for the attainment of their organisational goals.

7.3. Macro Structure of CIM

Chapter-6 has presents a detailed analysis of Brook Hansen manufacturing systems using the GI-SIM modelling method. The analysis illustrated the strengths and weakness of existing manufacturing functions. This provides a good basis for developing some existing aspects into new components for the new manufacturing strategies which consider several alternatives for both production programs and manufacturing technologies. To design CIM as a new manufacturing strategy, the GI-SIM modelling method can be used to reconstruct and simulate strategic components and their relationships in terms of decision, information and material flows. This will give an integrated model for CIM systems and illustrate changes from traditional manufacturing to advanced manufacturing concepts. The GI-SIM method can be used to process the design phase using both top-down and bottom-up analysis (see Chapter-5). It would be most advantageous to employ this integrated modelling method, because it is a well-structured modelling method which defines all manufacturing system functions and interfaces and verifies the consistency of all decisions, information, entities and dynamic aspects. In addition, the use of GI-SIM for CIM design will also illustrate how a complex and advanced manufacturing system can be systematically modelled using the method developed. Figure 7.2 illustrates how the GI-SIM method is structured for the CIM strategy.

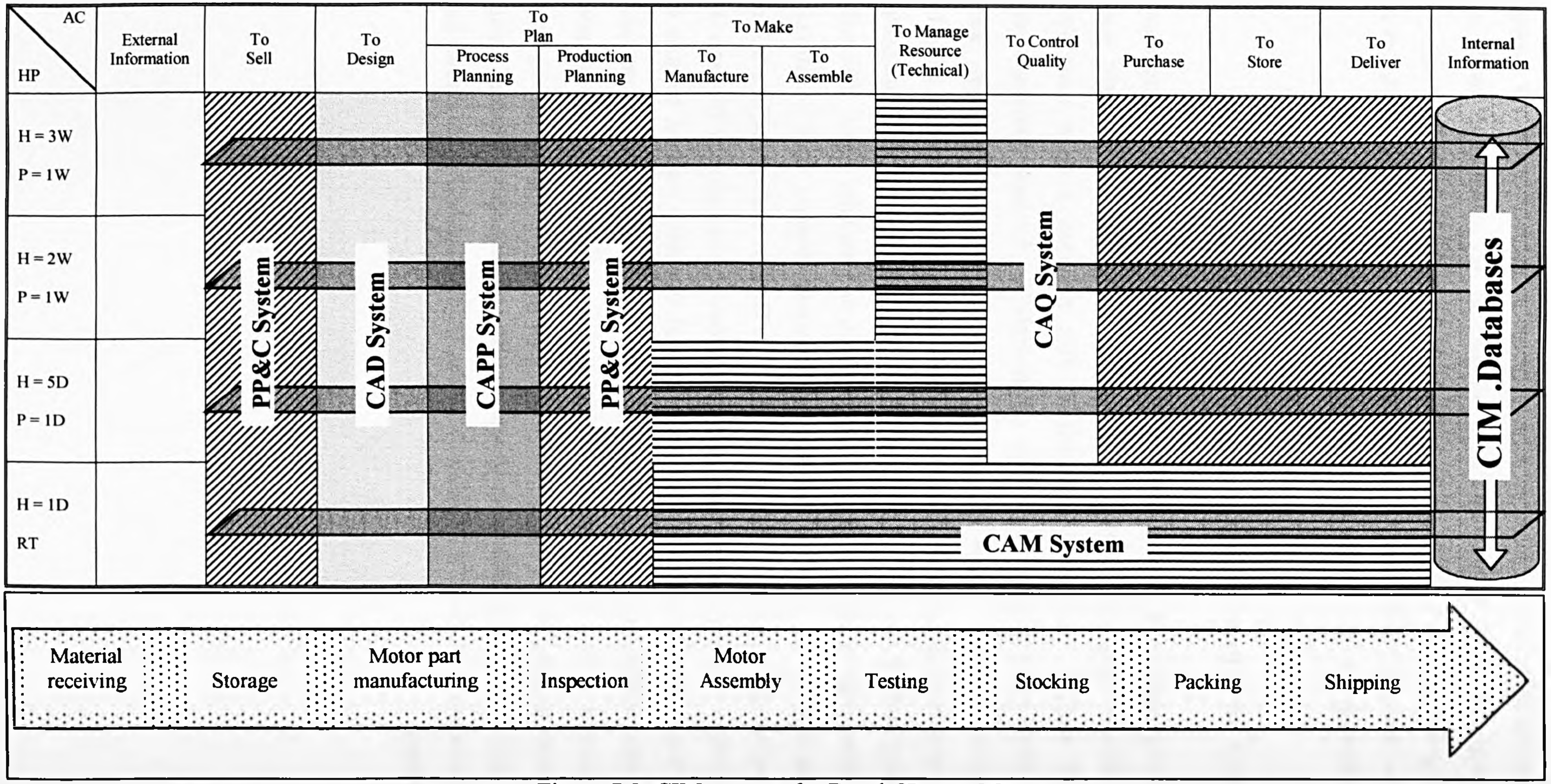


Figure 7.3. CIM concept for Brook Hansen Motors.

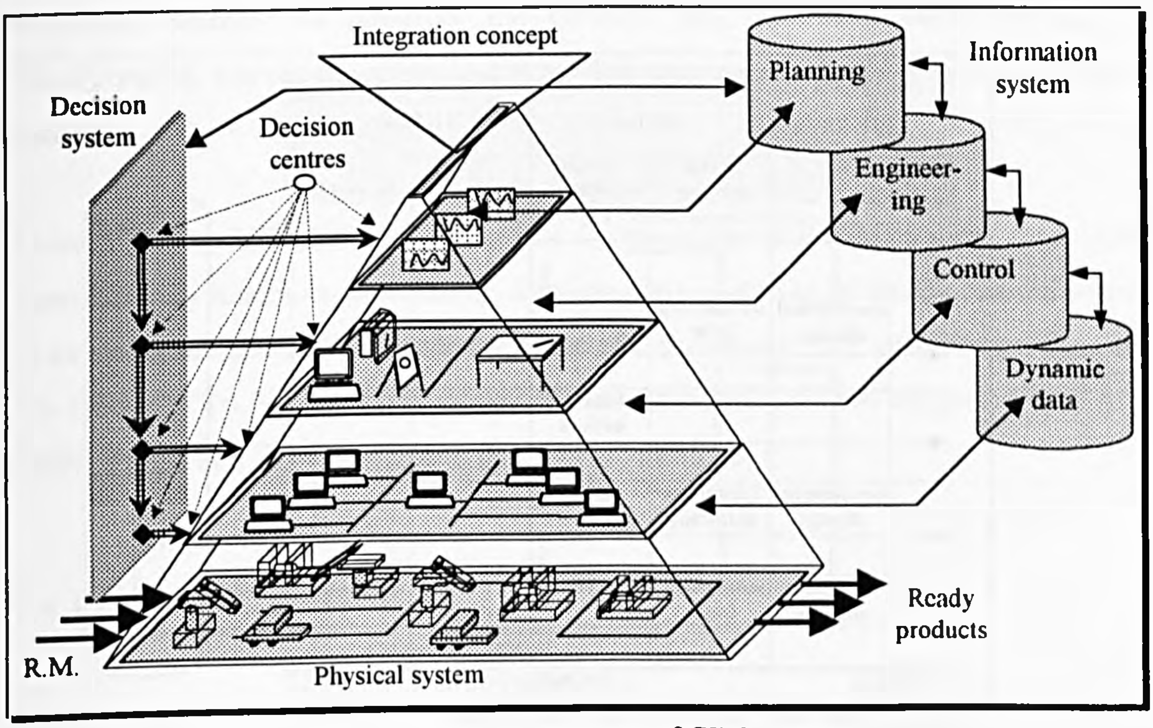


Figure 7.2. Macro structure of CIM systems.

It is necessary to understand the macro structure of CIM to gain understanding of the complex interactions between different system components and to show the necessity of using a modelling method for analysing these complex domains.

7.4. Modelling CIM at Brook Hansen Motors

In the modelling of CIM, static models (at conceptual and functional levels) are used for system definition and a framework around which dynamic models can be constructed. System functions used in conventional manufacturing systems can be modified and supported by child strategies to attain planned goals. Classification of system functions and their associated decision activity (D/A) centres using CIM concepts is a very complex task. This requires clear definitions of computer-aided components (CAD, CAM, CAPP, CAQ, PP&C, etc.) which are considered the main components of the CIM strategy. Figure 7.3 illustrates the main concept of CIM for Brook Hansen Motors. It can be noted from Figure 7.3 that CIM comprises the main functions of design, planning, manufacturing, sales, etc. The CIM components play an important role in interconnecting and integrating the manufacturing system functions using an intensive information flow and general database system. This model is well suited for introducing

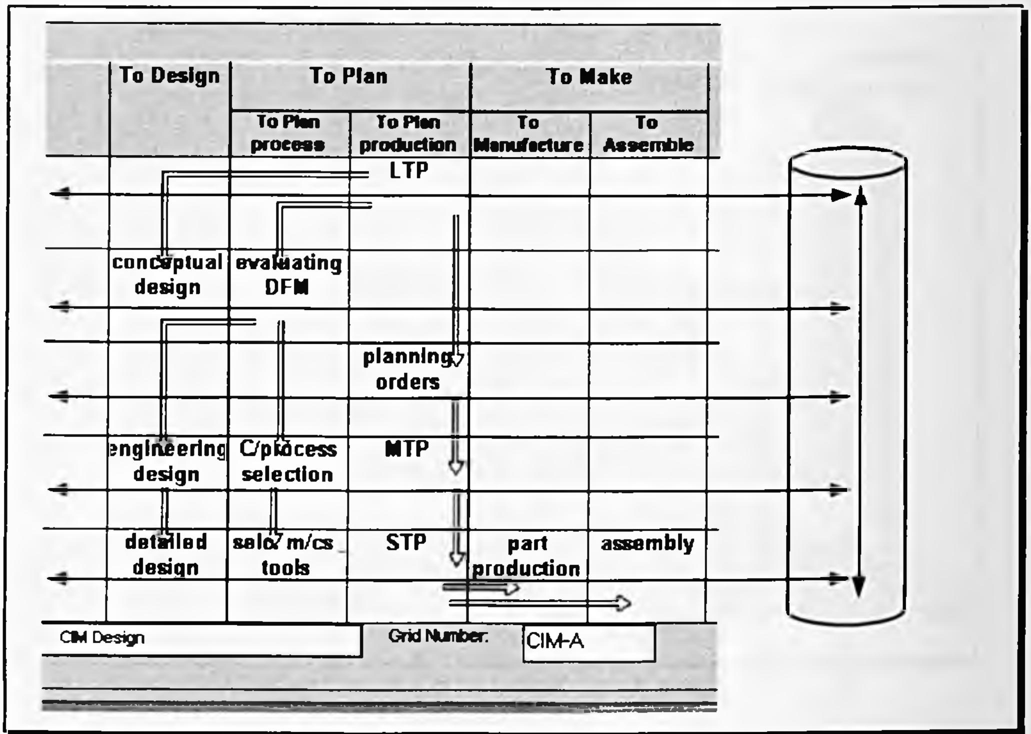


Figure 7.4. GI-SIM grid for CIM operational functions selected.

manufacturing systems into the general concept of CIM, as well as into the GI-SIM modelling method. To construct the GI-SIM grid, the main objectives of the manufacturing system functions and the CIM component should be integrated and tested.

To evaluate the GI-SIM modelling method for the design of a CIM strategy, three main manufacturing functions are selected. The complete re-design of Brook Hansen would be an extensive piece work outside the scope of this research. The selected functions are 'To Design', 'To Plan' and 'To Make'. These three functions are supported by CAD, CAPP, PP&C and CAM systems in the CIM environment.

7.4.1 GI-SIM Grid for CIM

Constructing the GI-SIM grid for CIM requires a definition of the system functions, sub-functions, levels, time scales and D/A centres. The systems functions should be defined using the operational specifications of Brook Hansen Motors and the CIM concepts, as illustrated in Figure 7.3. The derivation of the D/A centre will be based upon system activities considered in Chapter-6 and the manufacturing objectives to be achieved using the CIM strategy. The level time scale will be fixed using planning horizons and review periods of the CIM D/A centres. Flexibility of time scale depends on production plans and the complexity of data flow between the upper and lower levels of the GI-SIM grid. It is very clear from the main objectives of systems integration that lead times become short because cycle times of activities are developed using new manufacturing strategies. For example, using the CAD system reduces the cycle time of design activities; hence, this contributes to a reduction in lead-time and an increase in system flexibility. Figure 7.4 illustrates the GI-SIM grid for the CIM operational activities. Typical D/A centres will be considered in the next sections based upon the computer based systems and manufacturing system functions presented in the GI-SIM grid.

7.4.2 To Design

As presented in Chapter-6, there are several design problems related to both electrical and mechanical motor design. To overcome these problems the CAD system should be developed to handle design tasks and integrated into other manufacturing functions. 'To design' is a key function in Brook Hansen Motors. It determines the function and design of the motors using customer specifications. The design function has a major influence of the manufacturing processes selected for producing different components of the electric motors. This D/A centres and sub-activities are illustrated in Figure 7.5.

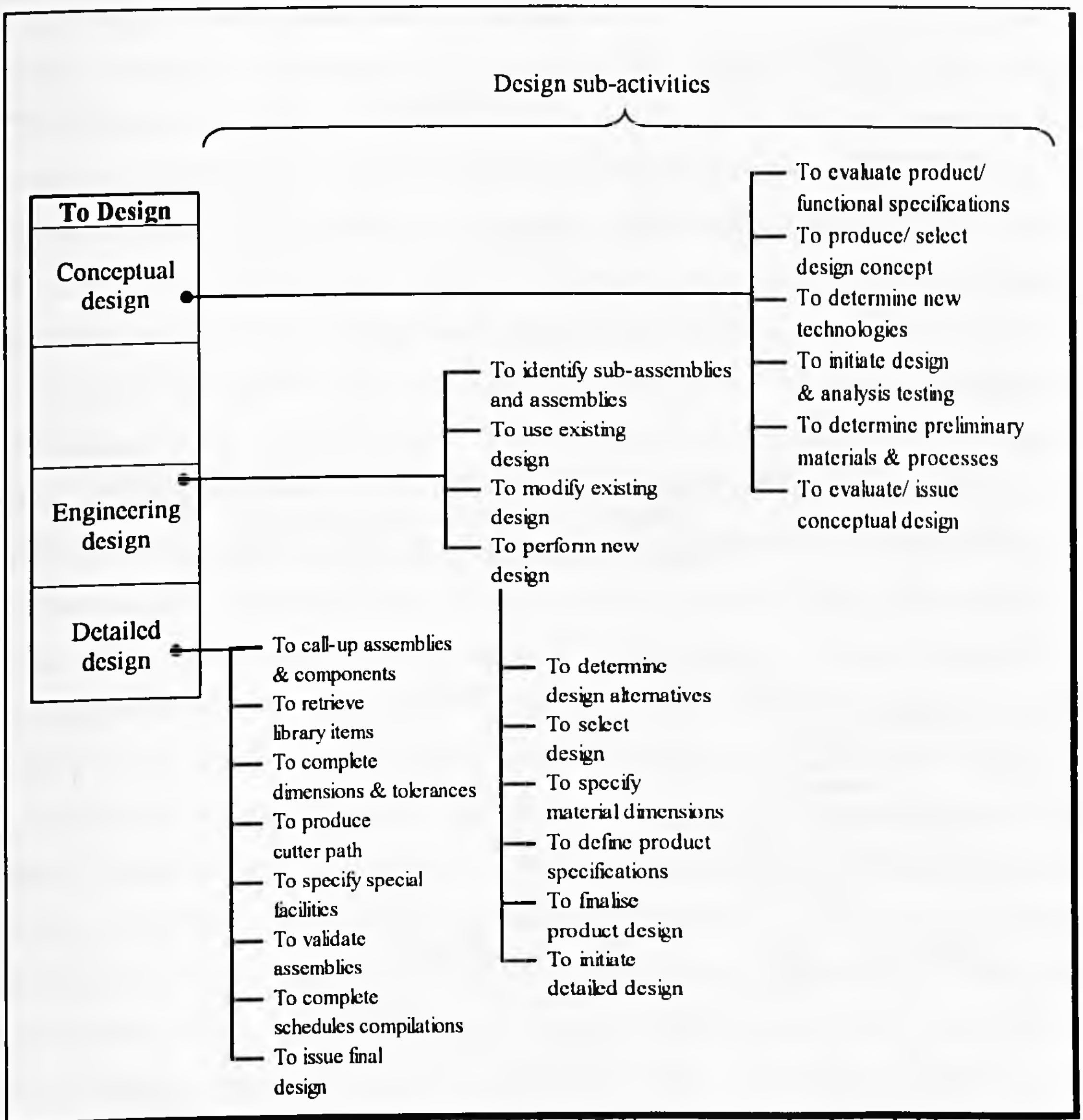


Figure 7.5. CAD concept/'To design' D/A centres and sub-activities

'To design' involves three main D/A centres (conceptual design, engineering design and detailed design) based upon the CAD concept, as shown in Figure 7.5.

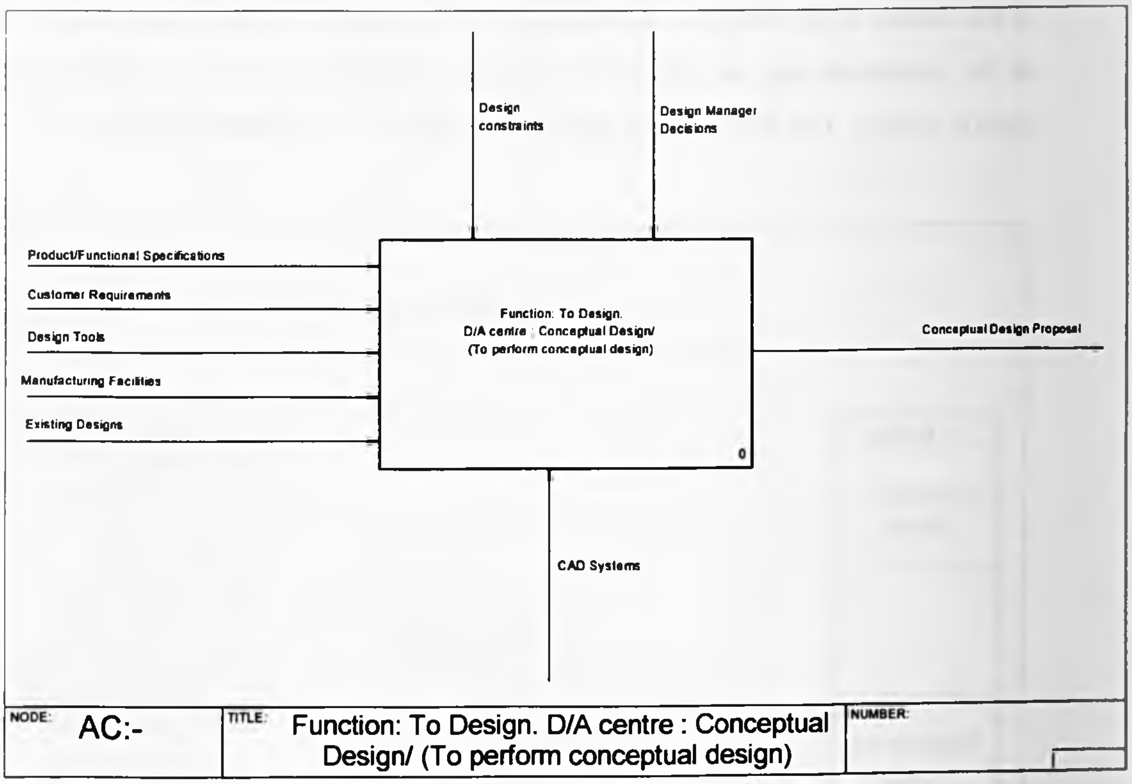


Figure 7.6. Conceptual design (top function).

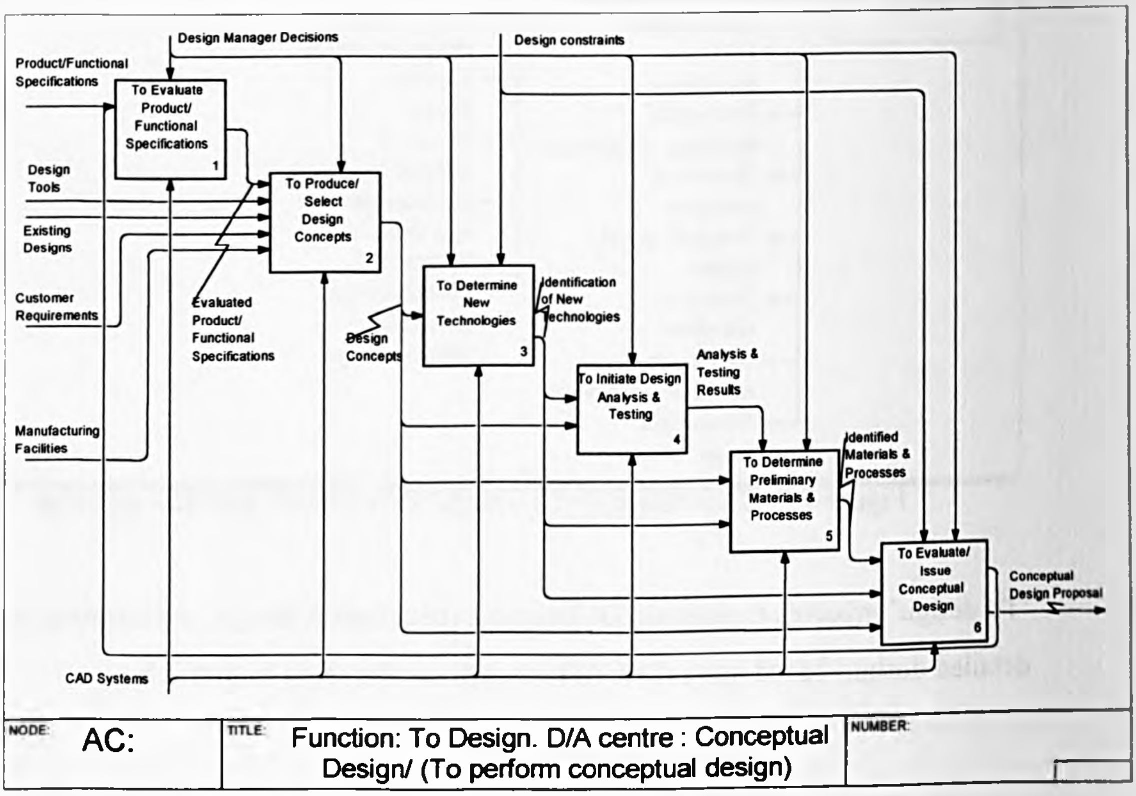


Figure 7.7. Sub-activities of conceptual design D/A centre.

