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An Approach to Resource Modelling in Support of the Life Cycle Engineering of Enterprise Systems

by

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A Doctoral Thesis

Submitted in partial fulfilment of the requirements for the award of

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Synopsis

Enterprise modelling can facilitate the design, analysis, control and construction of contemporary enterprises which can compete in world-wide product markets. This research involves a systematic study of enterprise modelling with a particular focus on resource modelling in support of the life cycle engineering of enterprise systems.

This led to the specification and design of a framework for resource modelling. This framework was conceived to:

- classify resource types;
- identify the different functions that resource modelling can support, with respect to different life phases of enterprise systems;
- clarify the relationship between resource models and other modelling perspectives
- provide mechanisms which link resource models and other types of models;
- identify guidelines for the capture of information on resources, leading to the establishment of a set of resource reference models.

The author also designed and implemented a resource modelling tool which conforms to the principles laid down by the framework. This tool realises important aspects of the resource modelling concepts so defined.

Furthermore, two case studies have been carried out. One models a metal cutting environment, and the other is based on an electronics industry problem area. In this way, the feasibility of concepts embodied in the framework and the design of the resource modelling tool has been tested and evaluated.

Following a literature survey and preliminary investigation, the CIMOSA enterprise modelling and integration methodology was adopted and extended within this research. Here the resource modelling tool was built by extending SEWOSA (System Engineering Workbench for Open System Architecture) and utilising the CIM-BIOSYS (CIM-Building Integrated Open SYStems) integrating infrastructure.

The main contributions of the research are that:

- a framework for resource modelling has been established;
- means and mechanisms have been proposed, implemented and tested which link and coordinate different modelling perspectives into an unified enterprise model;
- the mechanisms and resource models generated by this research support each life phase of systems engineering projects and demonstrate benefits by increasing the degree to which the derivation process among models is automated.

Key Words: Resource Modelling; Enterprise Modelling; Enterprise Integration; Enterprise Engineering; Resource Classification; Resource Capability Classification; CIMOSA.

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1.0 Introduction

1.1 A Brief Review of the History of Technology Development

No other animal has systematically tried to improve its living conditions in the way that man has. An evident characteristic of man is the need to progress.

Archaeological evidence of our early history confirms the presence of tools, fire and artifacts even though the dating of their earliest use is not always possible. As communities have organised and progressed by the aid of specialisation and the division of labour so civilisations and empires have risen and fallen. Knowledge and invention have developed and died, only to be reinvented and to spring up elsewhere. Communities physically cut off by geography or race - such as in China - have often developed or used technology in parallel with, or even in advance of, more studied civilisations of the Middle East, Indus Valley and Mediterranean Basin. History and prehistory is largely a study of society and the technology that has underpinned its developments.

A commonly accepted classification of the history of technology is to describe the development by “ages”; such as “Stone Age”, “Pottery Age”, “Iron Age”, “Machine Age”, “Power Age” and “Information Age”. Therefore, historical periods have been classified according to the “dominant technology” of that period of time. Based on this common knowledge, a brief historical review of the development of technology is presented by author in Table 1¹. This review supports the following observations:

- Human beings have taken a very long time to progress from making simple tools to making machines; approaching 3 million years.

- The so-called “Industrial Revolution” followed revolutionary progress in technology. It only took about one and a half centuries for Britain to become industrialised.
- Today, “Information Technology” is the dominant technology. It already has a tremendous impact on all aspects of our lives and the pace of its development is much quicker than at any previous age including the “Industrial Revolution”. It is still difficult to predict its potential for the future.

On reviewing the development of technology from a manufacturing engineering view point, it is possible to consider the degree to which “automation” and “integration” have been achieved. The basis of the author’s observations in this area are summarised by Figure 1 which emphasises the following facts:

- There has been a clear trend towards increased levels of “automation”² and more recently (systems) “integration”³. Thus far movement along these directions has been made in a step by step manner. For example, the automation of tools has led

1. In order to gain a good understanding of the technological developments and position this research, the author conducted a broadly-based literature survey of the history of technology development. The survey was carried out from two angles and the outputs are presented by Table 1 and Figure 1. The references used to develop Figure 1 are clearly marked in the diagram with each step of industrial advance. Also a number of books and papers were reviewed to produce Table 1. The information shown in this table is largely abstracted from Bracegirdle et al [Bracegirdle et al, 73] (for the machine age and power age), Clark [Clark, 85] (for the stone age, pottery age, bronze age, iron age and information age), Cossons [Cossons, 75] (for the machine age and power age), Henderson [Henderson, 69] (for the machine age and power age) and Martin [Martin, 70] (for the information age).

2. Automation: the original meaning of automation was described by Groover: “automation is a technology in which a process or procedures accomplished by means of programmed instructions usually with automatic feedback control to ensure the proper execution of the instructions. Although automation can be used in a wide variety of application areas, the term is most closely associated with manufacturing.” [Groover, 94].

3. Integration: in the manufacturing arena use of the term “integration” has become increasingly commonplace since the term “computer integrated manufacturing” was coined in 1973. Now the term “enterprise integration” is used commonly, particularly by academic researchers worldwide. A holistic view of an enterprise including manufacturing, organisation, business strategy, etc. is emphasised and is discussed in more detail in the following chapter.

Ages	Industrial Revolution						Information Age
	Stone Age	Pottery Age	Bronze Age	Iron Age	Machine Age	Power Age	
Approx. Period	3 million - 3000 BC	5000 - 2000 BC	3000 - 1000 BC	1500 BC - 1000 AD	1750 - 1850	1850 - 1914	1940 - to Date
Brief Description of Progress of Technology	Humans only made tools with stones; Chipped flints with polished edges for cutting, slicing and piecing; Use of fire; Hunting, fishing and food gathering society; Simple shelter Beginning of settled agriculture	With settlement came crafts such as Pottery; Weaving of wool; Basket work; Simple earthenware pottery; led onto decorated and fired pottery	First metallurgy, metals separated from their ores e.g. copper artifacts; Copper with arsenic and tin impurities were harder; Use of copper and tin to yield hard alloy bronze; Worked edge tools; Specialisation in the workplace; Improvements in agriculture; Communication and trading developed	First use of iron was from nickel rich meteoric iron; Iron replaced copper bronze as iron ores discovered in Middle East; Origins of chemistry; Glass making; Paints and dyes; Soaps and perfume.	Use of coal and coke instead of charcoal for making iron and steel made large quantities of iron and steel available; Development of machine tools; Cotton spinning techniques; Horse and water power used; First factories; Roads, Bridges, Canal and Railway developed; People moved to towns from countryside	Britain became the "workshop of the world" supplying portable engines; Steam engine had been further developed; Electrical power came into use; Use of oil; New and improved machines using electric powered rotary and reciprocating motion for metal cutting; Mechanically driven automatic machines; Hydraulics textile machines; Printing; Electric motor trams - transport; Electric telegraph - communication.	Need for code breaking in Second World War triggered the development of the first computer Colossus; Numerical control machines; Computer used in manufacturing process control; Office Automation; Design Automation; Planning Automation; Computer into banking, shopping, education, children games, etc. Internet / World Wide Web;
Examples of Typical Tools, Devices and Machines Invented	Stone axe; Scrapers; Flint arrow head; Knives and Bone needle.	Beakers; Flasks; Statuettes Utensils; Woolen cloth Solid wheel; Clay tablets.	Bronze tools and weapons; Swords Daggers; Lance heads; Gold and silver ornaments; Coins; Spoked wheel; Sickles for cutting crops.	Shovels; Adzes; Saws; Plowshares; Weapons; Armour; Cooking pots; Nails; Advanced harness for pulling plows; Carriages.	Steam engine / pump (in mines); Beam engine; Textile machines for spinning cotton; Spinning Jenny and spinning mule; Boring mill; Drilling machine; Grinding machine.	Steam power-turbine; Otto cycle internal combustion engine; Electric motors; Electrical power distribution; Lathe; Telegraph; Powered flight	UK Colossus computer; USA ENIAC computer; Transistor; Integrated circuit; Microprocessor; Personal Computer; CNC machining centre; FMS; Word processor; AUTOCAD; etc.

TABLE 1. Illustrative Historical Review of Technical Development

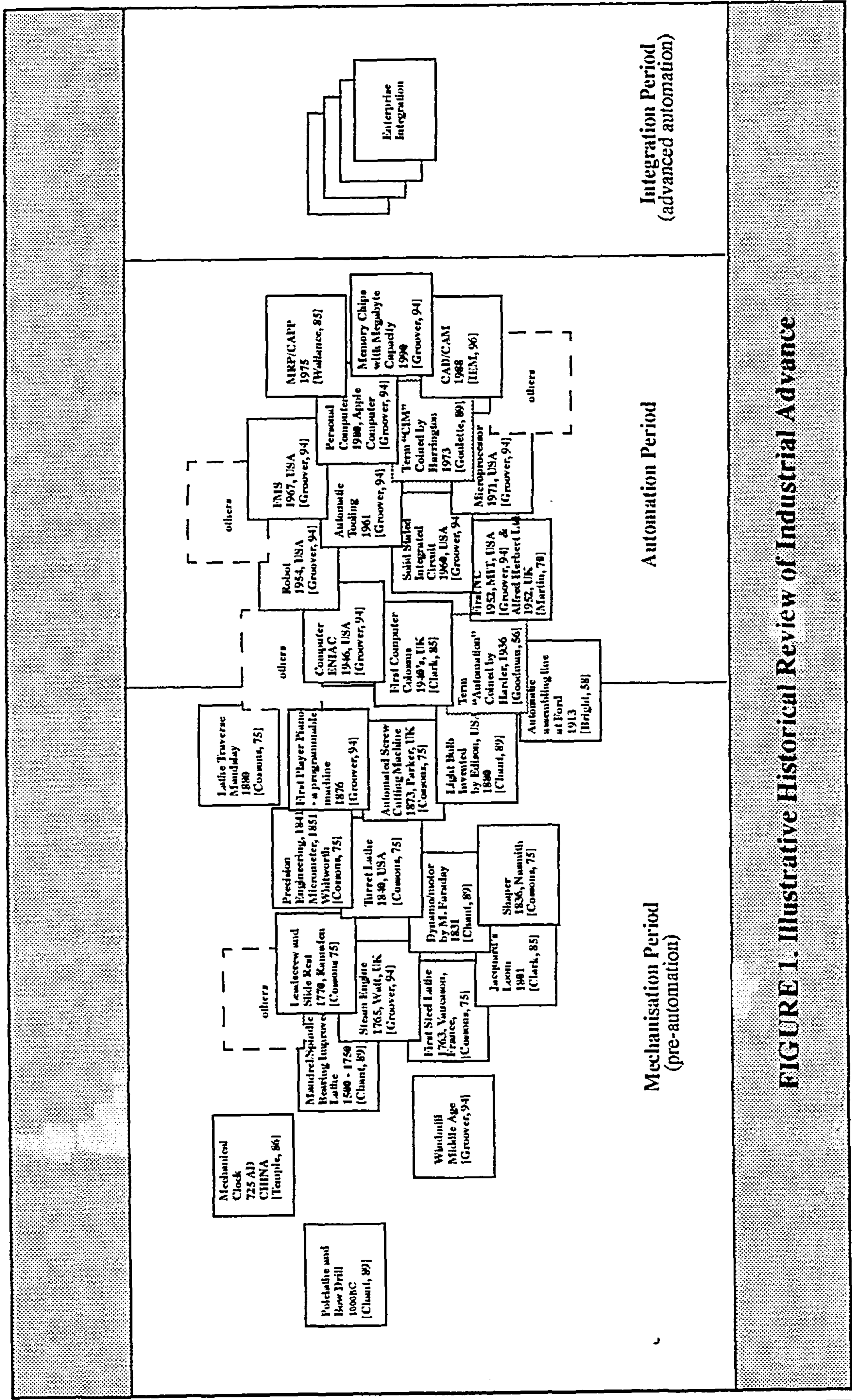


FIGURE 1. Illustrative Historical Review of Industrial Advance

to the automation of machines, and then automated systems, involving small scale systems then progressively systems of larger scale. Related to such developments have been advances in integration technology which have been necessary to facilitate automation through the integration of components on an increasingly wider scale.

- During the mechanisation period components and machine tools were developed in a mechanical sense. This can be viewed as laying necessary ground work for the subsequent “automation period”; as it provided well-proven reusable components which could subsequently be integrated into systems.
- The term “automation” was initially and commonly used to refer to electro-mechanically controlled machine tools, material handling systems, production lines, and the control of the process industries where human actions and simple decisions were carried out by machines. After computers were applied in manufacturing, the use of the term “automation” was extended to encompass the combined use of alternative forms of technology (eg electronic devices, electro-mechanical components and various sensing elements) such as to that used to produce computer controlled machines (NC, CNC, DNC). The term was also used in other manufacturing domains such as cell control systems, flexible manufacturing systems (FMS), continuous process control systems, computer-aided design and manufacture (CAD/CAM) tools, computer-aided process and production planning (CAPP/MRP, etc.), and office automation. Over the period 1965~1980 the focus of automation moved perceptibly from individual machines to small scale systems.
- The “automation period” has not ended in as much as further advance in supporting

or replacing man can be expected. Nonetheless the scope of the term “automation” has already been widened well beyond the original meaning to encompass the “integration” of components into systems, and the integration of systems into business process and enterprises. Indeed as reusable components have begun to emerge, increasing emphasis in the field of automation has been placed on integration aspects. This has given rise to what the author refers to as the “integration period”, which essentially presumes the availability of suitable reusable building blocks (components) of a system which can be integrated together and used in many different ways.

- In respect of the integration period, the full shape of developments remains unknown. As does the nature of the next period after the “integration period”. However, the much increased research focus on “Enterprise Integration” (detailed discussion of which will be included in Chapter 2) is a natural recognition of the growing importance of “integration science” and the wide scope of modern systems which need to be controlled as a unified entity.

1.2 The Nature of Enterprise Integration

Enterprise Integration concepts have arisen to solve problems of developing large scale business systems and to cope with issues which apparently have not been addressed before on a similar scale.

- Enterprise integration issues traverse *physical integration* and *application integration* problems, and also their relationships with *business integration* issues⁴;

4. These terms are used in conformance with CIMOSA terminology [CIMOSA, 93] which will be considered in detail in later chapters.

- Enterprise integration concepts embrace the coordination, management and control of various manufacturing processes, business processes, strategy formulation, human and organisation factors etc.
- The focus of enterprise integration is not on how things should be made, rather it is on how things demonstrate collective behaviour. This requires an understanding of how each component of an enterprise system behaves and how it interacts with other components; hence it concerns issues such as how to connect and coordinate system components so that they achieve business and production goals.
- Arguably, research in the field of enterprise integration is for the first time treating complex manufacturing enterprises as a single system; therefore its concepts need to encompass and build upon system theory, system thinking, system engineering, human behaviour, organisation research etc. In this way various research disciplines are actively contributing to enterprise integration research. “Enterprise Modelling”, which could encompass and unify many disciplines within a methodology, has widely been recognised as a primary means of specifying enterprise integration requirements and thereby enabling the design and analysis of alternative enterprise configurations and systems.

1.3 The Research Project

In view of the foregoing, the author believes that:

- the development of enterprise integration concepts will be key to the design of the next generation of manufacturing systems;
- enterprise modelling is a key technology which requires further development to realise the full potential of enterprise integration.

Based on the above understanding and a consideration of research environment needs, the author's PhD research project seeks to advance enterprise modelling research with a particular focus on enabling and using resource modelling in support of the life cycle engineering of enterprise systems.

In order to cope with inherent complexity in enterprise systems, it is necessary to model enterprises from different viewpoints; commonly accepted modelling views include function, information, resource, organisation and cost views. Significant work has already been carried out in respect of function modelling and information modelling, but far less emphasis to date has been placed on resource modelling, organisation modelling and cost modelling.

Resources are the building blocks of an enterprise. Resources generally can be considered to be "components" which can be reused in different ways. Knowledge about resources in terms of their nature, their relationships with each other and with other aspects of an enterprise provide the means to explore alternative enterprise configurations. In turn, information technology can be deployed to describe resource modelling constructs which can underpin enterprise integration in a formalised way. Hence, a systematic study of resources and the establishment of a framework for resource modelling are critically necessary.

This PhD research focuses on establishing a framework for resource modelling. The author has specified a framework which involves a definition of basic concepts, a classification of resources and a clarification of the function of resource modelling and relationships between resource models and other modelling views. This work has

helped identify key research issues and means of solving associated problems. Furthermore this framework has required the definition of appropriate resource information constructs. Having defined a resource modelling framework, a resource modelling toolset was designed and implemented to test the concepts in two case study domains. Also the framework established by this research has been partially evaluated and opportunities for improvement outlined. Detailed research objectives and plans of this study are presented in Chapter 3.

1.4 The Structure of the Thesis

The structure of this thesis and the focus of each chapter is represented diagrammatically by Figure 2. Also if the reader requires a short form summary of the thesis contents and findings reference to Figure 69 at the end of the thesis.

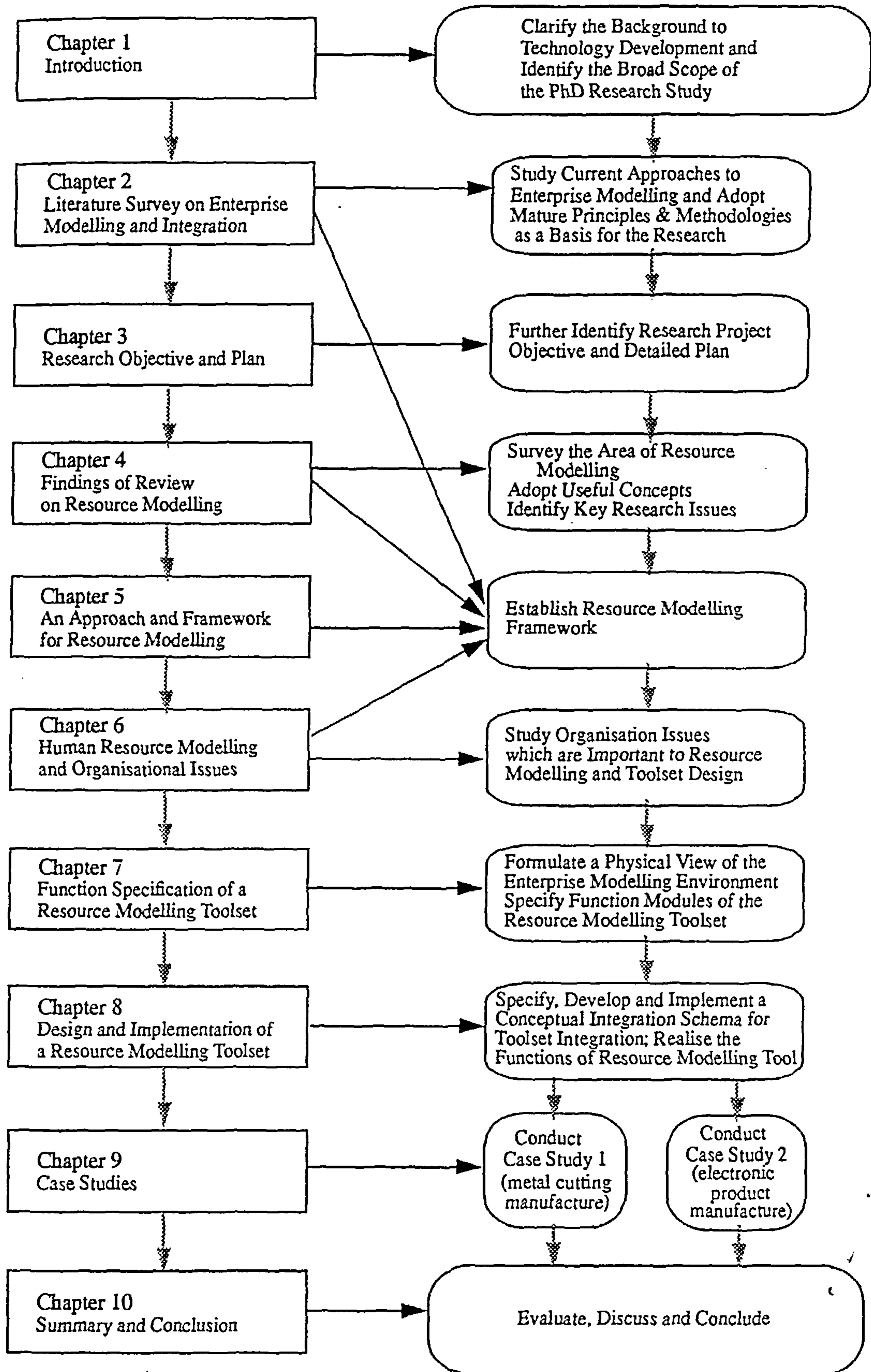


FIGURE 2. Overview of the Structure of the PhD Thesis

2.0 Literature Survey on Enterprise Integration & Modelling

In the previous chapter, the history of technology development and industrial integration was briefly reviewed. This highlighted the need for *enterprise integration* and to study its implications for the next generation of manufacturing systems. It also highlighted a need for *enterprise modelling* as a potential technology which can support multi-disciplinary perspectives and methods involved in enterprise integration. This chapter reports on a detailed survey in the area of enterprise integration and enterprise modelling.

2.1 Enterprise Integration and Modelling Requirements

2.1.1 Background and General Enterprise Requirements

With technical advances (especially the development of information technology) and socio-political economic developments, the background environment for manufacturing has been changing rapidly [Lamarsh, 89] [Weston, 91] [Storey, 94]. Product-oriented marketing is giving way to 'customer-oriented' thinking. Customers, with money in their pockets, are dominating the shape of the markets [Iacocca Institute, 91a] [DTI, 93]. The manufacturer cannot just produce what they want to produce, instead, they have to produce what their customers want. Within a contemporary socio-political economic environment, free-trade and competition have brought about conditions where there are global markets open to manufacturers. [Browne et al, 95]. However, increased freedom means increased competition. Thus increased freedom means greater challenge as competition becomes very severe, even ferocious [Ladet & Vernadat, 95].

Primary factors which govern competition are *quality, variety, cost, service and speed* [Eversheim & Heuser, 95] [Mertins et al, 95]. Companies have to produce good quality products with variety of choice, low price, fast delivery and excellent after-sales service.

Companies could improve their product quality by establishing quality control systems continuously [Dawson, 94] [Browne et al, 95]. Companies should also have the ability to operate flexibly, so that they can produce a variety of products and / or respond quickly to changing markets and environmental need [Greenwood, 88] [Mital, 91]. Companies should reduce their costs by various means and in respect to their various business processes [Hammer & Champy, 93] [Barber & Weston, 96]. Also companies should adopt well defined business strategies, with well trained, managed and coordinated staff involved in the associated marketing, product design, production planning, manufacturing, delivery and after sales activities [Siemieniuch & Sinclair, 93]. Through sharing common, holistic goals, all activities related to the design, production, sales, delivery and service of products should be geared toward rapid response to changing conditions and needs [Siemieniuch & Sinclair, 93] [Gilbert & Siong, 94].

With increased globalisation and reduced product lifetimes, issues for world class manufacturing are: *change* as defined by the DTI in the UK [DTI, 93] and *agility* defined by the US Agility Forum [Iacocca Institute, 91a]. Traditional manufacturing and management paradigms no longer produce competitive behaviour in volatile markets [Weston, 96]. Not only is change inevitable, but also change needs to be realised quickly and continuously, i.e. with agility.

2.1.2 Current Approaches

In order to remain competitive, manufacturers and their advisors (i.e. consultants, system integrators and academics) have evolved certain paradigms, methods and techniques to provide a competitive edge in manufacturing enterprises. Examples of these innovations are summarised by Table 2.

On reviewing why and how each paradigm or strategic response has been developed, it is evident that:

- New approaches have been centred on improving the competitive performance of companies. During the period 1970s to late 1980s various approaches centred on reducing cost and increasing the speed of response of companies (e.g. MRP/MRP II (Material Requirement Planning/ Manufacturing Resource Planning), CIM, JIT (Just In Time), CE (Concurrent Engineering) and others have centred on improved product quality (e.g. TQM (Total Quality Management), Cost Management). More recently greater emphasis has been placed on seeking a total system view (e.g. BPR (Business Process Reengineering), EE (Extended Enterprise), VE (Virtual Enterprise), Agile Manufacturing).
- Typically each paradigm is focused primarily on a key issue. For example, Concurrent Engineering emphasises product and/or process design in a simultaneous fashion. Cost Management has a focus on more accurate cost management of products and services. Arguably BPR has a broader scope but it still has a definite focus on the re-organisation of management processes, with the subsequent reengineering of those processes being assumed to be driven by re-organisation requirements identified during business process analysis.

Title	Origin	Focus * Technology Deployed * Application Areas	Comments	References
MRP / MRPII	MRP originality developed by Orlicky of IBM in the 1960s. MRPII was developed based on MRP but with some fundamental differences from 1970s.	MRP is a material control system based on use of a forward production plan. MRPII is an integrated approach to the effective planning and control of all resources of a manufacturing company using a computer-based information system.	MRPII provided a software application that allowed computers to move beyond the accounts department and into manufacturing management for the first time.	[Wallace, 85] [Luscombe, 93] [Spreadbury, 94] [Browne et al, 95] [Miltenburg, 97]
CIM	The term 'CIM' was coined by Harrington in 1973.	Integrating 'islands of automation' within a company by deploying IT technologies to link applications, such as: distributed computer network; data processing technologies; artificial intelligence; database management systems. Its original scope included physical integration and application integration and centred on shop floor and engineering systems.	Considered integration from physical and software application viewpoint within a company. Developed the fundamental techniques needed for system integration.	[Ranky, 86] [Scheer, 88] [CIMOSA, 89] [Koenig, 90] [Rembold, 93] [SEMATECH, 94]
JIT	JIT originated from the Toyota production system introduced by Taiichi Ohno with support of Shigeo Shingo. It became known in the west from late 1970s. The term JIT is typically western embodiment of Japanese manufacturing philosophy.	Producing exactly what is needed and conveying it to where it is needed precisely when required. Emphasising simplification and the elimination of waste to shorten manufacturing leadtime. A 'KANBAN' method used in typical JIT system; Most successful application in order flow processes within any industry domain. The principles can be applied to all business activities.	Stimulated a new direction of planning and means of performing activities in manufacturing.	[Schonberger, 82] [Lubben, 88] [Golhar & Stamm, 91] [Gunasekaran et al, 93] [Harrison, 94] [Kidd, 94] [Hallihan et al, 97] [Miltenburg, 97]
TQM	TQM, originated in the US during the 1940s and was developed in Japan from 1950s. It has been widely recognised in the west since 1980s.	Full participation of every function and person in the organisation in producing goods and services to meet their customers' requirements. TQM includes the use of quality tools such as quality function development, Taguchi Methods and Statistical Quality Control. TQM is necessary to achieve today's world class quality standard.	From the viewpoint of product quality control to promote improvement and changes on all aspects of enterprise activities.	[Bendell et al, 89] [Zairi, 91] [Munro-Faure, 92] [DeVor et al, 92] [Dawson, 94] [Oakland & Porter, 95]
Cost Management	Activity Based Costing (ABC) was developed in US in 1980s; Target Costing (TC) in Japan since 1960s. Throughput Accounting (IPA) in UK.	Traditional costing systems based on either direct labour hours or machine hours as an allocation base, are not accurate enough any more due to change in manufacturing systems. The ABC method attempts to model more cost information, such as set-up times number of orders and number of deliveries to customers in enabling a more representative allocation bases.	Further development of new costing methods is required in supporting enterprise performance analysis.	[Hiromoto, 88] [Cooper, 89] [Shaharoun, 94] [Winters et al, 94] [Hayakawa, 95] [OMG's MSIG, 96]
Concurrent Engineering	The term 'Concurrent Engineering' was coined in the US in 1987.	It centred on the use of cross-functional teams to realise one or more business processes. It has been most successfully applied in respect to product and process design. The development time from concept to product can be significantly reduced.	Integration of the activities of producing a product from customers requirement, concept design to product manufacturing.	[Broughton, 90] [Eversheim, 90] [Siemieniuch et al, 93] [Evbuomwan, 94] [Syam, 94] [Prasad, 96] [Brookes & Backhouse, 96]
Lean Production	The author of the book 'The Machine That Changed the World' coined the term to describe the key aspects of Japanese Manufacturing in 1990.	Concerned with manufacturing products with less of everything, less time, less inventory, less workforce, less defects and so forth; It deploys the concept and means such as team work, continuous improvement, zero defects, JIT and extends the system from the design centre, research lab, factory and suppliers to the dealers and customers.	It was proposed to be more competitive than JIT. Arguably it is basically JIT with some emphasis on organisational and cultural changes in the enterprise.	[Womack et al, 90] [Harrison, 94] [Storey, 94] [Rehder, 94]
Agile Manufacturing	The term came into common usage with the publication of the report '21st Century Manufacturing Enterprise Strategy' from America, 1991.	Agile manufacturing can be viewed as a strategic American response to a critical economic situation. The competitive foundation laid down by this approach consists of <i>continuous change, rapid response, evolving quality journey</i> and <i>environmental responsibility</i> . It attempts to combine all current concepts and means (e.g. JIT, CIM, CE and VE) with respect of all dimension of a manufacturing enterprise (e.g. manufacturing and organisation) to achieve the world class manufacturing.	It tries to deploy all current approaches to achieve world class manufacturing. To build nation-wide infrastructure to support agile manufacturing, virtual company is impressive.	[Iacocca Institute, 91a] [Iacocca Institute, 91b] [Kidd, 94] [Rattner & Reid, 94] [AGILE, 96] [Warnecke, 93] [Goldman et al, 95]
BPR	The term was attributed to Hammer and Champy in 1993.	BPR focuses on business targets and breaks up the traditional ways of improving enterprise performance by reorganizing the business process. Cancelling redundant activities is a key feature of BPR. Target is to achieve dramatic improvement in company performance in a relatively short time.	Reengineering business process causes dramatic organisational change. Arguably, it starts the second revolution of management.	[Hammer & Champy, 93] [Gilbert & Siong, 94] [Vidgen et al, 94] [Bradley et al, 95] [Barber & Weston, 96]
Extended Enterprise	It appears on the literature survey from early 1990s.	The enterprise system is more than a sum of internal components. It has to take into account external enterprises and functions associated with it to face changing market. The integration takes place across a complete value chain including suppliers, distributors and customers.	Integration involves the whole value chain. The boundary between enterprises was broken up.	[Browne et al, 95] [O'Neil, 95] [Weston, 96] [Weston & Hodgson, 96]
Virtual Enterprise	It appears on the literature survey from early 1990s.	A VE is a temporary consortium of companies that come together over a short time frame to explore fast-changing opportunities. Within the VE, companies share costs and skills to access global markets. Each participant will contribute its core competence to the partnership and share information and knowledge. This concept relies heavily on the extensive use of standards, advanced computer communication facilities, or electronic data interchange techniques.	Integration of the best competence globally to face severe competition in the world markets.	[Iacocca Institute, 91a] [NIIP, 94] [Herman et al, 96] [Cobb et al, 96] [Horstmann et al, 96] [Vernadat, 96]

TABLE 2. Characteristics of Current Manufacturing Paradigms

- Boundary and underlying principles of the paradigms overlap. For example both JIT and BPR focus on simplification (of manufacturing and business processes respectively) and the elimination of waste in terms of the time, material, cost etc. The difference between them is that BPR is more focused on business processes and organisation issues whereas JIT is primarily developed for reducing the cost of work in progress and for the more efficient organisation of manufacturing processes and their control.
- All paradigms have a similar ultimate goal, namely to achieve improved enterprise performance (e.g. in terms of good quality products, low cost, short cycle times, quick delivery times or excellent service). However each paradigm is essentially a different strategic response which reflects particular conditions of the product and service markets and socio-political economic environment in which the enterprise has to operate.
- No single paradigm (or strategic response) could satisfy the ultimate goal of establishing both a generic and world class enterprise. Strategic choice and use among different paradigms is necessary to cater for different operating circumstances and conditions. For example BPR should lead to CIM and the use of integration technology; also JIT implementation may follow a BPR exercise. Any paradigm may require the application of cost management and TQC strategies.
- Though each paradigm has great emphasis on one key issue, all seek to move along the dimension “improved coordination” and hence require improved integration. This encompasses: manufacturing integration; component and system integration; and management and business strategy integration. It will also concern inter- and intra- enterprise integration, including extended enterprises comprising multi-

companies (possibly virtual enterprises). This in turn may well require more agile enterprises in which their behaviour is “integrated” more effectively with that of corresponding social, political and economic systems.