7.4.2.1 Conceptual Design

The conceptual design D/A centre is concerned primarily with establishing the basic elements such as shape and appearance of the electric motors based upon a business decision. It also represents the broad evaluation of different ways in which specifications of the electric motors could be satisfied. This requires graphic systems to create complex motor shapes using CAD capabilities. Different motor colours can be applied to enable motor designers to visualise the final appearance of the electric motor. The CAD system database will provide more facilities to this D/A centre such as geometric data. Figures 7.6 and 7.7 show the IDEF0 model for this D/A centre. As discussed in the previous chapters, the electric motor functional specifications consists of a statement of the parameters relating to the motor appearance, performance, weight, size, time, etc. This wide range of motor specifications comes from other functions such as 'To sell'. Sub-activity AC1 represents evaluation motor functional specifications. The designer at the CAD system will provide the majority of the design and the original work, through which it contributes to the formulation of the electric motor specifications. Once the electric motor functional specifications have been satisfied, the production and selection of motor design concepts can begin. This is represented by sub-activity AC2 in the IDEF0 model. This sub-activity is very important for establishing alternative approaches to designing the basic shape and appearance of the electric motors rather than component details. The design concepts obtained from sub-activity AC2 are used as input for subsequent activities in the conceptual design D/A centre. Sub-activity AC3 represents the determination of new technology or changing current technology for motor part or assembly operations, if any, to evaluate these changes at an early stage of design. The analysis and testing of identified new technologies, if any, and motors design concepts will be carried out by sub-activity AC4. Analysis results obtained from AC4 are used by sub-activity AC5 where determining preliminary materials and processes are represented. Finally, sub-activity AC6 represents the evaluation and issuing of the conceptual design proposal for motor orders which include sketches and motor models carried out by this D/A centre. Conceptual design sub-activities are supported by the CAD system which involves human and computer-aided resources.

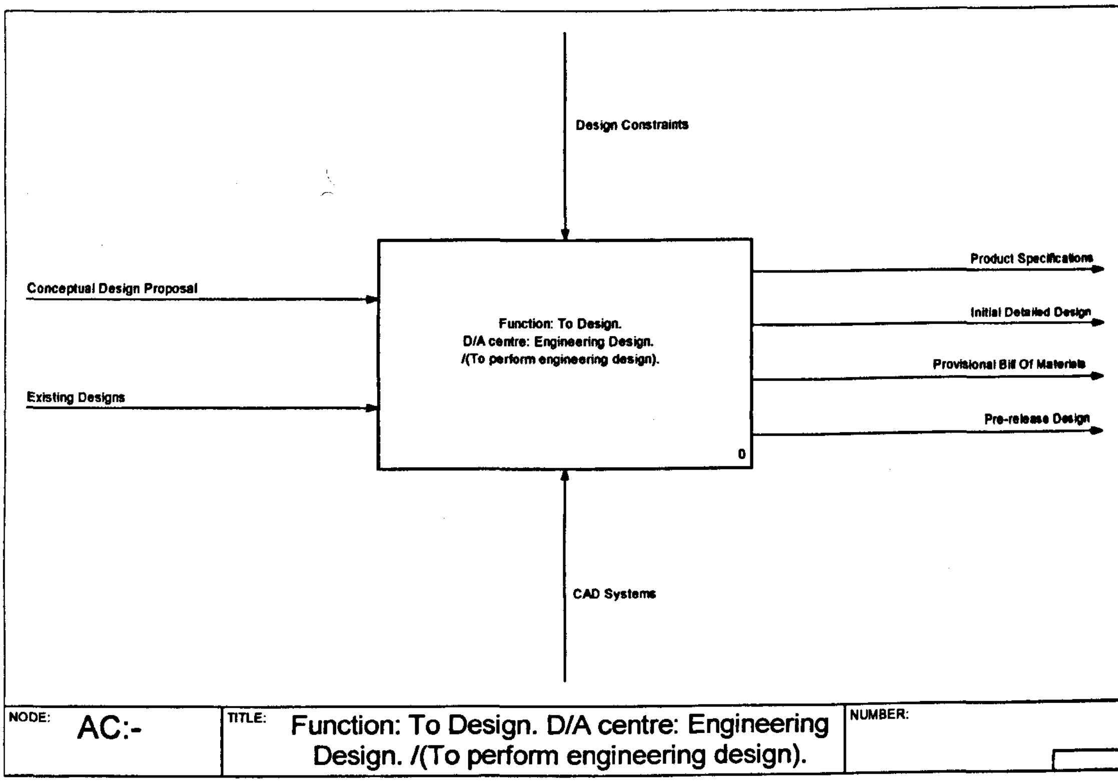


Figure 7.8. Engineering design (top function).

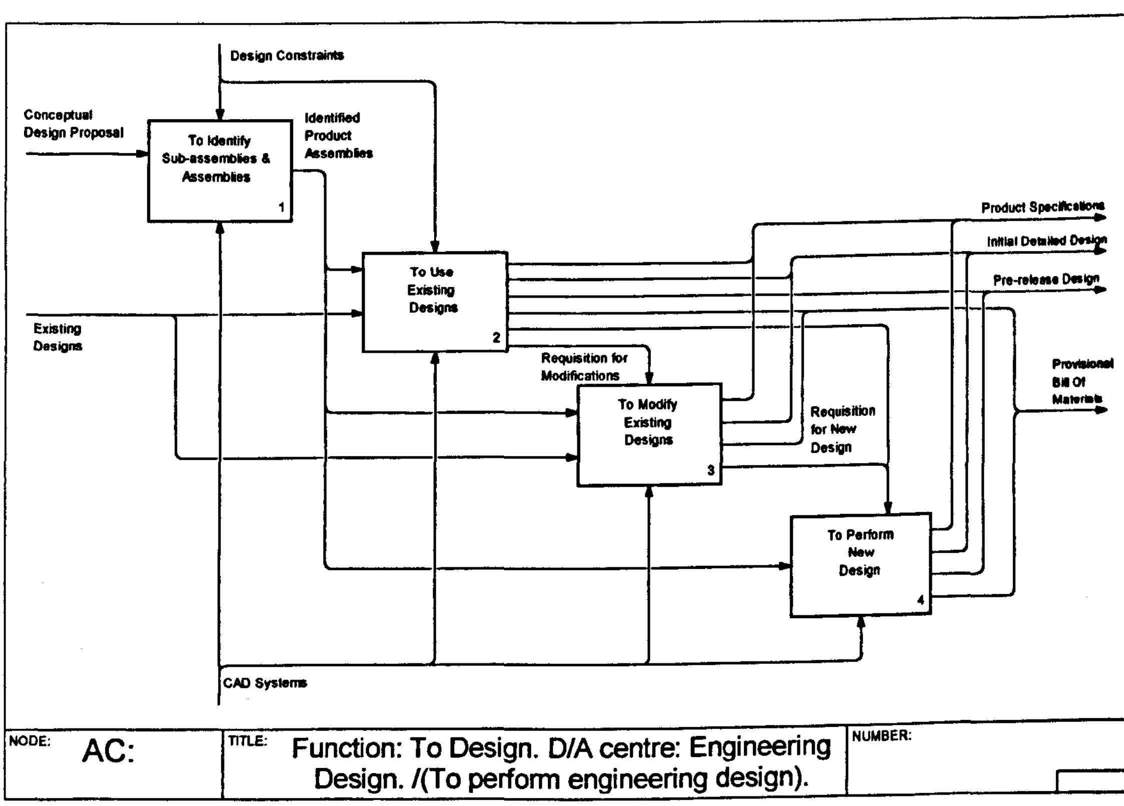


Figure 7.9. Sub-activities of engineering design D/A centre.

7.4.2.2 Engineering Design

The engineering design D/A centre is concerned with the identification and design of motor components, sub-assemblies and final assemblies. The nominal geometric motor design will be carried out based upon design analysis and engineering test. This requires the development of existing motor designs or development of new designs according to order constraints and the design proposals. Materials used in different motor components will be identified; the BOM of motors will be initiated at this D/A centre. These operations of design can be applied to different types of electric motors and the more complex parts, such as windings, can be simulated at this stage of design. Figures 7.8-7.10 illustrate the IDEF0 models for the engineering design D/A centre. The model shows two inputs, namely, conceptual design proposal and existing designs, and one control, design constrains. Once the conceptual design proposal has been accepted, engineering design will start to identify motor assemblies and sub-assemblies (this is represented by sub-activity AC1). Motor sub-assemblies and parts should be defined using a unique identification code to enable this definition to be used in subsequent design and manufacturing activities. This is also important to initiate the BOM for different types of electric motors. Using identified parts and subassemblies, and the existing design database, it may be possible to reuse some motor components or sub-assembly designs produced for previous customers, taking into account the new design constraints, as represented by sub-activity AC2. Information about previous designs should be provided and classified by the CAD system using reference numbers, key attributes or coding and classification techniques such as Group Technology. Sub-activity AC3 represents the operation of identifying existing design to meet new specifications. If no existing design can be modified, then it would be necessary to produce new designs for the whole motor sub-assemblies or parts; this is represented by sub-activity AC4 in the model. The sub-activity of constructing new designs for whole or parts of the motors can be broken down into six sub-activities (AC41-AC46), as shown in Figure 7.10. These sub-activities represent the logical procedures for the development of new designs. Sub-activity AC41 represents the preparation of new design alternatives based upon identified motor assemblies taking into account design specifications involved in the new design requisitions. The CAD system will be used to test new alternatives for preparing engineering factors. Sub-activity AC42 represents selecting a suitable design from the prepared alternative motor designs. The selection of design is supported by the CAD system which has static and dynamic means of

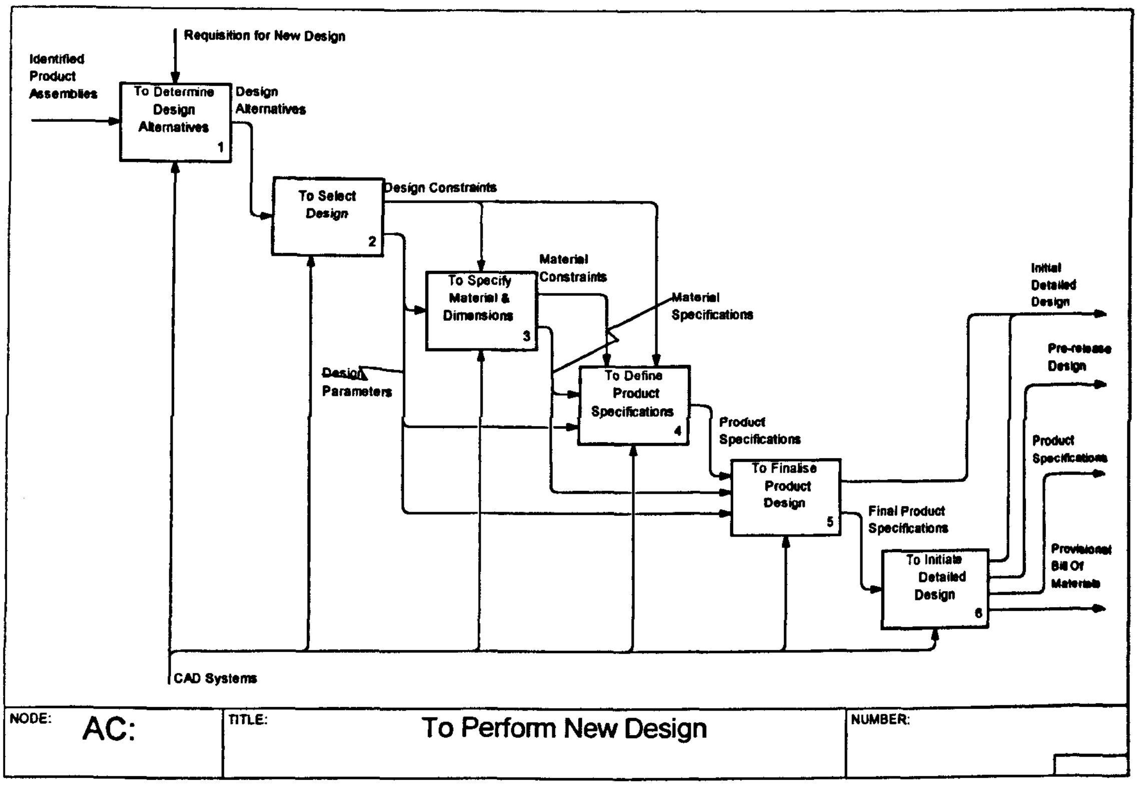


Figure 7.10. Sub-activities of new design activity.

evaluating design. The design selected will be used for specifying materials and geometrical features of the product; this operation is represented by AC43. Sub-activity AC44 represents a definition of product specifications based upon design parameters and constraints obtained from sub-activity AC42 and material specifications obtained from AC43. Following this, sub-activity AC45 represents the finalisation of motor design using product specifications given by sub-activity AC44. Any missing information for design must be checked and provided at this sub-activity. Finally, sub-activity AC46 represents the last step for engineering design where the detailed design will be initiated. The motor design at this stage may be referred to as the 'pre released motor design'. However, outputs of the engineering design D/A centre are initial detailed design, pre-released design, motor specifications and professional BOM. These outputs should include each motor part being considered for manufacture, the description for building BOM and design reference numbers. In addition, other information relating to design data should be provided such as geometric data, geometric elements, design description and 3D views.

7.4.2.3 Detailed Design

The detailed design D/A centre is concerned with identifying complete lists of all parts to be incorporated in the electric motor and providing a complete specification of each part to enable motor components to be manufactured. These specifications of motor components include sets of detailed mechanical drawings together with build and assembly instructions. Detailed drawings are generated by the CAD system. In some cases the drawings can be read directly from the CAD systems using integration interfaces between manufacturing system functions. This D/A centre commences its tasks with the pre-released designs which are generated by the engineering design D/A centre, as discussed in the previous section. Using the pre-released design, standard part library, initial detailed design and the provisional BOM, the D/A centre of detailed design can produce the fully released design, final BOM, engineering drawings, NC cutter path and other special facilities. All these tasks are completed, taking into account CAD system rules, manufacturing constraints and design specifications. Figures 7.11 and 7.12 show the IDEF0 model for the detailed design D/A centre. Sub-activity AC1 represents calling up motor components and sub-assemblies to be designed. This sub-activity is repeated until all components have been called up; then it will be possible to use common standard parts in design, which are retrieved from the CAD database and

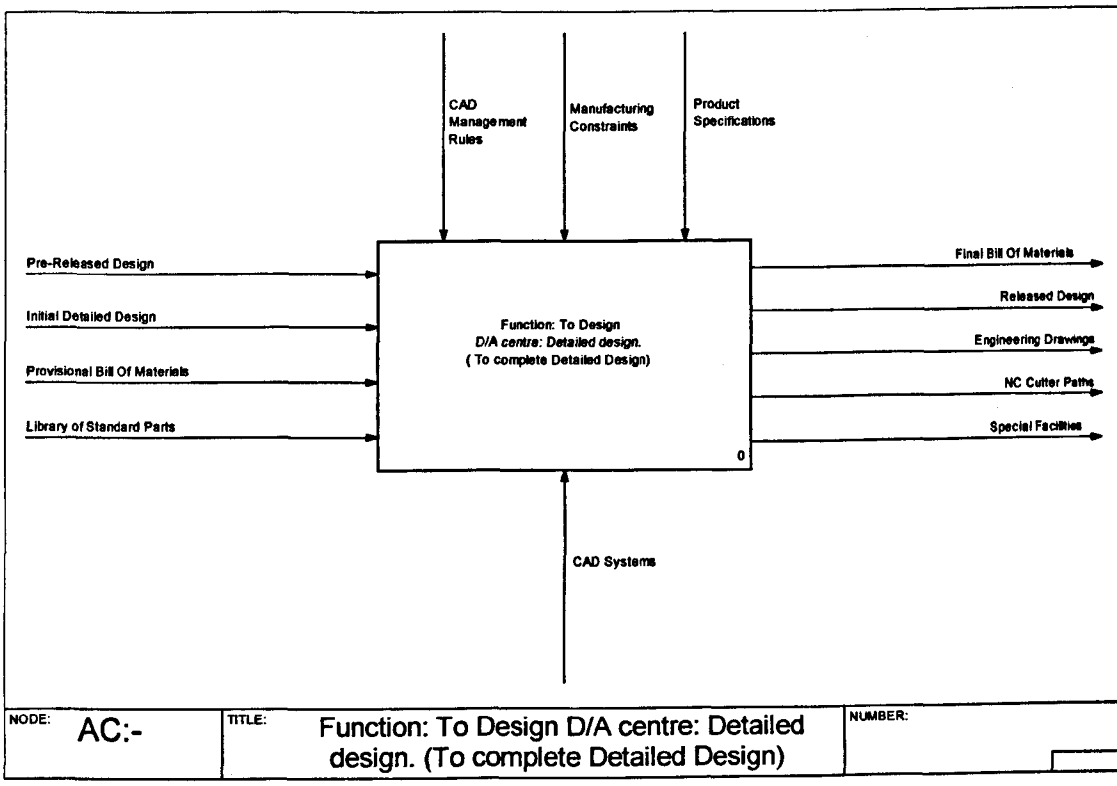


Figure 7.11. Detailed design (top function).

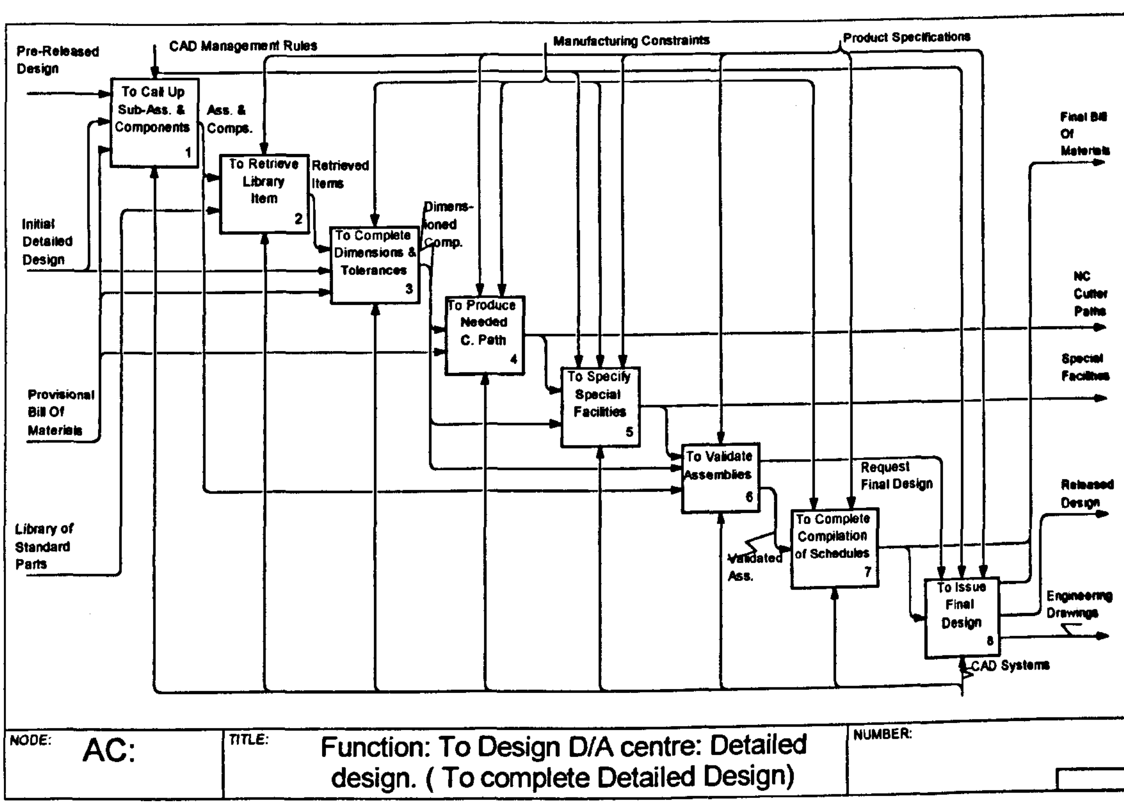


Figure 7.12. Sub-activities of detailed design D/A centre.

incorporated in the current design in order to reduce design time and costs. The operation of retrieving library items is represented by sub-activity AC2. Sub-activity AC3 represents completing design dimensions and tolerances. The engineering design D/A centre provides full details of dimensions and tolerances of motor components. Sub-activity AC4 represents generating simulation for components and sub-assemblies if required using some CAD functions to validate design tasks and engineering tests. Detailed design usually requires some other facilities such as the inclusion of textual information to describe special features specified by the customer. This operation is represented in the model by AC5. When all motor components have been designed in detail, motor assemblies should be validated to be ready for generating schedule of component combinations based upon the motor BOM. Validation of motor assembles is represented by sub-activity AC6. The BOMs should be tested and simulated to predict manufacturing features such as expected cycle times for other manufacturing functions, as represented by AC7. Finally, sub-activity AC8 will issue the final released design and relevant engineering drawings.

7.4.2.4 Data Modelling for the CAD System

The GI-SIM modelling method uses the IDEF1X technique to model information relationships between system entities. IDEF1X has been discussed in detail in Chapter-4. To model data for the CAD system using IDEF1X, model entities must be defined. CAD system entities can be defined using information flows presented by the GI-SIM grid and related functional models. Table 7.1 illustrates common entities used in the design function. These entities have a common set of attributes and characteristics.

Entity number	Entity name	Entity number	Entity name
E-1	CUSTOMER	E-9	STANDARD PART
E-2	ORDER	E-10	DESIGNER
E-3	PRODUCT	E-11	CUTTER PATCH
E-4	CUSTOMER SPECI.	E-12	MFG. FACILITY
E-5	DESIGN	E-13	CONCEPTUAL DESIGN
E-6	CAD SYSTEM	E-14	DETAILED DESIGN
E-7	EXISTING DESIGN	E-15	DRAWINGS
E-8-	DESIGN TOOL	E-16	BOM

Table 7.1. Design entity pool.

The relationship between entities are identified and defined. The initial form of modelling relationships between entities is illustrated in Table 7.2. This matrix

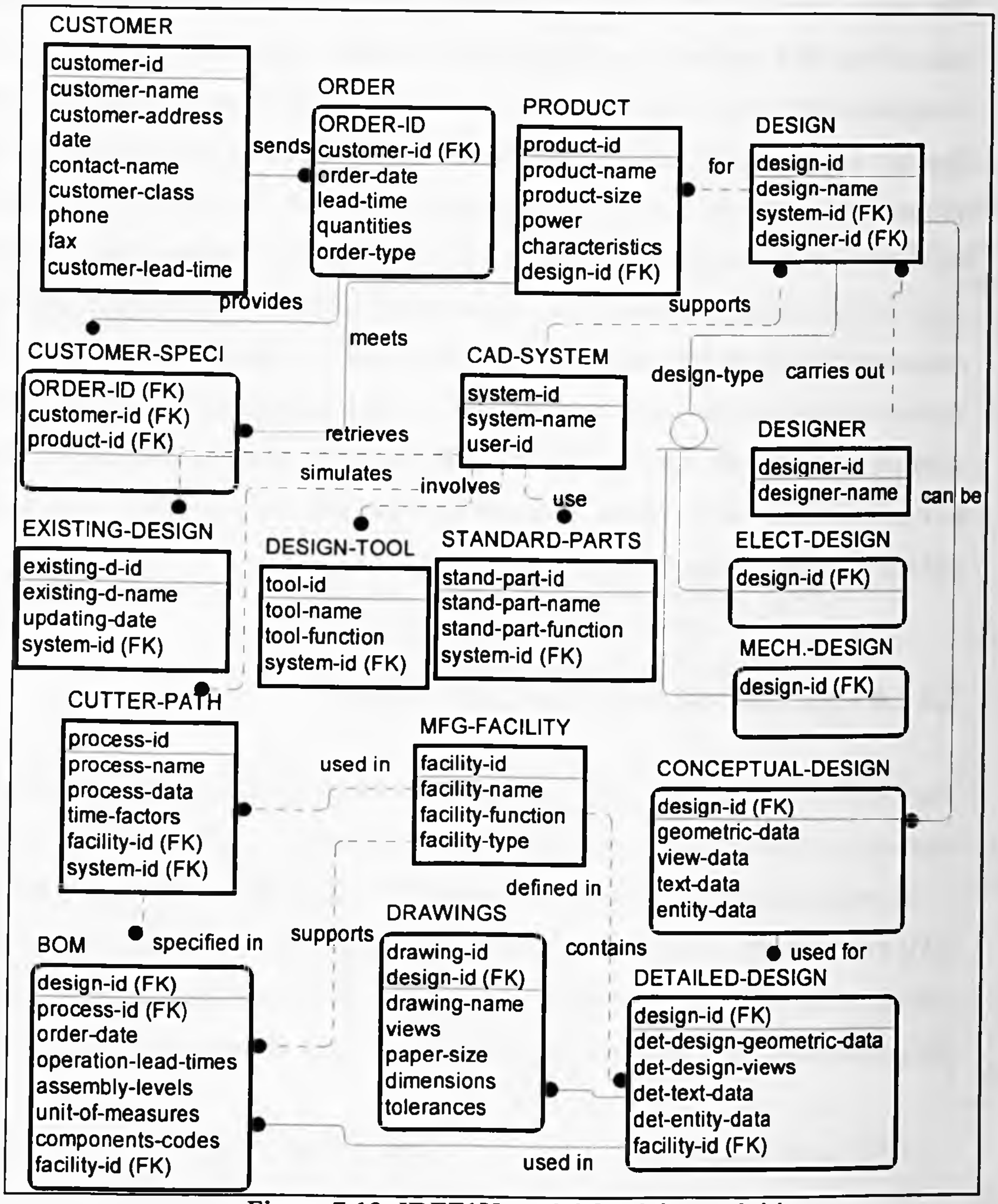


Figure 7.13. IDEF1X model for deign activities.

illustrated in Table 7.2 identifies the relationships between entities. The sign (✓) placed in location (E-1,E-2) indicates that there is a relationships between entity E-1 and entity E-2.

	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8	E-9	E-10	E-11	E-12	E-13	E-14	E15	E-16
E-1		✓														
E-2				✓												
E-3				✓												
E-4																
E-5			✓										✓			
E-6					✓		✓	✓	✓		✓					
E-7																
E-8																
E-9																
E-10					✓											
E-11																✓
E-12											✓			✓		✓
E-13														✓		
E-14															✓	✓
E-15																
E-16																

Table 7.2. Relationship matrix

Key attributes of design entities are defined; non-specific relationships are refined; primary keys are derived to represent foreign keys in child-entities. Figure 7.13 illustrates the final IDEF1X model for design activities. This model represents and documents information flow between D/C centres of the design function. Design data is important for other manufacturing functions and represents a cornerstone for the integration of different CIM sub-systems. Hence, the unique identity of each part in a new motor order considered for manufacturing is derived by the design function. BOM details are also created by design activities. These details represent the complete construction of the final motor in sufficient detail to enable manufacturing and production planning functions to plan and produce motors. The shapes of motor parts are identified and the design is based upon both customer requirements and manufacturing resource capabilities. In general, the information provided by the design function should be validated based upon entity type and the associated attributes. For example, BOM and detailed design represent the most important outputs of the design activities. These entities must clarify sufficient design data, for example, motor part description, quantities, identification, geometric data, view data, text data and attribute data.

7.4.3 To Plan Process

This Function ('To Plan') is divided into two main sub-functions 'To Plan process' and 'To Plan Production', as illustrated in Figure 7.4. There are three main reasons for dividing the function 'To Plan':

- To obtain more details about these important functions;
- To separate the D/A centres related to design and manufacturing processes from those which are related to production planning and manufacturing;
- To illustrate that there are two computer-aided systems supporting the planning function; the Computer Aided Process Planning (CAPP) system and Production Planning and Control (PP&C) system.

In motor manufacture, process planning involves the act of preparing a plan which outlines the operations, routes, machines, tools and parameters required to transform a motor part or sub-assembly into a finished motor. Most process planning activities in Brook Hansen Motors still involve either manual preparation of the process plans or semi-automated process planning. Appendix-A discusses process planning and the CAPP system in detail.

The process planning system normally uses the information presented on function 'To Design'. Hence, the CAPP system is the process of deciding how to produce a motor component that has been designed and specified by the CAD system - design function. The function 'To plan process' can be represented in three D/A centres. Figure 7.14 illustrates the process planning function and its associated D/A centres. Sub-activities of the D/A centres are also shown in Figure 7.14.

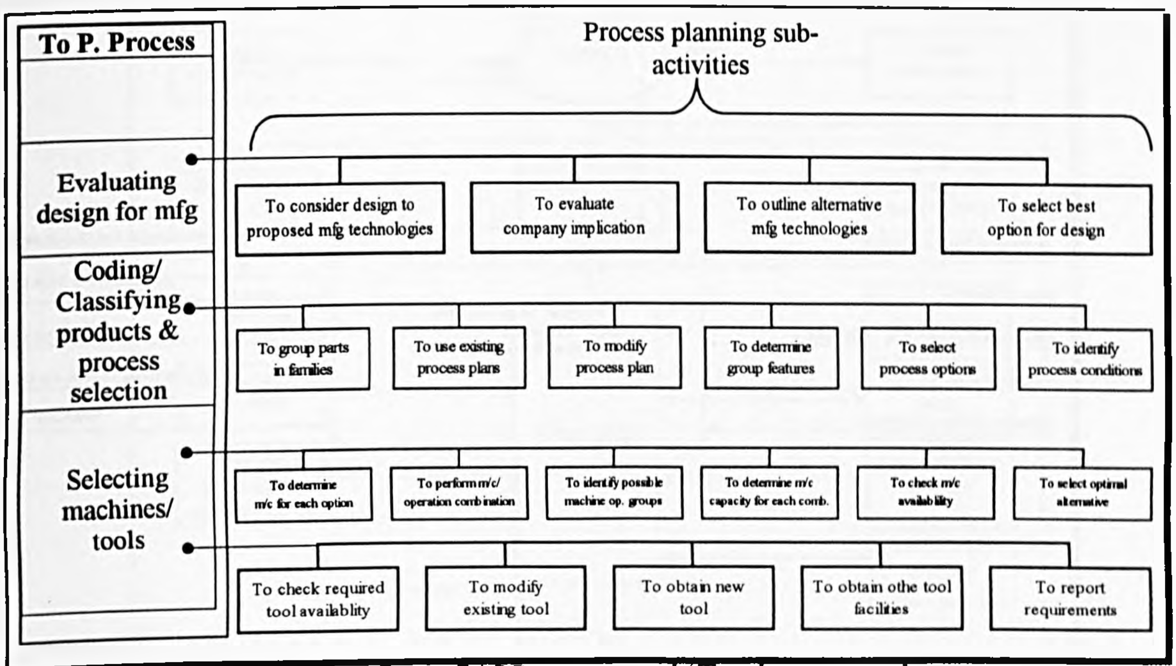


Figure 7.14. CAPP system and 'To plan process'.

Following sections discuss the D/A centres of the process planning function and their related sub-activities.

7.4.3.1 Evaluating Design for Manufacturing (DFM)

Once a decision is taken to design and produce a new motor order, recognised by the marketing function, it becomes necessary to design the new motors and determine how it should be produced. However, the costs of producing new motors or new components can be greatly influenced by the detailed design generated by the D/A centres described in the design function; to ensure that the optimal manufacturing is selected by the integrated manufacturing functions, it is necessary for 'To Design' function (CAD system) and 'To Plan Process' function (CAPP system) to apply DFM concepts to the conceptual design proposal and produce a detailed design of new motor component or assembly.

With completion of the conceptual design, the design now enters an analysis stage, in which the design is evaluated for a specific type of manufacturing with the objective of minimising the cost while retaining the functionality and high quality of the product (Anjanappa and Wang 1994), as illustrated in Figure 7.15.

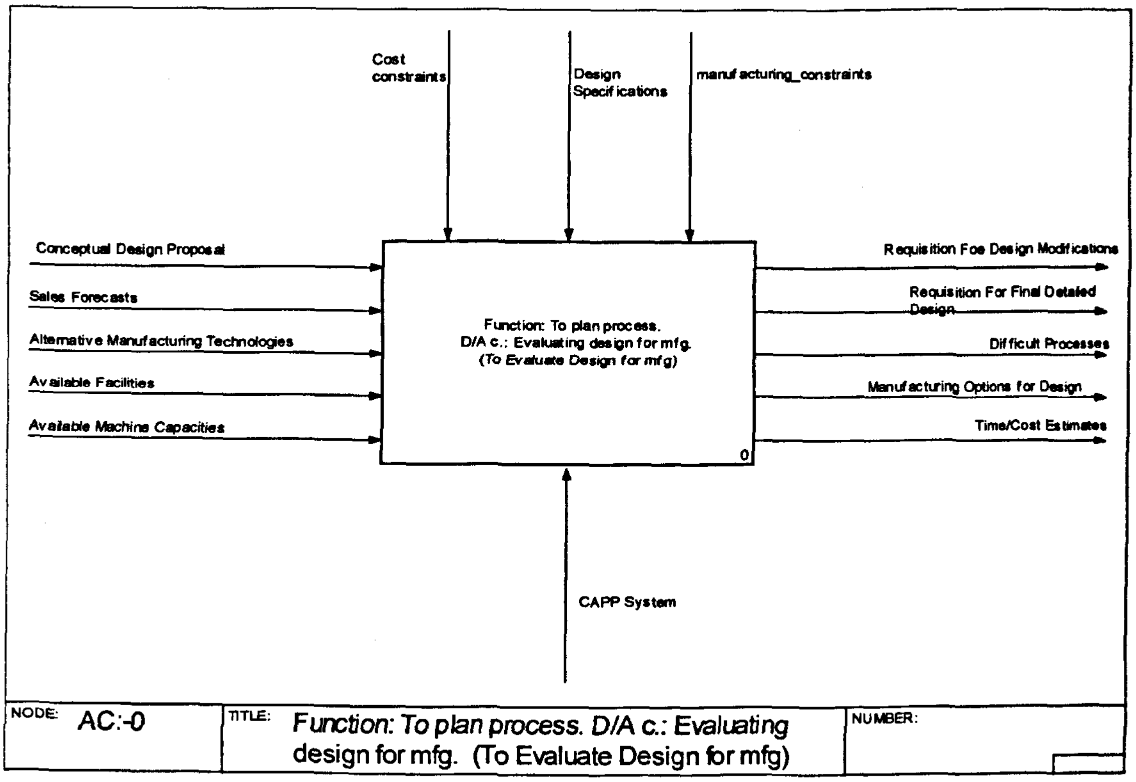


Figure 7.16. Evaluating DFM D/A centre.

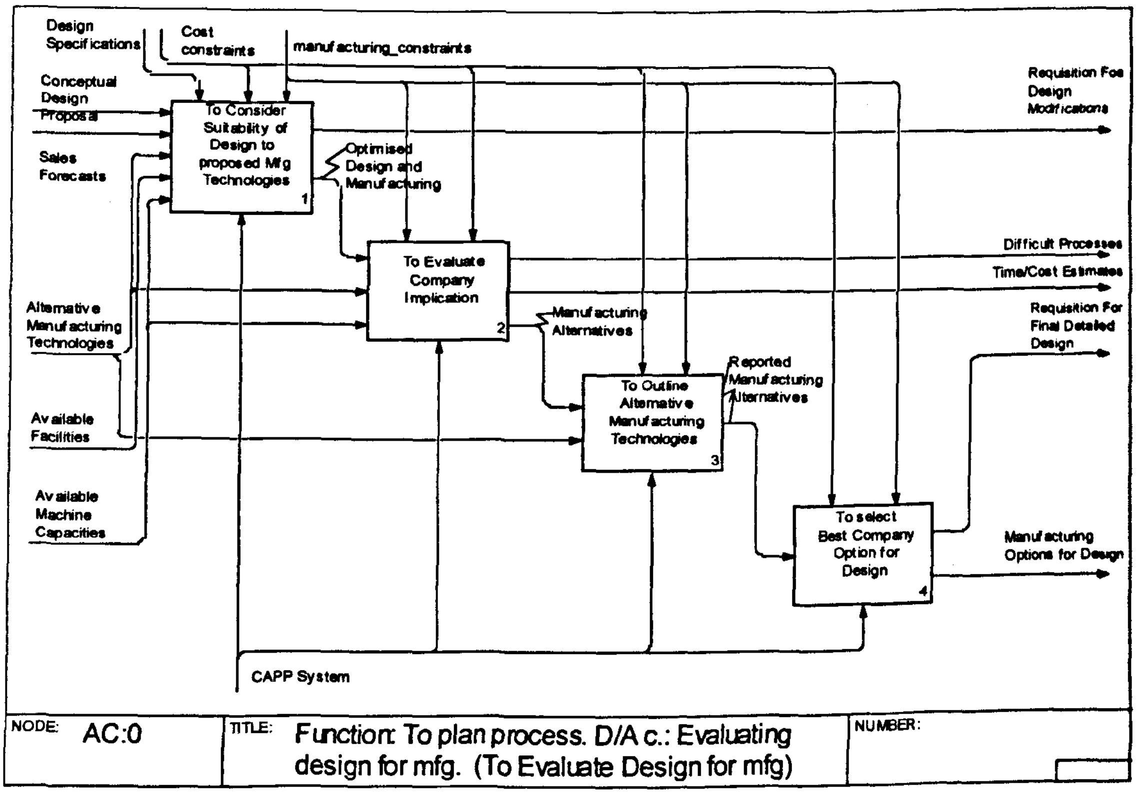


Figure 7.17. Sub-activities of evaluating DFM D/A centre.

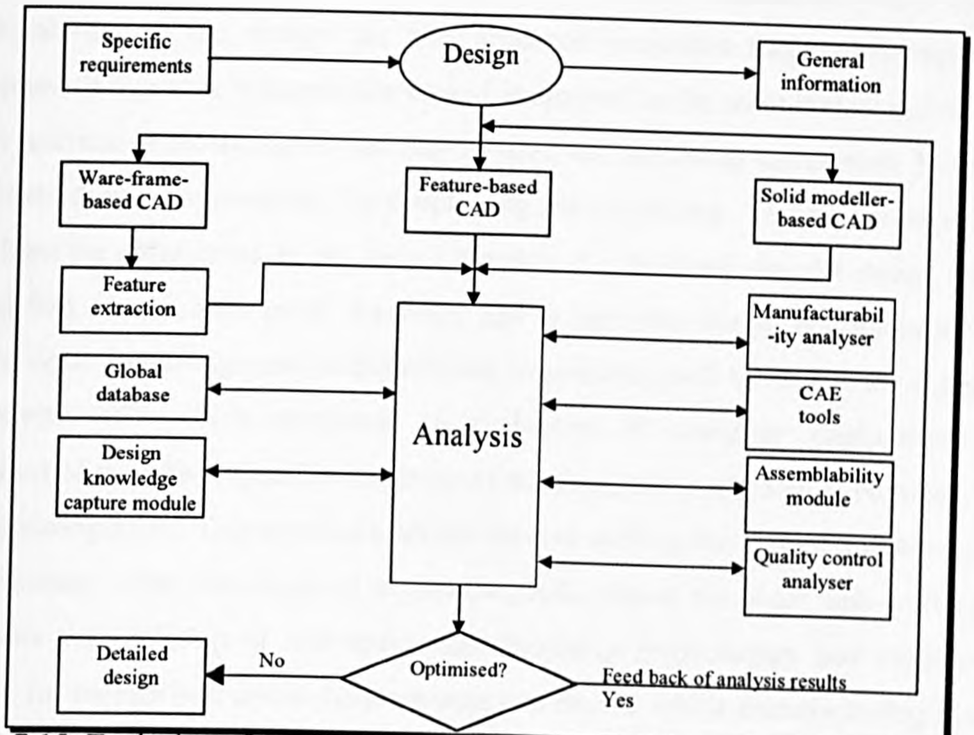


Figure 7.15. Typical configuration of design for automated manufacturing (Anjanappa and Wang 1994)

This D/A centre is concerned with the formal evaluation of the costs of alternative manufacturing technologies which might be considered. It will keep the integration of design and manufacturing through requisitions for design modifications by the manufacturing function. The successful electrical and mechanical design modifications will be fed back to provide the design principles for design department. If the conceptual design is satisfactory, the D/A centre will give estimates of the times required to manufacture the design, based upon the different technologies being considered by the process planning function, using the CAPP system. These time estimates from the DFM D/A centre, together with a knowledge of the order quantities for different sizes of motors, will allow estimates to be made of capacity requirement which will be compared to the available manufacturing capacity over the planning time horizon determined.

Figures 7.16 and 7.17 illustrate the IDEF0 model for the D/A centre of evaluating DFM. The top function of the model is decomposed into four sub-activities (AC1 - AC4). The main inputs of this D/A centres are the conceptual design proposal received from the design function, sales forecast from market research; alternative manufacturing technologies and available facilities from the manufacturing function; and available machine capacities from the production planning function. Sub-activity AC1 considers the suitability of the design for the proposed manufacturing technologies. The conceptual design should be considered and evaluated by the manufacturing function to review alternative technologies that may be used for producing component designs and to validate design requirements for simplifying manufacturing. This D/A centre sends a requisition for redesigning to the design function if it is found that the design needs to be modified. On the other hand, if a motor part or assembly design is suitable for DFM, then the optimised design and manufacturing information will be sent to the subsequent sub-activity AC2 which represents an evaluation of company implications. This evaluation of the effect upon the company of adopting the method must be made in any manufacturing plant. This considers several factors such as the cost of a new station or modifications, or the time required to start the production of the order. Sub-activity AC3 represents the outlining of alternative manufacturing technologies and reporting the findings for comparison and to help managers to decide which manufacturing facilities should be adopted and introduced. Sub-activity AC4 represents the selection of the best option of manufacturing the alternative for design. This will support the decision criteria to requisite for final design details and to report manufacturing options for design.

This D/A centre is considered as a part of the CAPP system and must provide a mechanism for evaluation of design factors which effect the decision-making process. Other factors can be considered in this D/A centre related to manufacturing alternatives, human factors, etc.

7.4.3.2 Coding/Classification and Process Selection

It is an important step, after designing and taking the decision on producing the new motor, to determine how the new motor specifications ordered by the customer should be manufactured. This step is commenced in the last D/A centre. In this D/A centre (coding/classification of products and process selection) the coding of characteristics of a motor part can be determined or created to retrieve motor information relating to the existing parts that will help in the design and manufacture of the new motor. This information will be different for the design information. Both design information and manufacturing data will be used to meet specific requirements related to this D/A centre. The CAD system can provide design data automatically. The CAPP system will use this data to generate more product characteristics. All this will be used to retrieve

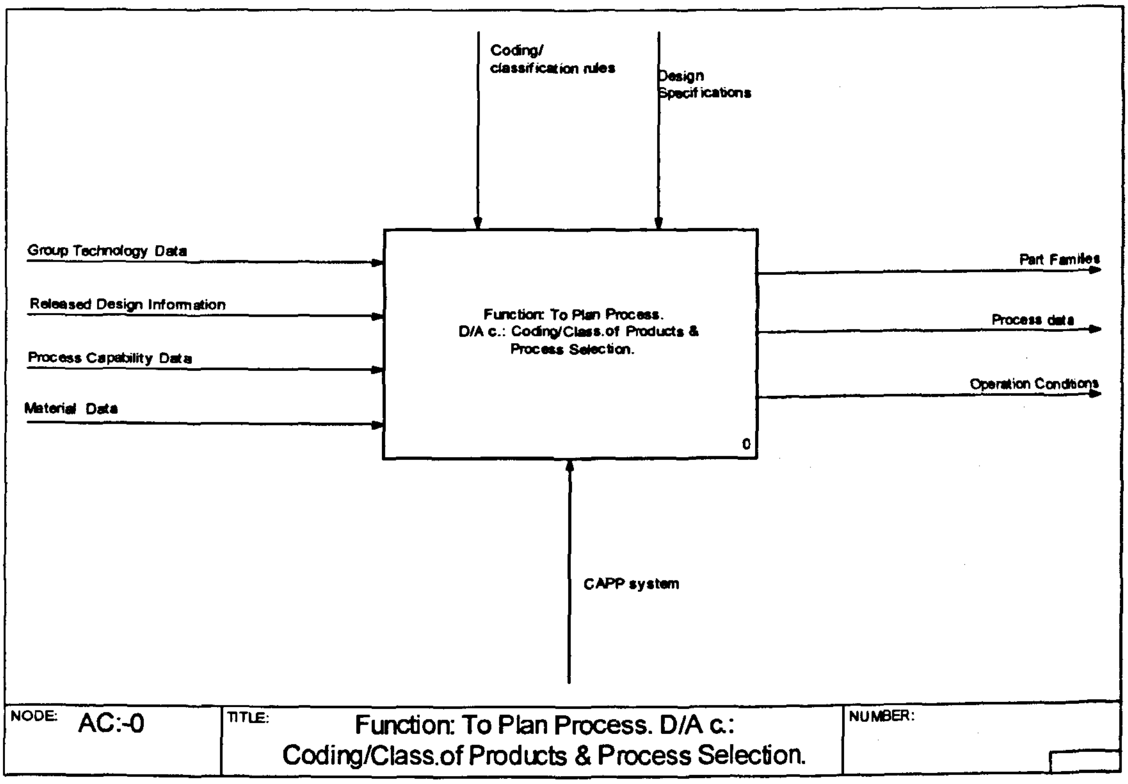


Figure 7.18. Coding/classification and process selection D/A centre.