2.1.3 Enterprise Integration & Enterprise Modelling - Realising Next Generation Manufacturing Enterprises

2.1.3.1 Enterprise integration

In order to support the realisation of effective paradigms, methods and techniques in a company it is necessary to simultaneously consider many issues [Burnes et al, 89] [Hitomi, 90]. These will include: dimensions of market competition (e.g. quality, variety, cost, service and speed) [Evasheim & Heuser, 95] [Mertins et al, 95] [Weston, 94] suitable organisational structure (including virtual enterprise systems) [Iacocca Institute, 91a] [Petrie, 92] [Levy et al, 93] [Liu, 94], socio-political economic environmental factors [DTI, 93] [Sayer, 94] and a variety of technical possibilities (including possible systems and enabling technologies) [Iacocca Institute, 91a] [Weston, 97]. It is also important to understand the nature of connections between these issues, such as: relationships between organisational systems and manufacturing systems and their components and component interactions [Li, 95]. The effects of internal and external cultures on the behaviour of an enterprise needs to be understood in terms of meeting the requirements of its operating environment [Champy, 95]. Bearing such issues in mind the importance of achieving integration at the enterprise-level has been widely recognised, i.e. the new paradigm *enterprise integration* (EI) has emerged [Ladet & Vernadat, 95] [Bernus et al, 96]. Indeed the fact that enterprise integration has emerged as a current area of research study indicates that:

1. "Success in the new manufacturing era will be achieved by dealing with the enterprise as a whole. It cannot be achieved by dealing only with manufacturing as it is narrowly viewed today." [Iacocca Institute, 91b]. Hence a *total systems approach* [Fraser, 94], or *holistic solution* [Warnecke, 93] is needed when studying enterprise systems. The principles, methodologies and frameworks which can be used to guide processes of achieving enterprise integration are of fundamental concern when seeking a holistic approach.
2. Viewing an enterprise as a complete system is not enough. It is important to emphasise that it is a *changing* system and the frequency of change has become much greater in recent decades. Today the enterprise itself needs to be treated as a product [Bernus & Nemes, 96] which has its own life cycle [CIMOSA, 89].
3. To be able to cope with the levels of complexity and rates of change typical in an enterprise it is necessary to study and analyse, design and redesign, engineer, and implement, manage, maintain and re-engineer an enterprise system. All such activities should be carried out in a systematic way by means of structured approaches relying on sound principles. Where appropriate the activities should also be supported by efficient methods and tools [Ladet & Vernadat, 95]. This is the task of *enterprise engineering* which can be viewed as being a new discipline which has emerged "hand in hand" with enterprise integration [Bernus et al, 96].

2.1.3.2 Enterprise modelling

How then can enterprise integration be achieved? What kind of methods and technologies need to be developed to facilitate enterprise engineering?

The answer to these questions advocated by many among the integration community is to use modelling - i.e. so called *enterprise modelling* [Petrie, 92] [Burkhart, 92] [Wortmann, 92]. Clearly it is necessary to develop conceptual models of suitable enterprise systems as a prerequisite of enterprise integration [Vernadat, 96].

Why does enterprise modelling provide the basis of a generic solution?

Based on the foregoing discussion, (a) a systems approach, (b) the need for a quick response to change and (c) the use of structured, consistent methods and tools are key issues which can be addressed and supported via enterprise integration. And, (d) the knowledge that humans have about enterprise systems needs to be capitalised and reused. This knowledge can take the form of systems theory, system engineering principles, operational research, mathematics, computer science, integration technology, etc. In addition, (e) current available technology, (i.e. computer-based systems) naturally support modelling. Hence it is generally believed that enterprise modelling can help to re-apply the knowledge people already have to develop generic models of "better" enterprises which will lead to the effective deployment of available IT (including emerging Information Technology) to serve the purpose of realising enterprise integration in an effective and efficient way.

What kind of benefits can be obtained by deploying enterprise modelling?

A model is an abstraction of something [Jeffers, 82]. Hence an enterprise model is an abstraction of an enterprise. If we can obtain a 'good' model of an enterprise, and computerise it then we can analyse attributes of the enterprise in a structured, analytical and possibly reusable and relatively easy way. It can help people to

understand properties of generic or specific enterprises; such as to improve the enterprise, to predict its future and its capability to create certain products, and to redesign an enterprise when changes occurs or are required. Potentially, by using computers to process information and models it is possible to meet contemporary rates of change. However, such benefits rely on being able to obtain the right models.

How then can we model an enterprise? What is the main target of enterprise modelling? And what are the main tasks involved in enterprise modelling?

How to model enterprises is the essence of enterprise modelling research. This will be discussed in following sections and chapters.

Initially the focus of enterprise modelling was on producing a means of achieving analysis and support for business processes [Kotsiopoulos, 96]. However, the rapid development of enabling technology has allowed this demand be extended to facilitating the control and monitoring of enterprise operation [Burkhart,92] [Gruninger & Fox, 96]. Hence the main target of enterprise modelling has been redefined as being to support enterprise engineering through the whole life cycle of an enterprise [CIMOSA, 89][Bernus et al, 96].

On considering the main target of enterprise modelling, key tasks can be identified as following:

1. to understand and analyse the enterprise (requiring an ability to abstract meaningful models [Wortmann, 92] [Bernus et al, 96]);
2. to express this understanding by providing computable (computer processable) models (model building methods and technology development) [CIMOSA, 89];

3. to study how to manipulate these models in support of system analysis, design, implementation and operation (model enactment methods and technology development, such as emulation, simulation, rapid prototyping etc.) [Fraser, 94] [Weston & Gilders, 96]. The first of these tasks reflects the need to develop and capture new knowledge about an enterprise whereas the second and third concern methods and tools to support enterprise design and development (and their redevelopment when change occurs).

Figure 3 provides a generalised overview of section 2.1.

2.1.3.3 Complexity of enterprise modelling

Enterprise modelling is a key emerging technology which will support the realisation of a new generation of manufacturing systems. It is exploring the use of information technology and deploying interdisciplinary knowledge (discussed before) to integrate enterprises from a total system viewpoint [Vernadat, 96]. It has much wider scope in respect to automation than that achieved before. However, the inherent complexity of an enterprise determines that the task of modelling an enterprise has its own difficulties [Petrie, 92].

Many challenging problems remain to be solved in respect to the specification, capture, validation and deployment of models [Weston, 96-1] as follows:

1. Typically, there is a very large number of system components in an enterprise [Norrie et al, 95]. These components include: 'machines', 'humans', and 'software components' [CIMOSA, 89]. These components may be arranged into various organisational units [Norrie et al, 95]. Thus considerable information is needed to

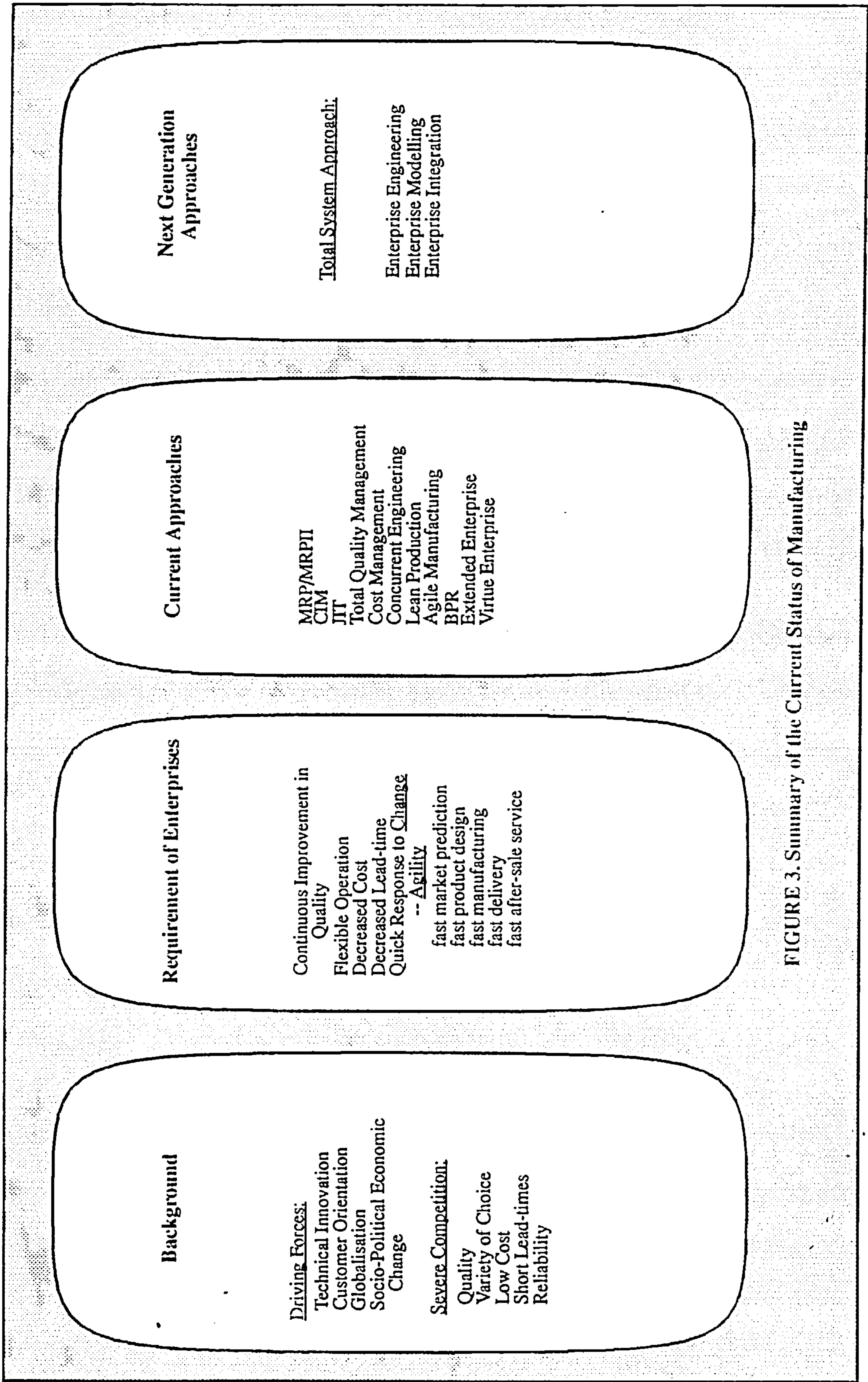


FIGURE 3. Summary of the Current Status of Manufacturing

describe a system in detail [ICEIMT/WSIII/WG1, 92]. Similarly, large amounts of information about the status of system components needs to be managed and controlled [ICEIMT/WSIII/WG1, 92]. Correspondingly, information systems used to support the operation and management of enterprise systems (which may also need to be modelled) need to be more sophisticated than ever before.

2. There are various forms of interaction among system components and subsystems (which may be hierarchically or heterarchically organised and involve inter, and intra interactions, different time scales, different geographic area etc.). Hence significant effort is necessary to identify and characterise these interactions and relationships, to structure them, to decouple them, and to represent them properly.
3. There is a mixing of competencies embedded in an enterprise (which cover for example engineering, organisation, social and economic factors). As a result, enterprise modelling is an interdisciplinary task [Vernadat, 96]. However, research in the field of enterprise integration so far primarily embraces manufacturing engineering, production engineering, system engineering and information systems engineering [Ladet & Vernadat, 95]. It also relies on methodologies and techniques developed from organisation study, management science and applied mathematics etc. [Ladet & Vernadat, 95]. Generally an interdisciplinary professional team will be needed to carry out the task of enterprise modelling [Vernadat, 96].
4. A total systems approach in the context of enterprise integration means that organisation and human issues must be included [Kidd, 94] [Williams, 94]. However the integration of organization, human and technological issues raises difficult problems and many open research questions [Wortmann, 92]. The

relationships between “technology structure” and “management structure” need to be studied [Li, 95]. Proper methods to model the relationship have yet to be determined [Vernadat, 96].

5. An important target of enterprise modelling is to support decision making [Doumeingts et al, 93] [Wortmann, 92]. Though significant research on decision making support has covered all aspects of manufacturing activities, e.g. production planning, marketing, business strategy analysis etc., there is still much that needs to be done to really understand the procedure of human decision making. How to develop and integrate this knowledge into an enterprise modelling framework and how to design the framework to support human decision making processes are a crucial issue in enterprise modelling. However the task of establishing system design techniques which support all levels of decision making may need the development of new constructs.

2.2 Influential Frameworks in the Area of Enterprise Modelling

Pioneering work on enterprise modelling has been carried out worldwide. This section will present a literature survey of some of the most influential architectural frameworks which have shaped contemporary enterprise modelling. The frameworks considered in some detail will be CIMOSA, GRAI-GIM, PERA, ARIS, IEM and GERAM. Other architectural frameworks which have emerged, including the ISO Reference Model, the NIST AMF [Simpson et al, 82], [ISO, 90] TOVE [Fox, 92], SEMATECH [SEMATECH, 94], Model-Driven CIM [Weston et al, 95], OPENframework [OPENframework, 93] and the framework from Object Management Group’s Manufacturing Special Interest Group [OMG MSIG, 96]. Since

researchers have approached enterprise modelling in different ways, their research outputs have taken various forms.

2.2.1 CIMOSA

2.2.1.1 Introduction

The Open System Architecture for Computer Integrated Manufacturing (CIMOSA) was conceived and developed by the European CIM Architecture Consortium (AMICE) as part of ESPRIT projects 688, 2422 and 5288. This work was initiated in 1984 and thereafter was called CIMOSA [CIMOSA, 89]. The scope of CIMOSA modelling is characterised by the well-known CIMOSA cube (see Figure 4). It supports the life cycle of enterprise systems through use of an Enterprise Environment (Engineering Environment and Operation Environment) and an Integrating Infrastructure [CIMOSA, 89].

2.2.1.2 CIMOSA architectural framework

The CIMOSA architectural framework (see Figure 5) consists of three important parts, namely the CIMOSA modelling framework, the System Life Cycle and CIMOSA Enterprise Environment and the CIMOSA Integrating Infrastructure (IIS) [CIMOSA, 91] [CIMOSA, 93] [CIMOSA, 96].

- *The CIMOSA Modelling Framework*

The CIMOSA modelling framework embraces definitions of the three dimensions of the CIMOSA cube [CIMOSA, 91], namely 1) the dimension of genericity and stepwise instantiation, 2) the dimension of model and stepwise derivation, and 3) the dimension of view and stepwise generation. The following describes these

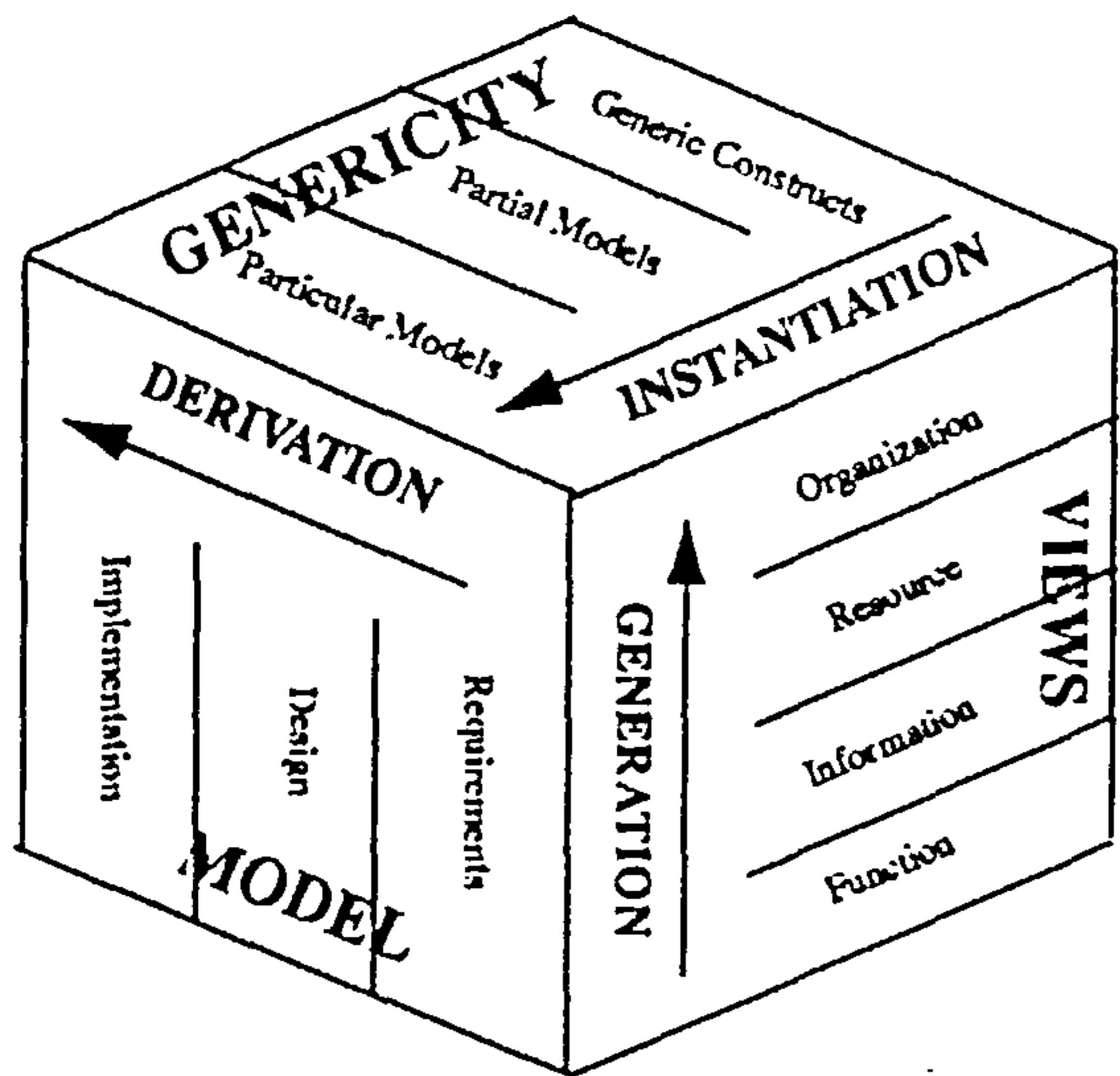


FIGURE 4. The CIMOSA Cube

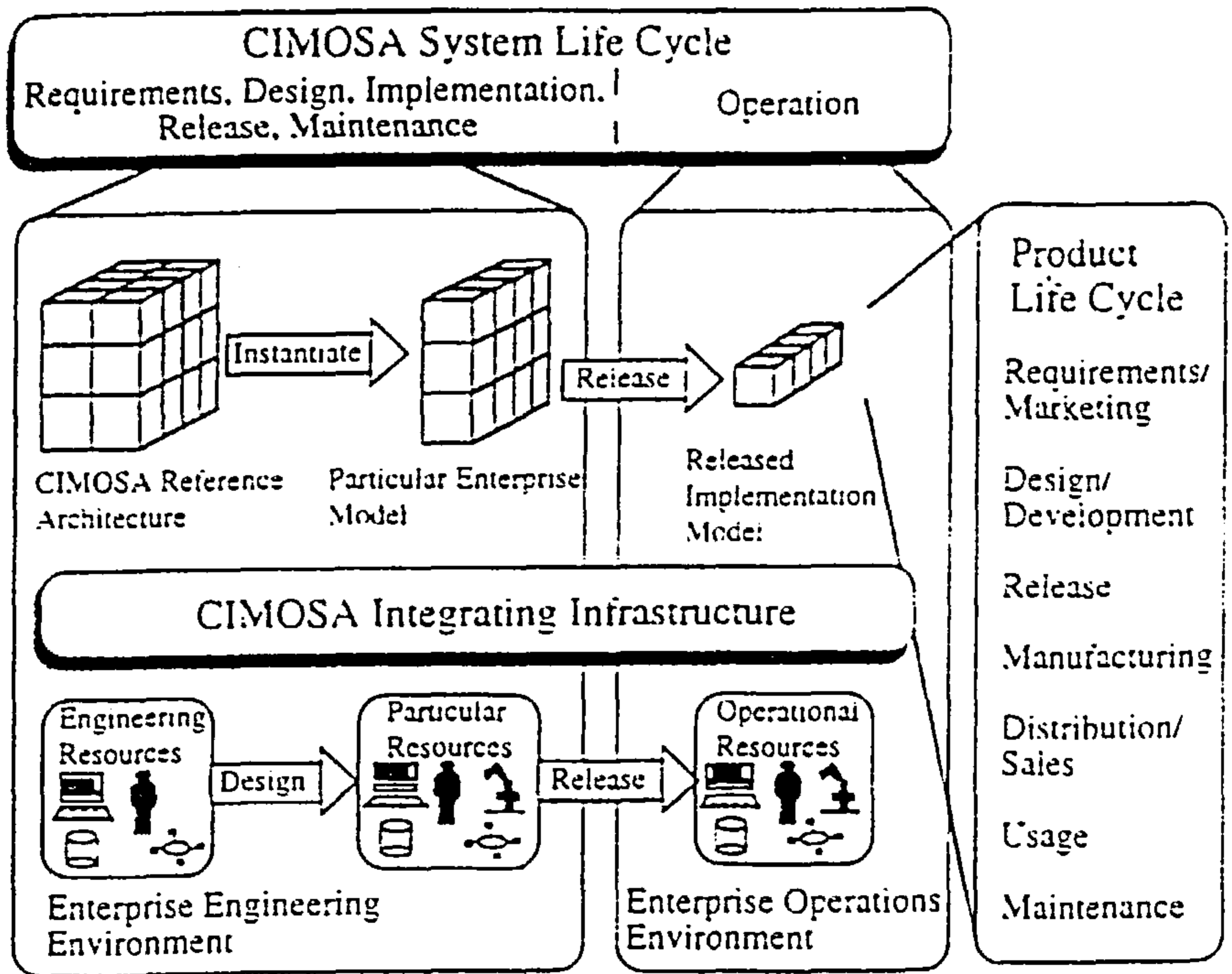


FIGURE 5. The CIMOSA Architecture Framework

dimensions in greater detail.

(a) The dimension of genericity and stepwise instantiation

CIMOSA has defined three levels of genericity: *generic, partial and particular* [CIMOSA, 91].

Generic level: a collection of constructs which are basic architectural building blocks that can be re-used in various architectural configurations. It includes CIMOSA generic building blocks and building block types for functions, objectives, constraints, services and protocol. Potentially the constructs described at this level can be used in a very broad range of application areas.

Partial level: These are incomplete skeletons of models related to particular types of enterprises. Partial models are applicable to a wide range of specific domains corresponding to industrial sectors, types of company organisation and/or manufacturing strategies. Partial models are the prime means by which CIMOSA encapsulates different industries' needs, and provides a more realistic and usable tool for a particular type of enterprise.

Particular level: This is concerned with one specific enterprise. The CIMOSA particular model embodies all necessary knowledge about a target enterprise in a form which can be used directly for the specification of an integrated set of manufacturing technology and information technology components.

The *instantiation process* concerns the particularisation of a generic construct so that it can be applied to a specific case according to the needs of a specific enterprise.

The CIMOSA Reference Architecture contains generic and partial levels of

genericity, whilst the CIMOSA Particular Architecture contains the particular level.

(b) The dimension of model and stepwise derivation

This dimension is a system life cycle view of the modelling process [CIMOSA, 91]. It defines three separate but interrelated modelling levels (requirement definition, design specification and implementation description) which imply a translation from a business description language into a system description language [CIMOSA, 91].

At the *requirement definition* modelling level, the business requirements of an enterprise are identified. This modelling level describes the enterprise from a user's point of view.

At the *design specification* modelling level, user requirements are restructured, detailed and optimised based on a consistent model which simultaneously takes into account business and technical constraints in order to specify solutions which meet those requirements.

At the *implementation description* modelling level, means of executing the enterprise model are defined by selecting information technology and manufacturing technology components such as human resources, machines and application programs required to support the enterprise operation.

The *derivation process* concerns the way in which the three modelling levels are interrelated and the means by which models are transformed between these levels.

Thus, at the end of a derivation process a complete and consistent set of documentation of the CIM system can be made available.

(c) The dimension of view and stepwise generation

This dimension defines four views, namely: *function*, *information*, *resource* and *organisation* [CIMOSA, 91]. Each view corresponds to a particular modelling perspective taken when characterising an enterprise.

Function view is concerned with system functionality and system behaviour. It provides a hierarchically structured description of enterprise functions and their static and dynamic behaviour. The descriptions are based on the objectives of the enterprise and reflect external constraints imposed upon the enterprise.

Information view describes all pieces of data and knowledge identified as being required to meet the needs of enterprise users and applications.

Resource view contains all the relevant information on the enterprise resources which is required to support the execution of enterprise functions.

Organisation view identifies and defines responsibilities and authorities over functions and resources within an enterprise. This view structures and supports human interaction and decision making.

The different views of CIMOSA can be unified by event-driven, process-based modelling [Vernadat, 93].

The *generation process* concerns the process of generating the content of the above four views in a coherent manner. This is claimed to create a concise and consistent Particular Model [CIMOSA, 91].

- ***System Life Cycle and the CIMOSA Environment***

CIMOSA has extended concepts normally applied to the life cycle engineering of products and re-applied them to the life cycle engineering of enterprise systems [CIMOSA, 91]. Whereas a product life cycle typically consists of marketing,

design, release, manufacturing, distribution, usage, and maintenance, the system life cycle typically includes system requirement definition, system design specification, system implementation description, system release, system operation and system maintenance.

To decouple the processes involved in the engineering of enterprise systems from day-to-day operations involved in the run-time control and management of enterprise systems, CIMOSA provides two mutually independent execution environments, namely: the Enterprise Engineering Environment and the Enterprise Operation Environment [CIMOSA, 91]. The execution of tasks related to the engineering of enterprise systems takes place in the former environment and the execution of product life cycle tasks take place in the latter.

- *The CIMOSA Integrating Infrastructure (IIS)*

The CIMOSA Integrating Infrastructure is the mechanism specified by the AMICE consortium to provide transparent support to heterogeneous components (software, hardware, etc.) to enable their integrated operation [CIMOSA, 91]. This can be achieved (it is claimed) without the need for significant IT knowledge. Thus the CIMOSA IIS is a platform which supports system model execution and thereby ensures that the enterprise operates in a consistent manner.

2.2.1.3 Latest developments and ongoing work within CIMOSA

A new version of the CIMOSA Technical Baseline was published in 1996 and is available on diskette as a hypertext document [CIMOSA, 96]. Enhancements to the dynamic behavioural description of non-deterministic processes have been introduced. Also revisions have been made to the resource and organisation view. In addition a re-

editing of the section on business modelling has been completed [CIMOSA, 96]. Work on the CIMOSA modelling process and economic measurements (potentially leading to an Economic View) have been started [Kotsiopoulos, 96].

2.2.1.4 CIMOSA application

Since CIMOSA first emerged, it has attracted a lot of attention among researchers involved in modelling enterprises. Interest has also been shown by end-user manufacturing companies and IT product vendors, not only in Europe but also in America, Asia, the Pacific Basin and Australasia. Knowledge of the CIMOSA methodology, its architectural framework and its fundamental concepts have been accepted by many in the modelling community, particularly as a basis for further research.

A significant body of work has been carried out in applying CIMOSA, especially in Europe. However, successful outcomes of these activities have been hampered by a lack of proprietary tools which support the methodology in an effective way. Despite these limitations, it is evident from certain reports [Didic, 94] [Williams et al, 94][Kosanke et al, 95] [Bruno et al, 95] [Kotsiopoulos, 96] that significant benefits have been demonstrated.

- It has been concluded that the CIMOSA modelling approach is comprehensive, well-structured and consistent and the event-driven and process-based modelling which can unify resource, information and organisation into a whole is practical [Vernadat, 93].
- The ability to execute CIMOSA models has also been demonstrated [Aguiar &

Weston, 93] [Didic, 94] [Katzy, 96]. On-line real-time control and monitoring of system operation, over an integrating infrastructure has also been achieved.