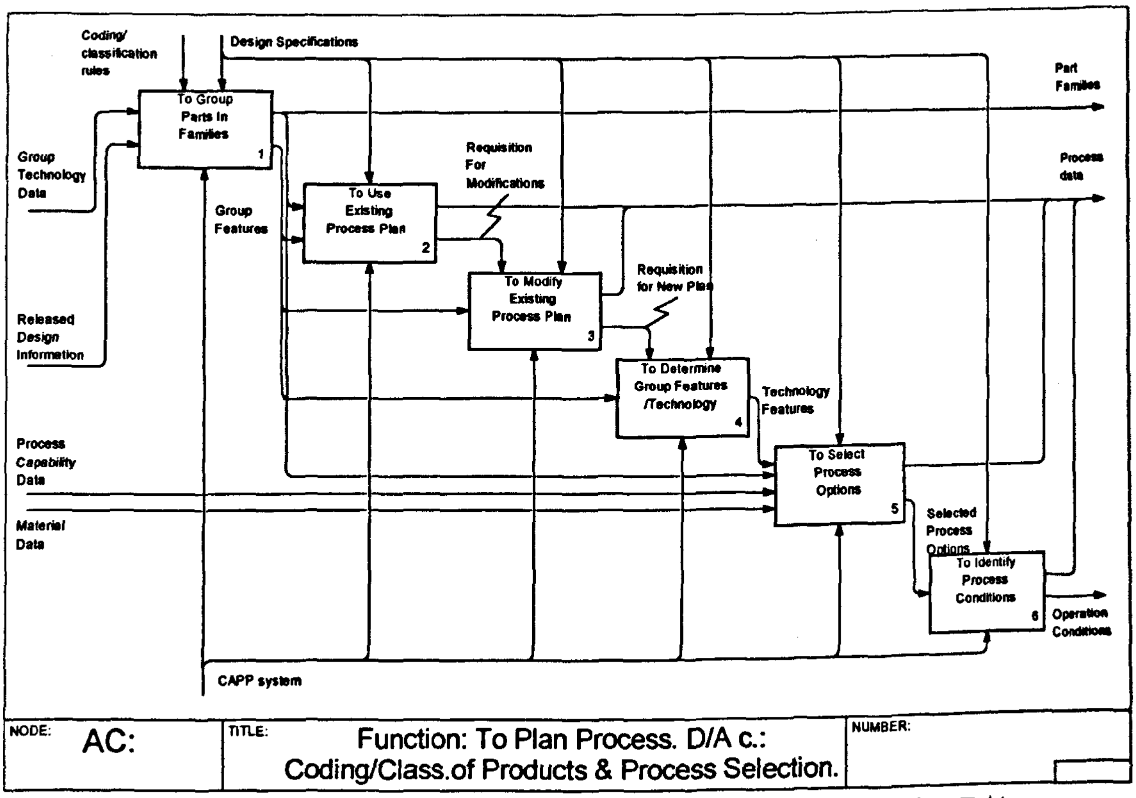


Figure 7.19. Sub-activities of coding/classification and process selection D/A centre.

motor part information from a CAPP database. The CAPP system should interact with existing parts to find a part family that includes the new motor part defined. If there is no similar part family for the new product, then a new part family will be created and coded.

This D/A centre also carries out the process selection for the new motor part. This can be completed by examining the motor component details and conversion into finished product. More details about coding systems and process planning types are presented in Appendix-A.

Figure 7.18 and 7.19 illustrate the IDEF0 model for this D/A centre. The top activity of this D/A centre (Figure 7.18) is decomposed into four sub-activities, as shown in Figure 7.19. The model illustrates four types of inputs, namely, group technology data, material data, detailed design information and process capability data. It is controlled by coding system rules and design specifications. The CAPP system represents the main support of this D/A centre and the outputs are part families, process data and operation conditions. Sub-activity AC1 represents the process of grouping parts into families to use the existing methods in planning the manufacture and assembly of motor parts that are similar to the detail. This can be achieved using part numbers or any other unique attributes to describe the new item or retrieve the existing one. Sub-activity AC2 represents using existing manufacturing plans. The existing plans normally require some modification to achieve the new part characteristics; this is represented by sub-activity AC3 in the model. The existing plans may not achieve the requirements of the new part; hence, a new plan should be generated. Generating a new plan is represented by sub-activity AC4. This sub-activity identifies the feature groups that are to be manufactured or assembled. Following this, a process option will be selected based upon these features, as modelled by sub-activity AC5. Finally, sub-activity AC6 represents the process of identification of process conditions, using process options defined by the preceding sub-activity.

7.4.3.3 Machine and Tool Selection

After a new motor component has been analysed and referred to a similar group or new part family and the process has been selected for achieving production operations to produce or assemble the electric motor components, it is necessary to select machine

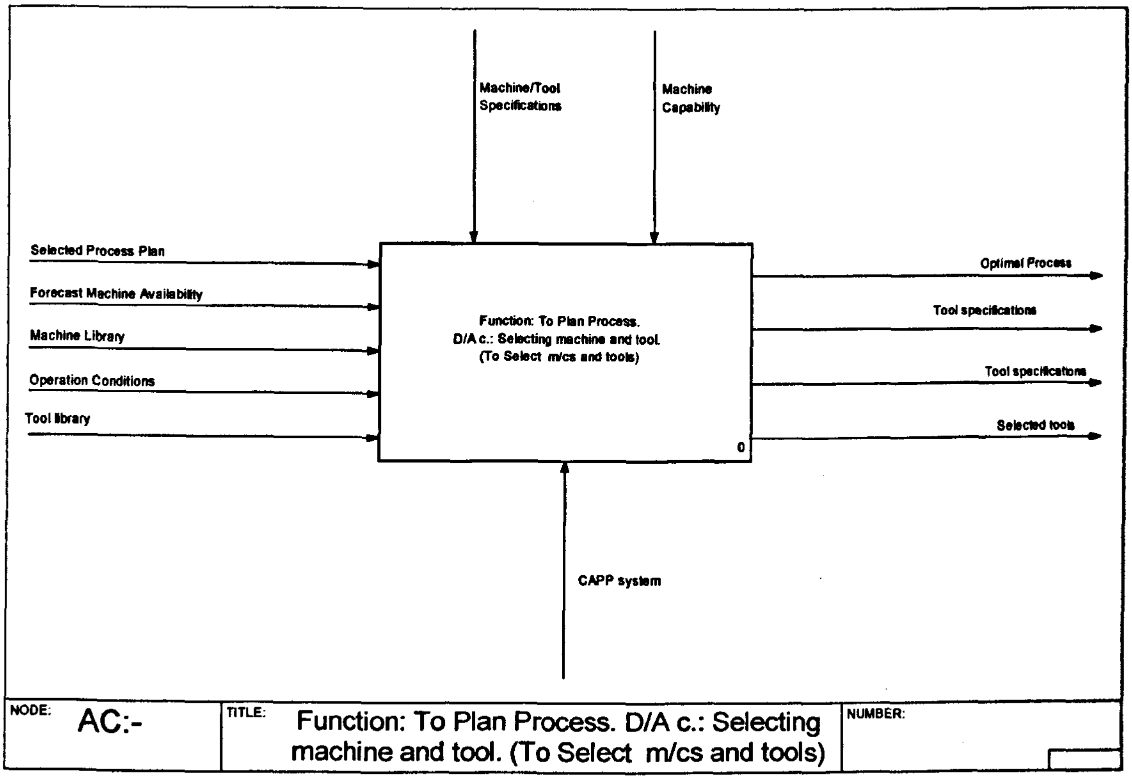


Figure 7.20. Machine and tool selection D/A centre.

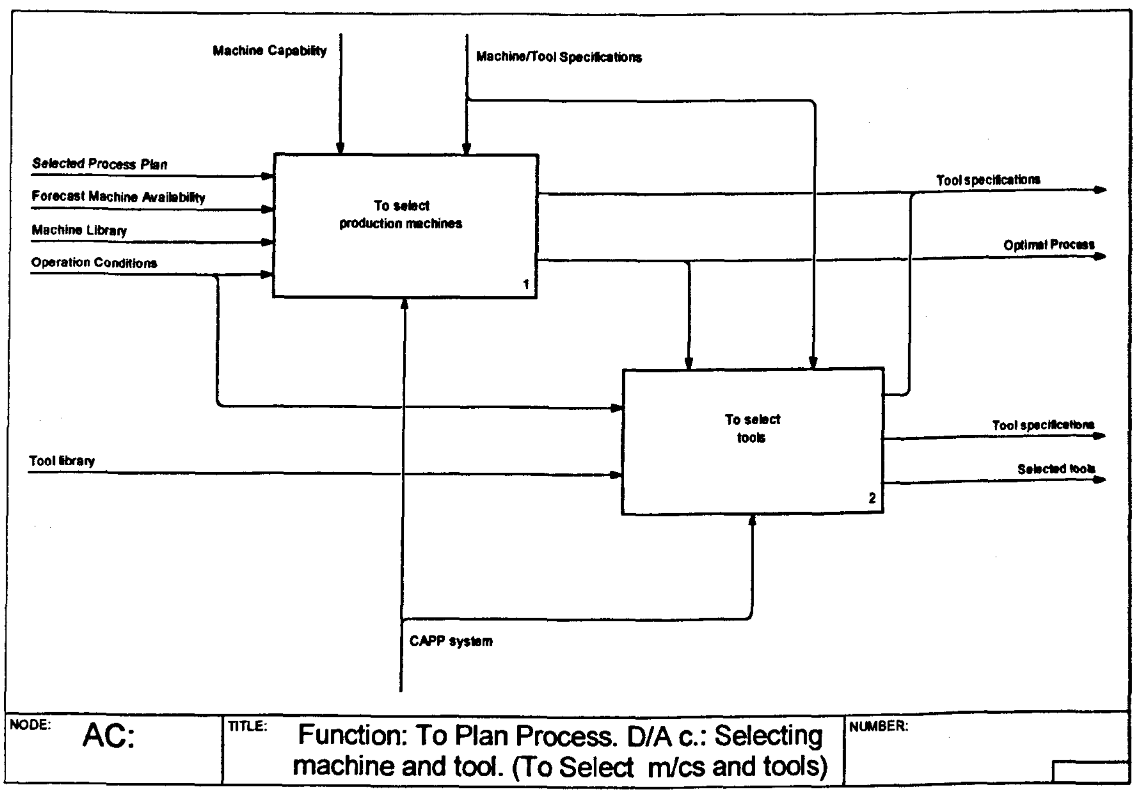


Figure 7.21. Activities of machine and tool selection D/A centre.

tools and operation sequences. It is also necessary to determine tools, fixtures and dies to be used in these manufacturing operations.

The D/A centre of machine and tool selection is concerned with selection of machines and tools based upon information obtained from the previous D/A centre, together with additional data obtained from manufacturing function. This D/A centre considers each manufacturing operation based upon the availability of resources that satisfy the process requirements of the motor component. Following this, combinations of manufacturing stations and operations will be used to generate possible routes for the motor component considered. The product routings are used for computing other manufacturing factors such as operation time, set-ups, etc., to predict production station utilisation and capacities using CAPP system capabilities. These calculations can be used for other purposes such as comparison of several routings and current station capacities. A decision should be taken by this D/A centre concerning the feasibility of the product routing generated and the preferred alternative manufacturing resources. All these tasks are supported by the CAPP system.

Figures 7.20 to 7.21 illustrate the top level of the IDEF0 model for the machine and tool selection D/A centre. The selecting machine and tools D/A centre is broken down into two activities 'to select production machine-AC1' and 'to select tools-AC2', as illustrated in Figure 7.21. Activity AC1 is decomposed into six sub-activities (AC11-AC16), as illustrated in Figure 7.22. The model illustrates four inputs; process plan selected, machine availability, machine library and operation condition. The controls are machine capacities and machine/tool specifications. The outputs are tool specifications and optimised process. Sub-activity AC11 represents the selection of machine for every operation related to the motor component. The machine operations identified are used to perform machine/operation combinations (sub-activity AC12) to identify possible machine and operation groups (sub-activity AC13). The machine and operation groups are delivered to the next sub-activity AC14 to determine the station or machine capacity for each combination. The result of this sub-activity will be used to check machine availability as represented by sub-activity AC15. Finally, sub-activity AC16 represents the selecting of optimal alternatives, which gives the optimal process.

Activity AC2 - 'to select tools' - is decomposed in to five sub-activities (A21-A25), as illustrated in Figure 7.23. The main inputs are the tool library and operation condition.

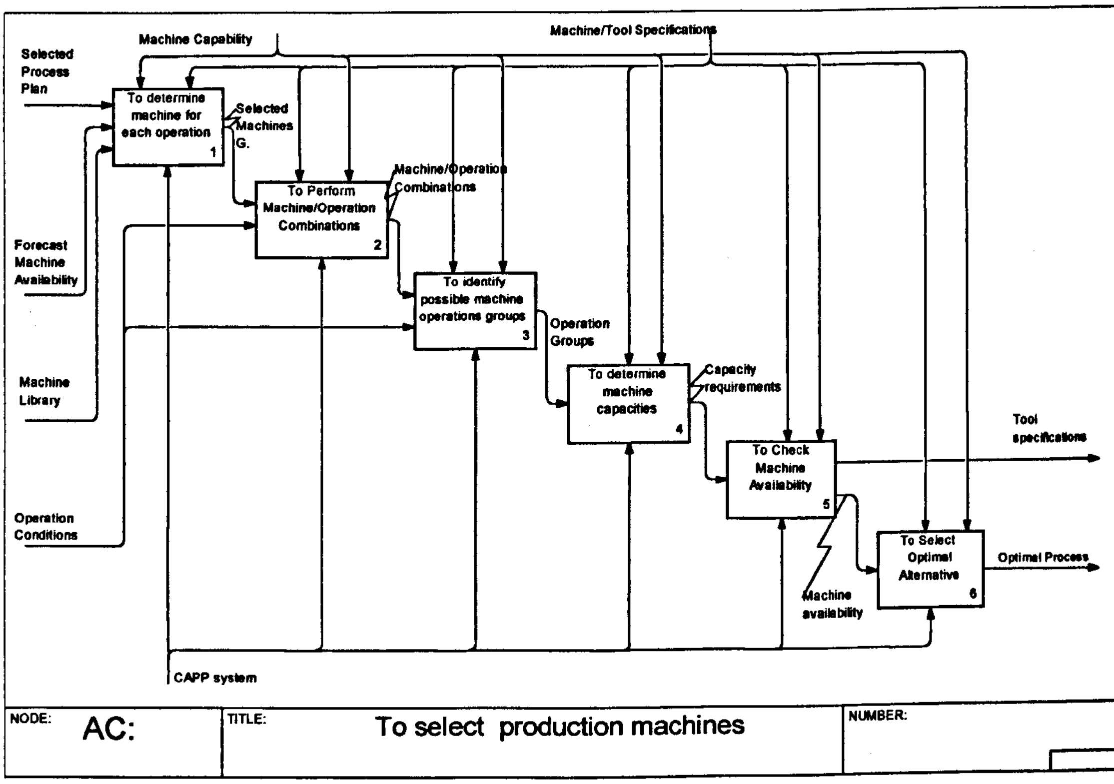


Figure 7.22. Sub-activities of machine selection function.

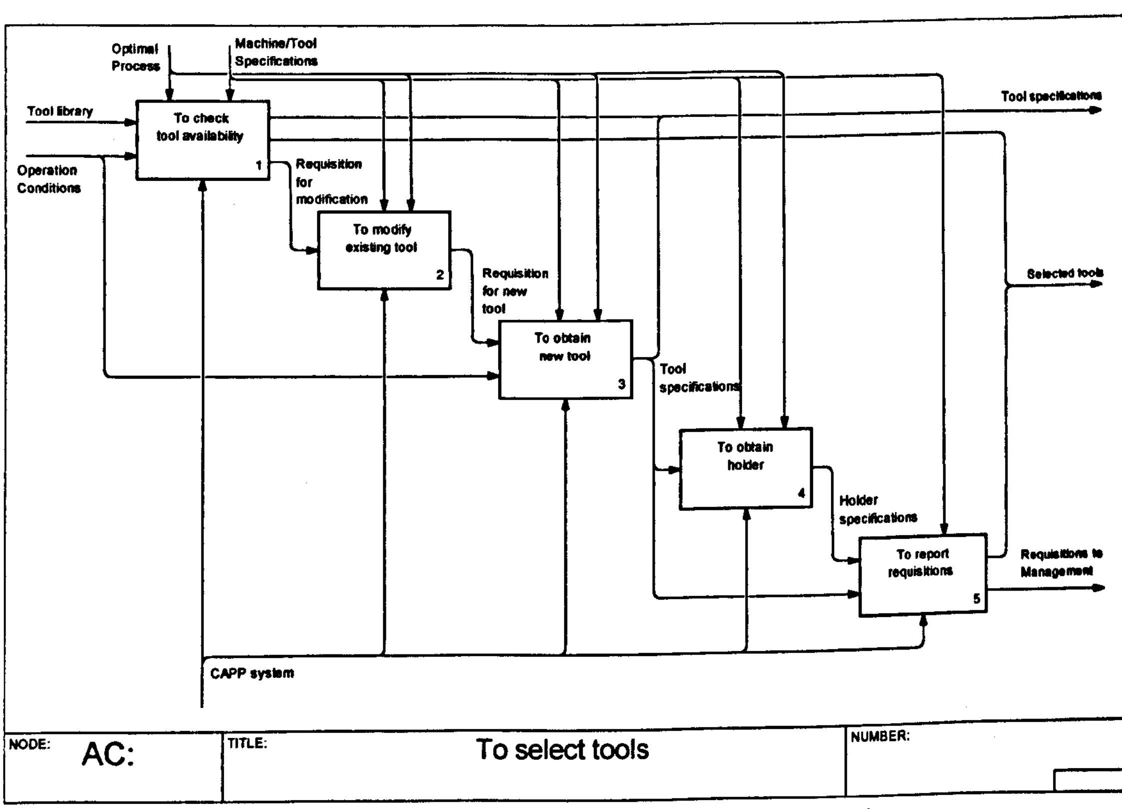


Figure 7.23. Sub-activities of tool selection function.

The controls are optimal process and machine/tool specifications. The outputs are requisitions to management, selected tools and tool specifications. The model sub-activities are supported by the CAPP system. Sub-activity AC21 represents the process of checking existing tools and getting tool specifications or report requisition for some modification, if any, in sub-activity AC22. The type of tool or die required for an operation will be compared with the library of standard tools available. If a tool that satisfies the manufacturing requirements exists, this will be used or modified to reduce the cost of purchasing new tools. If a die or tool cannot be modified, then tools have to be purchased, as modelled by AC23. The new tools or dies will be added to the tool library and the database will be updated. Information about new tools will be used to get tool holders, as modelled by sub-activity AC24. Finally, Sub-activity AC25 represents the process of reporting requirements for tools and dies related to new motor orders. It should be noted that machine and tool selection problems can be formulated using several methods such as knowledge-based systems, mathematical models, leaner programming, etc. to get the optimal solutions and support the decision making processes. These techniques can be programmed and implemented using the CAPP system to deal with different process planning problems related to electric motor components.

7.4.3.4 Data Modelling for CAPP System

The CAPP system can support several steps of process planning in Brook Hansen Motors. It involves a number of activities that are essential in generating process plans: Analysis of conceptual design; selection of process; determining manufacturing operations and their routings; selection of machines and tools; determining manufacturing conditions (cutting speed, feed, etc.) and manufacturing times (set-ups, cycle times and lead times). The CAPP system is discussed in Appendix-A.

To construct a generic data model for the CAPP system it is necessary to identify the main entities related to the process planning function. It is very difficult to specify all entities of the CAPP systems because the integration concept means everything is inter-related in the CIM sub-systems. Hence, the general entities represent the common data support process planning D/A centres are modelled. Table 7.3 illustrates the entities used in the data model of the CAPP system.

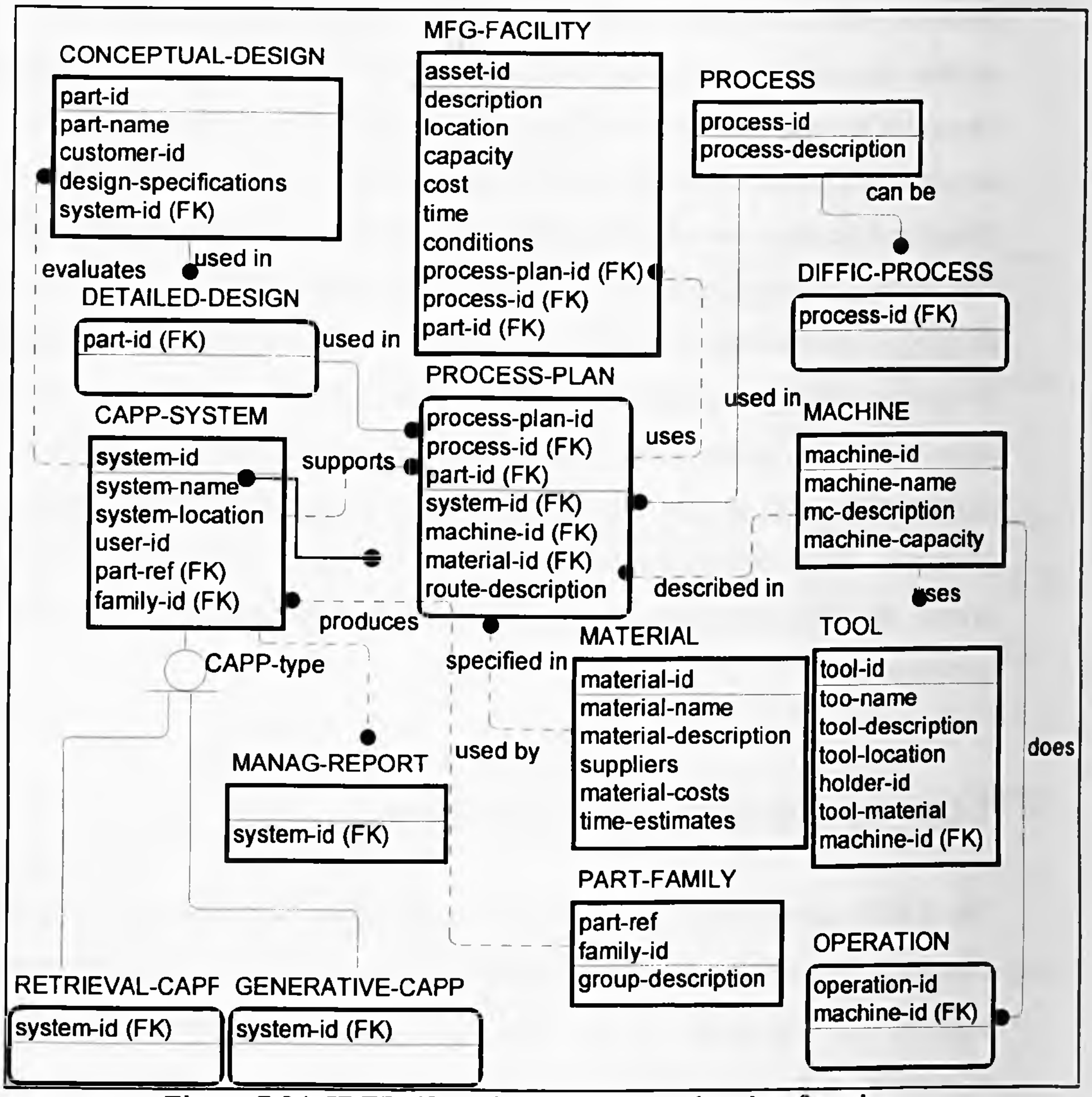


Figure 7.24. IDEF1X model for process planning function.

Entity number	Entity name	Entity number	Entity name
E-1	CONCEPTUAL DESIGN	E-7	MACHINE
E-2	DETAILED DESIGN	E-8	OPERATION
E-3	CAPP SYSTEM	E-9	PART FAMILY
E-4	PROCESS PLAN	E-10	PROCESS
E-5	MFG FACILITY	E-11	DIFFIC PROCESS
E-6	MATERIAL	E-12	TOOL
		E-13	MANAG REPORT

Table 7.3. The main entities of data model.

	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8	E-9	E-10	E-11	E-12	E-13
E-1		✓											
E-2				✓									
E-3				✓									✓
E-4					✓								
E-5													
E-6					✓								
E-7				✓				✓				✓	
E-8							✓						
E-9					✓								
E-10											✓		
E-11													
E-12													
E-13			✓										

Table 7.4. Primary relationships of process planning entities.

In general, the CAPP system should be capable of evaluating the set of factors and their alternative values for a particular motor design using internal and external information. This data will be considered using decision-making tools to allow re-evaluation and comparison of alternative specifications involving a variation of parameters and algorithms.

Figure 7.24 illustrates the IDEF1X model for the process planning function. Conceptual design data should be accessible by the CAPP system to evaluate design proposals in the early stage of design. This will reduce design time and optimise design and manufacturing activities. Other information resources must be integrated with the CAPP system such as manufacturing facilities, process specifications, machines, tools and materials. Information can be obtained from the internal and external system databases.

7.4.4 To Plan Production

The production planning function is supported by the PP&C system. This function includes several activities and tools for forecasting long term motor demands, MRP based upon demands for standard and non-standard motors and scheduling orders for manufacturing using associated resource profiles. This function provides key

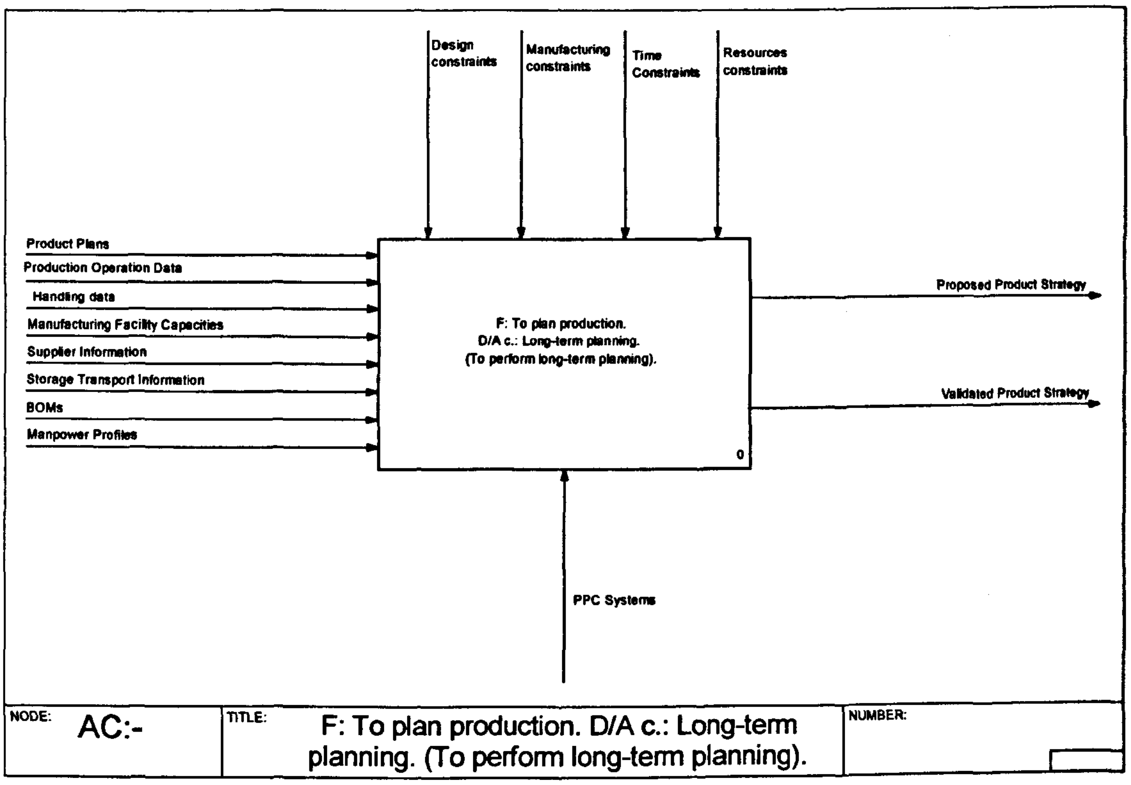


Figure 7.25. Top activity of long-term planning.

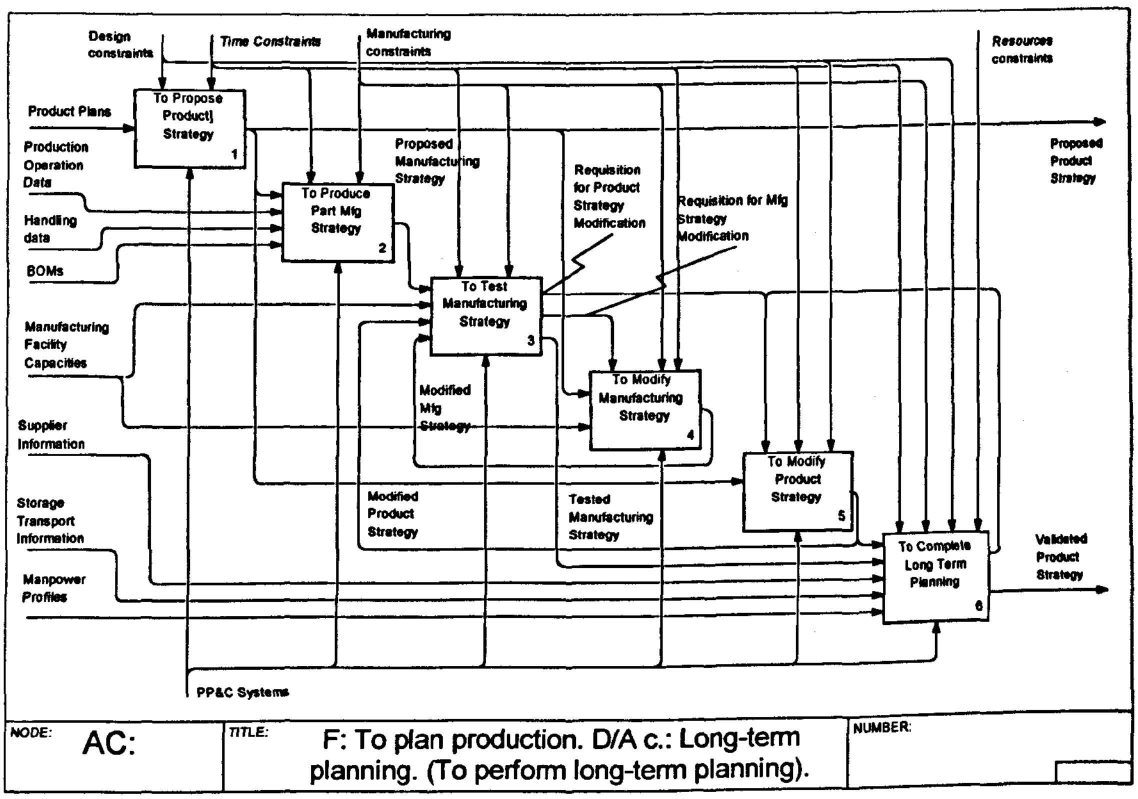


Figure 7.26. Sub-activities of long-term planning D/A centre.

information and links top management to the shop floor manufacturing systems. It is not possible to adopt the CIM strategy without a thoroughly effective PP&C system (Maisch 1993).

Forecasting of motor orders for a long period involves the simulation of manufacturing and assembly processes using data on forecast order profiles for both MTS and MTO productions. This requires mathematical modelling and effective data communication between system functions. The potential of different manufacturing systems resources should be identified within sufficient time scales to permit the advance planning of changes or development. Actual customer orders for electric motors and the orders resulting from weekly or daily statistical forecasting techniques provide the basis for planning production.

The production planning function involves four main D/A centres; a long term planning, order planning, medium term planning and short term planning, as illustrated in Figure 7.4. The following sections discuss these D/A centres in detail.

7.4.4.1 Long Term Planning

The electric motor involves many specifications that are changed and developed from time to time. The long term planning D/A centre plans and assesses the viability and effect of future product strategy and plans, including the introduction of new motor ranges, changes in volumes, etc. This D/A centre should provide effective results that enable production and product strategy to be assessed in terms of their effect on current manufacturing resources. These results can be used for other functions such as financial and marketing functions to evaluate any new or developing strategy in terms of cost and profit. Evaluation of strategies should be supported by powerful tools that enable the planner to examine the results using meaningful performance measures.

Figure 7.25 illustrates the D/A centre of long term planning as the top activity of the IDEF0 model. The model shows several inputs including product plans, production operation data, handling data, manufacturing capacities, supplier information, storage/ transport information, BOMS and manpower profiles. The controls are design specifications, manufacturing constraints, time constraints and resources constraints. This D/A centre is supported by the PP&C system. The outputs are proposed product

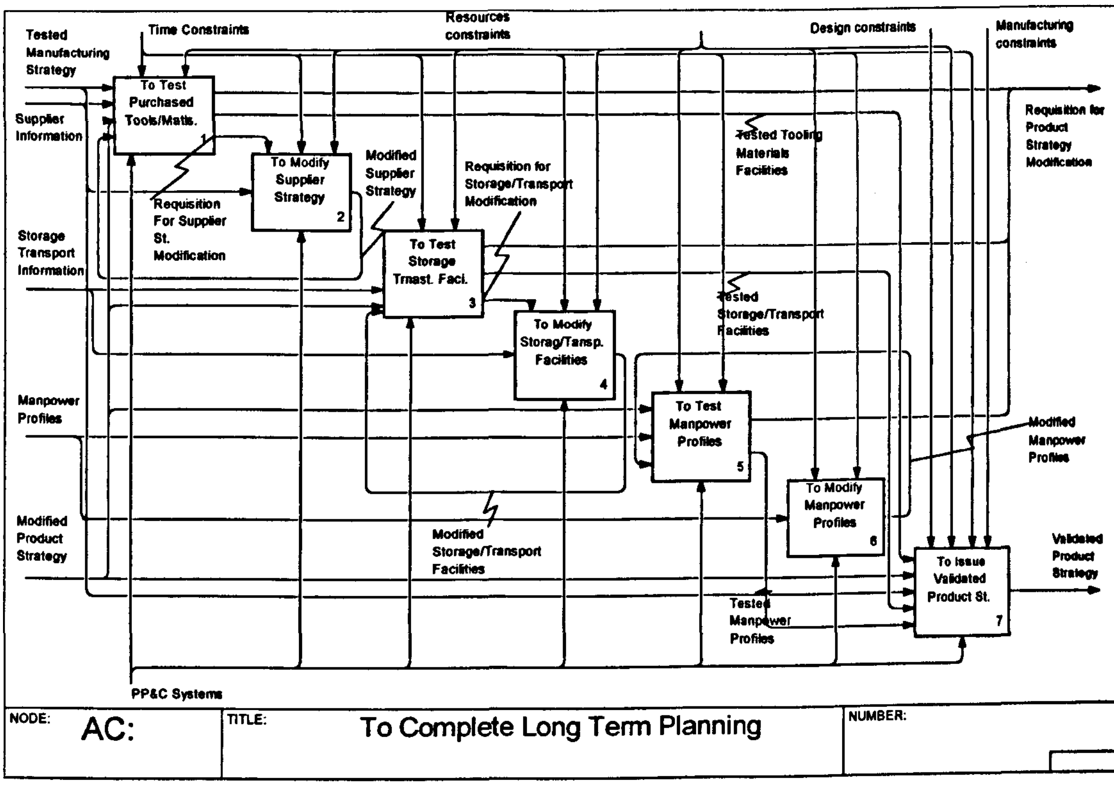


Figure 7.27. Child-activities of long-term planning D/A centre.

strategy and validated product strategy. The top activity is decomposed into several sub-activities as illustrated in Figure 7.26. Sub-activity AC1 represents formulating the product strategy and proposing different attributes related to specifications, volumes, powers, quantities, etc. The product strategy proposed in sub-activity AC1 provides general identification of products (motors). These new products proposed must be considered in more detail to modify the product strategy according to manufacturing and assembling operations using BOMs, as modelled by sub-activity AC2. It is important of this stage to identify the manufacturing facilities needed to produce the new product. Data related to manufacturing facilities should also specified. Sub-activity AC3 represents testing the manufacturing strategy based upon results obtained from preceding sub-activities. The manufacturing strategy can be tested using resource capacities during a specific time period. Manufacturing facilities can be compared and identified using different evaluation factors and attributes. New technologies can be also specified or requested at this stage. A comparison of existing technologies and planned technologies should also be prepared using capacity factors over the time period. Other factors such as adopting new manufacturing technologies and the removal facilities should be taken into account during testing and modifying manufacturing facilities. Sub-activity AC4 is carried out to modify the current manufacturing facilities based upon the proposed product strategy requirements. The modifications of manufacturing facilities are carried out based upon management decisions. Facilities capacities are very important factors in this D/A centre; hence, the removal of redundant facilities or introducing any facility modifications should be considered, if it is possible, to increase the manufactured volumes. These modifications will be tested again by sub-activity AC3 to optimise the capacities and requirements of the proposed product strategy. The proposed product strategy can also be considered and modified using results obtained from manufacturing facility considerations and other related resources. This is carried out by sub-activity AC5 in the model. Sub-activity AC6 represents other related components of the D/A centre that should be tested and modified. This sub-activity is broken down into seven sub-activities (AC61 - AC67), as shown in Figure 7.27. This child-model is regarded as part of the model illustrated in Figure 7.26 and its sub-activities carry out the same procedures as sub-activities AC3 and AC4 using different factors effecting the proposed product strategy. Sub-activities AC61 and AC62 are carried out to test and modify purchased items and supplier strategy according to the proposed product strategy. Testing purchased items and modifying this strategy and the product strategy will continue until satisfaction results are obtained. Sub-activities

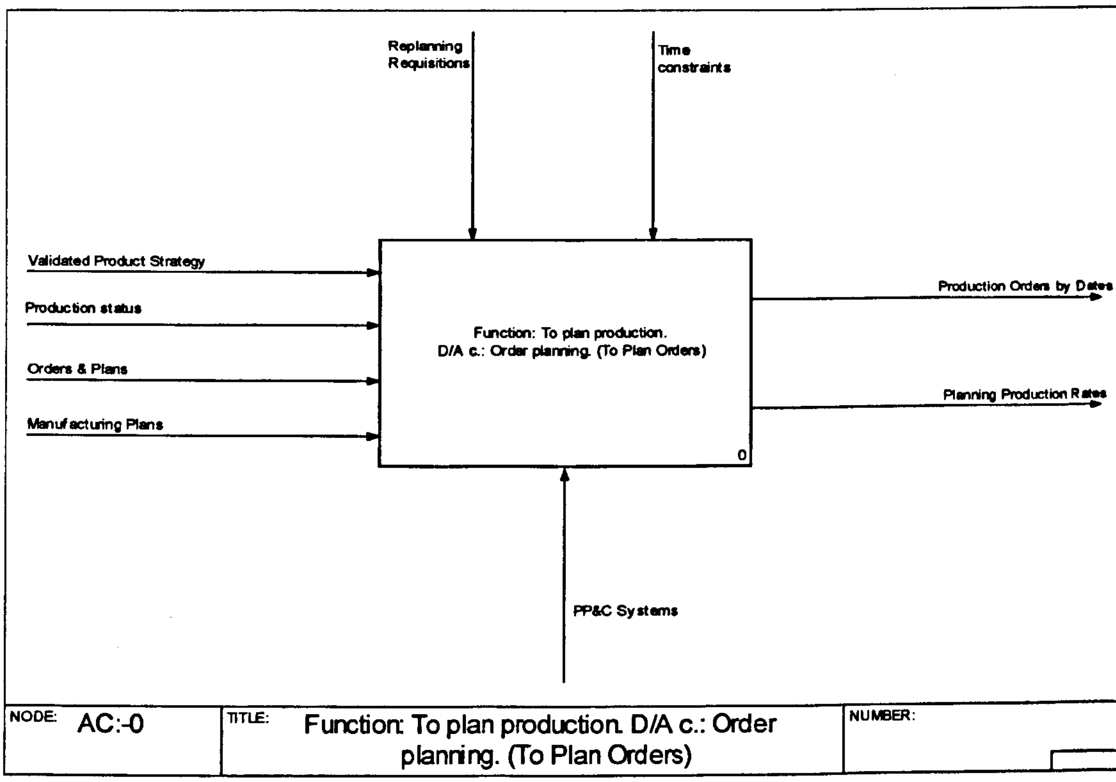


Figure 7.28. Planning orders D/A centre.

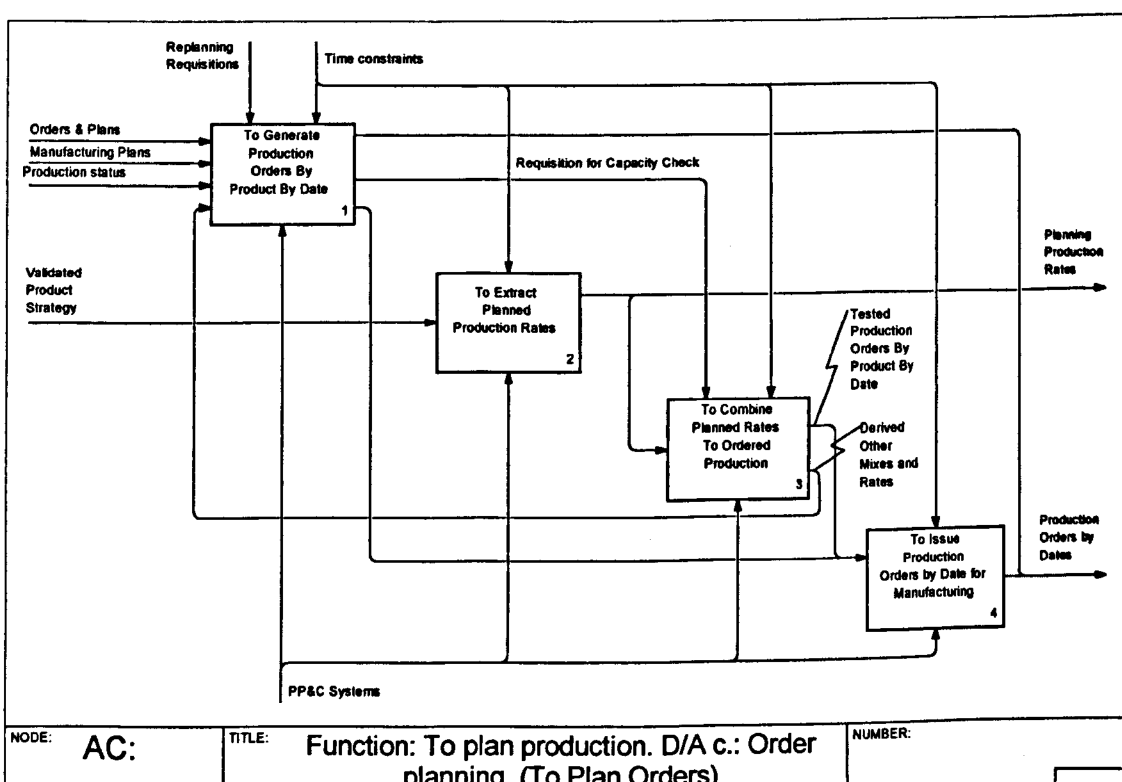


Figure 7.29. Sub-activities of planning orders.

AC63 and AC64 consider storage and transportation facilities and carry out any modification required. Sub-activities AC65 and AC66 are carried out to test and modify manpower profiles according to the proposed product strategy. Finally, Sub-activity AC67 is carried out to issue the product strategy as the basis for future planning in all company functions.

7.4.4.2 Order Planning

The order planning D/A centre is concerned with collecting orders together prior to manufacturing so that forward manufacturing requirements can be dealt with. The requirements of end motors may be to satisfy the known need of a customer, or it may be an internally generated speculative requirement to have finished motors available to meet customer specifications which are forecast for the future.

Figures 7.28 and 7.29 illustrate the IDEF0 model for the D/A centre of planning orders. Four inputs are illustrated by the model; they are orders and plans, manufacturing plans, production status and the validated product strategy. The controls are re-planning requisitions and time constraints, and the outputs are planned production rates and production orders by date. This D/A centre is decomposed into four sub-activities (AC1 - AC4) and supported by PP&C systems, as shown in Figure 7.29. Sub-activity AC1 is carried out to establish the requirements from production functions; it is necessary to compile motor orders to be produced with required lead times and quantities. There are several sources of orders such as customer orders, stock orders, special orders, re-order levels, etc. Sub-activity AC2 is carried out to retrieve production rates derived from the upper D/A centre. Both planned rates and order rates are combined in sub-activity AC3 to make changes to the manufacturing facilities or resource levels. Finally, sub-activity AC4 is carried out to issue a production order, by date, for manufacturing.