- Application studies carried out in the machine tool, paper and process industries show that the CIMOSA framework can be used in various industrial sectors [Didic, 94] [Kosanke et al, 95] [Schlotz, 96].

The feasibility of CIMOSA concepts, traversing model creation to model execution, has been demonstrated in proof-of-concept form and the CIMOSA concept can be viewed as a promising basis for advancing enterprise integration methods and tools.

2.2.1.5 Contributions and limitations

As arguably the most influential contemporary enterprise integration framework, CIMOSA has made a fundamental contribution to enterprise modelling. The author believes that the following are the most significant strengths and weaknesses of CIMOSA.

- *Contributions*

(a) A comprehensive modelling approach (within a wide, albeit limited scope);

(b) Early pioneer of the concept of producing computer executable models and the derivation process among modelling levels.

- *Limitations*

(a) Gaps between different modelling levels and lack of links between different views;

(b) The resource and organization views have not been well established;

(c) CIMOSA deals with deterministic well structured systems but doesn't support

notions of informal loose coupling between entities, organic system behaviour and casual links between elements.

- (d) Model execution is only directly targeted on the top down approach to system coordination and behaviour analysis. Limitation of executing models in the way specified by the CIMOSA IIS;
- (e) Very limited coverage of strategy planning and business analysis issues;
- (f) No well-developed links to state-of-the-art software engineering practice;
- (g) Resource component description is not complete;
- (h) In some respects it mixes up method and modelling capabilities;
- (i) It does not have a well developed view of model based simulation;
- (j) It does not have a well developed view of model enactment¹.

2.2.2 GRAI-GIM (the GRAI Integrated Methodology)

GRAI-GIM (the GRAI Integrated Methodology) was developed by the GRAI Laboratory of the University of Bordeaux in France [Doumeingts et al, 93]. This work was an output of production management studies initiated at the GRAI Laboratory as early as 1974. Since 1984 this approach to enterprise modelling has been referred to as GRAI-GIM [Doumeingts et al, 93].

GRAI-GIM is characterised by its use of the GRAI model which unifies four co-operating systems, namely: *decision*, *information*, *operating* and *physical* systems. It

1. 'Model enactment' is a term used by MSIRI researchers to denote the process of automating or semi-automating the transformation of fragments of models (used to describe some aspect of a problem space) into physical elements of a working systems [Weston et al, 95].

is also characterised by the GRAI-GIM structured approach to supporting the life cycle of CIM projects [Williams et al, 94].

- ***The GRAI Model-- Global Model***

The GRAI Model is referred to as a *global model* (see Figure 6) [Doumeingts et al, 93]. It consists of four co-operating systems which are:

(1) The *physical system* which embraces people, facilities, materials and techniques which transforms materials into final products and thereby adds value to the material flow.

(2) The *decision system (DS)* which splits up decision making into levels according to several criteria. Each level comprises one or several *decision centres (DCs)*. In the decision system, two parts are specified. The upper part is driven periodically.

(3) The lower part acts as the interface to the physical system: it can therefore contain numerical control systems, programmable controllers, etc. The lower part of the DS is typically event driven, and is referred to as the *operating system*.

(4) The *information system* which contains all the information needed by the DS. It is structured in a hierarchical way whilst maintaining the defined structure of the DCs. The decision system and information system comprise a *control system*. The decision system includes the operating system [Doumeingts et al, 93].

- ***The GIM Modelling Framework***

The GIM modelling framework encompasses the following views and levels of abstraction.

Views: information, decision, physical, functional, organisation, information

technology and manufacturing technology.

Abstraction levels: conceptual, structural and realisation.

- ***CIM Structural approach***

Based on their vision and global model, researchers in the GRAI Labs developed a structured approach to CIM system design (see Figure 7). One of the main features of this methodology is that it splits up the design phase into two subphases [Doumeingts et al, 93]. These are *user-oriented design* and *technical-oriented design*. This separation is claimed to help system designers to more readily cope with changes in terms of new technologies, new requirements and so on.

- ***GIM Applications and Tools***

The GRAI method has been used extensively in industry with many test cases being reported in the literature since 1980. More than 50 applications of GRAI method are listed in various publications [Doumeingts et al, 93].

A key aspect of the GRAI framework lies in its accompanying techniques and tools. The GRAI Laboratory has developed several techniques and supporting tools, which potentially can have widespread use in industry. These are GRAI-GRID, GRAI-NET, ECOGRAI, GRAI Model [Doumeingts et al, 93] [Williams et al, 94].

- ***Contributions***

The author believes that the special contribution from GRAI Framework is that its global model gives strong support for the decision making processes at all levels of an enterprise.

- ***Limitations***

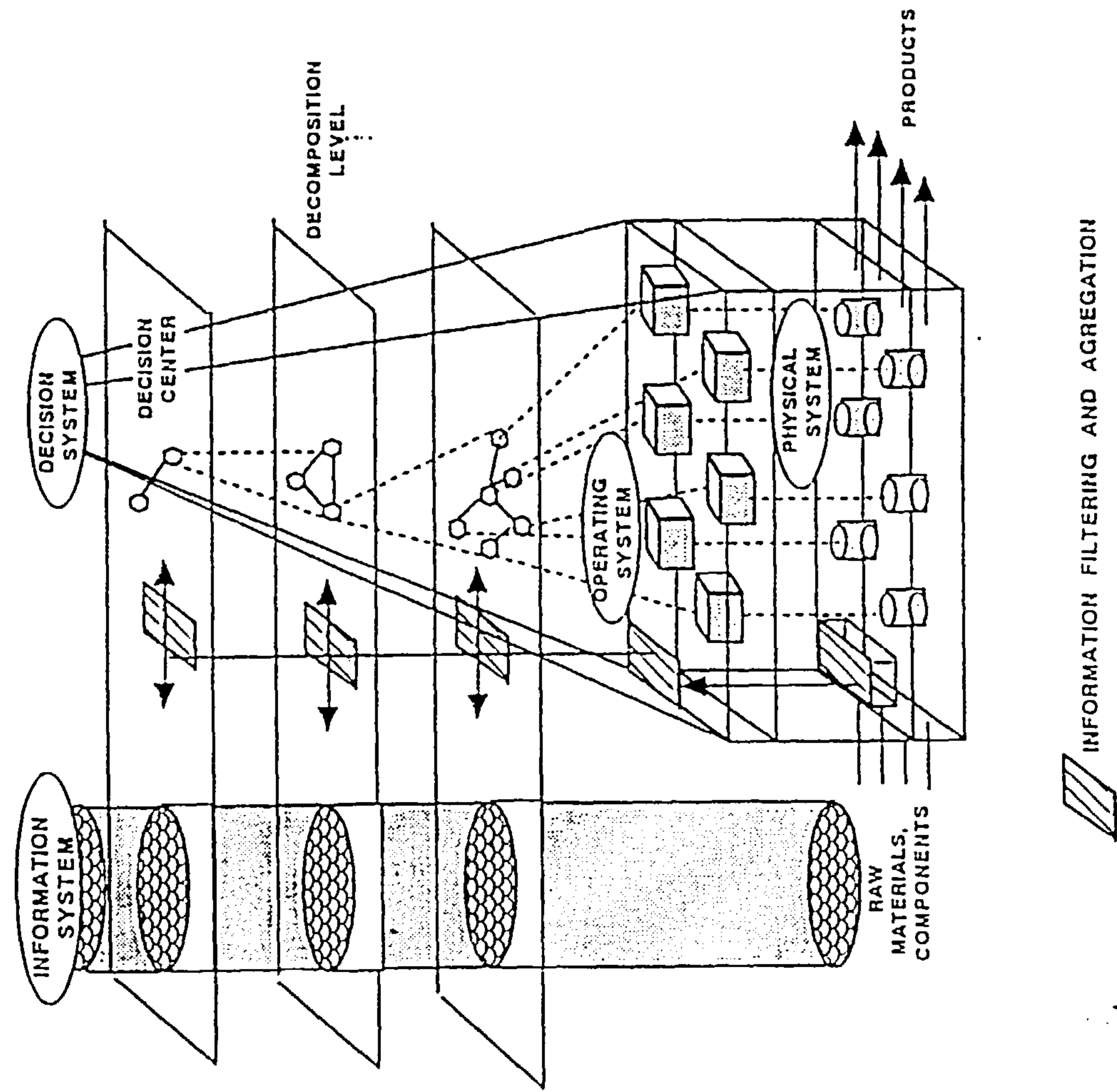
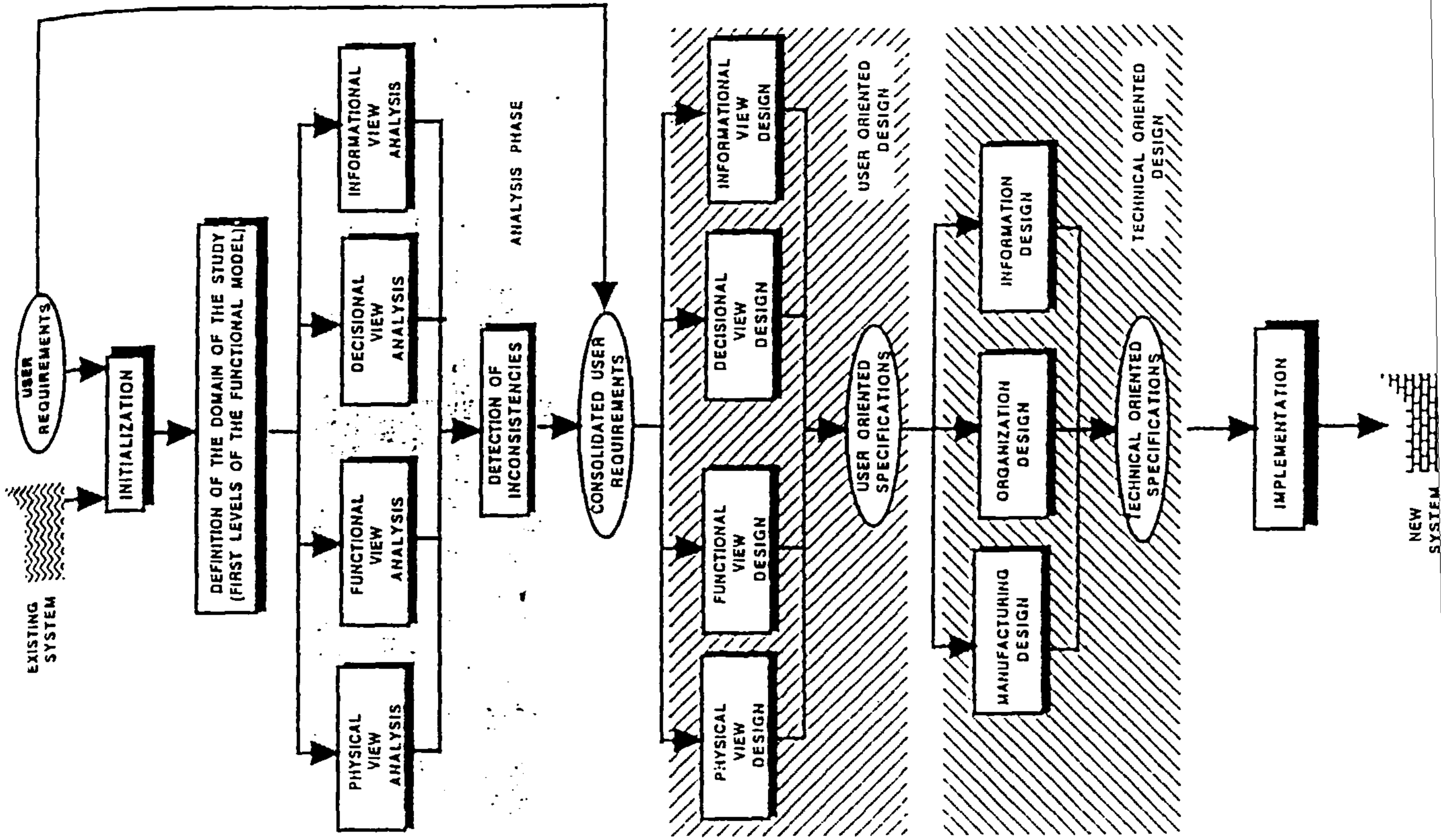


FIGURE 6. The GRAI Global Model

FIGURE 7. GRAI-GIM Structured Approach ->

- (a) No behavioural view;
- (b) No system implementation description level;
- (c) No support for formal description.

2.2.3 PERA- Purdue Enterprise Reference Architecture

- *General Introduction*

The Purdue Enterprise Reference Architecture and the related Purdue Methodology were developed at Purdue University in USA as part of the work for industry by the Purdue University Consortium for CIM [Williams, 94]. The primary architectural work started formally in 1989 but it arose out of the Purdue Reference Model developed in 1986 and on earlier work at the Purdue Laboratory on Applied Industrial Control which dates back to the mid seventies [Williams, 94] [Williams et al, 94].

The Purdue architecture (see Figure 8) is characterised by its very detailed layering of life cycle elements. This extends down to the task level and explicitly represents the place of people in the enterprise.

Its detailed layers can include the following,

- (1) Identification layer
- (2) Concept layer
- (3) Definition layer
- (4) Functional design layer
- (5) Detailed design layer
- (6) Construction and installation layer

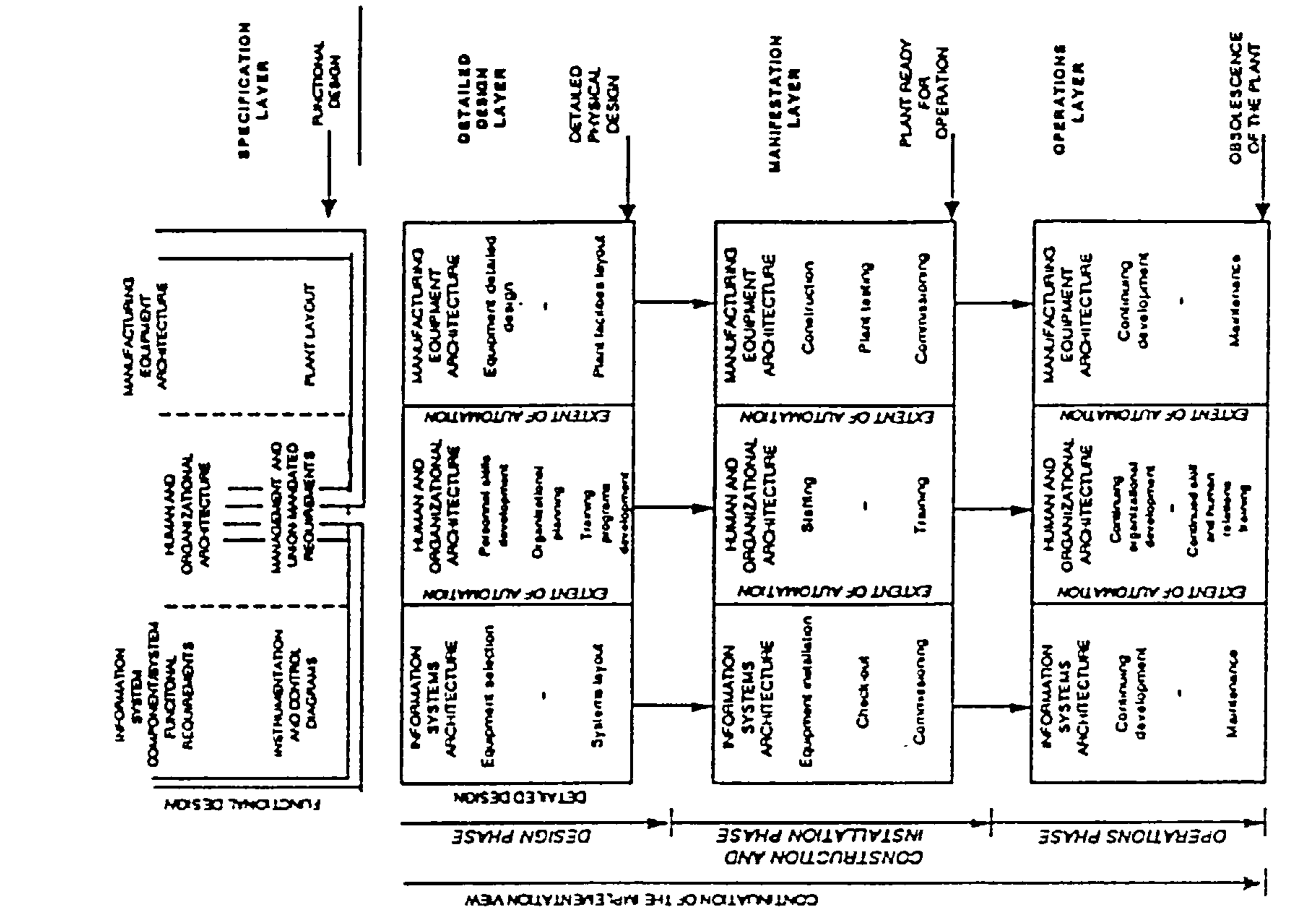


Figure 8: Continued

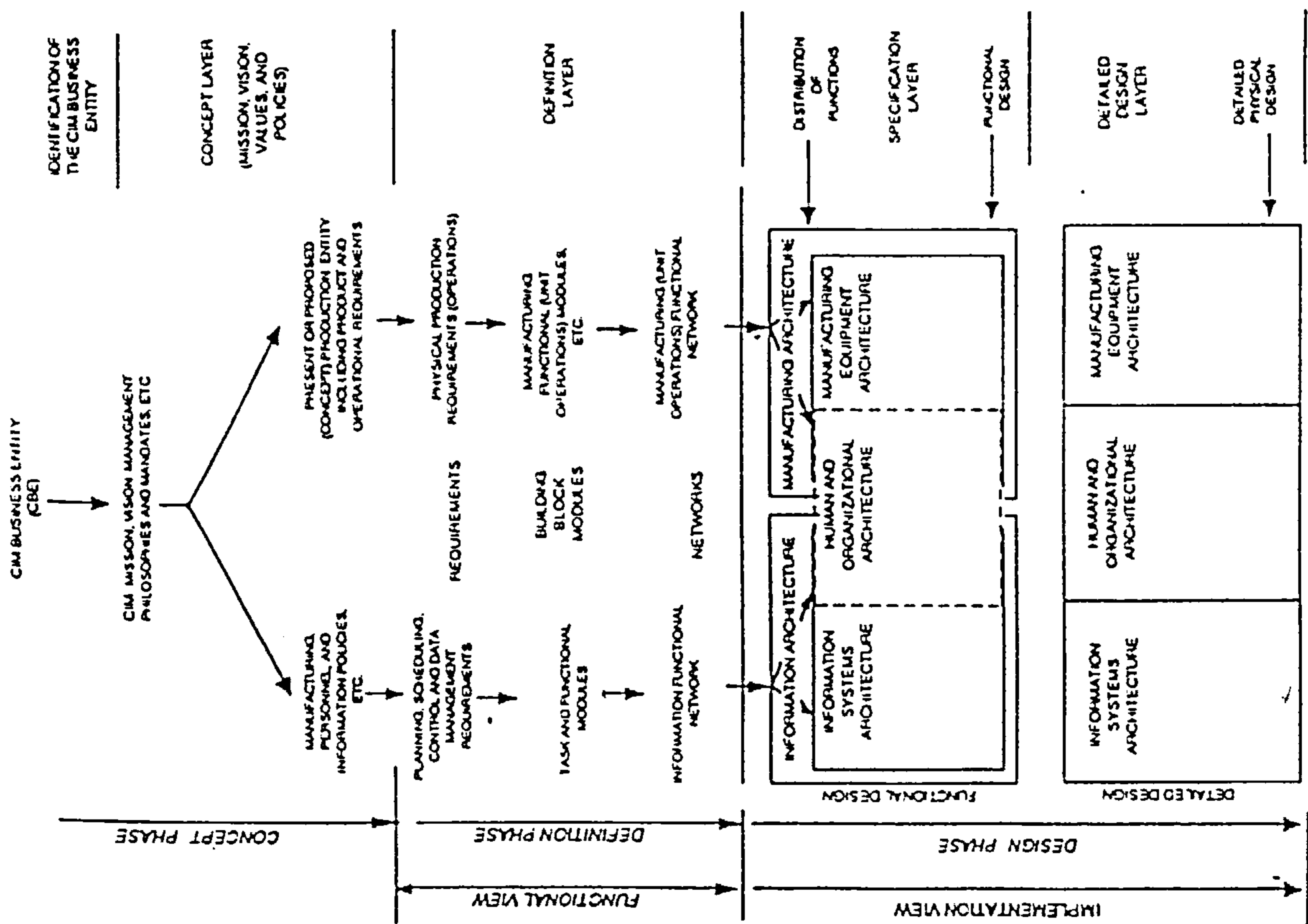


FIGURE 8. Phases of CIM Programme Development in PERA

(7) Operation and maintenance layer

(8) Renovation or disposal layer

(9) Enterprise dissolution layer.

From the functional design layer downwards the *human and organisational architecture* has been taken into account. This incorporates a *manufacturing equipment architecture* and an *information system architecture* [Williams, 94].

Another important facet of the Purdue methodology is that it emphasises the importance of strategy planning and identifies the benefits of enterprise integration programmes. In Purdue model strategic planning is referred to as *master planning*.

The key to the Purdue methodology is the notion that each enterprise integration project should start from a master plan which outlines the specification of a proposed program or project, its schedule, its benefits, its risks, etc. [Williams et al, 96].

Furthermore, to help structure and facilitate *master planning*, "A Handbook on Master Planning and Implementation for Enterprise Integration Programs" has been developed. This was released in June 1996 [Williams et al, 96] and provides practical guidelines for enterprise integrators.

Contributions

The author believes that the Purdue methodology places special emphasis on human issues in the context of enterprise integration. It also focuses greater attention on strategic planning issues than does CIMOSA, GRAI and ARIS etc.

Limitations

The Purdue methodology lacks the set of mathematical modelling techniques and

formalism necessary to enable its architecture to be realised and supported in a computer-processable form [Williams et al, 94].

2.2.4 ARIS

- *General Introduction*

ARIS (the ARchitecture of Integrated information Systems) has been developed by August-Wilhelm Scheer and his colleagues in Germany since 1976. More than six versions of ARIS have been published. Two English-language editions were published in 1989 and 1994 respectively (titled “Enterprise-wide Data Modelling” and “Business Process Engineering - Reference Models for Industrial Enterprise” [Scheer, 94]).

Based on the belief that ‘computer supported business information systems provide the vehicle for linking business applications concepts with information technology’ [Scheer, 94], Scheer and his colleagues generated new enterprise integration concepts with a sharp focus on the data view [Goossenaerts & Yoshikawa, 93], see Figure 9.

ARIS builds on generally accepted ideas used in database design and entity-relationship data-models with the direct aim of supporting existing business processes.

To facilitate the analysis and modelling of business processes (this being the first step when ARIS modelling), ARIS incorporates strategies for generating models which represent different views and lifecycle phases of an enterprise. The views supported by ARIS include: *function view*; *data view*; *organization view*; *resource view*; and *control view*. Function (processes and activities), data (events &

conditions), organisation (users & organisation units) and resource (IT components only) are all used in ARIS to describe business processes, and their relationships and interactions (in terms of position, sequences, etc.) are described in a unified way within the control view of ARIS. By separating out the interaction part of business processes and assigning it to individual views, the control view of ARIS distinguishes its architecture from other architectures, considered in this section. Figure 10 illustrates the ARIS architecture which is referred to as the “ARIS House”.

Another key feature of ARIS is that it has developed a set of graphical symbols which are based on constructs associated with the different views. This facilitates the description of business processes in terms of their component views (function, data, organisation units) and their relationships.

- *Contributions*

(a) ARIS supports the modelling of business processes in a very practical way.

(b) Many “reference” business process models have been developed for ARIS, based on many years experience of its use in many different industries. These models can provide valuable and practical reference models. This potentially enables enterprise modelling to begin from a higher entry point, by building on the experience of others encapsulated within the reference models.

(c) The control view provides a means of linking the different views together. This is very important and can be considered to imply both a strength and a weakness.

The strength comes from the fact that other views can be linked together in a highly flexible way which can be tailored to a specific method or approach. Conversely

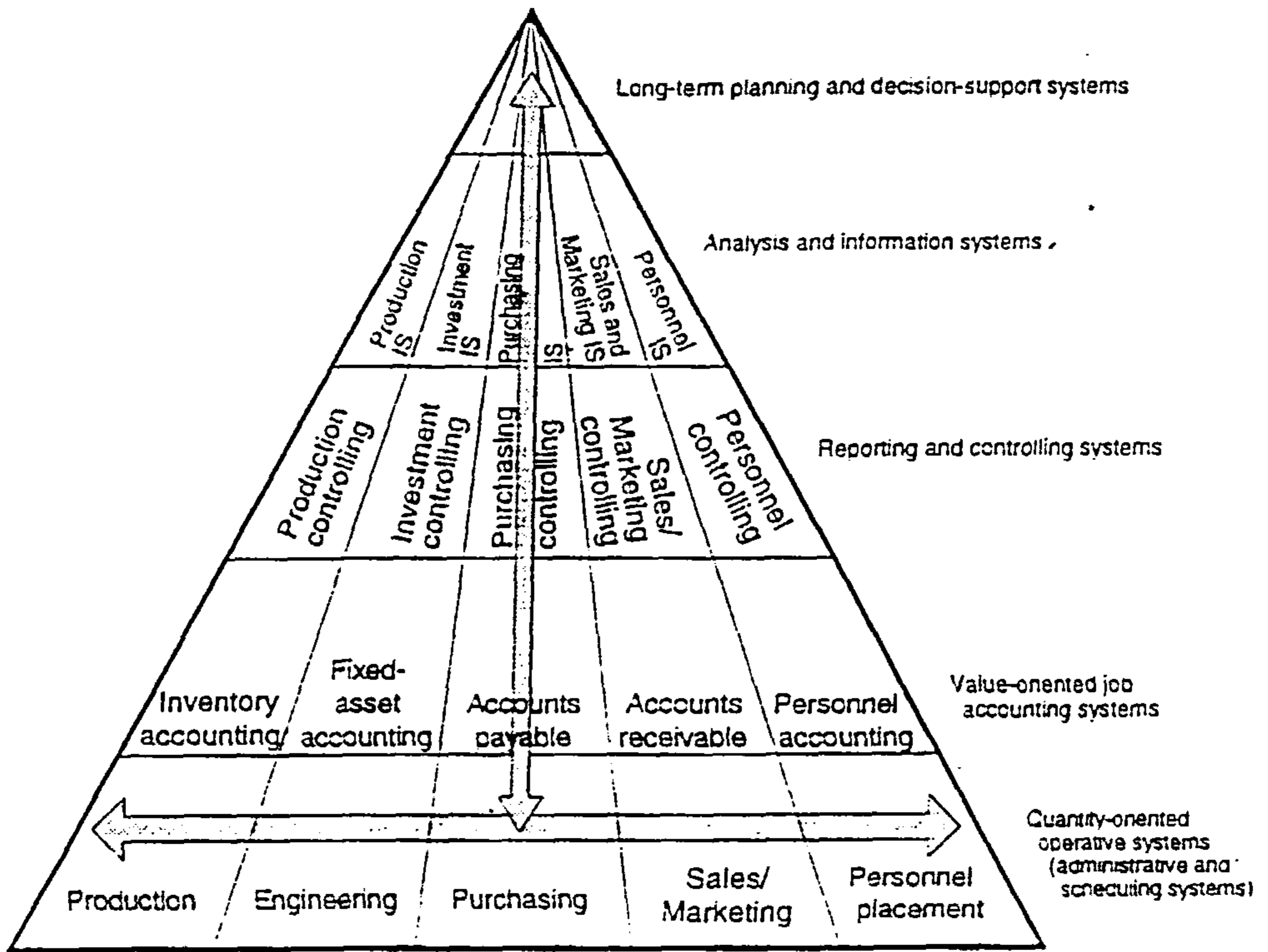


FIGURE 9. ARIS Integrated Information Systems

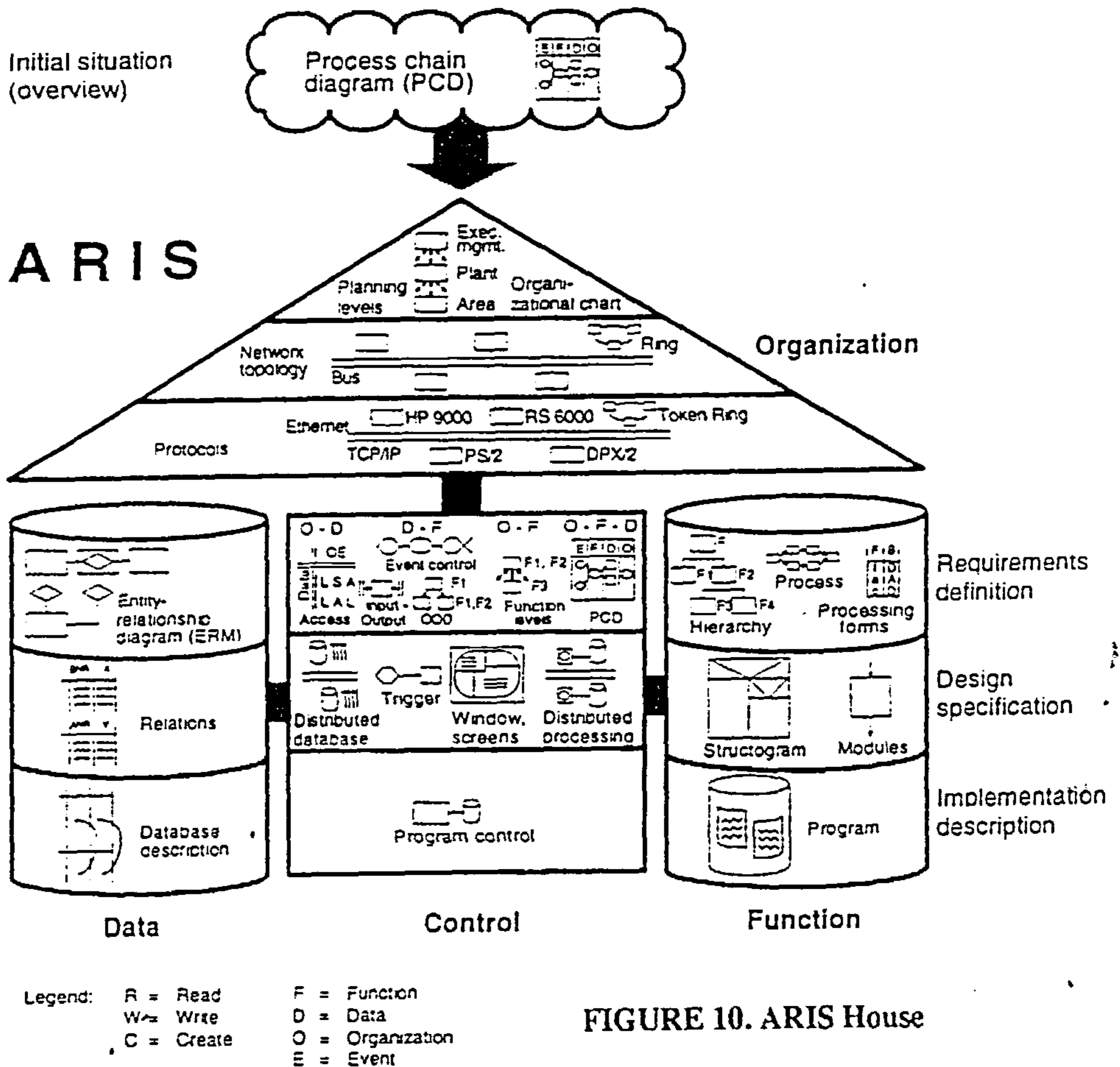


FIGURE 10. ARIS House

this also means that there is no method imposed and designers can do things they should not [Gilders, 95].