7.4.4.3 Medium Term Planning (MTP)

The MTP D/A centre is concerned with generating manufacturing programs based upon identified requirements. These programs are supported by sophisticated tools such as MRP systems and fed by relevant data from other manufacturing and design functions. This D/A centre is very important to forward planning for the next manufacturing

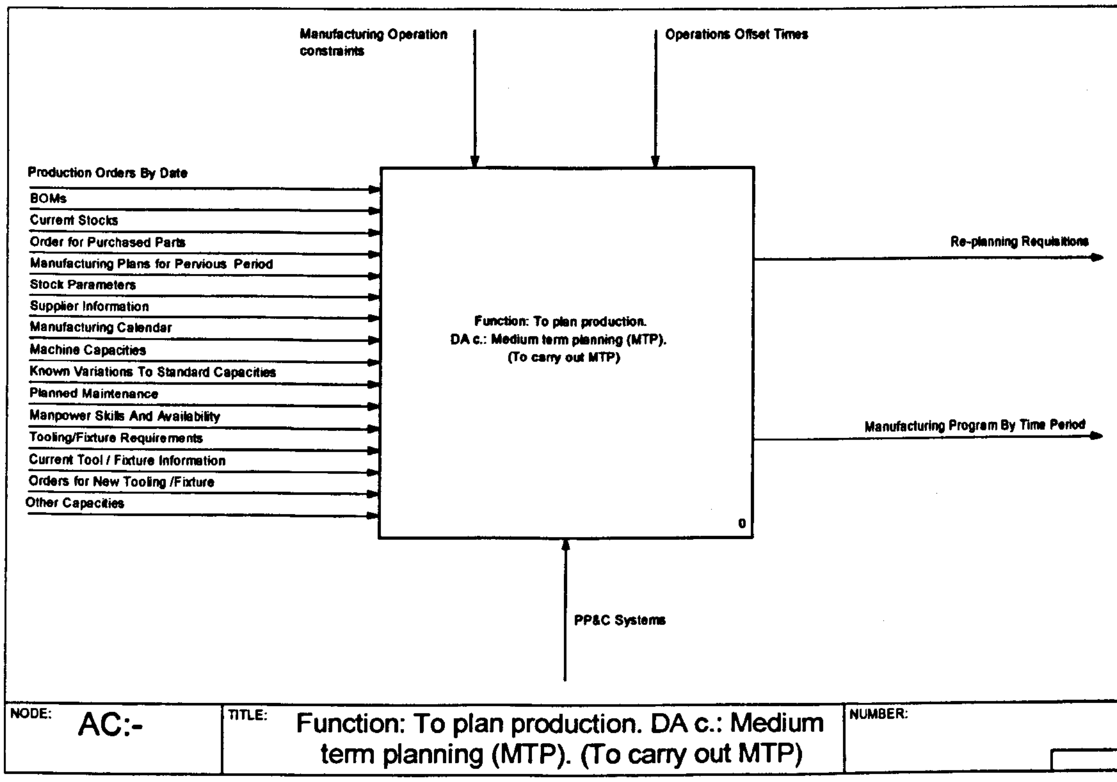


Figure 7.30. D/A centre of MTP

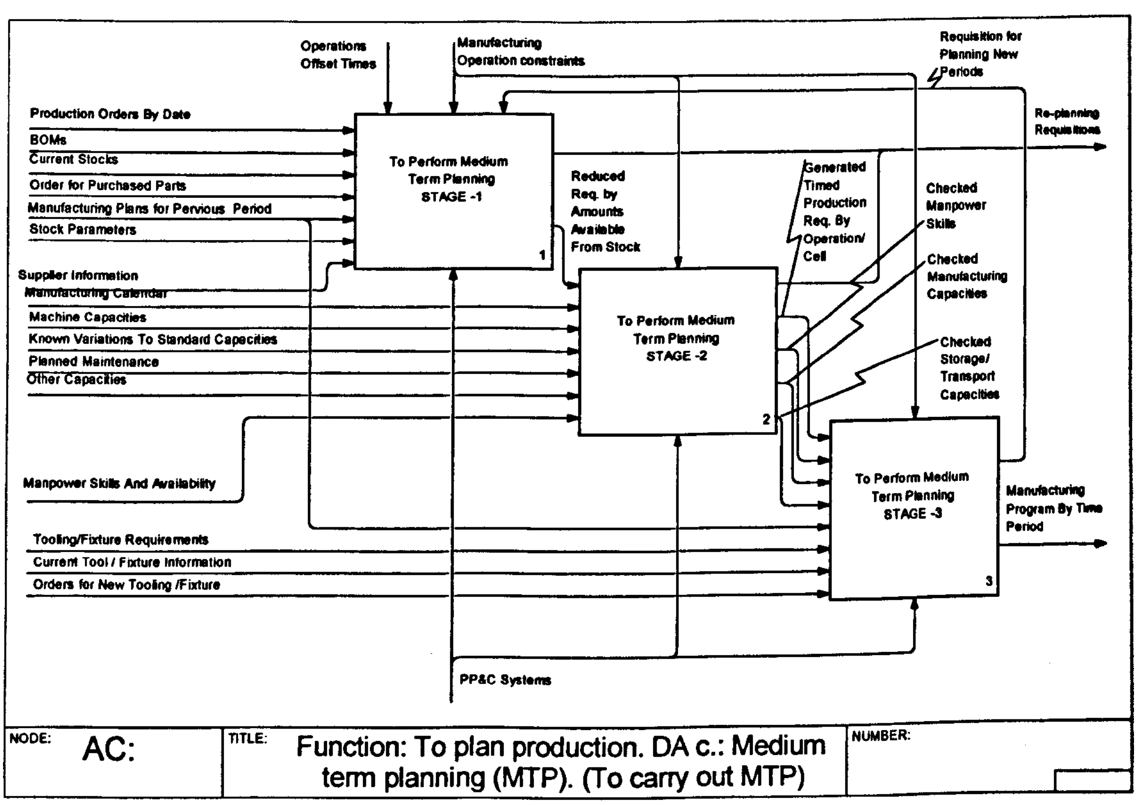


Figure 7.31. Stages of MTP.

system activities. This level is very difficult because all requirements need to checked within a particular time period. Figure 7.30 illustrates the MTP D/A centre as a top activity of the IDEF0 model. The model shows several inputs that are considered to produce manufacturing programs and/or requisitions for re-planning. The top activity of the model is decomposed into sets of child-activities which are grouped into three main groups for the purpose of simplification, as illustrated in Figure 7.31. Figures 7.32-7.34 illustrate the basic sub-activities of this D/A centre. Sub-activity AC11 is carried out to derive all parts requirements by time period. This requires motor BOMs and production orders by date. All manufacturing levels should be listed and timed from basic items and raw materials to finished motors. All production time can be considered period by period. Hence, the subsequent time period is modelled using results obtained from the preceding time period, as presented by sub-activity AC12. Sub-activity AC13 computes component or motor stocks levels at the beginning of each time period, using different data resources such as stock data, order for purchased parts and motor production for the previous period. Sub-activities AC14 and AC15 are carried out to deal with stock status according to stock obtained and supplier information. The company should consider the material or purchased parts for motors to be supplied from outside using computerised tools in order to utilise manufacturing facilities that meet customer lead times and eliminate supply problems. After examining the production requirement for each motor order, the production time required from each manufacturing element is derived. The manufacturing elements include assembly cells, part production stations, etc.; this is carried out by sub-activity AC21. The results obtained from AC21 are used by sub-activity AC22 which compares manufacturing requirements with capacity available. Sub-activities AC23 and AC24 are carried out to test existing storage/transport and manpower respectively. Sub-activity AC31 represents the generation of tooling, die, and fixtures associated with the motor parts or assemblies to be produced. The results obtained from AC31 can be used by sub-activity AC32 which checks existing tools, dies, and fixtures. When the plan for the period of motor production has been totally evaluated, plans should be recorded for the time period, as modelled by sub-activity AC33. Finally, sub-activity AC34 is carried out to issue a complete manufacturing programme for the time period. If all time periods of planning horizon have been evaluated and tested, final information can be delivered to other relevant manufacturing activities.

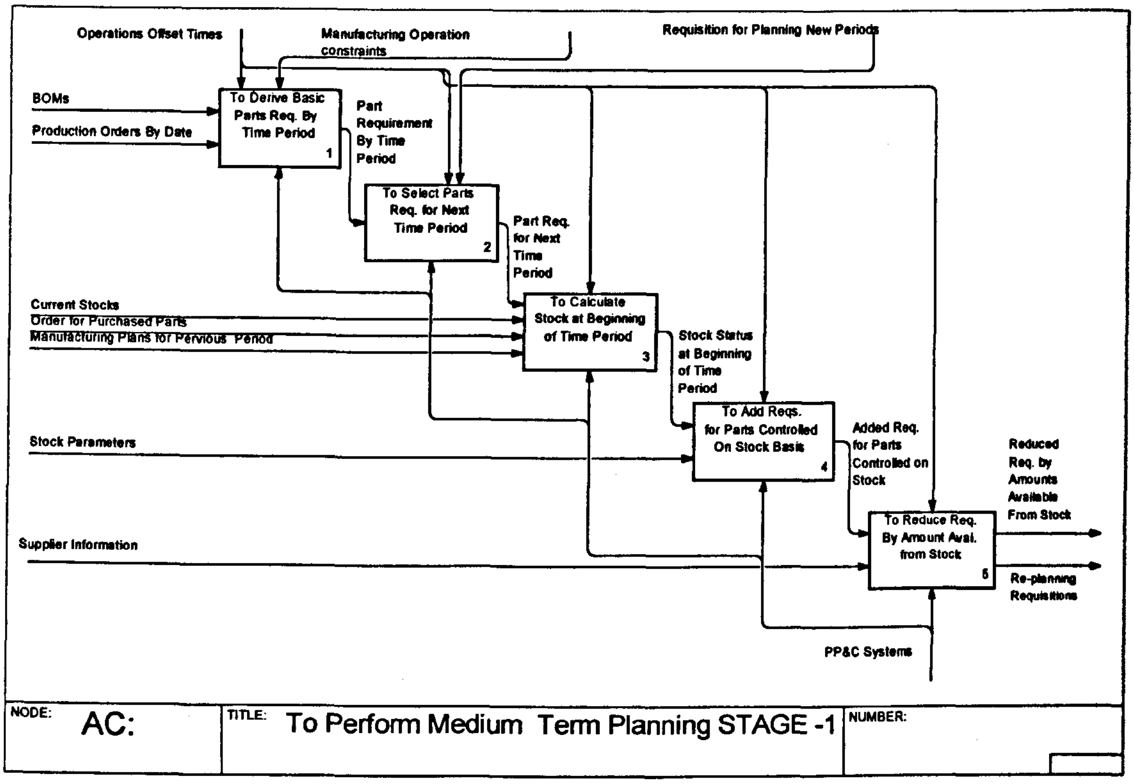


Figure 7.32. Sub-activities of stage 1 of MTP.

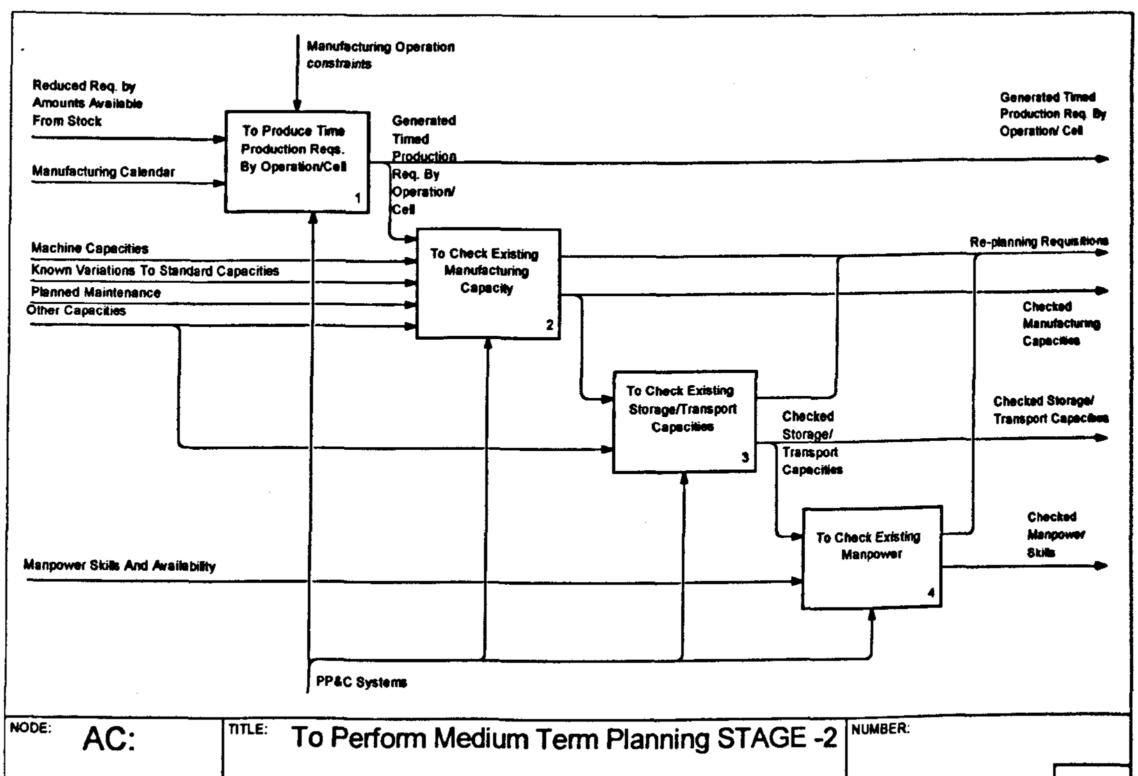


Figure 7.33. Sub-activities of stage 2 of MTP.

7.4.4.4 Short Term Planning (STP)

The STP D/A centre is concerned with actual scheduling and sequencing of production operations and the related facilities and functions. It achieves this by releasing orders for production in required volumes and frequencies. This is carried out for a short horizon; hence, it is important to consider the planned orders and compare them with current sources and facilities. The previous D/A centre (MTP) formulates the manufacturing programmes for a set of time periods. The STP D/A centre is very close to shop-floor activities; hence, several tasks can be changed and re-programmed at this level of decision based upon management decisions and manufacturing data. It considers only one time period according to the time scales identified.

Figure 7.35 illustrates the top activity of the IDEF0 model for the STP D/A centre. The model has several inputs; they are manufacturing programmes, production data, and time and attendance records. The controls are mix balance and sequence rules, time constraints and CAM restrictions. The main output of this model are re-planning requisitions and prioritised production schedules. The PPC systems support this D/A centre as well as other planning D/A centres. The top activity of the IDEF0 model is decomposed into eight basic sub-activities (AC1 to AC8), as illustrated in Figure 7.36. Sub-activity AC1 is carried out to determine the time period that needs to be considered for the current manufacturing programme. At the same time, sub-activity AC2 is carried out to check and identify finished motors and WIP levels using information provided from completed production files. Sub-activity AC3 inserts any modifications required to current programme based upon the current manufacturing environment. Using the output of sub-activities AC2 and AC3, the new production requirements are completed, as represented by sub-activity AC4. The results obtained from sub-activity AC4 are compared with the original requirements. This can be done using simulation tools, as modelled by sub-activity AC5. Following this, if the balance is different, a decision should be taken to re-plan production requirements (sub-activity AC6). Otherwise, the process can continue to start sub-activity AC7 which re-prioritises requirements. Many rules can be used for setting priorities based upon the computerised tools and scheduling techniques used. Finally, sub-activity AC8 is carried out to produce the prioritised current production requirements.

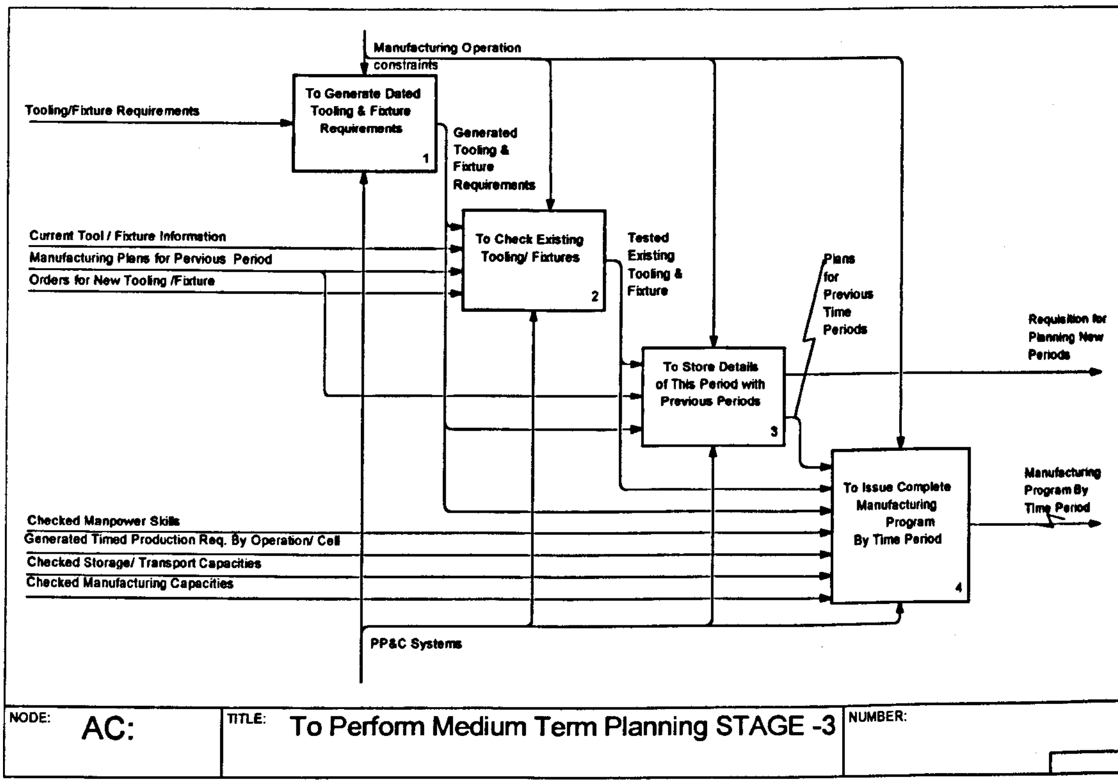


Figure 7.34. Sub-activities of stage 3 of MTP.

7.4.4.5 Data Modelling for PPC

The planning function represents the cornerstone for the manufacturing system of any industrial organisation. It involves important D/A centres that consider a variety of planning and control problems. It is be necessary to provide these D/A centres with the information required for decision-making. The PPC systems use many policies and philosophies such as MRP II, JIT, Kanban, OPT, etc. that can be employed for modelling planning activities based upon data collected from both internal and external resources.

The PPC systems have been developed considerably in recent years. The PPC philosophies, methodologies and techniques have been promoted as important supports for planning function. This function is totally different from one organisation to another; hence, no particular common structure can be derived for all D/A centres. Each manufacturing organisation should develop their own structure based upon new manufacturing strategies and their business and manufacturing objectives. For this case study, Brook Hansen must develop systems that support their planning and control functions, because most of the new software packages that are being brought into the market combine different functions in different ways. All this requires effective data modelling for all manufacturing activities.

Constructing data models for production planning function requires the identification of all the system entities relating to product strategy, structure of motors, existing capacities and capacity requirements. Because of the complexity of the production planning function and its direct and indirect relationships with other organisation functions, the data model is constructed to reflect the common subjects in planning function and to illustrate the main system entities related to the D/A centres of this function. Table 7.5 illustrates the D/A centres entities used for data modelling and Table 7.6 illustrates the initial relationships between the entities selected. These two tables are used to construct the IDEF1X model for the planning function.

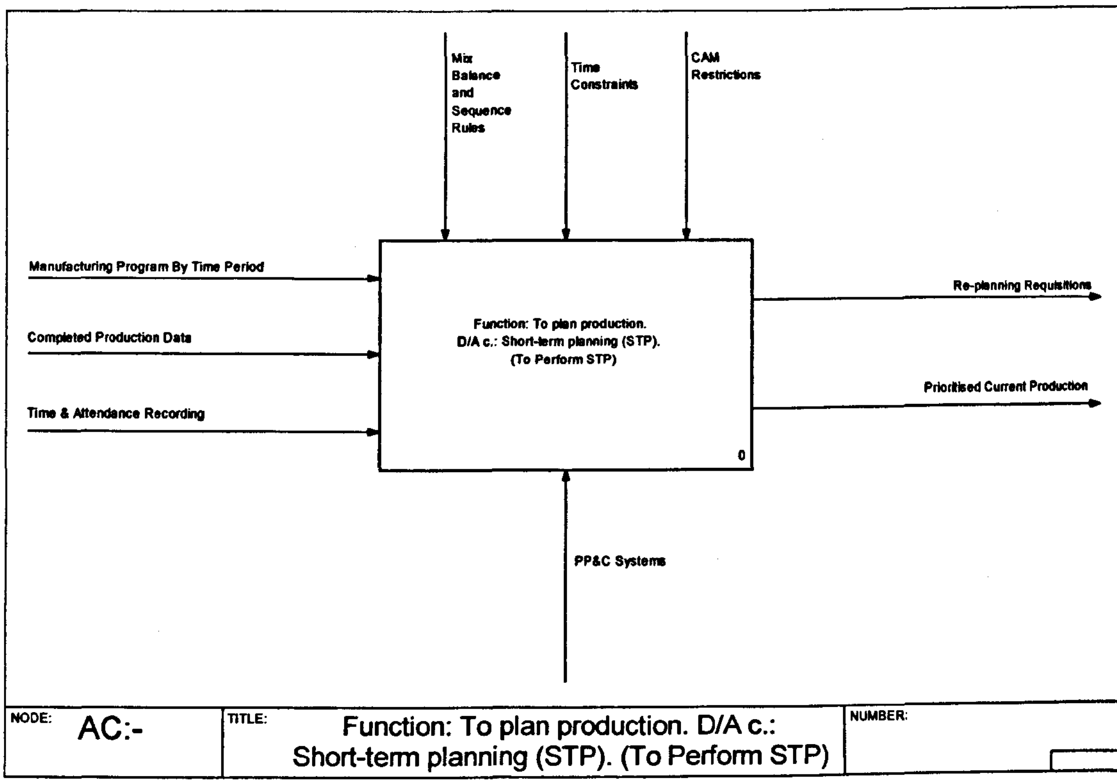


Figure 7.35. Top activity of STP.

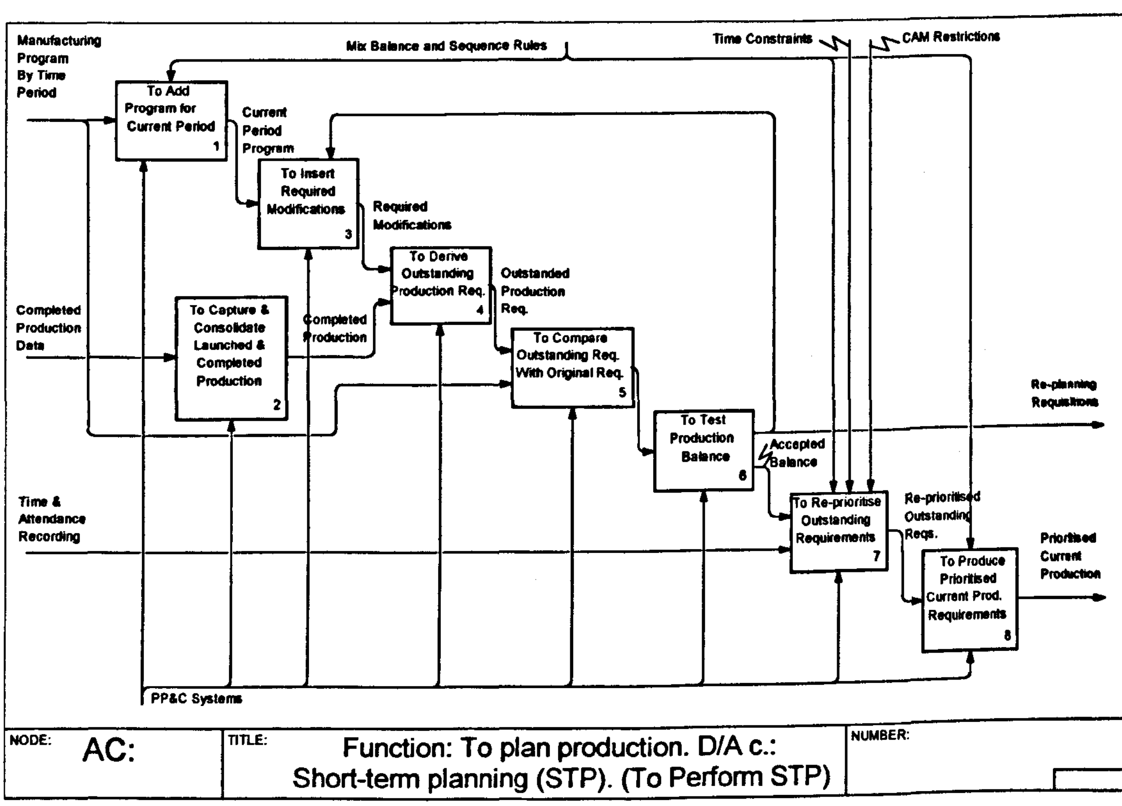


Figure 7.36. Sub-activities of STP D/A centre.

Entity number	Entity name	Entity number	Entity name
E-1	PRODUCT PLAN	E-12	TRANSPORTER
E-2	BOM	E-13	PLANNED PRODUCTION
E-3	PRODUCT	E-14	PRODUCTION ORDERS
E-4	PRODUCT STRATEGY	E-15	ORDER
E-5	MFG FACILITY	E-16	CURRENT PRODUCTION
E-6	STORAGE	E-17	COMMON PART
E-7	PART	E-18	MFG PROGRAM
E-8	HANDLING SYS	E-19	MFG CALENDAR
E-9	SUPPLIER	E-20	MFG TIME PERIOD
E-10	MANPOWER	E-21	SEQUENCE TECH
E-11	OPERATION	E-22	ATTENDANCE RECORD
		E-23	PRIORITISED PRODUCTION

Table 7.5. The main entities of data model.

	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8	E-9	E-10	E-11	E-12	E-13	E-14	E-15	E-16	E-17	E-18	E-19	E-20	E-21	E-22	E-23
E-1				✓																			
E-2			✓															✓					
E-3		✓		✓		✓	✓																
E-4	✓		✓		✓	✓			✓	✓	✓												
E-5				✓				✓		✓	✓												
E-6		✓		✓													✓						
E-7		✓						✓															
E-8							✓					✓											
E-9				✓													✓						
E-10				✓	✓																✓		
E-11				✓	✓																		
E-12				✓				✓															
E-13		✓												✓									
E-14													✓		✓	✓							
E-15			✓											✓									
E-16														✓									
E-17						✓			✓									✓					
E-18		✓			✓									✓			✓		✓				✓
E-19																		✓					
E-20																							✓
E-21																							✓
E-22																							✓
E23																		✓		✓	✓	✓	

Table 7.6. Primarily relationships of production planning entities.

Figures 7.37 and 7.38 illustrate the final IDEF1X models for the planning function. This model provides the basic data needed by the D/A centres of planning functions. This data should be in a form which will facilitate reformatting and reuse by different manufacturing activities. Production orders, priorities, date, quantities and other related data are associated by decision links from planning D/A centres to decision destinations.

7.4.5 To Make

The 'To Make' function in this model involves two main sub-functions 'To manufacture' and 'To assemble'. This function is supported by the CAM system which

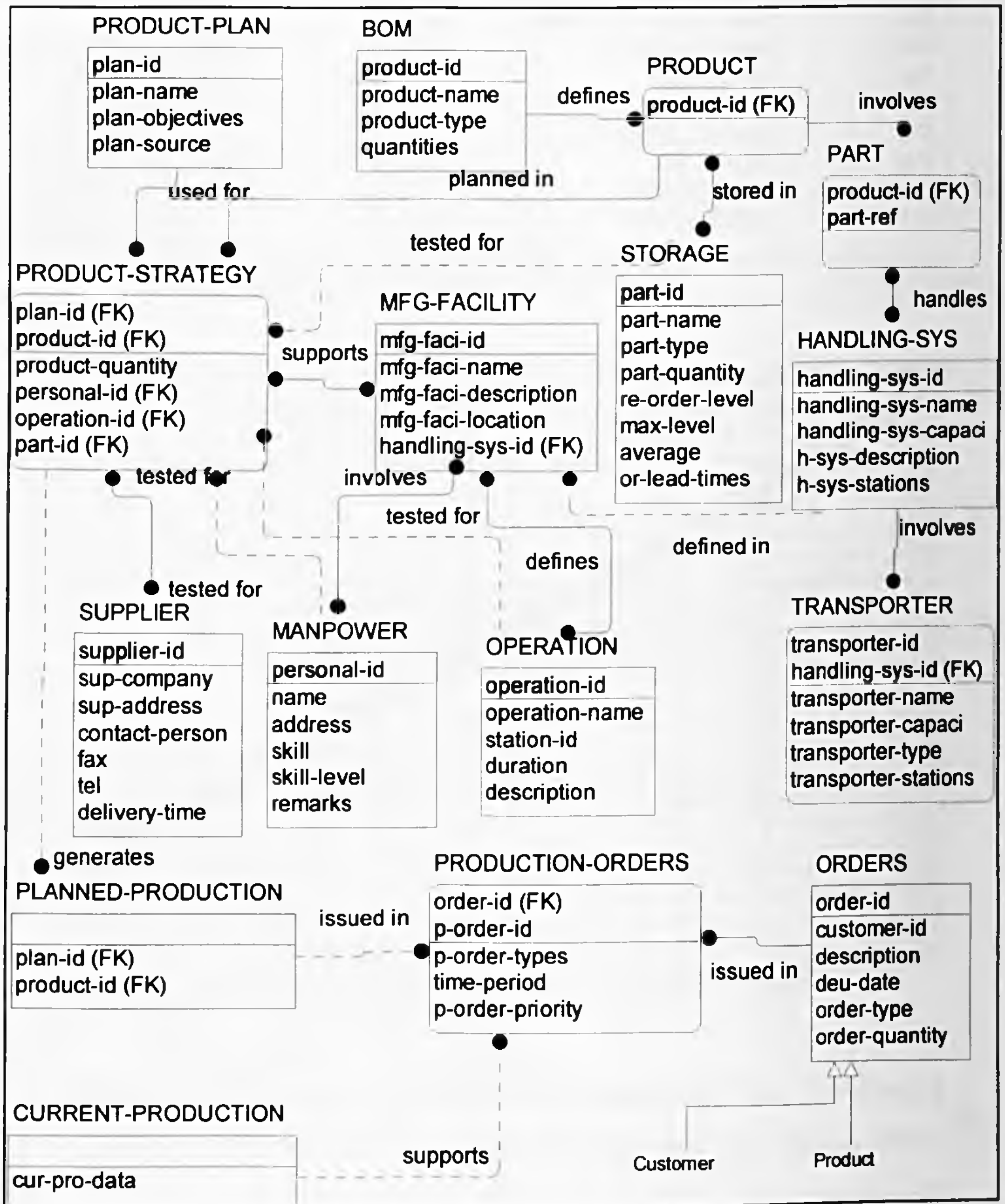


Figure 7.37. IDEF1X model for planning function (View-1)

controls and operates the production process according to the CIM concept. It should be noted that the manufacturing function is one of the most complex functions in any industrial organisation because it represents the basic environment for implementing management decisions and involves the interaction point between different sub systems (information, physical, and decisional sub-systems).

Modelling manufacturing functions is based upon the objective of the study. For example, the introducing of new manufacturing technology is based upon a management decision, but this decision should be supported by an effective analysis of the new facility suggested. This leads to the modelling of the new system using new manufacturing technologies obtained from facility suppliers. GI-SIM supplies the decision-makers with the required performance measures concerning the new technologies. On the other hand, modelling may be carried out to test manufacturing strategies or production programs using existing manufacturing technologies. This can be modelled according to data collected from other functions and management decisions. For example, implementing JIT, MRP II, Kanban, OPT, etc. can be tested to develop system performance levels and achieve planned objectives.

As previously described, this function involves two D/A centres; part production and assembly. Part production includes rotor, shaft and die-casting components. The assembly D/A centre involves motor assemblies and sub-assemblies, as discussed in the previous chapters. The final assembly line in Cell-100 is selected for demonstration in this research (assembly D/A centre).

7.4.5.1 Motor Assembly

Assembly lines are controlled and operated using components, data and decisions received from the related D/A centres. The GI-SIM modelling method can be used to design a JIT-Kanban system for the Cell-100 assembly line. According to the GI-SIM steps, the IDEF0 model is constructed for the assembly line selected. Figure 7.39 illustrates the top activity of this D/A centre. The model represents motor production procedures using data, material, and decisions obtained from other system functions. The top activity is decomposed into several sub-activities (AC1-AC6), as shown in Figure 7.40. Sub-activities AC1 and AC2 represent shaft and rotor production based upon JIT-Kanban orders received from the rotor assembly box. Rotor assembly is

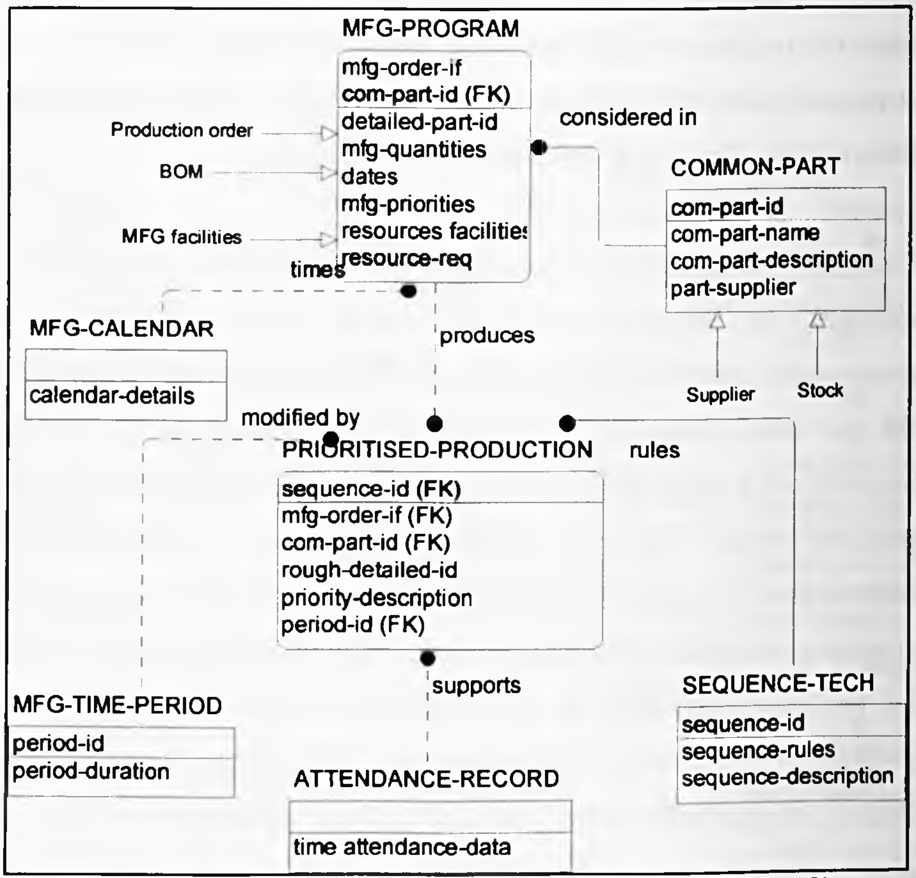


Figure 7.38. IDEF1X model for planning function (View-2)

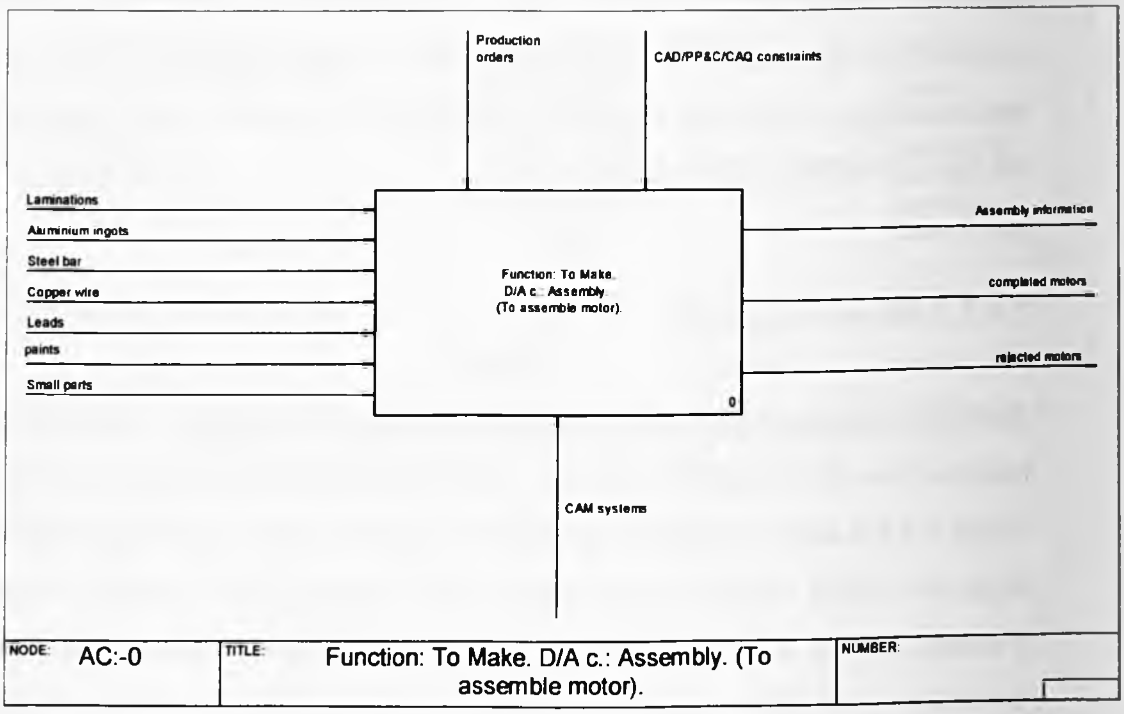


Figure 7.39. Cell manufacture of AI-100.

represented by sub-activity AC4, as illustrated by the IDEF0 model in Figure 7.40. Die-casting production is activated by assembly orders based upon production programs represented by sub-activity AC3. Sub-activity AC5 represents assembling windings which are controlled by the final assembly sub-model. Finally, all components and sub-assemblies are transferred to the final assembly line using a pull system, as represented by sub-activity AC6.

The final assembly line is fed by motor components based upon production orders. This is modelled by sub-activity AC6 which is decomposed into seven child-activities (AC61-AC67), as illustrated in Figure 7.41. Sub-activity AC61 represents the operation of the motor frame and wound pack assembly. Following this, machining operations are completed, as represented by sub-activity AC62. Then Terminal box, rotors and motor ends are assembled, as represented by sub-activities AC63 and AC64 respectively. The electric test is carried out by sub-activity AC65. If the motor meets the specification requirements, it is conveyed to a painting station which is represented by AC66. Finally, sub-activity AC67 represents fitting the motor fans and covers.

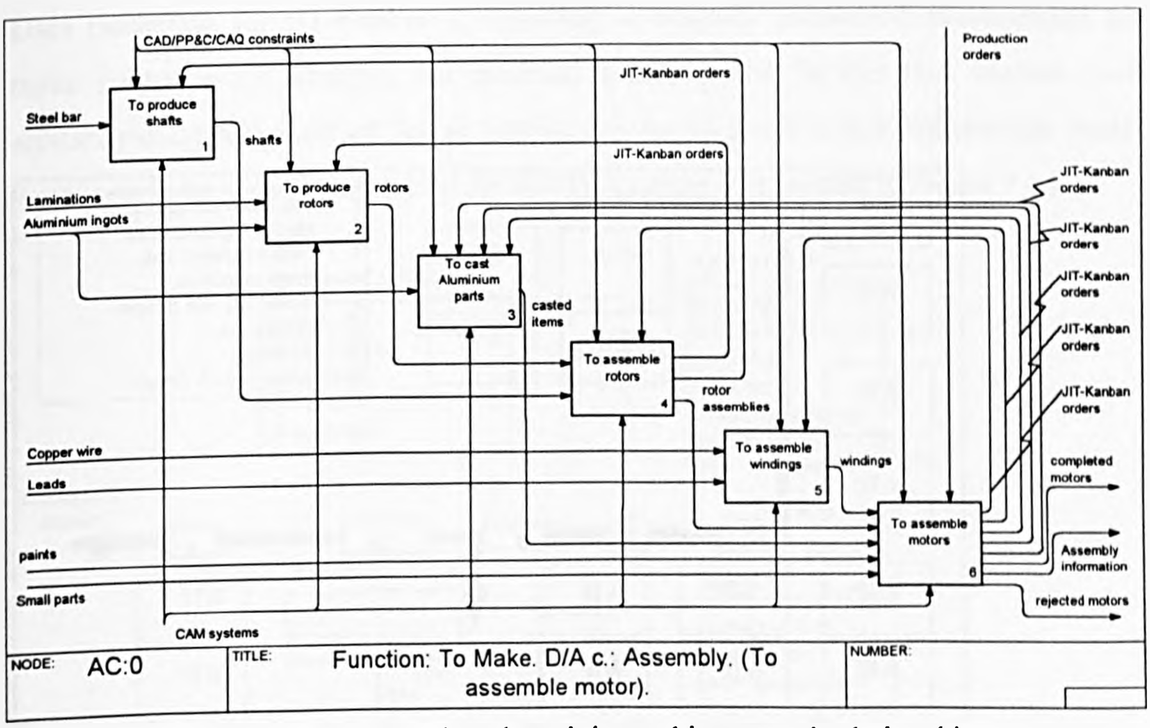


Figure 7.40. Assembly sub-activity and its control relationships.

Cell-100 is operated using MRP orders. It has been found that the WIP levels are very high, as discussed in chapter-6. Figure 7.42 shown the general layout of the final assembly for Cell-100 (existing system). Using the GI-SIM concept discussed in chapter-5 and CIM strategy, this assembly line can be re-designed using a new

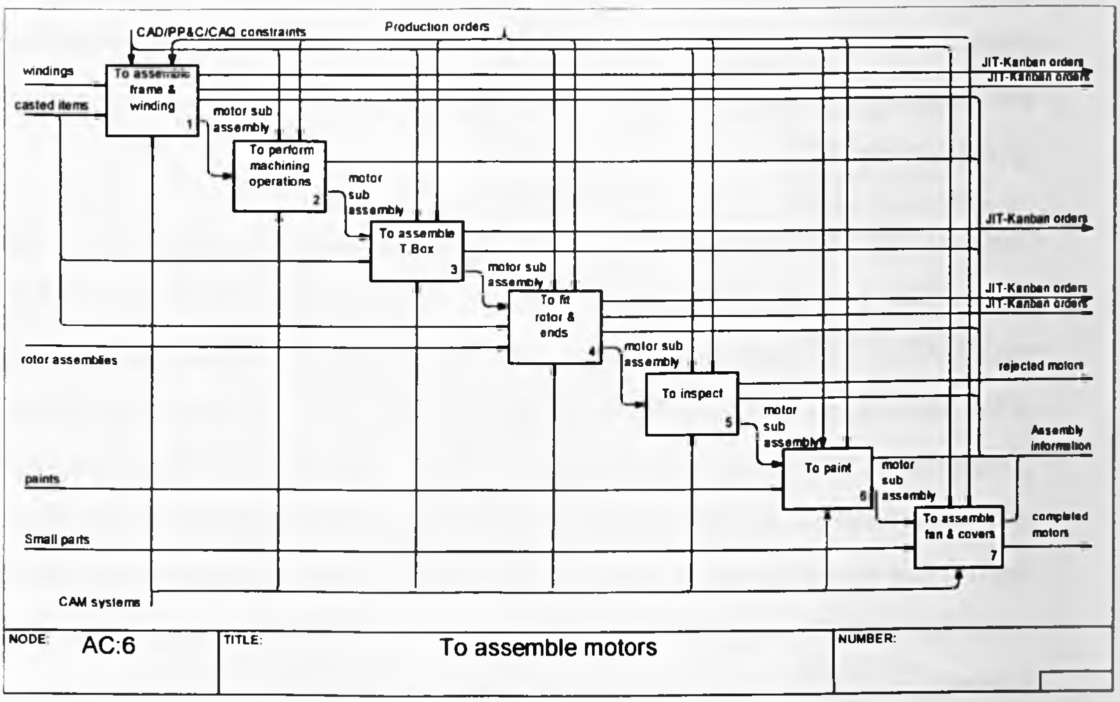


Figure 7.41. Child-activities of motor assembly line.

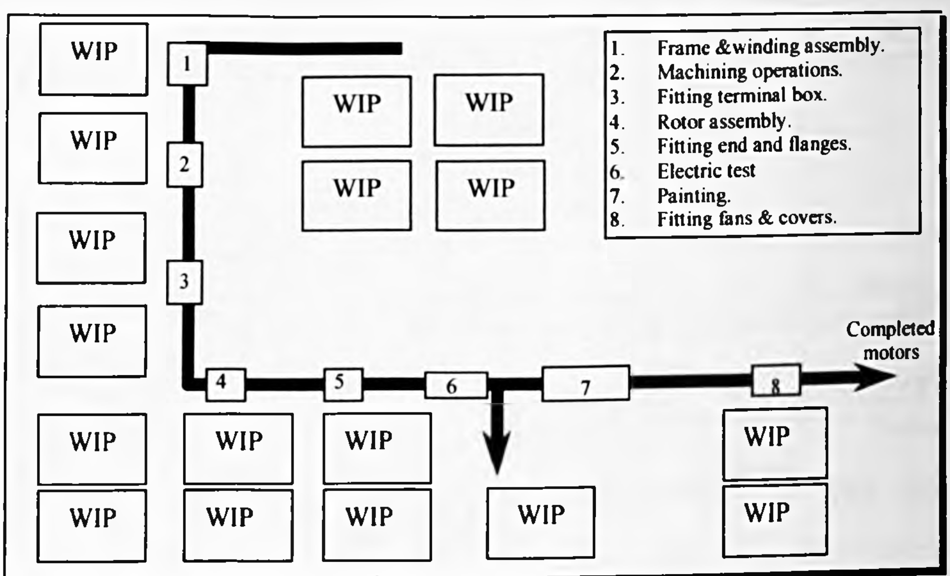


Figure 7.42. Current configuration of assembly line (Cell-100).

production program (JIT-Kanban) as well as other production models. This new production programme can be tested and simulated to reduce WIP levels and increase system flexibility. The proposed system is illustrated in Figure 7.43.