- *Limitations*

Because of its monolithic nature and the complexities that arise in data model integration, an enterprise-wide data model can hamper an enterprise's responsiveness to change. Also the formal and modular development of complex application processes is ignored [Goossenaerts & Yoshikawa, 93].

Arguably it is less generic than CIMOSA, GRAI-GIM and Purdue and its specification is less available for public domain reference.

2.2.5 GERAM

GERAM (Generalized Enterprise Reference Architecture and Methodology) has been developed by IFAC/IFIP² Task Force on Architectures on Enterprise Integration [Vernadat, 96].

This Task Force was formed in 1990 and at the 1993 Congress, the Task Force reported on its extensive analysis of the three major enterprise integration architectures available at that time: CIMOSA, GRAI-GIM and PERA [Williams et al, 94]. As a result, the group recommended that a consolidation of the best features of each should be realised. The first major proposal for such a generalised architecture was authored by Bernus and Nemes in 1994 [Williams, 95]. Six major components which comprised the GERAM framework were proposed [Bernus & Nemes, 94].

2. IFAC/IFIP: the International Federation of Automatic Control/ the International Federation for Information Processing.

These are:

- ***Generic Enterprise Reference Architecture (GERA)***

This is the definition of enterprise-related concepts, with the primary focus on the life-cycle of an enterprise. Since the life-cycle of an enterprise will include a design process, the architecture will also have to identify the results and the components of this design process. A matrix representation of the enterprise life cycle has been developed and is illustrated by Figure 11. A revised GERAM representation of the life cycle of an enterprise is proposed (see Figure 12) primarily by combining CIMOSA and PERA architectural representations.

- ***Generic Enterprise Engineering Methodology (GEEM)***

This is a generic description of the processes of enterprise integration. In other words the methodology is a detailed process model, with instructions for each step of the integration project.

- ***Generic Enterprise Modelling Languages and Tools (GEML&Ts)***

The engineering of an integrated enterprise is a highly sophisticated, multi-disciplinary management, design and implementation exercise during which various forms of descriptions (i.e. models) of the target enterprise need to be created. To formally describe elements of these models more than one modelling language and tool may be needed. So, GEML&Ts is a set of recommended languages and tools which can be used for enterprise modelling. The final choice of tools and languages is left to the user. In the current version of GERAM, recommended GEML&Ts are as follows:

- (a) the IDEF suit of modelling methods complemented by IDEF3
- (b) the CIMOSA modelling language
- (c) GRAI grid

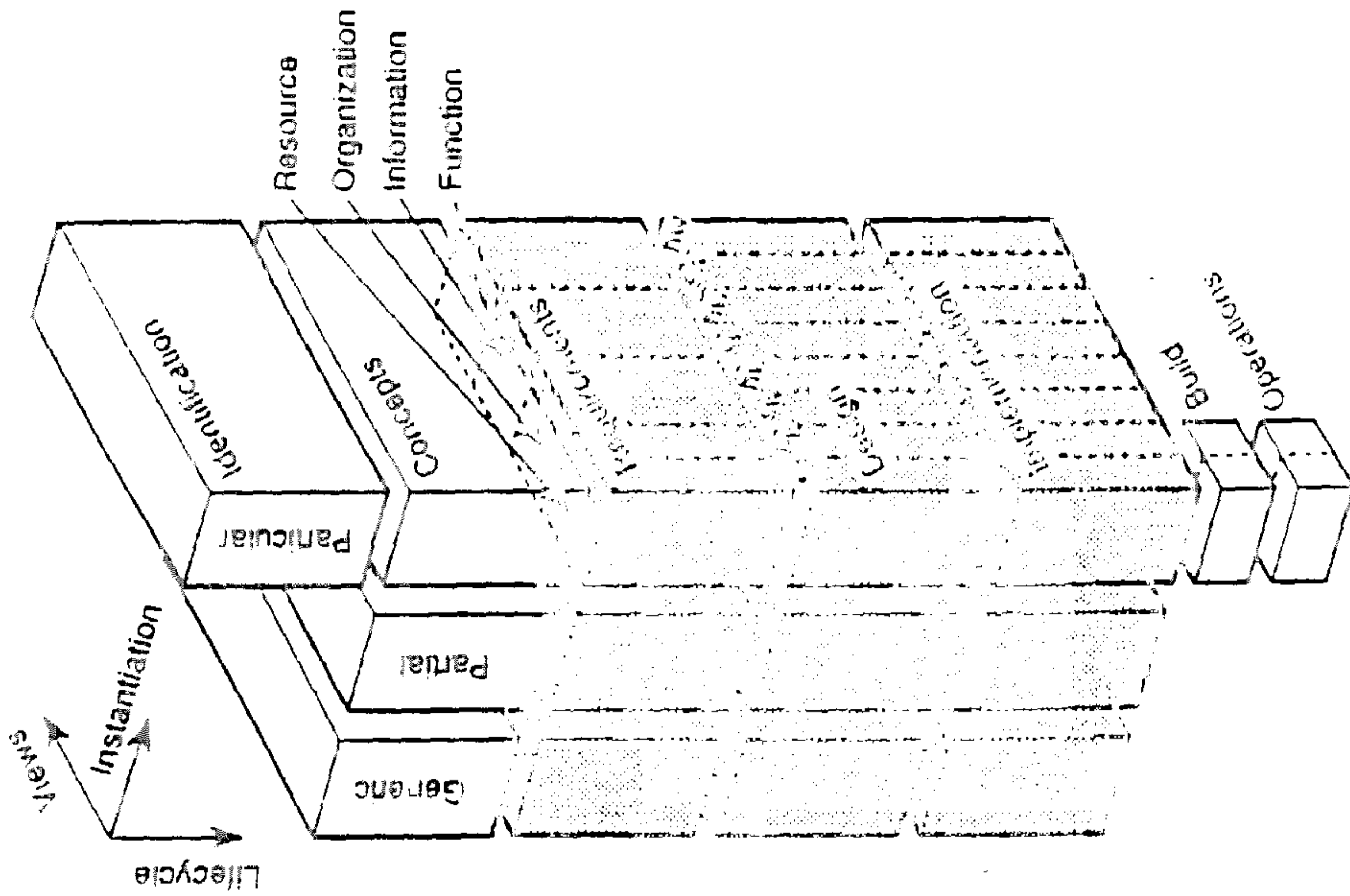


FIGURE 11. Revised GERAM Representation of the Life Cycle of an Enterprise

FIGURE 12. Matrix Representation of the Life Cycle of Any Enterprise

	Generic			Partial			Particular			Structure					
	sw	hw	hw	sw	hw	hw	sw	hw	hw	sw	hw	hw	sw	hw	hw
Operations	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human
Build	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human
Implementation	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human
Design	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human
Requirements	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human
Concepts	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human
Identification	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human	Machine	Human	Human

- ***Generic Enterprise Models (GEMs)***

Generic Enterprise Models capture concepts which are common to all enterprises. Therefore the enterprise engineering process can use them as tested components for building any specific enterprise model.

- ***Generic Enterprise Modules (GMs)***

Modules are products which are represented as standard implementations of components that are likely to be used in enterprise integration projects. Generic modules can be configured to form more complex modules for use in an individual enterprise.

- ***Generic Enterprise Theories (GTs)***

These are theories which describe the most generic aspects of enterprise-related concepts. Such theories may be referred to as ontological theories [Bernus & Nemes, 94]. They may also be considered to be “meta models”³ because they consider facts and rules about enterprise models.

Apart from combining the best features of CIMOSA, GRAI-GIM and PERA, an interesting observation made by Bernus and Nemes is that GERAM can be used to describe not only the life cycle of a *manufacturing enterprise* (Entity 3), but it can also be used to describe the life cycle associated with strategy definition and developments i.e. *strategic enterprise* (Entity 1), the life cycle associated with engineering an enterprise, i.e. *engineering enterprise* (Entity 2) and the life cycle connected with the development and production of a *product* (Entity 4). That is, Entity 1 is used to guide the development of Entity 2 which supports the development of Entity 3 and thereby

3. The term ‘meta model’ is used to denote that the model will actually comprise a number of sub-models or well defined meta model fragments [Monfared & Weston, 97].

Entity 4 (the product to be used by customer) [Williams, 95].

2.3 Human Issues in Enterprise Integration and Modelling

2.3.1 Classical Research Issues on Human Factors

The relationship between humans and machines and the suitability of related working environments represent an important area of study which has received significant attention since the end of World War I [Murrell, 65]. After World War II, this research area was developed into a new discipline referred to as *Ergonomics* [Murrell, 65]; although in North America the term *human engineering* was initially used [Bailey, 82] and now *human factors* is widely used.

Much of ergonomics research began from a study of the human body in terms of its physical and cognitive capabilities (so called *human performance*). The initial focus was on the design of products and equipment suitable for use by humans and the design of suitable working environments (considering issues such as workplace layout, lighting, effects of noise and control requirements). Subsequently, human factors research has been extended to include organisation design, human resource management (job design, selection and training etc.) and the study of social and economic environments. Thus anything related to the study of human beings can be viewed as belonging to human factors research. Inevitably, human factors research involves multi-disciplinary study. It is hard to identify clear boundaries between human factors research and other disciplines. Traditionally, human factors research concerns the following subjects [Murrell, 65] [Fitts & Posner, 67] [Woodson, 81][Bailey, 82] [Salvendy, 87][Wilson, 92]:

- Anthropometries (the nature of the human body, i.e. its capabilities, limits and differences, sensing, perception, cognitive processing, memory, motivation, human error and human reliability, speech communication etc.)
- Human-aspects of product design (physical and cognitive aspects of the design of human-machine interfaces)
- Human-aspects of working environment design (workplace layout, lighting, noise control etc.)
- Human resource management and organisation issues (job design, selection and training and organization design etc.)
- Relationships between humans and machines which govern function allocation between human and machines
- Human health and safety.

2.3.2 Contemporary Human Factors Research

With the advent of IT technology, manufacturing systems have gone through a period of significant change. This has had a strong impact on humans in term of the jobs they carry out, the methods they use to communicate, the structures adopted by their organizations, and hence the roles and the responsibilities they should have, etc.

Between the late 1970s and early 1980s, the potential of computer technology led onto visions of 'fully automated factories' or 'dark factories'. System design and implementation typically focused on aspects of technical design, and tried to replace people as much as possible. The fact that, early on, only marginal benefits were realised, despite heavy investment in notions such as CIM [Tucker, 89] [Goulette, 89] [Winograd et al, 91] [Badham & Schallock, 91] led to an understanding that

inappropriate replacement of human resources is counterproductive.

Indeed, following serious accidents such as those at Three Mile Island, Bhopal and Chernobyl [Meshkati, 91] increased effort was focused on human factors research. Around the late 80's and early 90's, debate centred on the *technocentric* versus *anthropocentric* leading to the use of terms like *technic-centred* or *human-centred* systems.

Important early *human-centred technology* research (lead by Professor H.H. Rosenbrock in Europe) developed a decentralised, "skill-based" model of computer-integrated manufacturing in respect of a number of European companies and institutions [Rosenbrock, 89] [Badham & Schallock, 91]. The term *CIM3 (Computer Integrated Man-Machine Manufacturing)* was coined by Peter Yim [Yim, 91], *HCIM (Human and Computer Integrated Manufacturing)* and its widespread use proposed by P.T. Kidd [Kidd, 90]. Also the term *Human Centred Automation* was used extensively by Professional Group C5 of the IEE (the Institute of Electrical Engineers, UK) [IEE/PGC5, 95]. As manufacturing methods and technology have advanced, the following concepts have become generally accepted:

- A drive towards the elimination of people from manufacturing is often a mistake. There is more to be gained by a judicious mix of humans, computing, and engineering technology [Sinclair, 88].
- For the time being (and probably for quite a few more years to come), the most critical success factor in a manufacturing enterprise is related to the capabilities and qualities of its people and particularly its management [Yim, 91].
- To be successful, CIM requires a different approach to the management and

allocation of human resources than that generally used by manufacturing companies [Young, 89].

- In the foreseeable future it is clear that technology will seldom be used to completely replace people. Rather it will be used to support (and thereby semi-automate) their tasks by providing computational tools, machinery and mechanisms to help them work better and faster and carry out more appropriate and timely actions. Hence we should look for more effective combinations of technology and people when seeking a solution to a set of requirements [Weston, 94].

Other important areas of human factors research relevant to advance manufacturing systems and computer integrated manufacturing concern the following:

- Change management [Lamarsh, 89] [Young, 89] [Levi, 92] [DTI, 93]
- The role of humans in CIM and job redesign [Sinclair, 88] [Blumberg, 88] [Majchrzak, 88]
- The relationship between automation and human beings [Cooley, 84] [Tucker, 89]
- Operator and supervisor control analysis and support [Sheridan, 87] [Sharit, 88] [Benson et al, 92]
- Human/machine and human/computer interaction [Clarke, 86] [Fahnrich and Hanne, 93] [Stahre, 95] [Balint, 95]
- Expert systems and artificial intelligence [Merchant, 91]
- Human knowledge integration [Sinclair, 88]
- Decision making support [Suri, 84] [Johannsen, 86] [Papastavrou & Nof, 92]
- Computer Support Cooperative Work (groupware) [Winograd, 88] [Bannon & Schimidt, 91] [Baecker, 93]

- Team work [DTI, 93][Naguib & Chen, 94][Aravindan & Hiregoudar, 95]
- New organisation structures [DTI, 93][Warnecke, 93][Liu, 94] [Le and Geitner, 94]
[McPherson and White, 94] [Mathews, 95] [Malone, 96] [Weston, 96]
- New relationships between owner, manager and employee of the enterprises and new distribution of responsibilities [Warnecke, 93]
- New management skills [DTI, 93] [Champy, 95].

2.3.3 Human Issues in Enterprise Modelling

Many of the above issues should be taken into account during enterprise modelling studies. However, in respect to enterprise integration projects, probably the most important and frequently occurring issues concern:

- Change management (e.g. Purdue's "Master Planning" approach to this problem)
- Support for human involvement including decision making support within a modelling framework (such as the way in which GRAI-GIM is used to integrate the decision making processes into the modelling architecture)
- Integration of human resource management, organisation systems and manufacturing and technology systems (such as in the way in which Purdue methodology seeks to integrate human and organisation architecture issues with corresponding issues concerned with manufacturing equipment architecture and information architecture)

Fundamental questions which still require an answer include:

- (1) how far can this form of support and integration go?
- (2) can this approach to integration be done in a structured and systematic way?

(3) are there any formal relationships between the human organisation systems and the manufacturing technology systems which should be explicit within the modelling framework?

2.4 Modelling Languages and Tools

A key issue to be addressed with embarking on any modelling exercise, concerning the selection and/or development of enterprise modelling languages and tools which could help put modelling theory into practice and thereby realise enterprise integration and engineering.

There are a variety of modelling languages and tools reported in the literature [Shorter, 94] [Bradley et al, 95] [Vernadat, 96] [Weston, 96]. It is only practical to consider a limited selection of these languages and tools in this section. Hence in the following choice of modelling language or tool has been made with reference to availability of the language or tool to the author and their relevance to this research. This has led to a consideration and analysis of the IDEF family of tools, EXPRESS and EXPRESS-G, the ARIS-Toolset and SAP, ProcessWise, SEWOSA, CIM-BIOSYS and Petri Nets. A summary comparison of the modelling languages and tools (often enabled within a framework or concept) is presented in section 2.5.3.

2.4.1 IDEF Suite Modelling Tools

The IDEF (Integrated Computer-Aided Manufacturing (ICAM) DEFinition) family of modelling technologies was developed by the United States Air Force as part of the ICAM program [ICAM, 81] since 1978. The IDEF suite comprises a set of tools which model manufacturing systems from different aspects. Figure 13 lists available IDEF tools [Mayer et al, 92]. Among these tools, IDEF0, IDEF1X, IDEF2 and IDEF3

appear to be the most well developed and widely applied IDEF tools. In 1993 IDEF0 and IDEF1X were announced as a national standards in the US [NIST, 93]. Indeed, use of the IDEF suit of modelling methods, complemented by IDEF3 was recommended by GERAM in 1994 [Bernus & Nemes, 94].

As a pioneering development of manufacturing systems modelling tools, IDEF has attracted the attention of both researchers and industries around the globe. It has been used as a foundation for enterprise modelling research. It has also influenced the later development of enterprise modelling methodologies such as CIMOSA. There is much written in the literature about IDEF. Authoritative reviews have been produced by Mayer et al [Mayer & Painter, 91] [Mayer et al, 92] [Mayer et al, 96].

Despite more recent IDEF innovations (such as IDEF4, IDEF5 even to IDEF14), today its relative strengths lie in function modelling and its widespread acceptance.

<p> IDEF0: function (static) modelling IDEF1: information modelling IDEF1X: data modelling IDEF2: function (dynamic) modelling IDEF3: process description language IDEF4: object-oriented design IDEF5: ontology description capture IDEF6: design rationale capture IDEF8: user interface modelling IDEF9: scenario-driven information system design specification IDEF10: implementation architecture modelling IDEF11: information artifact modelling IDEF12: organisation modelling IDEF13: three schema mapping design IDEF14: network design </p>

FIGURE 13. IDEF Suit Modelling Tools
 (* IDEF7 is missing from the literature)

2.4.2 EXPRESS

EXPRESS is a data schema specification language originally designed to support the development of STEP⁴ [Wilson, 92] [EXPRESS, 92]. Basically object oriented in nature, EXPRESS enables the modelling of entities (objects), relationships between entities and constraints on entities with unambiguous definition and specification. The definition of entities is implementation-independent. For such reasons EXPRESS has become a popular language for formal data specification and it is currently being progressed towards an ISO standard [Murgatroyd, 95].

Basic constructs of the EXPRESS language include schema, entity, type, function, procedure and rule. Originally EXPRESS took the form of a computer processable textual language. However there is also a graphical representation of EXPRESS, called EXPRESS-G [Wilson, 92].

2.4.3 ARIS-Toolset and SAP

The ARIS-Toolset was developed to realise ARIS principles. It is built on a relational database which stores reference models, such as data models, function models, process models and organisation models. On the top of this database, the ARIS-Toolset provides four main modules which function as an interface to the user, namely the

4. STEP (STandard for the Exchange of Product model data) has been under development since 1984 and is now an international standard. Its aim is to develop into a single internationally accepted standard which will be hardware-independent and is expected to be the only world-wide standardised mechanism for exchanging product data. It can be used by software applications for physical file transfer, shared database access and knowledge base access. In 1995 it was supported by standards bodies in 35 developed nations across all industries. The basis of the STEP standard is a logical description of the product using the data schema specification language EXPRESS and a mapping of the modelled entities, relationships and attributes to a physical file. The EXPRESS model does not hold real data but describes how data structured in STEP physical files [Murgatroyd, 95].

ARIS-Modeller, the ARIS-Analyser, the ARIS-Project Manager and the ARIS-Navigator.

Since 1988 SAP has been developed by SAP AG (System, Application and Products) in Walldorf, Germany [SAP, 96]. The SAP toolset builds on concepts embodied in ARIS [Scheer, 94]. SAP has developed an extensive library of predefined business processes models. These models characterise various functional requirements of software systems. The process models may be selected from the SAP library and used to guide the installation of SAP application software with the tailoring of application solutions being achieved to match user requirements as closely as possible. This being achieved within constraints imposed by the monolithic nature of contemporary software systems [Monfared & Weston, 97].

2.4.4 ITHINK

Ithink is a business process analysis tool, designed in 1993 by High Performance Systems Inc. in the USA [ITHINK, 94].

System diagrams (maps) are constructed via a graphical interface using a small (but what is claimed to be a comprehensive and wholly consistent) symbol set. Use of the symbol set allows simulation models to be constructed directly from system diagrams without the need for programming. The dynamics of systems and hence process behaviour can be exhibited in the form of programmable graphs and tables [BPRAG, 96] [ITHINK, 94].

The ITHINK methodology is based on 'system thinking' (mainly theories on system dynamics) originated by Professor Jay W. Forrester at Massachusetts Institute of

Technology, USA. Professor Forrester's definition of stocks, flows, converters, connectors, infrastructure and feedback loops can be used to provide abstract descriptions various levels of business processes modelling in a consistent, precise and comprehensive way. The ability to achieve direct simulation without additional programming appears to be a strong point of the tool. However, it has reported weaknesses in view of its lack of object-oriented features [Murgatroyd, 96].

2.4.5 ProcessWise

ProcessWise is a process modelling tool developed by ICL (UK) [ProcessWise, 94].

The ProcessWise portfolio consists of: (a) ProcessWise Guide: a methodology for identifying target processes and developing a strategy for design; (b) ProcessWise Workbench: a software tool to facilitate the modelling of business processes and the impact of change; (c) ProcessWise Integrator: an environment for the control and enactment of business processes [ProcessWise, 94]. It can coordinate the business activities carried out by various people involved in a business or production process, including the integration of IT applications and data. The last two features can be used separately or in tandem.

The Workbench is capable of building large and complex models, this may involve modelling teams. The main problems with ProcessWise concerns the programming expertise required [Browne et al, 95]. Browne et al claim that it is too technically specific to be adopted by ordinary users.

2.4.6 SEWOSA

SEWOSA (System Engineering Workbench for Open Systems Architecture), is a

systems engineering workbench, developed by researchers at the MSI Research Institute, Loughborough University, UK [Aguiar, 95]. Its constitution is centred on conformance with the CIMOSA framework. However it combines Petri Nets, object-oriented design and services of the CIM-BIOSYS infrastructure (see next section) to support the life cycle of integrated manufacturing enterprises.

SEWOSA can be viewed as being an instance of an organised method which conforms to the CIMOSA enterprise engineering method, this being implemented in a CASE tool [Aguiar, 95]. SEWOSA provides two groupings of capability for *model building* and *model enactment*. Used in combination these capabilities facilitate rapid prototyping, including requirements definition, system analysis and design, and semi-automated system build. This can lead naturally to reconfigurable, readily extendable and model-driven physical systems, which comprise distributed software processes which interoperate between different applications using the integration services of the CIM-BIOSYS integration infrastructure [Aguiar & Weston, 94].

2.4.7 CIM-BIOSYS

CIM-BIOSYS (CIM Building Integrated Open SYStems) was also produced by researchers at the MSI Research Institute at Loughborough University. It is an integration infrastructure which provides methods and tools for building “soft integrated” manufacturing systems [Weston et al, 90]. CIM-BIOSYS is structured so that it acts as a ‘federator’ of emerging international standards. It provides an open approach to resolving issues of data fragmentation, inter-process communication and interaction in manufacturing environments, which typically comprise a distributed and heterogeneous set of processes. Essentially, the CIM-BIOSYS integration

infrastructure provides integration services for software applications in an 'open' and "sealable" manner. Here the applications only need to have knowledge of how to use CIM-BIOSYS services (which themselves adhere to ISO and commonly used de facto communication, interaction and information standards) with the integration infrastructure taking responsibility for dealing with configuration issues. Furthermore CIM-BIOSYS can be used with a family of system building tools, (such as SEWOSA,) to provide a means of achieving interoperation between executable models and an 'as-is' installed base of real components [Coutts et al, 92] [Gascoigne, 94] [Aguiar & Weston, 93].

2.4.8 Petri Nets

Petri Nets are the basis of an important system modelling methodology which has had a significant impact on the modelling community.

Since Carl Adam Petri submitted a thesis, *Kommunikation mit Automaten*, for his doctorate in 1962 [Peterson, 81] Petri Nets have been continuously studied, extended and developed by theorists and practitioners from many disciplines world-wide [Molloy, 89]. Various extended forms of Petri Nets have been developed from the original Petri Nets. These forms include: place / transition nets (also called condition / event nets), High-level PNs (Coloured Petri Nets [Jensen, 87] and Predicate Transition Petri Nets [Genrich, 87]) and Stochastic Time Petri Nets [Molloy, 82]. The application areas of Petri Nets range from the formal specification of systems, computer architecture design, abstract control models of systems, the analysis system performance, to decision support, production scheduling etc. [Nof et al, 80] [Favrel et al, 85] [Ravichandran, 86] [Aguiar & Weston, 93] [Borusan, 94]. Developments in IT

technology have facilitated wider use of Petri Nets.

Characteristics of Petri Nets include: they can be easy to understand and read [Liu & Wu, 93]; they provide graphical representation suitable for describing distributed and concurrent systems [Wang & Wang, 95]; their formal mathematical definition readily enables executable computer programs to be produced [Knapp & Wang, 92]; they are suitable for rapid prototyping, real time control [Combacau & Couvoiser, 90]; and they are inherently capable of modelling and analysing discrete event systems which involve synchronization, concurrency, hierarchy, conflict and deadlock [Yim & Barta, 94]. These properties can be deployed within enterprise modelling environments.

On the other hand, limitations of many forms of Petri Nets have been reported by Ariffin [Ariffin, 96]. Primarily these limitations centre on the difficulties of handling highly complex systems. Ariffin worked on modular and object-oriented forms of Petri Nets to improve the reusability and scalability of Petri Net models.

2.5 Summary and Discussion

2.5.1 Summary of Each Methodology Surveyed

The special contributions from each framework are summarised bellow:

- **CIMOSA:** In certain quarters CIMOSA has gained a preeminent position and is often the first choice as the basis for the enterprise modelling paradigm. It has contributed fundamental principles which help guide and position other research by the enterprise modelling community. Its architectural framework is well known and its formal and comprehensive definitions offer important modelling constructs. It has also made important contributions in respect to offering an early specification

illustrating how it is possible to execute enterprise models and hence structure and semi-automate the construction of enterprise systems. The ability to execute models will be key to future enterprise engineering developments.

- GRAI-GIM: The special contribution of GRAI-GIM lies in its approach to decision making.
- PERA: The special contribution from the Prudue methodology is that its architecture takes special account of human involvement in enterprise systems. It also focuses attention on strategic planning issues.
- ARIS: Arguably the scope of ARIS's is not as comprehensive as some other enterprise modelling methods reviewed in this section. However its key features are a pragmatic approach (directly supporting business process modelling), its use of a control view (to unify other views), its well-proven reference models, and its availability in the form of proprietary modelling tools.
- GERAM was developed from an unification of CIMOSA, GRAI-GIM and PERA. It integrates the essence of each methodology into a new framework. As such it will help guide future modelling research.

A general comparison of each modelling framework and thereby their underlying modelling languages, constructs and tools is presented by Table 3. One aim of this literature search was to appraise and select suitable modelling methods, frameworks and constructs which can be developed to support resource modelling. This required the appraisal of a significant number of enterprise modelling approaches and narrower scope proprietary modelling tools. To some extent this appraisal was limited by the authors ability to access up to date and detailed information from the different research teams.

	CIMOSA	GRAI-GIM	PERA	ARIS	GERAM
Generativity	generic partial particular	not defined	not defined	generic reference models particular	generic partial particular
Views	function (static & dynamic) information organisation resources (economic)- under consideration	information decision physical functional organisation information technology manufacturing technology	information information system human and organisation manufacturing manufacturing equipment	function control data organisation resource	function information decision/organisation structure/resource
System Life-Cycle	requirement definition design specification implementation description (operation) model maintenance	concept level analysis structure level user oriented design realisation level technical oriented design	EBE identification (Enterprise Business Entity) EBE concept layer EBE definition layer EBE Specification layer EBE detailed design layer EBE manifestation layer EBE operation layer	operation concept IT system concept implementation	identification concept requirement design implementation operation system change
Special Features	CIMOSA Cube: (views, levels, genericity) CIMOSA life cycle and CIMOSA Environment CIMOSA IIS ultimate goal- executable models	decision making support	detailed layers human and organisation arch. master planning	separate control views process modelling focus reference models commercial ARIS Toolset	GERA GEEM GEML&Ts GEMs GMs GTs

TABLE 3. Summary of Modelling Frameworks Surveyed

Other appraisals have also been carried out on which the author could build. These include work of Aguiar [Aguiar, 95] and Shorter [Shorter, 94]. However earlier studies reported did not adequately cover an appraisal of modelling approaches and tools which were important in the context of defining a generic framework for resource modelling. In addition to drawing comparisons at the level illustrated by Table 3, much more detailed appraisal of CIMOSA and ARIS was carried out as the CIMOSA framework was identified as being a suitable starting point for resource modelling and because the ARIS tool was industrially accepted enterprise modelling tool available to the author.

Table 3 compares the coverage of key enterprise modelling approaches with respect to their: (1) genericity; (2) coverage of modelling views; (3) coverage of system life cycles and (4) special features.

These factors loosely correspond to the check list categories in the ENV 40 003 and used by Shorter to carry out a complementary study [Shorter, 94]. However, because of a lack of public domain information it was necessary to draw out comparisons in a fairly broad way. However the comparisons illustrated by Table 3 were drawn in sufficient detail to inform the design of a suitable resource modelling framework. Final choice of an enterprise modelling environment (on which to build the outputs of this research) was made between CIMOSA and ARIS. This is discussed later in Chapter 4.

2.5.2 Summary of Fundamental Principles for Enterprise Modelling Commonly Accepted

- Views: It is common practice to simplify the complexity of enterprise modelling

work by describing the enterprise from different viewpoints, such as the four views of CIMOSA, five views of ARIS etc. The process (function/behaviour) view among other views is essential, as it describes what needs to be done and aspects of how this can be realised. It can also be used to unify other views into a whole.

- *Phases (of the system life cycle) (also called Levels by CIMOSA):* It is common practice to decouple the complexity of enterprise modelling tasks by separating user requirements from formal system definitions, system definitions from system designs, concept designs from real system designs, system designs from system implementation details, and system engineering from system operation. These methods lead to the use of common concepts like: *system life cycle, enterprise engineering and enterprise operation.*
- *Integration Infrastructures:* The key to any sealable and implementable enterprise engineering approach will be the need to separate the integration technology problem from the manufacturing and organization system problems by building systems based upon *Integration Infrastructures.*
- *Reference Models:* It is also common practice to provide a framework which binds methodologies, principles and reference models and thereby guides modelling work. Reference models embrace common features of an enterprise, guidelines for model users, guidelines for the model builder to reduce the modelling time. They also promote standardisation and reuse.
- *Human, Organisation and Decision Making Support:* As enterprise integration naturally embraces human, organisation and technology issues, it is very important to take due account of the human issues and to integrate these into an architectural framework.

2.5.3 Summary of the Current State of Modelling Languages and Tools

A summary of the modelling languages and tools reviewed is depicted in Table 4. Though the survey is not complete, it illustrates general trends about the development and current state of modelling languages and tools. Based on the survey, a rough classification of modelling language and tools has been identified by the author (also see Table 4). The following represent the author's observations in this area:

- Enterprise modelling work is not completely new, significant work was carried out some time ago (such as IDEF's development, Petri Nets application, etc.). Indeed long standing modelling methods and tools are playing a very important role in current developments;
- Much of current modelling tool development was initiated by the need for improved system presentation and analysis in the areas of function and process modelling and in respect to information and data modelling. More recently, the importance of organisation and resource modelling has been recognised. The big picture is also shifting from mainly model building to greater emphasis on model enactment, though work in this area is still in its infancy;
- Function, process and information modelling languages and tools are now relatively well developed. However other aspects of enterprise modelling tools, such as organisation and resource have lagged behind and further effort is required with respect to developing model enactment tools.
- Many enterprise modelling languages and tools are described in the literature, but there are relatively few available in a commercial form. The number of propriety tools investigated by the author were less than expected and proved to be less

	Enterprise Engineering Environment										Enterprise Operation Environment			
	Model Building										Model Enactment			Integrating Infrastructure
	Function (static)	Function (dynamic)	Data Information	Organisation	Resource	Cost	Simulation	Model Immigration	Rapid Prototyping					
IDEF0	✓													
IDEF1	✓		✓											
IDEF2	✓	✓												
IDEF3	✓	✓												
EXPRESS			✓											
EXPRESS-G (IDEFIX)			✓											
Petri-net	✓													
Coloured PN	✓	✓												
Stochastic PN	✓	✓							✓					
ARIS-Toolset	✓	✓	✓	✓	✓									
SAP	✓	✓												
Ithink	✓	✓								✓				
ProcessWise	✓	✓	✓	✓										
SEWOSA	✓	✓	✓						✓	✓	✓			
CIMBIOSYS														✓

TABLE 4. Summary of Principle Features of Modelling Language and Tools Reviewed (✓ = yes)

powerful than expected. There is still much development to be done before enterprise modelling tools can be used like the spreadsheets of today.

2.5.4 Discussion of Problems and Research Ahead

Despite significant research effort on enterprise modelling around the world (involving manufacturers, IT vendors, consultants, research institutes, universities and government) it is still in its infancy. In particular, the author has identified the following general problems which have limited industrial take-up within enterprise modelling:

- Although many of fundamental principles associated with enterprise modelling have been established, none of the most influential and general modelling frameworks (such as CIMOSA, PERA, GRAI-GIM) have yet been developed to a mature and practical stage.
- It is commonly accepted that different modelling perspectives are needed. However, as yet relatively little attention has been paid to resource modelling, organisation modelling, and cost modelling. Without support for these views project justification and realisation becomes more difficult.
- Various stand alone process modelling and simulation tools are available in the market, but their enterprise engineering capabilities are still limited. The tools geared to supporting the life cycle of enterprise integration projects are still under development. The technologies for large scale system simulation, rapid prototyping and model enactment need significant further development.
- Significant emphasis has been placed on the design of architectural framework and reference models. However, still unanswered are questions such as: What should

be the scope and form of such an architecture and reference models? How useful can architectures and reference models be? New ways of approaching and resolving such difficult problems are required.

Further research and development effort is needed before enterprise modelling can become a mature discipline both theoretically and practically. In particular, the need for further research has been identified with respect to the following:

- On improving and widening the scope of modelling frameworks;
- Practically applying the principles embodied in modelling frameworks to test their applicability;
- Embedding refined principles into the next generation enterprise modelling tools to promote a wide spread practice of the principles involved and thereby the generation of better enterprises, more quickly and with reduced engineering and re-engineering effort.

3.0 Research Objectives and Plan

3.1 Requirements for Resource Modelling

The general literature survey on enterprise modelling, presented in Chapter 2, confirmed earlier findings of research in the MSI Research Institute that there remain important outstanding research challenges in the area of *resource modelling*.

The need to model resources is further emphasised by the following observations.

Resources are the building blocks of an enterprise [Li, 95-1]. Knowledge about resources in terms of their properties and their relationships is of primary concern when realising enterprise integration [Li, 95-1]. Hence there is a need for a systematic study of common enterprise resources in a way which defines a framework¹ for resource modelling

Enterprise resources can include resources used to realise manufacturing processes, such as machines and human beings, and their supporting resource elements (such as computers, application software, networks, integrating infrastructures, etc.). Also on taking a wider view, information, skill, knowledge, capital and so on can also be considered to be enterprise resources [TOVE, 92] [MOSES, 95] [IEM, 96]. It is appropriate therefore to define resource types and thereby classify them. Such a systematic approach can help support the allocation of jobs (i.e. enterprise processes, activities and tasks) to resources. However, in order that such a classification can have

1. In this context the term “framework” is used in the sense that it should “lend structure” to resource modelling processes. In so doing a framework could, for example, take the form of a modelling method or define relationships between models.

wide applicability initially such a study should concentrate on defining a generic set of resources. Potentially such a classification could then be applied to any type of enterprise.

It is necessary to have access to resource information, when making various decisions during the life cycle engineering of enterprise processes and systems [Li et al, 97]. For example typically during process modelling, it will be necessary to know what kind of resources are available to perform the functions (or activities) required [Aguiar et al, 96]. Ideally this kind of information should be classified, and systematically managed within a resource modelling environment so that it can be accessed in an appropriate form by members of an interdisciplinary team concerned with the engineering of an enterprise [Li, 95-1].

Indeed on considering the various phases of the life cycle of enterprise systems (such as *requirements definition, conceptual design, technical design, system implementation and real-time control and monitoring*) resource information is needed to support decisions made during each phase [Li, 95-1].

Common approaches to system design deploy the top-down methodologies [Weston, 96]. A consideration of factors such as choice between alternative technologies and available resources and their financial implications need to be understood as early as the requirement definition stage [Aguiar et al, 96]. Bottom-up approaches to resource modelling are also necessary to characterise properties of available systems and available components [Aguiar et al, 96]. In this respect it is important to bring together the best aspects of bottom-up and top-down approaches to realise enterprise design and construction in a holistic and effective way [Aguiar et al, 96] [Weston, 96].

The need to model resources has been recognized independently by leading enterprise integration research groups worldwide [CIMOSA, 89] [TOVE, 92] [SEMATECH, 94] [IEM, 96]. Significant work has already been carried out on process modelling and information modelling, but less emphasis has been placed on resource, organisation and cost modelling [Shorter, 94] [Vernadat, 96].

Despite the scale of the problem, information technology has advanced to such a stage that the holistic modelling of a company, including detailed information about resources, is now possible [Popplewell & Bell, 94].

Many BPA (Business Process Analysis) and BPR (Business Process Reengineering) software tools are based on the use of process modelling and their application promises important commercial benefits [Barber & Weston, 96]. However, generally speaking contemporary industrial process modelling projects have only resulted in improved analysis and identification of problems in an enterprise. To date there is little evidence that it has helped directly to redesign and hence control and run enterprise systems [Barber & Weston, 96]. Theoretically BPR implies a need to understand that resource and organisation problem and solution perspectives and to consider these views to compliment process views [Li, 95-1]. Arguably process modelling appropriately linked to resource and organisation modelling could provide an important step forward in enterprise design and construction [Li, 95-1].

A clear understanding of resources could also provide fundamental knowledge which can help support ongoing developments in 'component technology'. Significant ongoing effort worldwide is centred on deploying distributed object technology to create a new generation of reusable 'business objects' and their 'software components'

[MSI, 97]. Hence the availability of well defined resource models could, in the context of enterprise engineering help shape these developments.

3.2 Research Objective

The general objective of this research is to contribute knowledge in the area of enterprise modelling with a special focus on resource modelling.

Specific objectives are:

- to carry out a systematic study of the nature and characteristic properties of resources in the context of designing and constructing manufacturing enterprises, and to find a proper way of defining resources and classifying them. Also, to identify relationships between resource models and other modelling perspectives. Necessarily this will require a classification of the function of resource modelling during each phase on the life cycle of enterprise systems. It will need to identify key issues associated with resource modelling and thereby provide a framework for resource modelling.
- based on the framework developed, to design a resource modelling toolset and to implement it within a CASE (Computer Aided Software Engineering) tool. This will seek to illustrate the purpose of the resource modelling framework and the (re)use of the resource models in a proof-of-concept form.
- two case studies are planned to test the usefulness of the toolset and its underlying methodology and assumptions in different manufacturing domains. Based on the case study findings, ways in which the framework can be modified and improved will be considered.

Hence the initial, and arguably most important part of author's research work, is to establish a resource modelling framework. The objective was to do this bearing the following targets in mind:

- Where appropriate the CIMOSA Modelling Framework, would be adopted to contain the scope of the study, even though it was anticipated that this framework might have to be developed to a significant extent. Since, prior to the author's study, there had been limited practical use of CIMOSA's resource modelling ideas, a thorough study of its resource modelling concepts and framework had to be established at the beginning of the study.
- Any resource modelling framework proposed should be open and flexible. In addition to supporting the development of CIMOSA compliant models, the framework should be capable of supporting other modelling approaches.
- The resource models developed by the study should be extendable and reusable in order to cope with technological advance and other forms of change.
- Ideally the resource modelling toolset designed should be capable of being used in isolation. In this way it was envisaged that it could be used with other modelling tools (such as existing proprietary tools conceived to achieve process, information and organisation modelling).

Summarised below are the research objectives:

Objectives of the PhD Research

1. Better understanding the role of the resource modelling
2. To specify a modelling framework which links resource models and other enterprise models
3. To produce a proof-of-concept resource modelling capability which tests use of the framework

3.3 Research Plan

1. Carry out a detailed literature survey on resource modelling
2. Identify resource modelling requirements, difficulties and key problems
3. Develop a resource modelling framework
4. Design a resource modelling toolset which can demonstrate resource modelling principles in proof-of-concept form
5. Implement the resource modelling toolset
6. Carry out the two case studies
7. Appraise the findings

Figure 14 shows conceptually the scope and main thrusts of the author's PhD research.

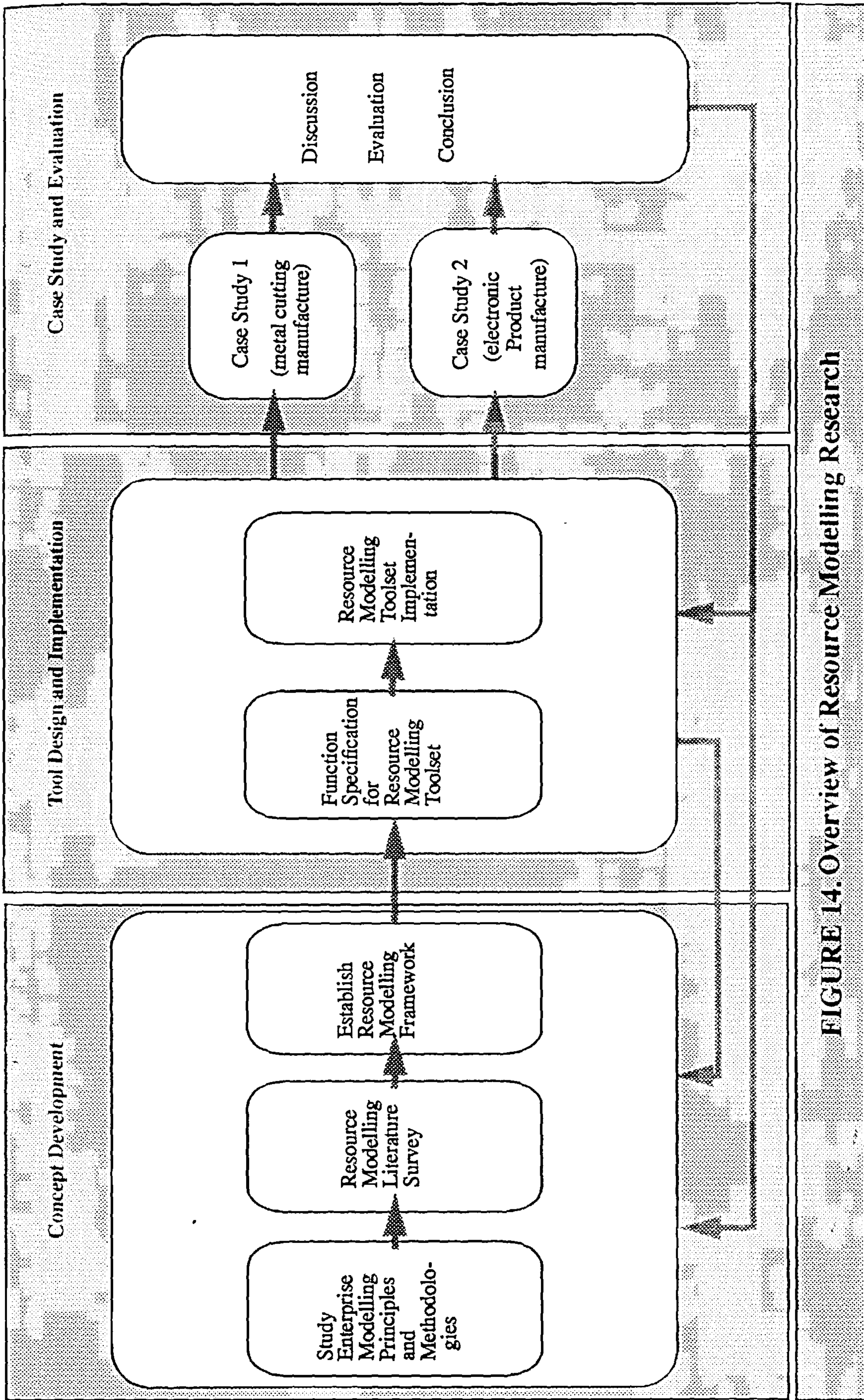


FIGURE 14. Overview of Resource Modelling Research

4.0 Findings of a Review of Research on Resource Modelling

4.1 Introduction

This chapter presents an extended literature survey on resource modelling as this was identified in the main literature survey as an area in which further research is required. This extended review exemplifies the purpose of resource modelling in respect to the lifecycle engineering of enterprise systems. Also relationships are considered between the resource modelling viewpoint and other modelling aspects which lead to a discussion of inherent linkages between resource models and other modelling perspectives. Thus the material presented in this chapter seeks to describe the status quo on resource modelling prior to the start of this research and to provide key inputs into the design of the author's resource modelling framework.

4.2 Resource Modelling Literature Review

4.2.1 Introduction

A number of papers on resource modelling are identified in the literature. The most influential works on resource modelling reported in this section are:

- resource view of CIMOSA;
- resource model constructs from IEM;
- resource ontology from TOVE project;
- factory model from the MOSES project.

In addition, other related research papers which have informed the author's work are also presented in this section.

4.2.2 Resource View of CIMOSA

The resource view is one of four views specified by CIMOSA. Its purpose is “to allow observation of the enterprise’s assets needed for carrying out the enterprise processes, including the use of the model to manage (control and monitor) these assets.” [CIMOSA, 93]. CIMOSA defines a methodology for resource modelling which can be summarised in the following sections.

4.2.2.1 Classification of manufacturing resources

CIMOSA classifies manufacturing resources into so-called *Functional Entities* (FEs) and *Components*.

Functional Entities are *Active Resources* which can perform functional operations. Examples of functional entities are: a person; an AGV; a Cell Controller; and a FMS system. *Components* are *Passive Resources* which do not provide functionality on their own. Rather they need to be used or manipulated by a functional entity to become part of that functional entity. Typical examples of components are tools, fixtures, etc.

CIMOSA classifies functional entities within three generic classes, namely: *human*; *machine*; and *application* (computer software). Figure 15 illustrates CIMOSA’s general classification of resources. It should be noted that there is no formal classification of components.

4.2.2.2 Resource modelling constructs¹

1. A construct, a term used among enterprise modelling community, is a generic building block which characterises an element of formalism for a modelling method or language [Aguilar, 95].

CIMOSA provides two essential modelling constructs to describe resources. One is called the resource *Capability Set* which models resource requirements, the other is a so called *Resource* which models resource objects within an enterprise.

At the *requirements definition* modelling level of CIMOSA, only the *Capability Set* construct is used to describe the resources required by specific enterprise activities. Whereas at the design specification modelling level of CIMOSA, both the *Capability Set* and *Resource* are used as constructs by other modelling views. The *Capability Set* is a CIMOSA modelling construct in as much that its purpose is to decouple process and resource models; this being a key property which facilitates the reuse of resources in different application areas. See Figure 16 and Figure 17 for examples of the use of the CIMOSA *Capability Set* and *Resource* constructs.

4.2.2.3 Particular resources

Particular resources are represented by *Resource Units* in CIMOSA. *Resource Units* can be defined as part of a resource model and used as a resource to carry out some activity class. This relates to the assignment of resources to activities (or processes) and means that all occurrences of an activity class will be executed by a specified resource unit.

The structure of a resource unit is inherited from the structure of the resource construct. However it adds relevant entries to describe the occurrence of an object such as: *location, capacity, availability, allocation mode* and *assignment mode*.

4.2.2.4 Enterprise description using the CIMOSA resource view

From a resource modelling standpoint, CIMOSA considers an enterprise to be a set of

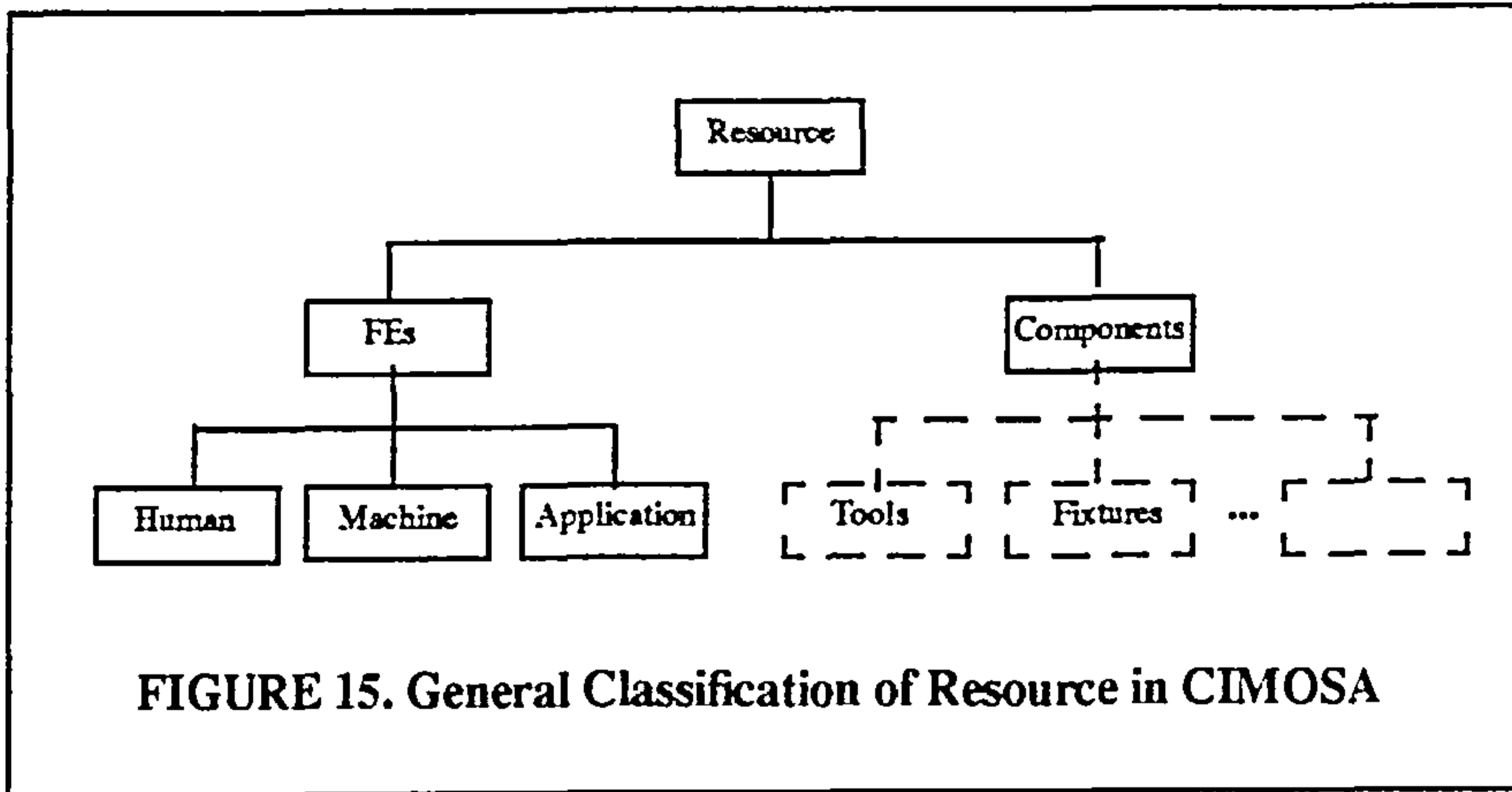


FIGURE 15. General Classification of Resource in CIMOSA

CAPABILITY SET

Type:	Shop Floor System Capabilities
Identifier:	CS-6
Name:	Shop-Floor-Operations-Capabilities
Design Authority:	B. Dupont / Engineering
CAPABILITIES:	
Function Related:	Functions: (to schedule, to display schedule, to modify schedule, to control schedule execution)
Object Related:	Schedule-Size: [-, 100] /* schedule has less than 100 operations */
Performance Related:	Schedule-Generation-Time: [-, 3] mn
Operation Related:	/* be able to modify a schedule in less that 10 mn */ Schedule-Rules: (SPT, SLACK, RDM, FIFO, EDO)

FIGURE 16. An Example of Capability Set Construct in CIMOSA
(source: [Vernadat, 96])

RESOURCE

Type:	Shop Floor Control System
Identifier:	FE-10
Name:	SFC-system
Design Authority:	B.Dupont / Engineering
DESCRIPTION:	Shop Floor Control System able to generate detailed manufacturing schedules from a manufacturing plan using classical priority rules.
CAPABILITY SET:	CS-6 / Shop-Floor-Operations-Capabilities
CLASS:	Functional Entity
QUANTITY:	1
OPERATION SET:	GenerateSchedule (IN MF: Mfg-Plan, OUT MO: Mfg-ORDERS, OK: FOSTatus); DisplaySchedule (IN S:Schedule); MoveOpe (IN S:Schedule, OP:Operation; Position:position); DeleteOpe (IN S:Schedule, OP:Operation);
OBJECT VIEW:	OV-90 /SFC-System
STRUCTURE	
PART OF:	
CONSISTS OF:	

FIGURE 17. An Example of Resource Construct in CIMOSA
(source: [Vernadat, 96])

interconnected functional entities. These entities can send requests to one another and execute functional operations when requested to do so by users or by business processes [Vernadat, 96]. Based on this concept, CIMOSA is capable of describing a given complex manufacturing system by grouping these functional entities together. Hence the two terms, *Resource Cell* and *Resource Set* have been introduced by CIMOSA.

A *Resource Cell* is a permanent aggregation of functional entities and / or resource components. Such a Resource Cell can be considered to be a single functional entity.

A *Resource Set* is a temporary aggregation of functional entities and / or resource components used, i.e. a single functional entity which exists temporarily for some purpose.

4.2.3 Resource Modelling Constructs of IEM

IEM (Integrated Enterprise Modelling) methods were developed within the KCIM project part 4 which was supported by the Federal German Ministry for Research and Technology from 1988 to 1993 [IEM, 96]. IEM presents a method for object-oriented enterprise modelling which is based on a comprehensive study of manufacturing processes and associated tasks. It supports the design of an information system architecture and its interfaces within an enterprise. The IEM method is designed to enable users to plan and design information systems based on the use of integrated enterprise models.

IEM has defined a so-called *generic activity model* of manufacturing systems (see Figure 18), which defines generic object classes (see Figure 19). The generic classes

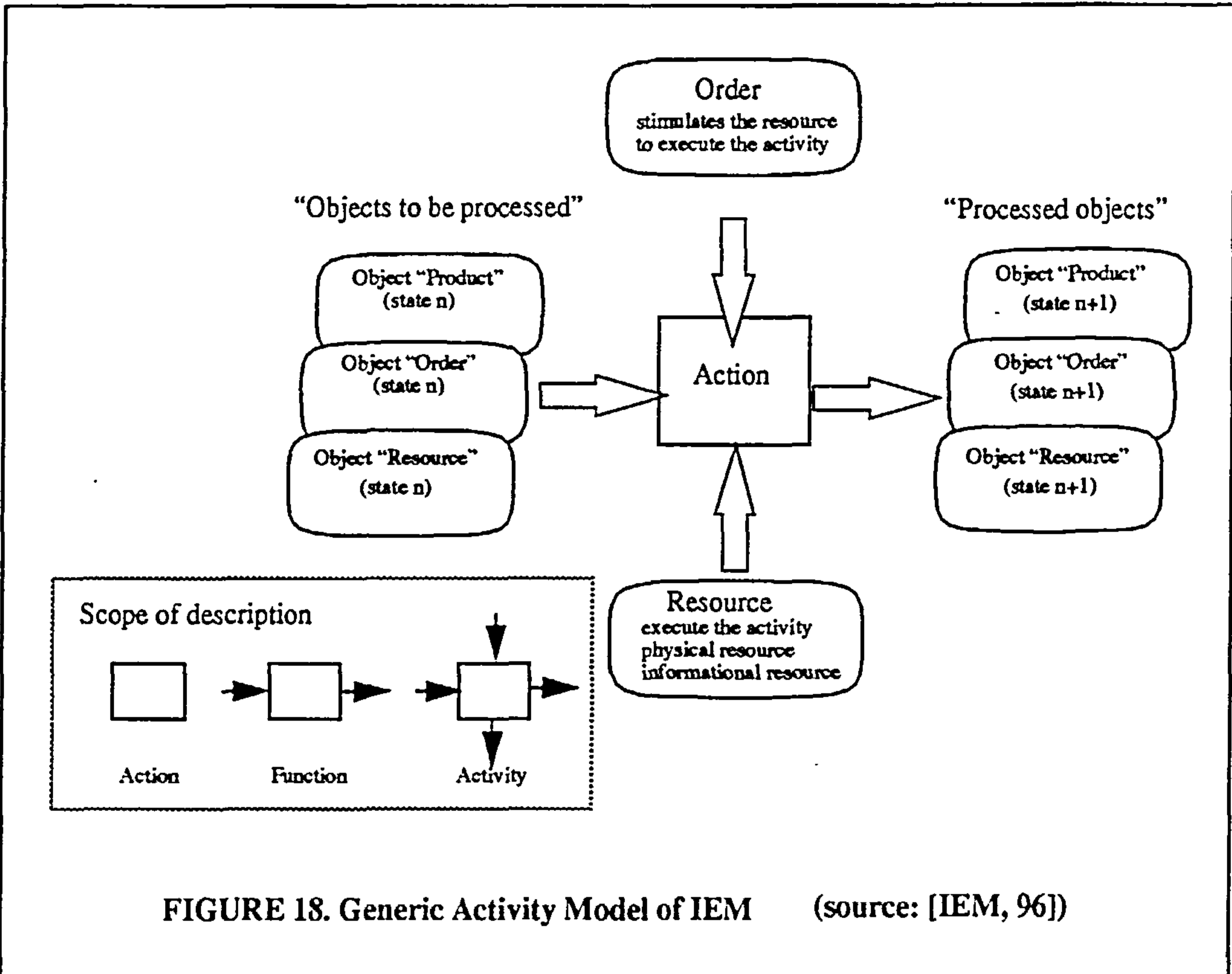


FIGURE 18. Generic Activity Model of IEM (source: [IEM, 96])