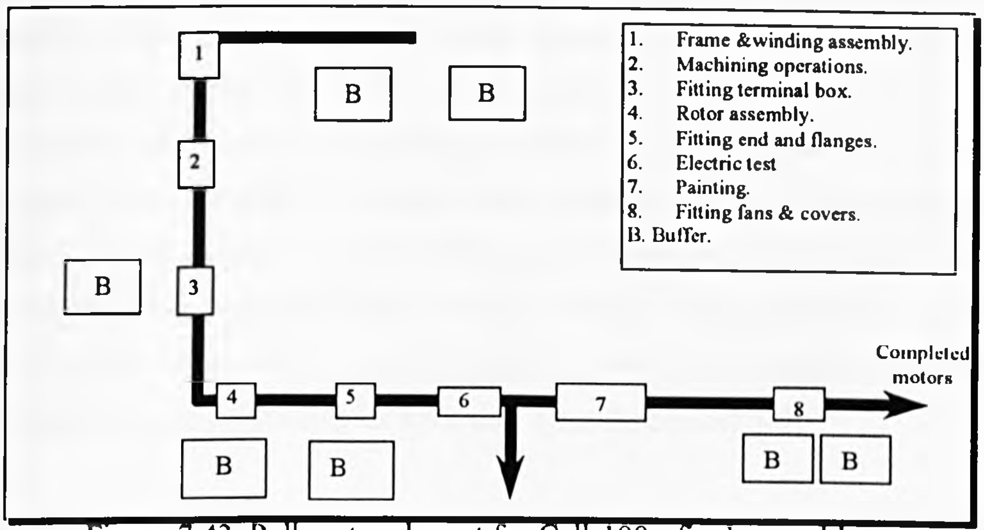


Figure 7.43. Pull system layout for Cell-100 - final assembly.

7.4.5.2 Data Modelling for Pull System

Data modelling for JIT-Kanban is requiring to simplify production management and make control more effective. To construct a data model for this D/A centres, basic entities should be identified. Many entities can be involved in this information model. An example for simple data model for this D/A centre is presented in Figure 7.44.

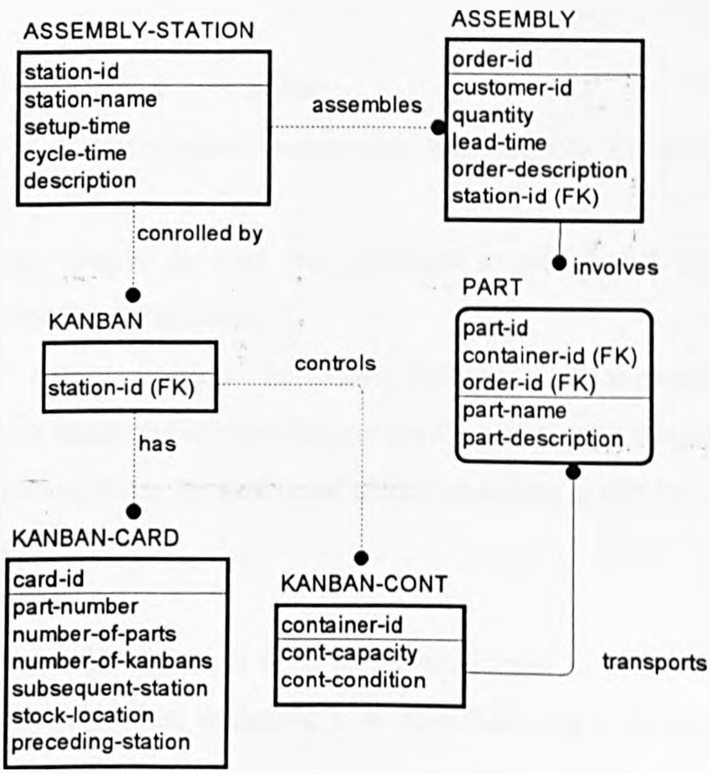


Figure 7.44. IDEF1X data model.

7.5. An Evaluation of GI-SIM for CIM Design

In this chapter, the GI-SIM method is demonstrated for the design of systems specifications for CIM components. The method has proved to be useful in the development of the complex manufacturing systems designs. By providing a well defined conceptual model of the CIM strategy, child-models of GI-SIM can be derived using functional objectives and modelling domains. Both top-down and bottom-up analysis approaches are used to integrate data modelling with functional modelling in the second phase of method procedure. CIM system design is a very complex task and still the subject of conflict, particularly in large manufacturing organisations. GI-SIM is a flexible method which can be used to model advanced manufacturing technologies and production programmes using its static and dynamic capabilities.

The D/A centres identified for CIM components can be specified the necessary level using the integrated concept of conceptual model and specifications of modelling domains.

Manufacturing objectives should be tested and measured for every function before adopting and implementing strategies. Decomposing manufacturing functions into their basic elements is not a difficult task but the most important thing is to determine how modelling outputs can be used to develop new systems.

Using GI-SIM for CIM design proves that:

- The method is comprehensive, expressive and capable of designing complex manufacturing systems;
- It is a coherent simple concept that provides a meaningful representation for different manufacturing functions;
- It enhances communication between different sub-systems in complex manufacturing systems and bridges the gap between static and dynamic aspects;
- It is flexible; hence, it can be generated using modelling goals for each D/A centre being considered.

Data linking between GI-SIM tools need to be considered to achieve a high level of accuracy and consistency when designing new manufacturing systems. This phase can be solved by supporting the method with sophisticated computerised interfaces which link the framework tools.

7.6. Conclusion

This chapter discusses CIM system design and illustrates how the organisation integration can be derived based upon business goals and manufacturing objectives. The importance of low level production programs i.e. tactical and operational programs is considered as basic and essential elements in business strategy.

The method introduces the design phase using a generic grid, combining the operational D/A centres of CIM and their associated control sub-systems, to demonstrate the benefit of integration by conceptual modelling. Every D/A centre is fed with the required data by linking different D/A centres using database systems as an internal information resource. Following this, the D/A centre is decomposed into its basic elements using GI-SIM tools. The method adopts both bottom-up and top-down analysis approaches during the design phase. Flexibility of the modelling method and the objectives of study control the size and complexity of design models for every D/A centre.

This chapter evaluates the modelling method developed in this research and demonstrates its capability for the analysis of complex manufacturing systems. GI-SIM is a comprehensive, expressive, flexible and simple modelling method suitable for system design. However, the method requires sophisticated computerised interfaces linking its tools to increase its capability and to eliminate data inconsistencies during model construction.

CHAPTER-8

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

8.1. Introduction

Throughout this thesis, specific conclusions related to the findings are presented at the end of each chapter. Therefore, this chapter presents a general discussion, conclusions, recommendations and the main findings of the research. This includes details of the work carried out, achievements and directions of future work.

8.2. Discussion

The need to develop an integrated modelling method for the analysis and design of complex manufacturing systems was the driving force behind this research. The initial motivation was obtained from a review of CIM systems and its modelling methods and techniques. Many authors have emphasised that the adapting a CIM strategy offers major opportunities for manufacturing and is a key to meet the challenges of future. It was discovered the lack of a modelling method to support the CIM analysis and design phases was a fundamental obstacle to CIM success.

To achieve business and manufacturing objectives by adopting a CIM strategy, a modelling method was required to support the analysis and design the advanced manufacturing systems. A modelling method should meet the requirements of complex manufacturing systems and avoid the limitations of existing methods. This provides an effective support to identify the shortcomings of systems and suggesting solutions to system complexities and problems.

8.3. Achievements of the Research Aims and Objectives

To achieve the objectives of this research, it was necessary to review the basic concepts of manufacturing systems. This review provided good background knowledge about the mission of manufacturing systems and their different classification methods. Several types of manufacturing systems were considered and compared, based upon a set of factors related to product type, quantities, sizes and layouts. It was found that manufacturing systems were moving towards low volume and high variety. This is because the consumer is becoming sophisticated and the market is becoming highly competitive. Therefore, flexibility is a very important factor in meeting customer requirements. To achieve an organisation's objectives such as systems flexibility, the general consensus agrees that manufacturing should be changed and a CIM strategy adopted (see Chapter-2). In Chapter-2 and Appendix-A, a review of CIM systems was carried out to consolidate the knowledge about this important strategy because the lack of a clear definition of CIM strategy affects its application and implementation. It was concluded that CIM should not be restricted to a specific definition; it is a direction, not a destination; it is an integrated manufacturing strategy not a set of technical organisational aspects; it is a concept not a computer programme; hence, it should be designed and configured and not purchased or transferred. The identification of CIM components and the method of integration are very important factors in CIM design. According to several studies reviewed in Chapter-3, there are different reasons for the success and failure of a CIM strategy. There have been frequent reports about the complexities and problems of CIM. Attran (1996) reported that the difference between success and failure of this manufacturing strategy depends on appropriate planning and the avoidance of pitfalls. Several problems and barriers to CIM success have been considered. These barriers can guide efforts to define and diagnose problems that occur during designing and implementing a CIM strategy. It was concluded that the effective modelling methods have an obvious contribution in solving many CIM problems. Without proper modelling methods, the analysis and design of CIM systems would be a very complex tasks. Based upon this, it is believed that the development of a new modelling method would benefit all CIM analysis and design aspects and assist analysts and designers to improve different manufacturing functions and sub-systems of this strategy. To achieve this, the objectives were established and approached, and completed as following:

1. Review of CIM Modelling Methods And Techniques

A modelling method can be defined as a set of principles which guide the analyst towards the solution of a problem (Chodari 1997). Modelling is the activity that is concerned with constructing system models, either for analysis or design purposes. Analysis models refer to an existing system and design models refer to the development of new system specifications. Several terms such as methodology, method, tool and technique have been widely used in modelling.

Models have been classified in different ways based upon different factors such as their ranging from the tangible to the abstract, corresponding to their application or according to their static and dynamic features. A literature survey identified several conceptual and structural modelling methods and techniques available for the analysis and design of CIM systems (Chapter-4). The conceptual structural methods selected were SSADM, IDEF techniques (IDEF0, IDEF1X, IDEF3 and IDEF4), SADT, OOM, GRAI, PN, IOA, GIM and MERISE. The reasons for selecting these modelling methods were: these methods have graphical components, show the hierarchical structure of complex systems, adopt the partition hierarchy and represent a comprehensive sample that covers most modelling objectives and system requirements.

2. Comparison and Evaluation of Modelling Methods

The methods and techniques selected were reviewed in detail. Several issues comparing and evaluating modelling methods were also presented (Chapter-4). These issues have been carried out based upon factors identified by the authors. It has been found that the evaluations and comparisons of modelling methods were very complex and that the results of any such work is likely to be criticised. However, a framework was developed for comparing and evaluating the modelling methods. This framework is composed of five elements; modelling objectives, inputs, practice, models and outputs. Each element in this framework involves several factors to test specific details of the modelling methods. The reasons for constructing the frameworks for comparison were that there is no general method known for the evaluation and comparison of modelling method. Most existing evaluation issues were developed for specific applications. Derivation of the framework factors was dependent on the modelling objectives and the complex manufacturing systems requirements. The framework developed was used to compare the modelling methods and techniques selected in this research, as illustrated in Table 4.4 (Chapter-4). It was concluded that no single modelling method or technique meets all the requirements necessary for the analysis and design of CIM systems. Most existing modelling approaches can only support particular aspects of manufacturing systems. Several researchers attested to this result e.g. Brandimarte and Cantamessa (1995), Chadha et al. (1991), and Aguiar and Weston (1995).

It was concluded that there was a need for an integrated modelling method that could be created by selecting potentially cognate groupings of existing modelling methods and techniques and extending and unifying them to support different aspects of CIM systems. The combination of systems methods brought together in CIM offers many advantages for modelling this complex system.

3. Simulation Modelling

CIM is a dynamic system thus it was necessary to review and discuss simulation modelling in CIM (Appendix-B). Simulation is one of the most important tools for the analysis and design of manufacturing systems. Its concepts, languages, advantages and disadvantages were discussed in this research. It has been found that the selection of the simulation language is a very complex decision because it is dependent on several factors. It has been concluded that simulation modelling needs to be integrated with static modelling approaches to achieve the vertical integration of abstraction levels and the horizontal integration of specification domains in manufacturing systems.

4. Development of an Integrated Modelling Method

An integrated modelling method (GI-SIM) was developed to support the analysis and design phases of CIM systems (Chapter-5). This modelling method was developed as a result of the CIM analysis and design requirements, and the limitations of existing methods and techniques. The method combines the advantages of existing methods and eliminates their drawbacks. It was formulated to integrate four modelling tools (GRAI grid, IDEF0, IDEF1X and SIMAN/ARENA). Several authors suggested that the integration between existing modelling methods and techniques would offer advantages for the analysis and design of complex manufacturing systems Colquhoun et al (1993), Hsu et al. (1995), Aguiar and Weston (1995), and Brandimarte and Cantamessa (1995). Therefore, GI-SIM was designed using a set of existing modelling tools and employs the strength of each to cover the systems modelling needs. The method achieved two types of integration; the first is a vertical one that links the levels of abstraction (conceptual, structural and dynamic) and the second integrates five system domains (decision, functional, information, physical and detailed) (chapter-5), as illustrated in Table 8.1.

GI-SIM tools	Abstraction level	Domains
GI-SIM grid	Conceptual	Decision
IDEF0	Structural	Functional Physical
IDEF1X	Structural	Information
SIMAN/ARENA	Dynamic	Detailed

Table 8.1. Matrix of GI-SIM structure.

GI-SIM was constructed to be simple to implement and to use. It also provided concise graphical representation for complex systems in order to understand the general behaviour of the sub-system environments using its first phase. In the second phase, IDEF0/1X were used in GI-SIM to assist in generating structured functional and information models for the D/A centres specified in the first phase of the method. Finally, the method adopted SIMAN/ARENA to develop its static model to include the dynamic model.

A computerised tool was developed to support GI-SIM and to increase its capabilities (Chapter-5). It assists in designing the conceptual level of the method developed by using several user interfaces. These were constructed using a visual computer language. The tool developed represents a key to defining the specifications of method for the future development.

5. An Evaluation The Method Developed For The Analysis of Manufacturing Systems

The GI-SIM modelling method was tested and demonstrated by the analysis of manufacturing systems. For this research, the manufacturing organisation selected was Brook Hansen Motors. A background of the company selected was presented in Appendix-D. The GI-SIM was applied to the existing manufacturing systems of the company selected (Chapter-6).

It was found that the GI-SIM was an effective modelling method for manufacturing systems analysis. It identified the main functions of Brook Hansen Motors in one level of grid and decomposed every decision/activity centre into its basic sub-activities and elements using IDEF0. The physical sub-system in the company was modelled dynamically using the third step of the method. This analysis proved the flexibility of the method and its simple procedures for considering existing systems. Modelling details are related to the study objectives and are different from one D/A centre to another. The objectives of the validation of GI-SIM using a case study were to validate the method and to help in intensifying any shortcomings within the manufacturing systems of the company selected. The analysis identified several problems within the system. The lack of effective interfacing between the GI-SIM tools caused difficulties in data exchange between the modelling levels and domains. Recommendations for the future improvements were suggested to the company in light of this analysis.

6. An Evaluation of The Method Developed For The Design of CIM Systems

The GI-SIM was also tested for the design of CIM components (CAD, CAM, CAPP, etc.). The objectives of this were to evaluate the method for the design of CIM systems and to construct a well-defined base for the design system specifications of CIM components. Designing of CIM components was established based upon the objectives of the D/A centre. It was suggested that CIM was a convenient manufacturing strategy for the company selected. General formulation of this strategy was presented and structured in Chapter-7. It was proved that GI-SIM was an excellent modelling method for the design of advanced manufacturing systems. The method lacks the computerised interfaces which support tool linking and data exchange between its models.

8.4. Directions for Future Research

This research is one step in the continuing process of building and developing modelling methods and techniques for the analysis and design of complex manufacturing systems. The following topics need to be investigated in future research:

- Linking business strategy and CIM strategy.
- Configuration of design specifications for operational CIM.
- Future developments of the GI-SIM method, include:
  - Interfacing the GI-SIM Method.
  - Linking its modelling procedures with a data dictionary.
  - Generating IDEF0 models.
  - Generating data modelling by identifying conceptual and functional models.
  - Generating simulation models and experiments using functional and physical models automatically.

8.4.1 Linking Business and CIM Strategies

The application of CIM strategy in the majority of manufacturing companies is currently incorrect. Most authors deal with specific aspects of CIM components (Gunasekaran et al. 1994). The strategic issues for linking the business and CIM strategy have not been considered properly. CIM impacts the strategic issues, and also affects detailed operational issues (Weatherall 1992).

The initial investigation within this research indicated the need for a new manufacturing strategy and highlighted the importance of CIM as a manufacturing strategy. The adoption of this strategy is not a day trip but needs established long-term plans, constructed and based upon identified business needs and low level production programs towards the attainment of business and manufacturing goals. Therefore, there is a need to develop a strategic framework for the development of CIM. This requires a clear understanding of the integration of different areas of the organisation. The suggested strategy should fully support the objectives of the business strategy and bridge gaps at an operational level.

8.4.2 Configuration of design specifications for the operational CIM

Suitable configurations of operational CIM should be designed according to established business and manufacturing objectives. This will help identification of the sub-activities and elements of the manufacturing system under consideration. This will also contribute to the definition of features of the new systems required by the new strategy to improve computability of manufacturing functions. To complete this work, an effective modelling is required such as GI-SIM.

8.4.3 Future Development on GI-SIM

This research established a very important concept and framework for the GI-SIM modelling method. To develop this modelling method and to increase its capabilities, the future development of the following is suggested:

1) Interfacing GI-SIM Method

The translation of modelling information between the method tools is very important. This requires sophisticated computerised interfaces that help the model builder to explore and use the same identifications of D/A centres on all modelling levels and domains. These interfaces should be designed to filter sub-system flows at a conceptual level and be defined according to IDEF0 rules at the structural level. Many decision and information links cannot be represented during construction of the GI-SIM grid. Using tool interfaces, the grid links should be classified according to modelling domains according to ICOM definitions. This step would be very important to eliminate inconsistencies in the inputs and outputs of modelling tools.

Translating structural models into simulation models also requires effective interfacing to obtain specific definitions for the lower levels of D/A centres. This interface should be flexible enough to transfer simulation modelling requirements based upon the objectives of the study. The definition of system entities for data modelling should also be derived from functional models. Then, the identification of IDEF1X elements can be generated using IDEF0/1X interface.

2) Linking GI-SIM Tools with Data Dictionary

It is suggested that the GI-SIM tools are supported by a data dictionary. This aims to provide the modelling method with the required information to define common features. This occurs gradually as an additional service across application systems. A data dictionary helps to produce models faster and with higher quality. It eliminates the problem of communicating data among specialised system models.

Identification of information enables the different levels and views of the modelling methods to share information. The data dictionary, imported from specific applications, can also be used to construct system models based upon high data accuracy.

Information identified by the data dictionary can be classified according to modelling domains and abstraction levels or according to the D/A centre type and its related system flows. This research will also contribute to solving data integration problems.

4) Generating IDEF0 Models

To improve timeliness and method consistency, the automatic generation of IDEF0 models in GI-SIM is proposed. This will reduce the construction time of the GI-SIM model and eliminate the inconsistencies problems of the current procedures. The generation of IDEF0 Models can be achieved using the GI-SIM grid data, data dictionary and knowledge-based system. The knowledge-based system involves rules that are used to translate the description of D/A centre and its related information into functional or physical models.

5) Generating Data Modelling

GI-SIM adopted the IDEF1X technique to support information modelling in manufacturing systems. The method used the main information links presented at the conceptual and structural levels to construct data models in one or more views for each D/A centre. The automatic generation of data models is a key issue. All information presented by the GI-SIM grid and IDEF0 should be captured using a computerised tool that can be developed to generate data models in IDEF1X format. This research will classify entities received based upon their dependencies and use a data dictionary to generate entity attributes. Existing IDEF1X software can be used to translate formatted data into graphical models according to the rules of the technique.

6) Generating Simulation Models and Experiments

Generation of SIMAN models and experiments for static models is a very complicated task owing to the large number of variables that need to be defined during the automatic generation. The dynamic behaviour of the system activities can be specified using a set of rules and conditions. This can be achieved for limited applications in manufacturing. It would be very difficult to use these rules and conditions for complex manufacturing applications because the identification of activities using static model tools would be more difficult than constructing SIMAN models and experiments directly. However, computability of static model tools and simulation packages may be achieved in the future. Hence, the development of computerised tools for the automatic generation of simulation models will be effective for limited applications but can also contribute to solving the problems of system inconsistency in the age of computability.

8.5. Concluding Remarks

The work described in this research had several initial objectives. The first was to review the main concepts of manufacturing systems. The thesis reviews several classification schemes of manufacturing systems. It has been found that there is a move towards patching production systems because of customer requirements and increasing competitiveness. It has been concluded that manufacturing organisations are looking for strategies and tools to develop their systems and to stay competitive. The literature review indicated that the CIM strategy was one possibility for the development of manufacturing.

The second objective was to review CIM systems in details. It was found that the difficulty in understanding CIM strategy and the difference between the success and failure of this manufacturing strategy depended on appropriate planning. Moreover, the lack of proper modelling methods for CIM analysis and design represented a fundamental obstacle to CIM success.

The third objective was to review existing CIM modelling methods and techniques. Several methods and techniques were reviewed and compared according to a set of factors related to the modelling objectives and systems requirements. It was concluded that no single modelling method or technique could support the different aspects of complex manufacturing systems: decision, functional, information, physical and dynamic aspects. This research found that the combination of modelling methods and tools to model CIM offers many advantages for the analysis and design of this complex manufacturing strategy.

The fourth objective was to develop an integrated modelling method for the analysis and design of CIM systems. This method has been developed in this thesis, based upon the establishment of a number of factors. The method developed combines four modelling components: the GRAI grid, IDEF0, IDEF1X and SIMAN/ARTENA to achieve vertical integration between levels of abstractions and horizontal integration between modelling domains. A computerisation of the method has been developed to support conceptual modelling and to identify tool specifications for more research work.

The fifth and the sixth objectives were to evaluate GI-SIM for the analysis of manufacturing systems and for the design of CIM. A case study was carried out using the method developed. It has been found that the method is simple and flexible to use in the analysis phases. The method was also used for the specifications of CIM components. It can be concluded that the method is an excellent and effective manufacturing modelling method. The main limitation of the method was found to be a lack of proper computerised interfaces to reduce model-building time and eliminate the inconsistencies of its models.

The directions of future research presented in this chapter will improve the method presented in this thesis and increase its applications in manufacturing.

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