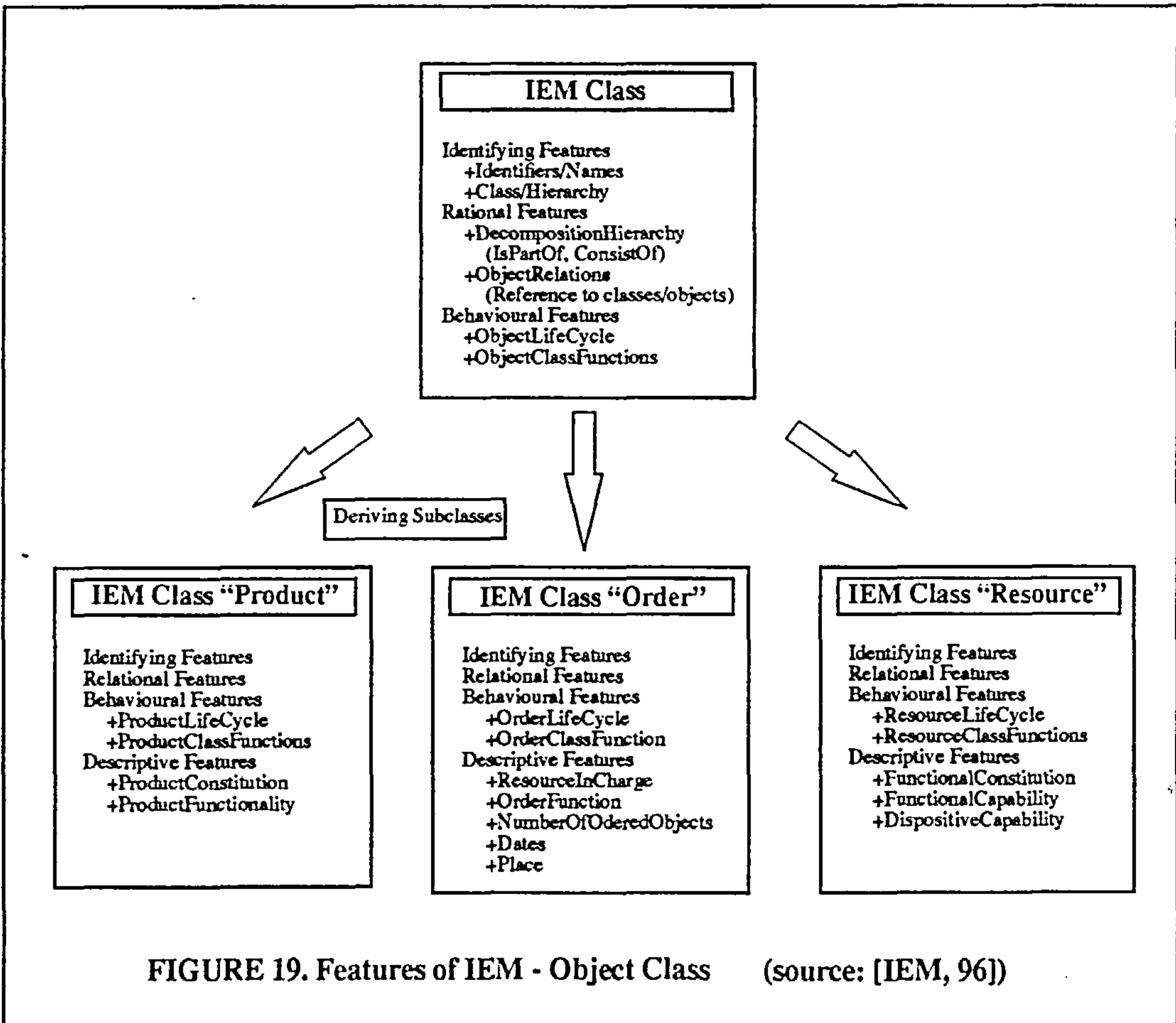
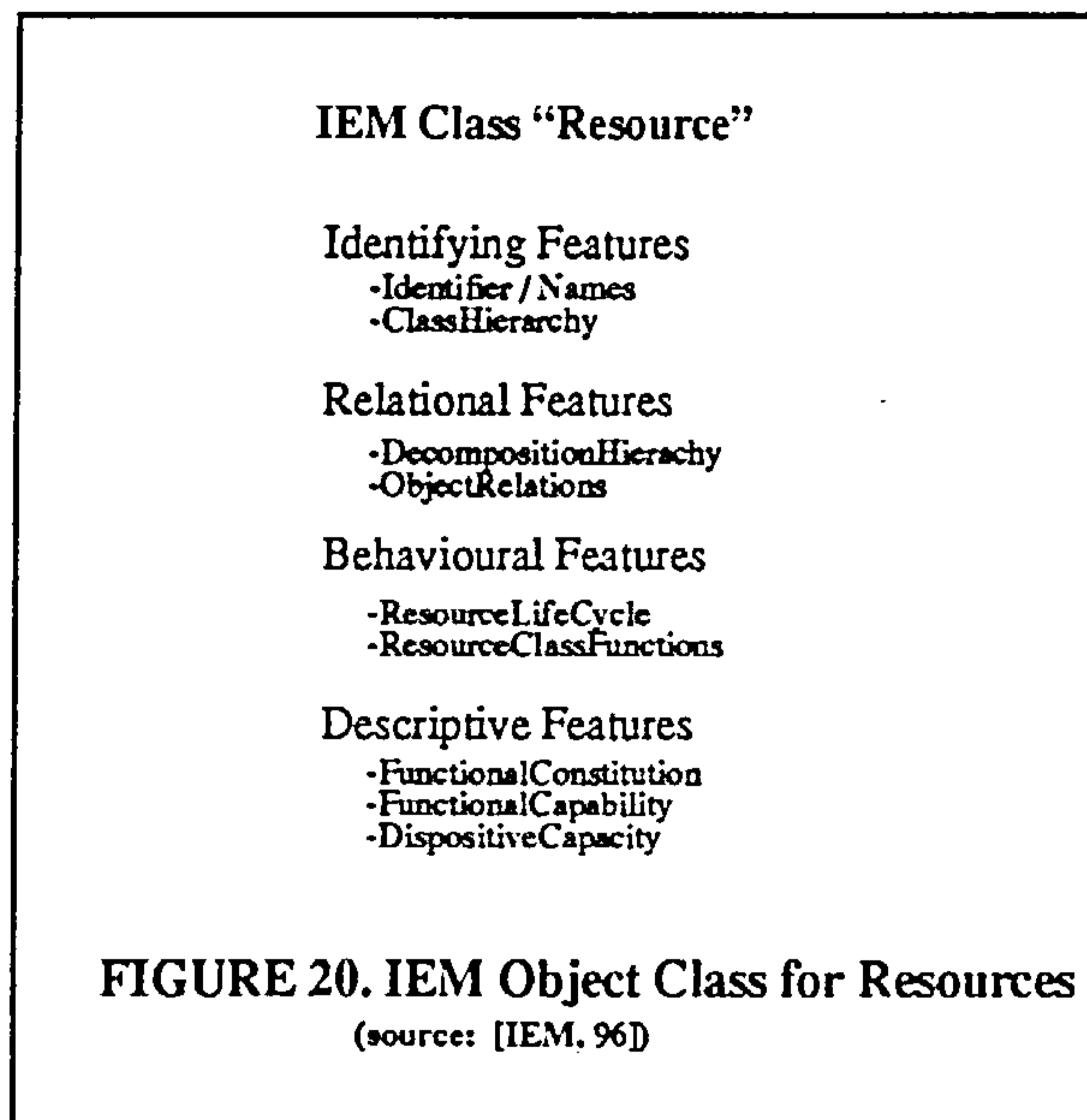


FIGURE 19. Features of IEM - Object Class (source: [IEM, 96])

include “product”, “order” and “resource” classes. The generic activity model is used to describe all material and information used to support functions carried out in an enterprise. This material and information includes machines, humans, facilities, tools, organisational structures, data processing equipment, document and information etc. Figure 20 shows the IEM template used to define a generic resource object class. The following describes each “feature” in the template.



4.2.3.1 Identifying features

- *Class Ident*: a short name for the resource class (alphanumeric)
- *Class Name*: the full name for the resource class (text), i.e. the general resource name
- *Instance Ident*: a short name for the resource (alphanumeric)
- *Resource Name*: the full name for the resource instance (text)
- *Class Hierarchy*:

SuperClass: If the class is defined, identifier or name of the superclass of the resource, otherwise empty.

SubClass: List of identifiers or names of the subclasses of the resource, if these are defined, empty otherwise.

4.2.3.2 Relational features

- *Decomposition Hierarchy*: This feature describes the structure of resources which cannot be described exclusively by the hierarchy:

Is-Part-Of: This is a list of identifiers or names of resource classes whose objects contain one or more objects of the class that should be described.

Consists-Of: This is a list of identifiers or names of resource classes for which one or several objects represent a part of an object of the class that should be described.

The number of corresponding objects should be determined for each identifier (name).

- *Object Relations*:

Workable Objects: This refers to object classes (Products, Orders, Resources) which comprises whose objects can be processed by resource objects of the class to be described.

Belongs-To: Reference(s) to resource class(es) representing organisational or structural units.

Requires: Reference(s) to resource class(es) necessary to execute functions (e.g. NC programs).

Controlling-Order: A stand-in for references to order classes whose order objects instruct and control the execution of functions on objects of the resource class to be described.

Processing-Resource: A stand-in for references to resource classes whose resource

objects perform functions on objects of the resource class to be described. These may be a responsible organisational unit or a processing resource (which provides a description of requirements or a temporary assignment of a resource to execute a function).

4.2.3.3 Descriptive features (behaviour)

- *Resource-Life-Cycle*: This characterizes the state of resource with regard to the availability/readiness to execute functions.
- *Object-Class-Functions*: This lists names of functions to be performed on the resource for the purposes of planning, production, provision and maintenance, etc.
- *Sequence-Of-Functions*: This describes a concatenation of the 'resource class functions' in one process.

4.2.3.4 Descriptive features (functional)

- *Functional Constitution*: This provides features which facilitate performance description:

Functional-Geometry: Geometrical performance parameters of a resource.

Workable-Material: Names and parameters which describe material which can be processed by resources of the class to be described.

Information: Further characteristics describing the performance characteristics, which cannot be represented by geometric or material descriptions.

- *Functional Capability*: This defines functions that can be executed by the resource; viz:
 - a) a list of names of actions
 - b) a list of names of objects and functions.

4.2.3.5 Limitations of the IEM resource constructs

- They are too specific to be used as a generic construct, primarily as they require too many pointers to other constructs [Vernadat, 96];
- They are rather specifically oriented to metal working domains (i.e. focused on geometrical description, processable materials, etc.)
- Inherently they impose a strong binding between resources and functions, processes and orders. This will severely restrict the flexibility and generality of the model [Vernadat, 96] [Weston, 97];
- Organisation units are considered to be a resource. However, there is no specific constructs to model such units, which is very confusing [Vernadat,96].

4.2.4 Resource Ontology from the TOVE Project

The TOVE (TOronto Virtual Enterprise model) Project at the University of Toronto [TOVE, 92] attempted to provide a generic, reusable ontology for modelling enterprises. The TOVE ontology currently spans knowledge of activity, state, time, causality, resource, cost and quality [Fadel et al, 94].

The Resource Ontology in TOVE seeks to reason about the nature of a resource and its availability to support planning and scheduling in an enterprise. The resources included within the TOVE Resource Ontology are machines, electricity, raw material, tools / equipment, capital, human skill and information. The following provides some examples included in the resource ontology [Fadel et al, 94].

- *Resource Known*: This specifies knowledge about a resource as opposed to its physical existence.
- *Resource Role*: In TOVE, a resource has a role with respect to an activity. These

roles are: raw material, product, facility, tool and operator.

- *Division of*: This term specifies that a resource can be divided into sub-resources. There are two types of divisions: physical and functional.
- *Divisibility of a Resource*: this term specifies that a resource has the property of a resource as being divisible with respect to an activity without affecting the role of the resource with respect to that activity. There are three types of divisibility: physical, functional and temporal divisibility.
- *Unit of Measurement*: This predicate specifies a default measurement unit for a resource, when it is associated with an activity. Accordingly, resource quantity or capacity should be measured using a specific unit of measurement. This term is used for specifying both qualitative and quantitative aspects of measurement.
- *Measured by*: defines the objects by which a resource is measured with respect to an activity. This term acts as a constraint on the “unit of measurement” term. Each term unit of measure must have a corresponding “measured by” assertion.
- *Component of*: specifies a resource as being a part of another resource implying that a resource consists of one or more sub-resources. A resource can be a physical or functional component of another resource with respect to an activity in which case each will not share the same role with the original resource.
- *Quantity*: A resource point specifies a resource’s quantity at same time and unit of measure.
- *Application Specification*: There are three types of application specification, namely: consumption; use; and produce specification. They specify the proportion of the resource that is to be consumed, used or produced over a time interval as well as the unit of measurement.

- *Continuous vs. Discrete Resources:* A continuous resource indicates a resource that is uncountable. Discrete resources on the other hand specify that a resource is countable.
- *Usage Mode:* Usage mode is used to indicate whether a resource supports an activity on a discrete or continuous basis. The term does not imply that the activity is discrete or continuous.
- *Simultaneous Use Restriction:* Simultaneous use restriction prohibits the simultaneous use / consumption of a resource by two activities.
- *Committed to:* This predicate specifies the commitment of a resource to an activity thereby making the resource unusable / partly usable / fully available by other activities. For example a resource will be committed to an activity as a result of a scheduling activity.
- *Total Committed:* This predicate specifies the total proportion of a resource committed to all activities at a specified time.
- *Capacity:* Capacity is defined as being the maximum set of activities that can simultaneously in use / consumed by a resource at a specific time.
- *Activity History:* This predicate specifies the history of usage or consumption of a resource before a specified time point.
- *Resource Configuration:* this term specifies the configuration of a resource with respect to an activity. This term implies that for a given activity the resource must have a specified configuration.
- *Set up Constraint:* This term specifies the duration required to set-up a resource for use by an activity.
- *Alternative Resource:* This term specifies an alternative resource(s) which can be

used or consumed by an activity. This is useful in cases when an alternative resource is required because of a machine breakdown or unavailability of a resource.

- *Relation between Resource Ontology and Activity-State Ontology:* A state in TOVE represents what has to be true in the world in order for an activity to be performed, or what is true in the world after completion of an activity. The status of a state, and any activity, is dependent on the status of resources that the activity uses or consumes.

The data model of the ontology has been implemented on top of C++ using the Carnegie Group's ROCK knowledge representation tool and the axioms are implemented in Quintus Prolog [Fadel et al, 94].

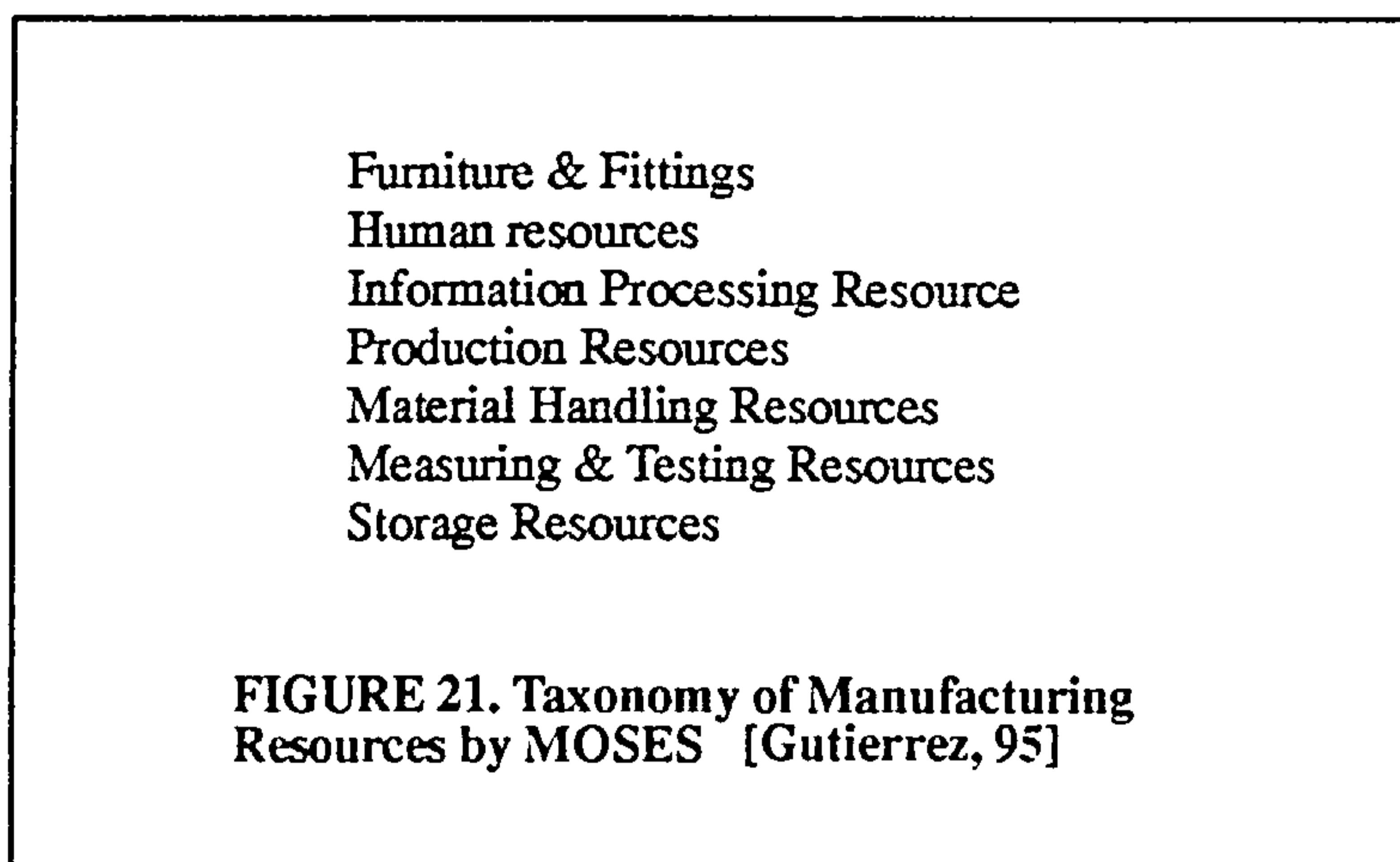
4.2.5 Factory Model from IMPACT and MOSES Projects

Popplewell and Bell sought to develop a family of tools and comprehensive methodologies for *factory modelling* [Popplewell & Bell, 94]. Their work formed part of two research projects IMPACT and MOSES funded by EPSRC and conducted at Loughborough University and Leeds Universities [IMPACT, 91] [Gutierrez, 95] [Ellis et al, 95].

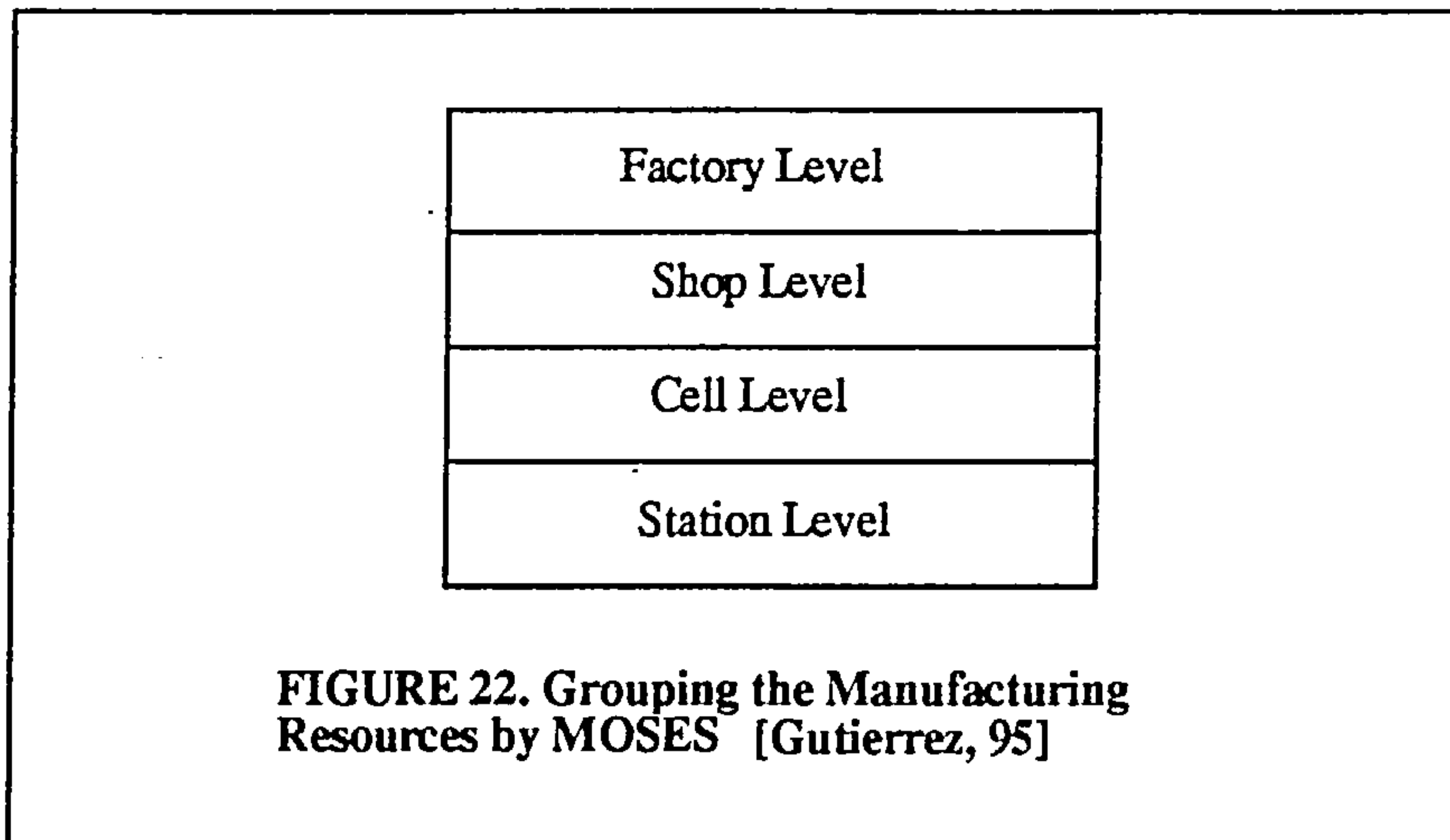
A basic assumption of this study was that essentially a *factory model* can take the form of an *information model* which should include a *product information model* (a so-called *product model*) and a *manufacturing information model* (also called a *manufacturing model*). The product model, which is defined during an IMPACT (Integrated Modelling of Products & Process Using Advanced Computer Technology) project, captures and structures information concerning a product and its components

through its life cycle. Whereas the manufacturing model developed within a MOSES (Model Oriented Simultaneous Engineering System) project, describes the manufacturing capability of an enterprise. Three information entities have been identified as core elements of a manufacturing model. These are: *manufacturing resource* (e.g. machines, tools, fixtures, machining cells, operators etc.), *manufacturing process* (e.g. injection moulding, machining process, etc.) and *manufacturing strategies* (e.g. how these resources and processes are used and organised).

As manufacturing resources are an important element in this manufacturing model, significant effort on this project was centred on resource modelling. The taxonomy developed to describe manufacturing resources is shown in Figure 21. Its resources



are grouped hierarchically according to a BSI standard [BSI, 90], see Figure 22. Other taxonomies were also defined, namely: a production manufacturing taxonomy; a machine tool taxonomy; a material handling taxonomy; and a manufacturing process taxonomy [Gutierrez, 95].



As emphasis was placed on modelling the manufacturing capability of an enterprise, the manufacturing model developed imposes a strong coupling between resource, process and strategic models. Also this manufacturing model is developed with a definitive focus on supporting the product life cycle engineering (i.e. encompassing produce design, manufacture and assembly).

In the context of this study, the limitations of this method are:

- there is essentially a 'product' rather than 'system' focus;
- the capture of resource information is linked onto specifics of a manufacturing process and/or a manufacturing strategy. Hence inherently the approach will have limited flexibility, openness and extendability;
- the strategy elements of this manufacturing model have yet to be defined in detail;
- the projects did not consider in detail, issues related to real time control of activities and information.

4.2.6 Other Findings

The following summarises concepts and constructs developed by various researchers

to define and facilitate the capture of models of resources.

1. Design capture views include [Karangelen et al, 94]:

- a) an environmental capture view;
- b) an information capture view;
- c) a functional capture view;
- e) a behavioural capture view;
- f) an implementation capture view.

2. The work of Aguiar and other researchers at the MSI Research Institute has supported the development and use of the following different resource modelling aspects [Aguiar et al, 96],

- a) a resource capability view;
- b) a resource behaviour view;
- c) a resource emulation view;
- d) a resource implementation view.

3. Other researchers have identified the importance of defining connections between resource models and other enterprise models.

a) Karangelen suggests that the “efficient employment of any resource capture method is dependent upon the existence of support for formal linkage with other key aspects of a system design including the system functional design,…” [Karangelen et al, 94];

b) Aguiar identified the need for connectance models to link *requirements definition*

and *design specification* [Aguar et al., 96];

4. With respect to criteria to evaluate the quality of resource models in the context of resource modelling,

a) Karangelen stated that [Karangelen et al, 94]:

(1) flexible and robust representation mechanisms are required;

(2) combinations of various resource characterization techniques need to be supported;

(3) any representation capability needs to be extendable;

(4) there is a need to support access, extraction and the organisation of resource models;

(5) the ability to reuse resource descriptions is important.

b) Fox [Fox, 92] describes a number of important qualities of resource models, namely:

(1) *Generality*: To what degree can a representation be shared between diverse activities such as design and troubleshooting, or even design and marketing? i.e. what concepts does it span?

(2) *Competence*: How well does it support problem solving? That is, what questions can the representation answer or what tasks can it support?

(3) *Efficiency*: Space and inference. Does the representation support efficient reasoning, or does it require some type of transformation?

(4) *Perspicuity*: Is the representation easily understood by the user? Does the representation “document itself?”

(5) *Transformability*: Can the representation easily be transformed into another more appropriate form for a particular decision problem?

(6) *Extensibility*: Is there a core set of ontological primitives that are partitionable or do they overlap in denotation? Can the representation be extended to encompass new concepts?

(7) *Granularity*: Does the representation support reasoning at various levels of abstraction and detail?

(8) *Scalability*: Does the representation scale to support large applications?

(9) *Integration*: Can the representation be used directly or transformed so that its content can be used by existing analysis and support tools developed in an enterprise?

4.2.7 Summary and Discussion

Based on the foregoing, the author has categorised research carried out by CIMOSA, IEM, TOVE, and MOSES in the manner depicted by Table 5. Furthermore the author has drawn the following conclusions:

- Much of the previous work on resource modelling has had an emphasis on system operation including: planning, scheduling, control and monitoring.
- There are certain differences in resource classifications among CIMOSA, IEM, TOVE and MOSES, but all have accepted that there should be resource hierarchy to describe resources at different levels, although there are differences between the hierarchy levels they suggest.
- CIMOSA and TOVE support the concept of enterprise modelling via use of

different modelling views. Both separate resource models from other modelling views and also offer means of decoupling these views. Whereas, IEM and MOSES have chosen a holistic way of binding together several modelling views.

- Based on an understanding of the different principles described above, arguably the information capture methods advocated by CIMOSA and TOVE can be considered to be more generic. Although they are not complete, they are open, flexible and relatively easy to extend. In contrast, the information representations offered by IEM and MOSES may be defined in greater detail but are too specific to be used generically. This will significantly limit reuse of their concepts in different domains.
- It is evident that although important exploratory resource modelling research work has been carried out available methods, frameworks and tools (which support resource modelling) are incomplete and fragmented. None-the-less there are important concepts and findings on which to build.

Hence, from the extended literature survey on resource modelling, it may be concluded that:

- it is timely to conduct further research on *enterprise resource modelling*. A systemic study of resource modelling is needed, and suitable resource models and modelling tools are urgently required;
- the general applicability of many of the CIMOSA concepts have been further confirmed by its resource modelling approach, even though it is far from complete. Although CIMOSA resource modelling has not been fully developed, and many open research questions remain, it may be concluded that its modelling

Purpose & Focus	Resource Classification		Relationships with Other Aspects Models		Characteristic of Resource Capture Methods	Resource Modelling Tools	
	General Classification	Hierarchy (Grouping)	Principle	Mechanisms		Environment	Function Achieved
CIMOSA support: system operation (management (control & monitor) resources)	FIs human machine application Components: (no further classifications)	Resource Cell Resource Set	decoupling resource model from other aspects models	1. Capability Set is offered to decouple process and resource models; 2. Capability Set and Resource object class are used to link to other aspects models	not complete, but open, flexible and extendable	—	—
IEM focus on: describing all things which support enterprise functions support: system operation & system analysis	employees resources materials information space time	ClassHierarchy -SuperClass -SubClass	holistic way of modelling: resource, process, function and order are bound together	—	specific machine-oriented not flexible not generic	C/C++; OODB SQL; IBM-PC 386/486 MS-Windows.	IEM Tool (no separate resource tool) Presentation of business process; Analyse system static; and dynamic with Petri-net support. (Prototype tool)
TOVE support: system operation planning scheduling	machine electricity raw materials equipment tools capital human skill information	Division of: physical functional Component of: physical functional	support different views	Relation between Resource Ontology and Activity-State Ontology has been defined to decouple from Activity-State Ontology	not complete, but open, extendable	C++; Carnegie Group's ROCK knowledge representation tool; Quintus Prolog.	TOVE Testbed: 1. a model of an enterprise; 2. tools for browsing, visualization, simulation, deductive queries (Prototype tool)
MOSES focus on: describing manuf. capabilities support: product life cycle design manufacture assembly	furniture & fittings human info. processing equip. production equip. material handling equip. measuring & testing storage equip.	factory shop cell station	resource, process & strategies strongly coupled together	—	specific	C++; DEC Object/DB; SIEP/EXPRESS Modelling Kit; ST-DEVELOPER; Booch Modelling Tool; RATIONAL. ROSE.	MOSES System (no separate resource tool) Manufacturing process presentation (Prototype tool)

TABLE 5. Summary of Literature Survey of Resource Modelling

methodology provides a suitable basis from which further research can be conducted.

4.3 Fundamental Concepts Involved in Resource Modelling

4.3.1 Function of Resource Modelling in Respect to the Life Cycle Engineering of Enterprise Systems

Resource modelling can support the design and construction of systems. For example access to information about different candidate resources can be extremely valuable during system evaluation and analysis. Also, access to resource modelling information can help support the operation of systems, such as during their planning and scheduling and the capture of resource utilization data. Furthermore during the system *requirements definition* stage it is often necessary to access resource information. Indeed the author's review of resource modelling emphasised the need to use resource modelling information in a consistent manner throughout the various life phases of systems.

No matter what method is adopted to define high level business goals it will be important to consider possible technical equipment and capital investment options and their availability before determining business and operational goals and drawing up requirement definitions. Although use of IT can improve the operation of enterprise systems, it doesn't mean that everything can be automated. Hence access to information on human and technical resources can help inform decisions about what should be automated. Hence requirement definition modelling has to be carried out whilst having access to enough information about available resources.

Thus the research conducted in this study is based on the premise that access to appropriately structured resource models can be of benefit during the life cycle engineering of enterprise systems, through their *strategic planning, system requirements definition, system analysis, system design, system implementation, system operation* and during *system maintenance*.

4.3.2 The Relationship between Resource Models and Other Modelling Perspectives

When modelling manufacturing enterprises it is therefore assumed that it is essential to capture process models and to use these in conjunction with other important models such as: information models, resource models, organization models and cost models.

Modelling work can naturally begin with the definition of a process model², because a process model can be used to describe “what” an enterprise should do (i.e. its function, behaviour and controls) and thereby provide a link between the “why” and “how”.

Typical procedures followed when describing an enterprise process include the development of functional and behavioural decomposition (down to an atomic level³ of description). Since this type modelling activity seeks to develop a description of *what to do* and *how to do* it, information about resources, organisations structures, costs etc. (to determine the feasibility of alternative ways in which functions can be performed) need to be linked to the process model. Similarly the use of process models, supported by appropriate resource models, can help develop and test “why”.

2. In this research, *process models* are viewed as a super class which may comprise *function models, behaviour models* and *control models*.

3. The term *atomic level* is used here to denote a level of granularity which is the smallest unit used in that context. Dependant on the focus of the system design or construction it may be appropriate to set this grain size differently.

questions commonly asked during strategy planning. Hence process models can be used to unify other modelling aspects into a syndicate model [Vernadat, 93] [Weston, 96]. Hence it may be argued that other modelling perspective should be capable of supporting process modelling, including resource models.

Secondly, one can argue that the relationship between resource models and organization models should be a co-operative one. Actually this work serves to develop the notion that resource models and organization models are closely related to each other. In some manufacturing domains it may be appropriate for all resources to belong to one organization unit. In such cases the organisational unit may be designated the authority to allocate resources or control them so that they perform a global enterprise function or a local set of activities which fulfil some function required from the unit.

Thirdly, this research is based on the assumption that relationships between resource models and cost models should also be of a co-operative nature. Obviously, the cost of resources will be an important consideration when developing cost information. Resource models can be structured to support the capture of cost information about each resource. Whatever, both resource and cost models should develop consistent definitions about resource costing.

Finally, the relationship between resource model and information model should be a co-operative one. Resource information represents one class of information which should be captured and represented by information models. Hence it is important to organise resource information objects so that they are "sympathetic" with information modelling needs.

4.3.3 The Type and Degree of Coupling (i.e. Linkages) between Resource Models and Other Modelling Perspectives

To cope with the high levels of complexity inherent in enterprise systems requires that typically they must be modelled from a number of different perspectives during the various phases involved in the life cycle. Indeed there is broad commonality between the modelling views adopted and the life phases supported by modelling tools. Therefore, there is a need for mechanisms which can be used to couple the different views and phases in a consistent and effective way, in order to unify them into holistic models of an enterprise. The nature of this coupling mechanisms represents the subject of on going research area of in the enterprise modelling.

On considering the need to decompose systems into smaller more understandable and manageable parts, it is necessary to understand the nature of the couplings (or linkages) between different modelling view points and life phases. When modelling, these couplings (or linkages) need also to be represented and captured onto a model, possibly in the form of defined “mappings” or possibly by using “common modelling constructs”. By capturing knowledge about these couplings it should be possible to (re)connect together various sharper focus models; developed to represent in a scalable way, and with sufficient clarity and detail, some aspect of an enterprise problem or software.

Thus “couplings” need to be characterised and modelled along the two dimensions: views and life-phases.

Consider the case where enterprise modelling requires the use of five views (namely

process, information, resource, organisation and cost) and three life phases (*requirements definition, design specification and implementation description*) then theoretically there will be 105 (combination of 3*5) relationships to characterise and model. However in real situation it may not be necessary to establish and maintain relationships between all 105 “linkages”, as for example, a process model captured during the requirements definition phase may have no meaningful relationships with organisation model at implementation phase. For this example (which is a common one in respect of CIMOSA, ARIS, GRAI and GERAM modelling), eleven important relationships (or “couplings”) have been identified by the author as being “key couplings” between model fragments developed in respect to the different views and phases in enterprise modelling. This observation is illustrated by Figure 22 and is explained further in the following two sections.

4.3.3.1 Inherent couplings between models along the dimension of views

1. Consider process and information models developed during the *system requirements definition* life phase. Arguably this will constitute a primary link between process models and information models. Process models developed during the *system requirements definition* phase should identify objects which can be properly managed by corresponding information models.
2. Consider process and resource models developed during the *system requirements definition* life phase.

Arguably this will constitute the primary link between process and resource models. Process models developed during the system requirements definition life phase will need to capture an understanding of the resource capability needs to

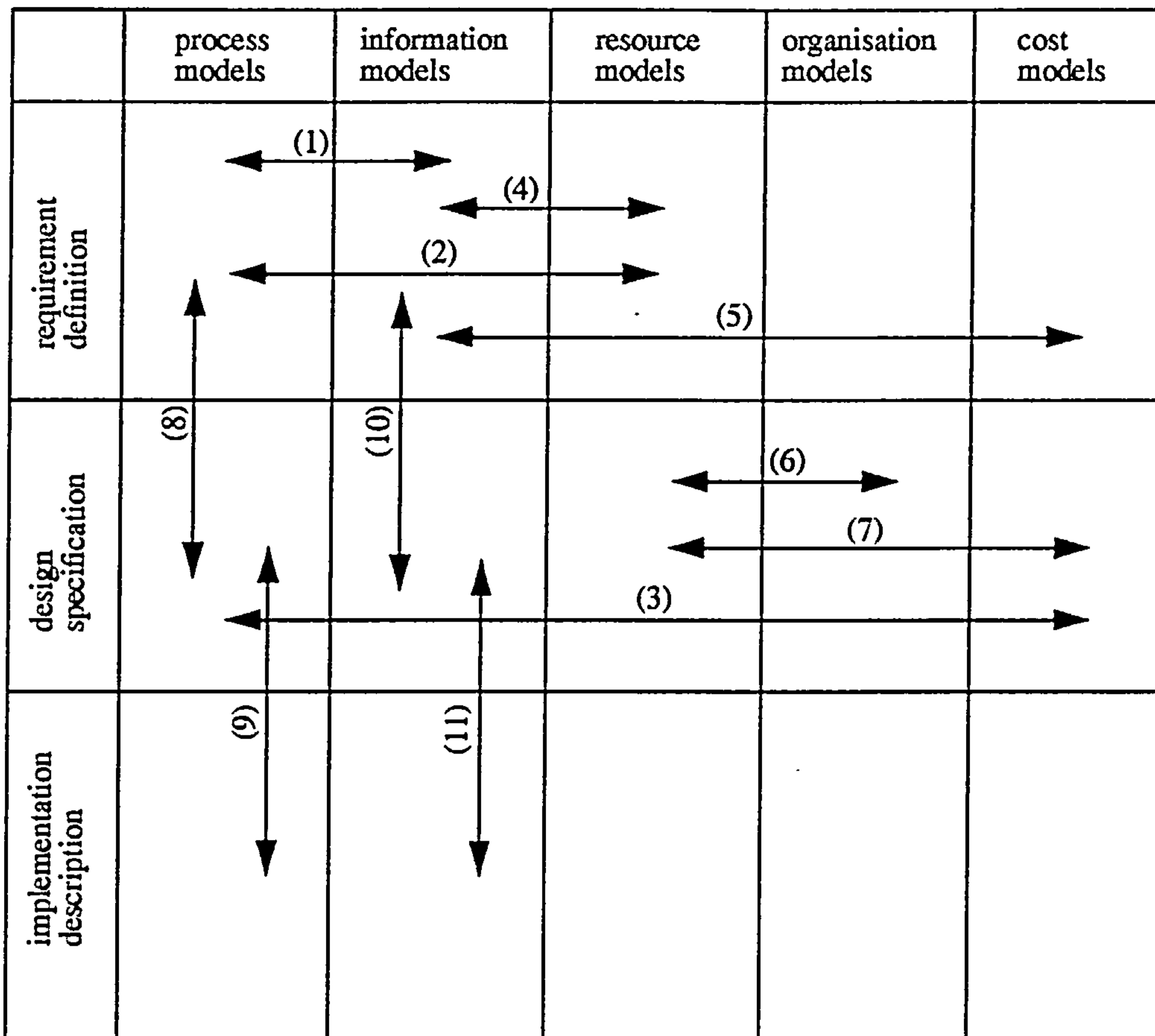


FIGURE 23. Important Relationships (Couplings) between Models with Different Views and Life Cycle Phases

perform the processes (i.e. functions, behaviour, links, operations and /or activities) identified. An identification of this capability requirement can provide a natural link between these two models. Thus further emphasising the need for a proper classification of resource capabilities.

3. Consider relationships between process and cost models at *system design specification* life phase.

As advanced costing method requires dynamic information about enterprise activities, establishing a link between these two viewpoints can be of paramount importance when modelling costs. Arguably costing is only meaningful having a clear understanding of available resources and related enterprise activities, hence

the prime focus of such a link should be established during the *system design specification* phase.

4. Consider relationships between information and resource models during *system requirements definition* life phase.

During resource modelling it is also necessary to identify resource objects which can be managed by the information model. Hence consistent resource and information modelling constructs should be developed to facilitate such a link or mapping.

5. Consider relationships between information and cost models during *system requirements definition* life phase.

During cost modelling, cost objects can be captured which can be managed by the information model. Hence consistent cost and information constructs should be developed to facilitate this link.

6. Consider relationships between resource and organisation models *during system design specification* life phase.

Inherently resource and organisation models will have a close relationship, as each typically resources will belong to one (or several) organisation unit, whilst organisation units will have the authority to deploy the resources. Therefore, proper linkages between these two modelling views need to be identified and maintained as required.

The literature review emphasised the need in the context of agile enterprises to avoid use of fixed (inflexible) relationships between manufacturing systems and their organisation structures. Hence the couplings between these views can be

expected to change from time to time. The means used to describe and maintain such linkages may need to cater for different organisation structures (hierarchy, heterarchy, tall or flat, holonic, expert-based, team-based, etc.), and business process reengineering methodologies (including means of realising function allocation to individual humans or teams).

7. Consider relationships between resource and cost models during *system design specification* life phase.

As cost information about resources represents primary cost information, study of support of this linkage is necessary to realise cost modelling. For the same reason as mentioned for 3, the focus of this link should be at the *system design specification* phase.

4.3.3.2 Couplings between models developed during different life phases

Along the life cycle dimension, this study has emphasised the importance of the following four couplings (8, 9, 10 and 11) to development of IT support capable of automatically generating fragments of enterprise models.

8. Coupling between process models developed during requirements definition phase and process models developed during design specification.
9. Coupling between process models developed during design specification phase and process models developed during implementation description.
10. Coupling between information models developed during requirements definition phase and information models developed during design specification.
11. Coupling between information models developed during design specification and

information models developed during implementation description.

Based on MSI experiences of real system design and implementation verified by the author, it should be noted that:

In some cases,

- boundaries between different modelling views can not be separated clearly.

For example, in the case of 8 and 9 listed above couplings between process models are also coupled to related resource models. Except in respect to requirements definition and concept design life phases process and resource models can be separated whereas between system design and system implementation life phases, resource and process models have to be merged into one model. This is because the detailed design and implementation of a enterprise system is primarily concerned with the selection of resources, and the integration of activity carried out by each resource.

- not all modelling viewpoints have clearly separate life phases nor is their use appropriate over the complete life cycle.

For example, cost modelling during the implementation description life phase is not really meaningful at all.

In the context of resource modelling, six primary couplings, namely 2, 4, 6, 7, 8 and 9 were considered to be important and hence were studied further in this resource modelling research. This will be reported in the next Chapter.

4.4 Conclusion

Having considered findings from the general survey on enterprise modelling, and the more detailed survey of resource modelling, this chapter has outlined key concepts and research issues. This can be viewed as a preparation for resource modelling research.

The following provides a summary of the conclusions drawn thus far:

- *Principles adopted from current research*
 - a) Need to support different modelling views (or perspectives), viz: process, information, resource, organisation and cost;
 - b) Need to support various system life phases (or levels, as phrases by CIMOSA), viz: *requirements definition, design specification, implementation description*;
 - c) Adoption of a general classification of resource types introduced by the CIMOSA consortium (this will be explained in the following Chapter).
- *Concepts further clarified (or confirmed) by the author's pre-study*
 - d) The function of resource modelling is key to supporting the life cycle engineering of enterprise systems; (1. resource information needed for system requirements definition in terms of formalising the model building process; 2. resource information needed to support system design specification, one example is the resource selection; 3. system operation needs to access resource information in support of production planning and control.);
 - e) Relationships between different enterprise model fragments, namely: (1) process model can be used to help unify other modelling viewpoints; (2) It can be argued (i.e. proposed) that other modelling viewpoints are supportive to process models and cooperative with each other. This second proposition is developed and tested

in the remainder of this thesis.

- ***Fundamental research issues identified by the author***

- a) Resource definition and classification;

- b) Classification of resource capabilities;

- c) Study the nature of six key linkages between resource models and other models and proved the means and mechanisms to realise the linkages;

- d) Resource information capture, constructs and techniques (e.g. resource objects).

5.0 An Approach to and Framework for Resource Modelling

5.1 Introduction

This chapter outlines the approach taken when defining and implementing a framework for resource modelling.

First a *resource definition* and *resource classification* is presented. Two terms, *resource type* and *resource architecture* have been defined to describe the nature of resources. Then, relationships between *resource capability* and *enterprise activity* and the importance of classifying *resource capabilities* is described. Based on these findings the attributes of six key linkages, between resource models and other system models, are considered in greater depth. Based on an understanding of the purpose of resource modelling (outlined in the previous chapter) guidelines for general resource information capture are classified with a view to supporting the life cycle engineering of systems. Finally, information templates are defined for each type of resource.

5.2 Resource Definition and Classification

5.2.1 Resource Definition

One generally accepted view of a resource is that it is something needed to carry out activities or tasks in a manufacturing enterprise. Resources may be considered to be basic building blocks from which an enterprise can be composed. More formally, resource has been defined by the IEM Consortium and Vernadat respectively as follows:

Resources are the chief performers which execute activities or are responsible for the execution of activities [IEM, 96];

A resource is an entity (human or technical) which can play a role in the realization of a certain class of tasks, when it is available [Vernadat, 96].

In the context of a manufacturing enterprise, the author prefers the definition:

Definition of Resources

Resources are basic components of an enterprise. Each resource has certain capabilities which enable it to carry out enterprise tasks or a part of them.

5.2.2 Resource Classification

To facilitate resources classification and to enable enterprise description from a resource point of view two concepts are introduced here, namely: *resource type*; and *resource architecture*.

5.2.2.1 Resource type - functional aspect

There are numerous different types of resource used by manufacturing industry. A broad classification of these was developed by the CIMOSA Consortium which grouped them into: "human" "machine" and "application" resource types. Each of these catalogues can be decomposed into sub-classes, e.g. the class machine can include processing machines, transportation machinery, inspection machines, etc. The term *resource type* is introduced here to characterise resources along this dimension. Mainly the class of resource in terms of *resource type* will reflect its functional aspects.

As discussed in Chapter 4, a number of alternative resource classes are defined in the literature, and have been summarised by Vernadat [Vernadat, 96] as follows:

- input items (parts, products, raw material, documents, etc.)
- human resources
- technical resources (tools, machines, devices, software packages, etc.)
- information resources (data & knowledge)
- financial resources
- energy resources and
- time.

Having appraised the literature in this area this research chose to use the CIMOSA resource classifications as a basis. The choice was made because its classification is generic and can be applied to different industrial sectors. However an extension of the CIMOSA classification of resource type was considered to be necessary as illustrated by Figure 24 (cf. Figure 15). This extended classification was produced following a consideration of the factors:

1. The extended CIMOSA classification has been defined with reference to the function of each resource type and the ease with which the information model of the resource can be derived from the classification.
2. Human resources have not been divided further, and the reason for this lies in the following factors: (1) humans can have functionality which covers the complete spectrum of enterprise activities, including designer, engineer, operator, manager etc. and they can be the operators of machines and applications. Hence there is no clear separate functional boundaries for humans; (2) A single person can have

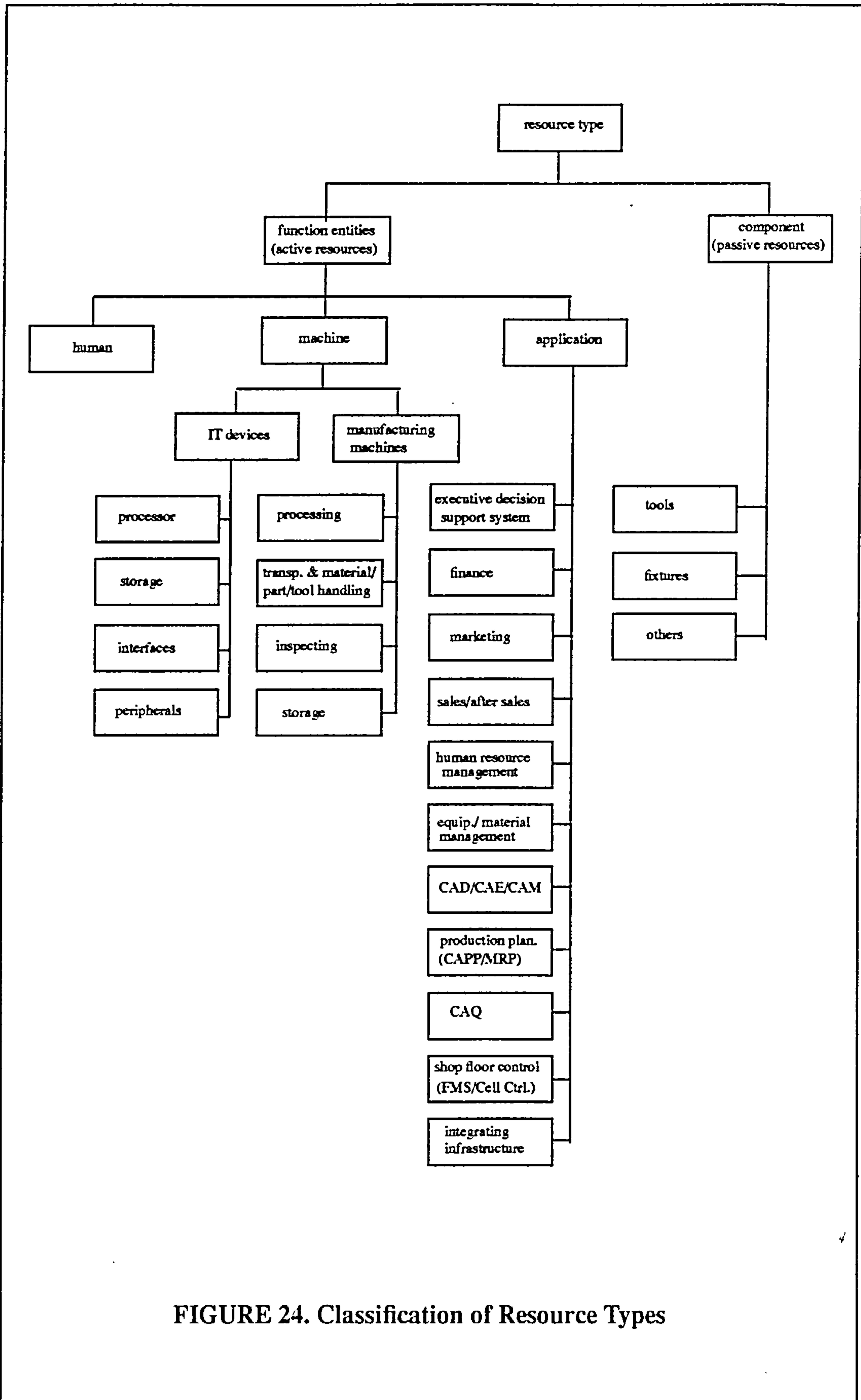


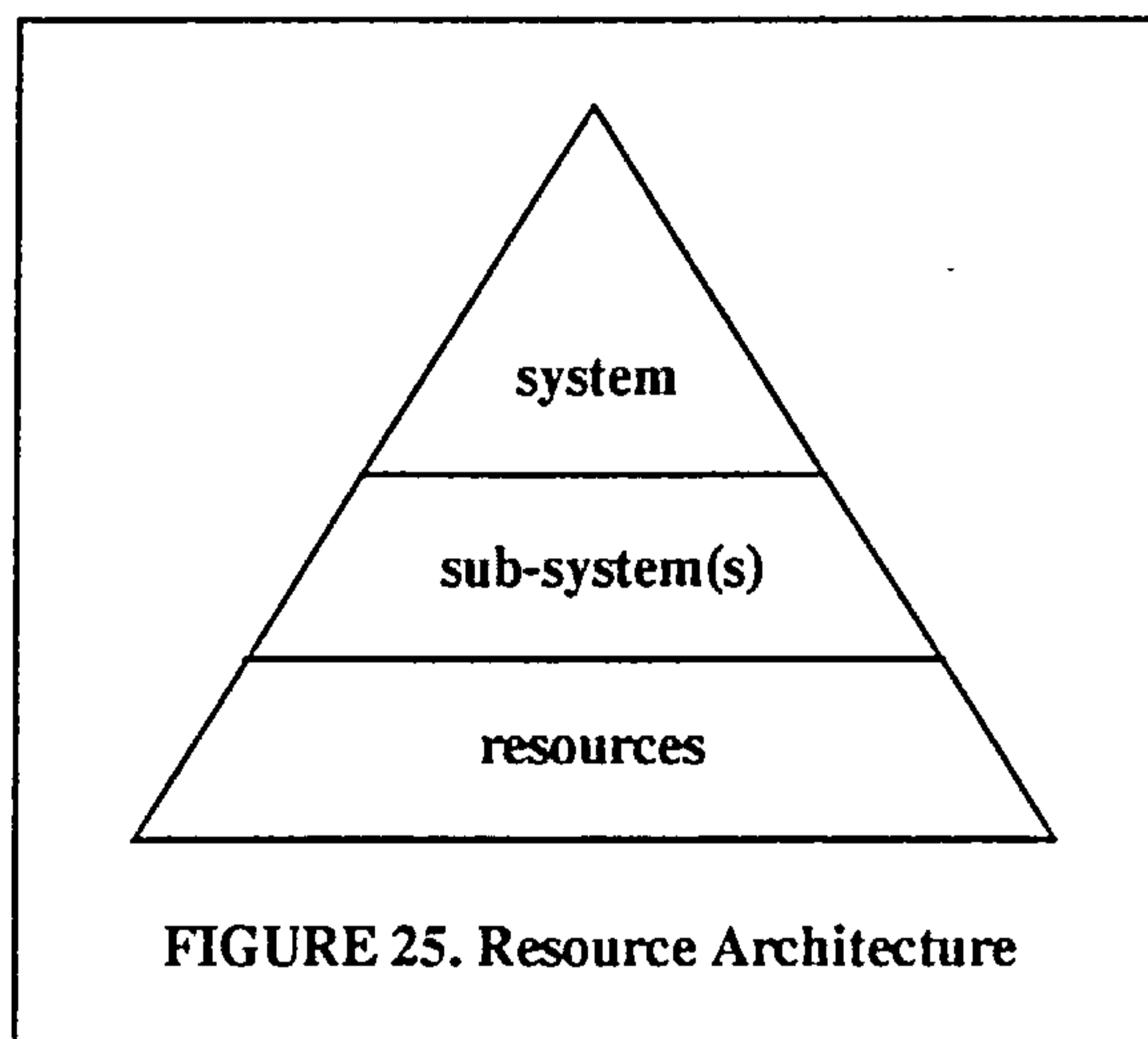
FIGURE 24. Classification of Resource Types

different and multiple roles in the company. For example a team manager can simultaneously be a team member and a machine operator whilst a finance director can also be an accountant. Hence it may be meaningless and confusing to further classify human resource types. However further consideration of human functions and their classification will be discussed in the next chapter.

3. With rapid developments in Information Technology, IT equipment has assumed new roles which can cover most of the spectrum of enterprise activities. Enterprise integration problems concern IT equipment integration issues as well as manufacturing equipment and human integration issues. Hence, it is necessary to take IT resources into account during resource modelling. However IT resources may play a very different (and more supportive) role from that of the direct manufacturing resources used in an enterprise. The author concluded that their characteristics should be classified differently. For classification purpose IT devices have been separated from manufacturing devices.
4. This classification in Figure 24 was modified several times, mainly as a result of feedback from parallel resource modelling and tool design, implementation and application activities carried out as part of this study.
5. It should also be pointed out that the classification is not intended to be complete, but provides a “proof-of-concept”. Therefore it is expected to be extended. It may even need to be structurally modified in the light of a broader experience of its use by different parties who may have different views of what can be separated from what.

5.2.2.2 Resource architecture - organisational aspect

Resource type can only be used to classify individual resources. However there is also a need to classify groupings of resources, such as a cell composed of several resources (e.g. a machining centre, robot, AGV, tooling, cell controller and operator(s) etc.). Hence the term *resource architecture* is introduced to cater for this need. See Figure 25.



On combining these two definitions (i.e. *resource type* and *resource architecture*), theoretically an entire enterprise can be described from resource point of view. This implies that even an enterprise can be treated as a single resource which has capabilities to realise a set of business activities. Clearly such a resource will comprise several resource sub-systems, such as a product design and engineering sub-system, a manufacturing sub-system and a sales sub-system, etc. Each sub-system will comprise several lower level sub-systems and/or individual resources and so on. In this way a complete enterprise can be described from a resource viewpoint. However the scope of this PhD study had to be constrained. Hence focus was centred

on describing typical components used to build groupings of such resources capable only of carrying out various subsets of enterprise activity.

Essentially the resource architecture reflects organisational aspects of the resources. See Figure 26 which shows an example of mapping the resource architecture defined onto an organisation structure.

5.3 Relationship between Resource Capabilities and Enterprise Activities

On considering the nature of linkages between resource models and other types of model to seek appropriate coupling mechanisms, the author conducted further study of relationships between *resource capabilities*¹ and *enterprise activities*². The aim here was to find appropriate modelling constructs and the levels of granularity at which the two can match each other. Initial study was focused on shop-floor manufacturing cells.

First the author tried to analyse common cell functions and to decompose typical processes realised by manufacturing cells into corresponding enterprise activities. Here decomposition was based on the use of CIMOSA methods. The decompositions were formalised using the SEWOSA case tool produced previously by other MSI researchers [Aguiar & Weston, 94] [Aguiar, 95]. According to the CIMOSA methodology functions (expressed as a business process) can be decomposed down to

1. Resource Capability is a concept adopted from CIMOSA. It defines the technical abilities required by an Enterprise Activity and constrains resource selection [CIMOSA, 93].

2. Enterprise Activity is also a concept developed by CIMOSA. It defines enterprise functionality in the form of elemental tasks which are defined by their inputs, their outputs, their function and their required capabilities.

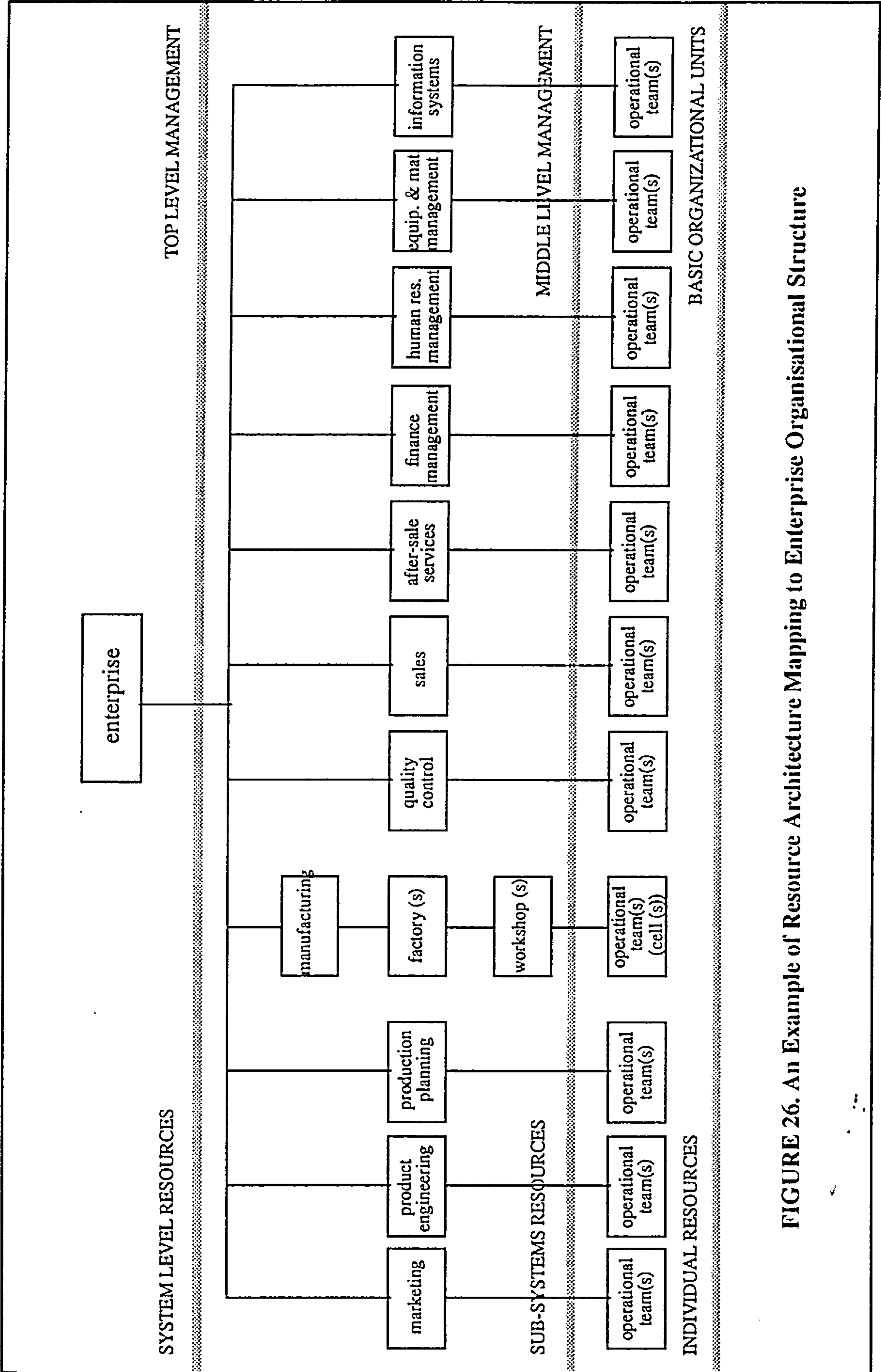


FIGURE 26. An Example of Resource Architecture Mapping to Enterprise Organisational Structure

any atomic level as defined by the system modeller. However on decomposing the common cell functions, the author observed the following phenomenon:

- The decomposition cannot be carried out in a meaningful way unless the capabilities of available resources have been understood (i.e. characterised in some ways). Once a proper classification of resource capabilities had been defined then a decomposition into enterprise activities can be completed with a well defined purpose in mind.
- The level of granularity to which enterprise activities are decomposed will normally correspond to a level at which appropriate human, machine or application resources can be assigned to enterprise activities.

This observation indicates that:

- System requirement definition cannot be carried out properly unless there is sufficient knowledge about candidate resources. This emphasises the importance of an earlier observation that resource information is needed in early phases of the life cycle engineering of enterprise systems.
- Resource capabilities and enterprise activities should be defined in a consistent way. A resource can have a capability or a set of capabilities. Considerable design simplification results in respect to systems in which a single enterprise activity is realised by a single resource. Hence it is appropriate to seek to model enterprise activities at a level of granularity which leads to a match with available resource capabilities. Where practical it may be appropriate to seek a one-to-one matching of enterprise activities to resource capabilities.
- Thus a classification of resource capabilities is essential as the basis of a formal

approach to enterprise modelling and integration. This can be viewed as providing a primary linkage between resource models and other enterprise modelling perspectives which centres on a link between process models (or function models in CIMOSA terms) and resource models.

Based on this understanding a classification of resource capabilities was carried out. A generic function decomposition of manufacturing cells was so derived and is represented by Figure 27³. This decomposition seeks to maintain consistency of classification with common resource capabilities. This led onto classification of common human resource capabilities required for the operation of highly automated cells, which complement common capabilities provided by cell controllers. See Figures 28 and 29 respectively.

A similar classification was carried out by the author in respect to common activities and resources used in the area of CAD/CAE/CAM. The aim here was not to develop definitive classification but to investigate further the nature of the inherent linkages between process (function) and resource modelling. On considering properties of commercial CAD/CAE/CAM software applications the capabilities of these packages were classified, as illustrated by Figure 30. Commercial software products studied to determine this classification included AUTOCAD, Unigraphics, CATIA/CADAM, Mastercam, Generic CADD and the GRAFTEK SMART Solid Modeller.

Furthermore an example decomposition and classification of common activities and resources was carried out in respect to CAPM/MRP/MRP II application software, see

3. Research work carried on cell controller by Monfared at MSI Research Institute was referenced for this classification [Monfared, 96].

1. New Order Management

- 1.1 receive new orders
- 1.2 check cell capability
- 1.3 check engineering data
- 1.4 confirm cell capability
- 1.5 accept new orders
- 1.6 refuse new orders

2. Scheduling

- 2.1 task scheduling
- 2.2 raw material scheduling
- 2.3 tool scheduling
- 2.4 machine scheduling

3. Dispatching

- 3.1 checking system status
- 3.2 provide work-to-list

4. Data Preparation

- 4.1 engineering data preparation
- 4.2 machine program preparation
- 4.3 system status
- 4.4 loading program

5. Machine Preparation

- 5.1 machine preparation
- 5.2 artillery machine preparation

6. Material Handling

- 6.1 raw material preparation
- 6.2 material moving

7. Part Handling

- 7.1 part loading
- 7.2 part unloading
- 7.3 part fixing
- 7.4 part unfixing
- 7.5 part moving

8. Tool Handling

- 8.1 tool preparation
- 8.2 tool moving
- 8.3 tool changing

9. Part Processing

(the following classification only
for metal cutting industries)

- 9.1 turning
- 9.2 drilling-1 (cylindrical centre only)
- 9.3 drilling -2 (other type of drilling)
- 9.4 milling
- 9.5 boring
- 9.6 grinding
- 9.7 reaming
- 9.8 punching
- 9.9 forming
- 9.10 forging
- 9.11 extruding
- 9.12 shaping
- 9.13 honing
- 9.14 threading-1 (internal)
- 9.15 threading-2 (external)
- 9.16 cutting
- 9.17 inspecting

10. Data Collecting

- 10.1 system static status data collecting
- 10.2 system dynamic status data collecting
- 10.3 static and dynamic system state presentation

11. Monitoring

- 11.1 problem diagnosis
- 11.2 unexpected event handling

12. Communication

- 12.1 information delivery between activities in the cell
- 12.2 communication with outside of cell

13. Coordination

- 13.1 human relationship coordination

FIGURE 27. Classification of Resource Capabilities in Typical Cells

Figure 31. The references used to develop this classification are [Toomey, 96] [Luscombe, 93], some commercial software information from companies including Kalamazoo (UK), Largotim Limited (UK), IBS Associates (UK), Kewill Group (UK), CSI (UK), and information from Web side [Softwareguide, 97].

It has to be noted that the classifications for CAD/CAE/CAM and CAPM/MRP/

- 1. New Order Management**
 - 1.4 confirm cell capability
 - 1.5 accept new orders
 - 1.6 refuse new orders
- 5. Machine Preparation**
 - 5.1 machine preparation
 - 5.2 artillery machine preparation
- 6. Material Handling**
 - 6.1 raw material preparation
- 8. Tool Handling**
 - 8.1 tool preparation
- 11. Monitoring**
 - 11.2 unexpected event handling
- 12. Communication**
 - 12.2 communication with outside of cell
- 13. Coordination**
 - 13.1 human relationship coordination

FIGURE 28. Capabilities Needed from a Team on a Highly Automated Cell

- 1. New Order Management**
 - 1.1 receive new orders
 - 1.2 check cell capability
 - 1.3 check engineering data
 - 1.4 confirm cell capability
 - 1.5 accept new orders
 - 1.6 refuse new orders
- 2. Scheduling**
 - 2.1 task scheduling
 - 2.2 raw material scheduling
 - 2.3 tool scheduling
 - 2.4 machine scheduling
- 3. Dispatching**
 - 3.1 checking system status
 - 3.2 provide work-to-list
- 4. Data Preparation**
 - 4.1 engineering data preparation
 - 4.2 machine program preparation
 - 4.3 system status
 - 4.4 loading program
- 10. Data Collecting**
 - 10.1 system static status data collecting
 - 10.2 system dynamic status data collecting
 - 10.3 static and dynamic system state presentation
- 11. Monitoring**
 - 11.1 problem diagnosis
- 12. Communication**
 - 12.1 information delivery between activities in the cell
 - 12.2 communication with outside of cell

FIGURE 29. Capabilities Provided by a Cell Controller

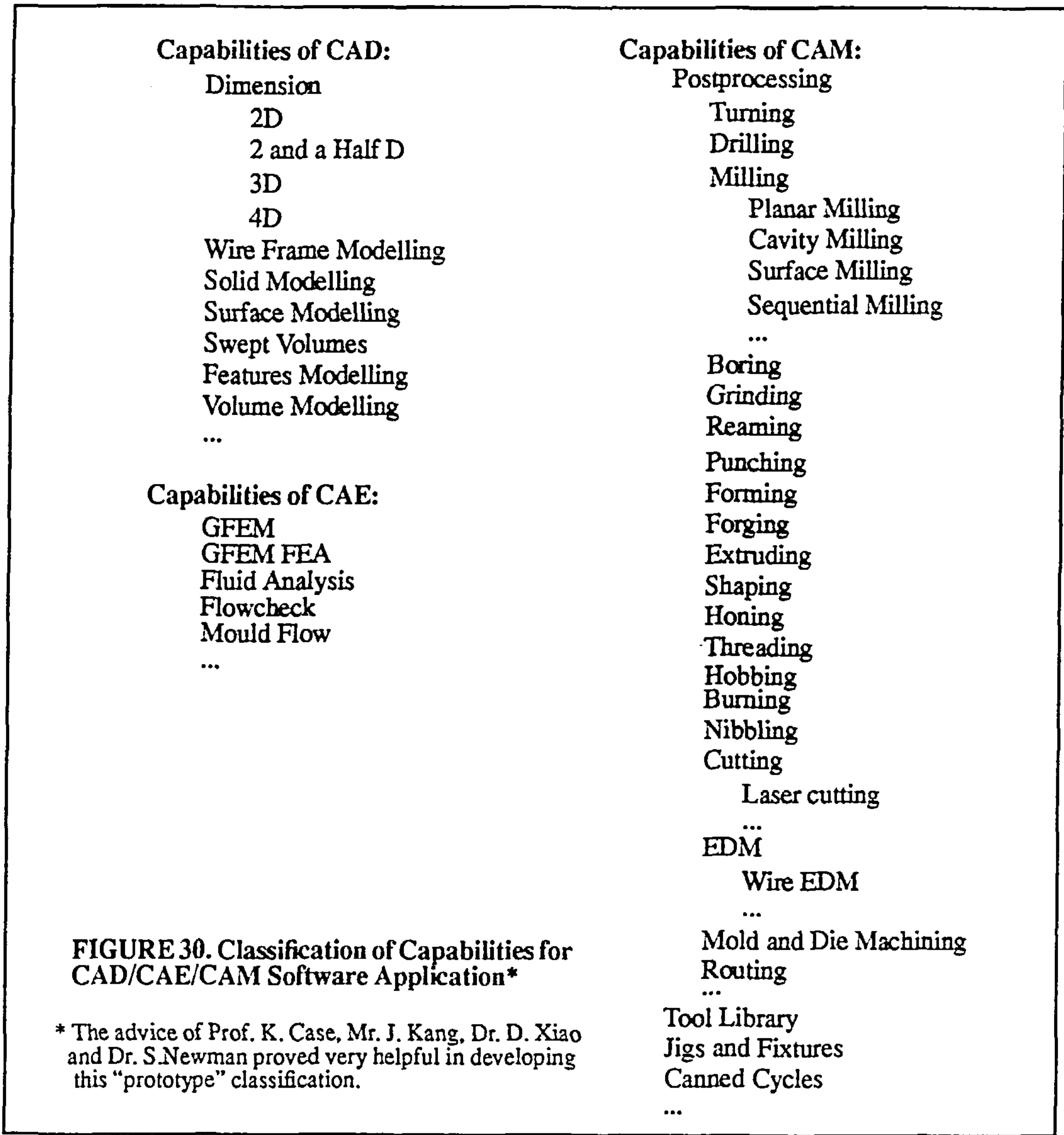


FIGURE 30. Classification of Capabilities for CAD/CAE/CAM Software Application*

* The advice of Prof. K. Case, Mr. J. Kang, Dr. D. Xiao and Dr. S. Newman proved very helpful in developing this "prototype" classification.

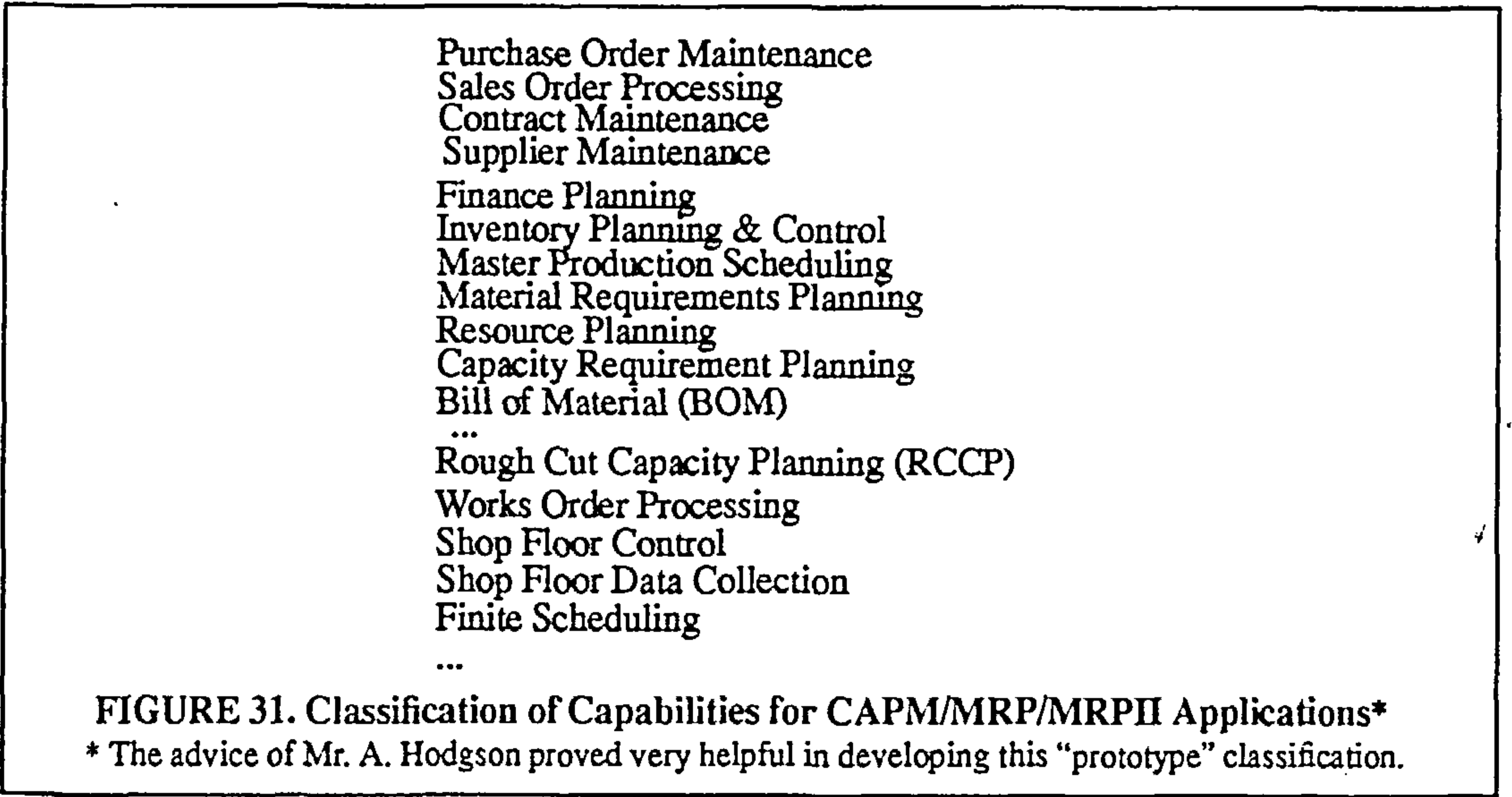


FIGURE 31. Classification of Capabilities for CAPM/MRP/MRP II Applications*

* The advice of Mr. A. Hodgson proved very helpful in developing this "prototype" classification.

MRPII represented a great difficult job, if it is not impossible. These are not claimed to be generic at all. These are just a start for further research.

The research method followed, when studying these domains, had the following characteristics:

- The classification was initiated following a study of available resources, either within a given enterprise or those commercially available in the market.
- Subsequent focus was on developing a standard classification of resource capabilities which can support enterprise modelling. The aim here was to provide a “common model”, which (in proof-of-concept form) could promote system and component developments (by vendors) which more closely meet process requirements of the end user manufacturers and the suppliers.
- Longer term research and development in this area could lead to the specification and implementation of a new generation of reusable enterprise components which better fit user needs.

5.4 A Means of Establishing Flexible Couplings between Resource and Other Models

As discussed in section 4.3.3, when engineering enterprise systems, six important couplings exists between resource models and other modelling perspectives. This section reports on means investigated to maintain linkages between models generated from these different viewpoints. A summary of the findings is illustrated by Table 6.

- *Resource Capability Construct*

Important Couplings Related with Resource Models	Means to Establishing Flexible Couplings between Resource and Other Models
between process and resource models	<i>resource capability</i> construct
between resource and information models	<i>resource information templates</i>
between resource and organisation models	<i>organisation unit code</i> for each resource
between resource and cost models	<i>cost information</i> construct for each resource
between process model at system requirement definition phase and process model at system design specification phase	<i>resource capability</i> construct <i>resource behaviour</i> construct
between process model at system design specification phase and process model at system implementation description phase	<i>resource interfacelintegration</i> construct
TABLE 6. Means to Establishing Flexible Couplings Between Resource and Other Models	

The discussion in the section 5.3 indicates that a description of *resource capability* can be used as a coupling between process and resource models at system requirements definition life phase. It was further identified that the *resource capability* can also be used as a coupling between process model defined during the system requirements definition and the process model defined during the system design specification. Appropriate classification of resource capabilities can support resource selection which is one of task for system design.

- ***Resource Information Templates***

Resource information templates (as described in section 5.5) are the resource information objects defined by resource view. Resource information objects should be managed and systematically constructed by information view, so naturally resource

information templates are the link first between resource and information models at the system requirements definition life phase. In fact, all the other constructs discussed in this subsection are derived from the resource information object and behave as object views to meet different user's requirements.

- *Organisation Unit Code Construct*

In order to understand inherent relationships between resource and organisation models, the author conducted a general literature survey on human issues which focused on organisation, team work, human job design etc. The findings are reported in the Chapter 6. It was concluded that the ability to support different types of organisation structures is important to cope with rapid change. Furthermore, proper links between resource and organisation models could help facilitate flexible business process reengineering and its potential requirement for organisational change. Hence, an Organisation Unit Code construct can be included within resource information templates. This study can then act as a linking mechanism between these two types of model.

- *Cost Information Construct for Each Resource*

Cost information about each resource can be included within the resource view but ideally should be separately accessed as a cost view. Use of cost information construct defined during resource modelling can therefore provide a natural coupling between resource and cost models.

- *Resource Capability Construct and Resource Behaviour Construct*

Resource capability and resource behaviour constructs can be used to establish the

linkage between process models defined during system requirements modelling and process models defined during system design specification.

Generally system design decision making needs support from resource selection and system simulation capabilities. A classification of resource capabilities can be used to inform initial resource selection. Whereas final selection of resources should be verified by results of a system analysis, possibly based on simulation; as it may be appropriate to analyse and characterise the performance of systems comprising alternative candidate resources. In order to simulate the operation of candidate systems, the dynamic properties of each resource (i.e. system components) should be well defined. Resource behaviour information is essential information needed to support system simulation.

Bear these observation in mind, resource capability and resource behaviour constructs were identified as means of defining flexible couplings between process models generated during system requirements definition and corresponding models generated during system design specification.

- *Resource Interface Integration Constructs*

It is impractical to seek to automatically generate a complete system implementation model from a system design model. However it is practical to automatically derive fragments of a system implementation model. Information needed to support such a derivation includes resource interface characteristics and resource behavioural interaction and information sharing requirements.

As achieving systems integration targeted at holistic defined business goals can be a

main target of enterprise modelling, it is important to classify information about resource interactions. This is particularly important when seeking to define structural relationships and coordination requirements of resources in a way which can facilitate implementation description modelling.

Clearly there are numerous types of enterprise resource, each with different characteristic properties and interaction requirements. Hence it is a difficult task to describe them systematically and consistently. It is even difficult to define and agree upon a common language which can be used to define resources in a way which will be understood by all parties, despite advances in interface description languages, such as Estelle, IDL, etc.

Early in this study, the author attempted to establish such a classification by defining a fixed set of attributes which can be used to describe common interaction properties of resources. However it soon became evident that the uncertainties and varieties involved in resource interactions would be prohibitive. Nonetheless it proved possible to separate out definitions for each class of resource and to represent them in the form of resource information templates which are described below.

- Two set of attributes which characterise “Environment Support” and “Interface Description” have been defined for machines and applications. One set of attributes relate to the need for “Environmental Support for Machines”, these include: human, power, other equipment, etc. Whereas a second set of attributes relate to “Environmental Support for Applications” including: computer operating system, computer networks, case tools, computer hardware, human-machine or human-computer interfaces, etc.

- The attributes of an “Interface Description” for any application include; input, output and others (any other information related to interface). However attributes of an “Interface Description for Machines” were not defined, because of the wide variety involved. Hence it was deemed necessary to leave the user to attribute definitions according to requirements of a specific (and hence more constrained) situation.
- No interaction information was defined for human resources because of the following considerations:
 - (a) It is not possible to classify a standard description of human interaction characteristics within a manufacturing system. Each individual can have distinctive characteristics and the way in which they interact with other parts of system can be very different with respect to the technology they deploy and the organisation structure (relationships with other personnel) and culture of their host enterprise. A consideration of example structures indicated that: if such interactions are described in a formal and structured way, it may overly constrain a system and result in inflexibility.
 - (b) In most situations it may not be necessary or practical to describe these characteristics as human beings have to adapt to new technology and to learn new ways of interacting all the time.

5.5 Resource Information Capture

5.5.1 Resource Information Capture Guidelines

Based on the previous discussion, this study assumed that the primary purpose of

resource modelling is to support the life cycle engineering of systems from requirement definition through system design and implementation description and realisation, to system operation and maintenance. Hence the need to establish flexible links between resource models and other enterprise models, so that resource information can be used to support decision making and as appropriate resource information fragments can be processed and included into other models of an enterprise. Based on an understanding of this requirement the structure of the resource information can be designed to support these linkages. Indeed this understanding led to the identification of guidelines for resource information capture illustrated by Figure 32.

5.5.2 Establishing Information Templates for Each Type of Resource

Resource information templates need to be generated for each type of resource, in conformance with the resource information guidelines of Figure 32. The schema specified and developed to structure the design of these templates is illustrated by Figures 33 to 38. In implementing the resource modelling environment in this study, common attributes need to be separated from each information template as outlined below.

- *Common Attributes for All Types of Resource (Figure 33)*

Name: the name of the resource in question

Resource Type: This is functional description of a resource, as discussed in the definition of resource type.

Organisation Unit: authority of the resource and its linkage to the organisation

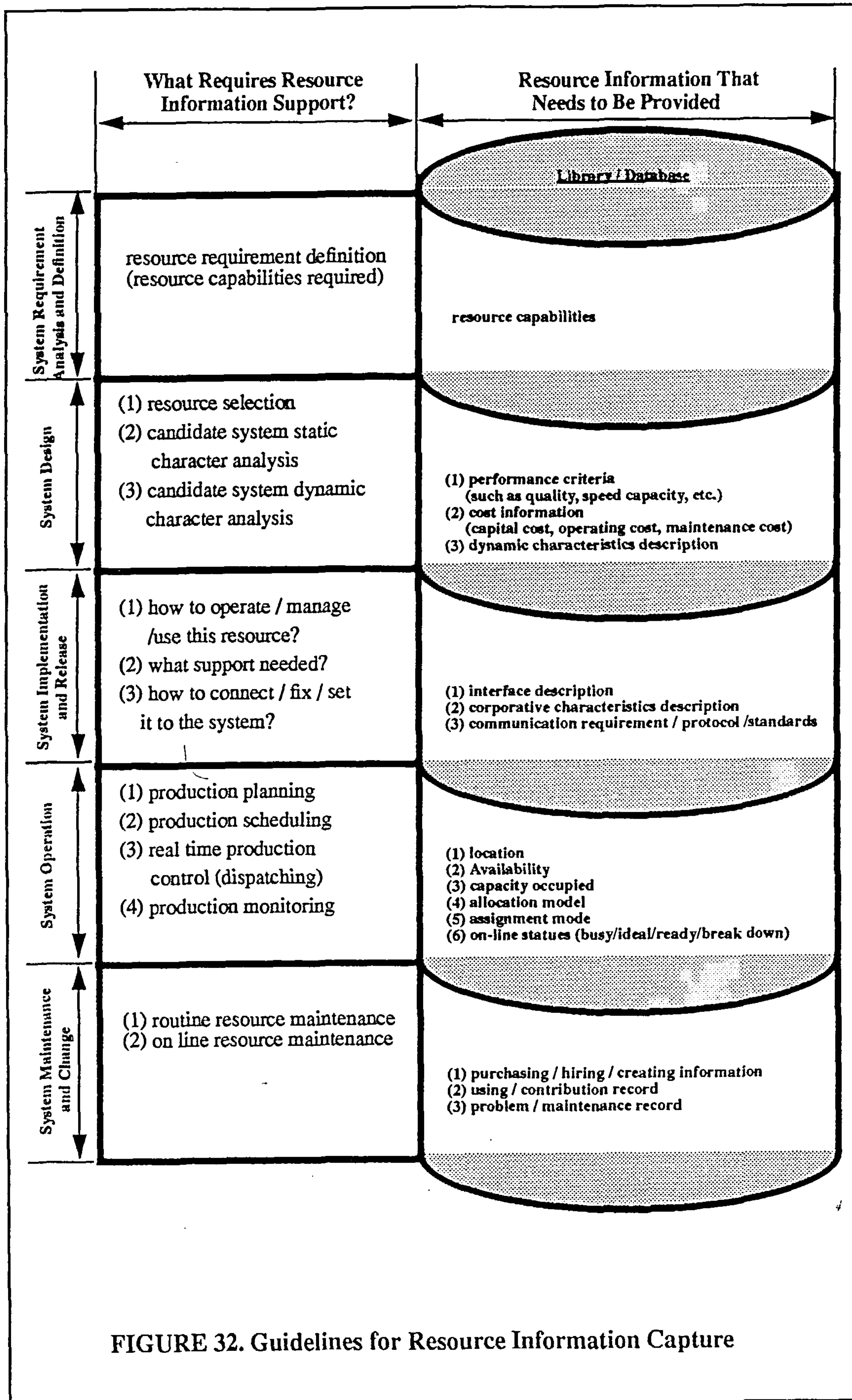
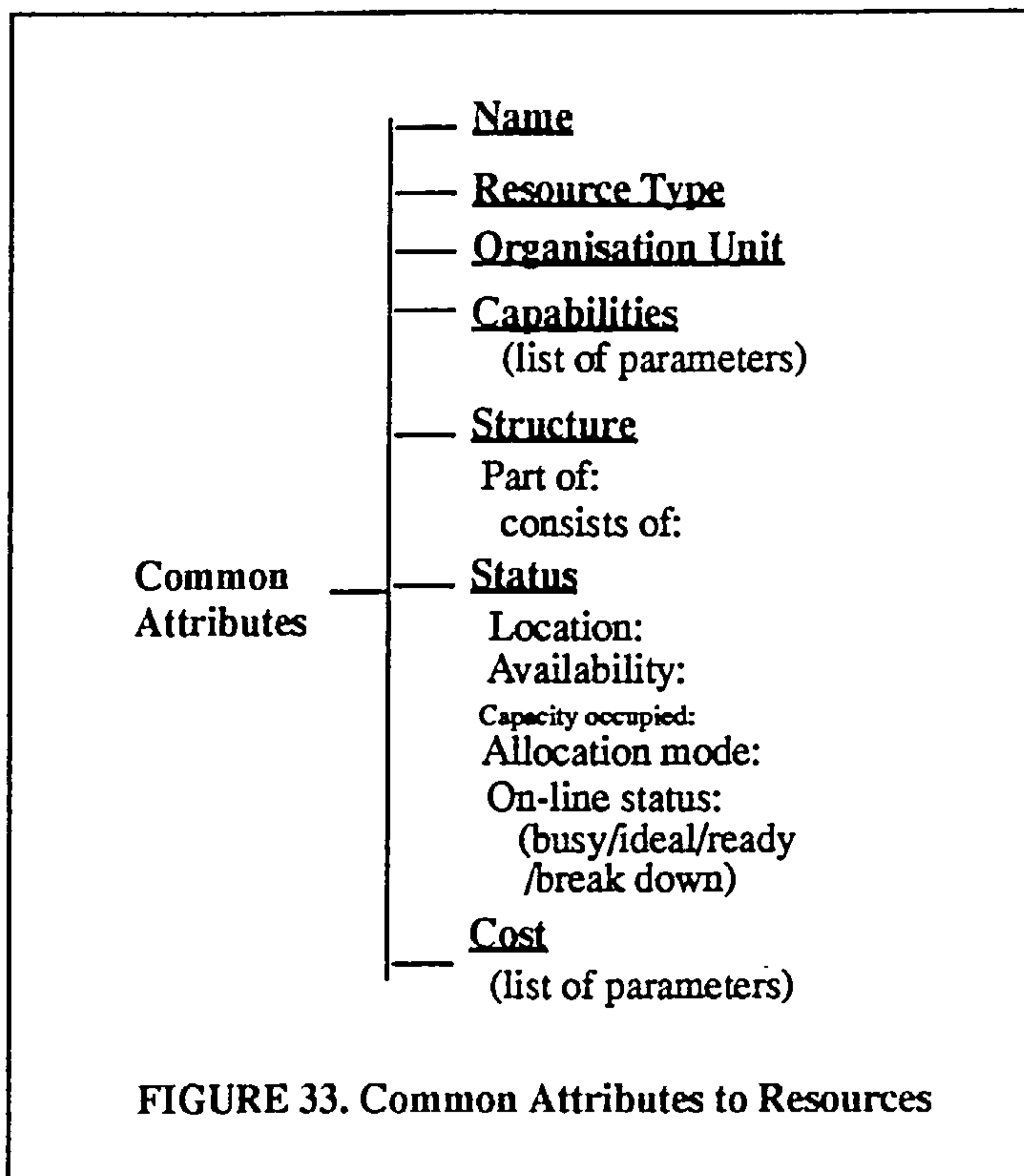


FIGURE 32. Guidelines for Resource Information Capture



model.

Capabilities: As defined by CIMOSA. In the author's scheme of things this provides the key linkage to the function model.

Structure: This information reflects relevant characteristics of the resource architecture.

Part of: name of up level resource group

Consist of: name(s) of lower level resource(s)

Status: This is information used to support on-line system operation

Location: Where the resources are

Availability: Available or not

Capacity occupied: percentage of capacity occupied

Allocation mode: if it is allocated to some other system at the moment

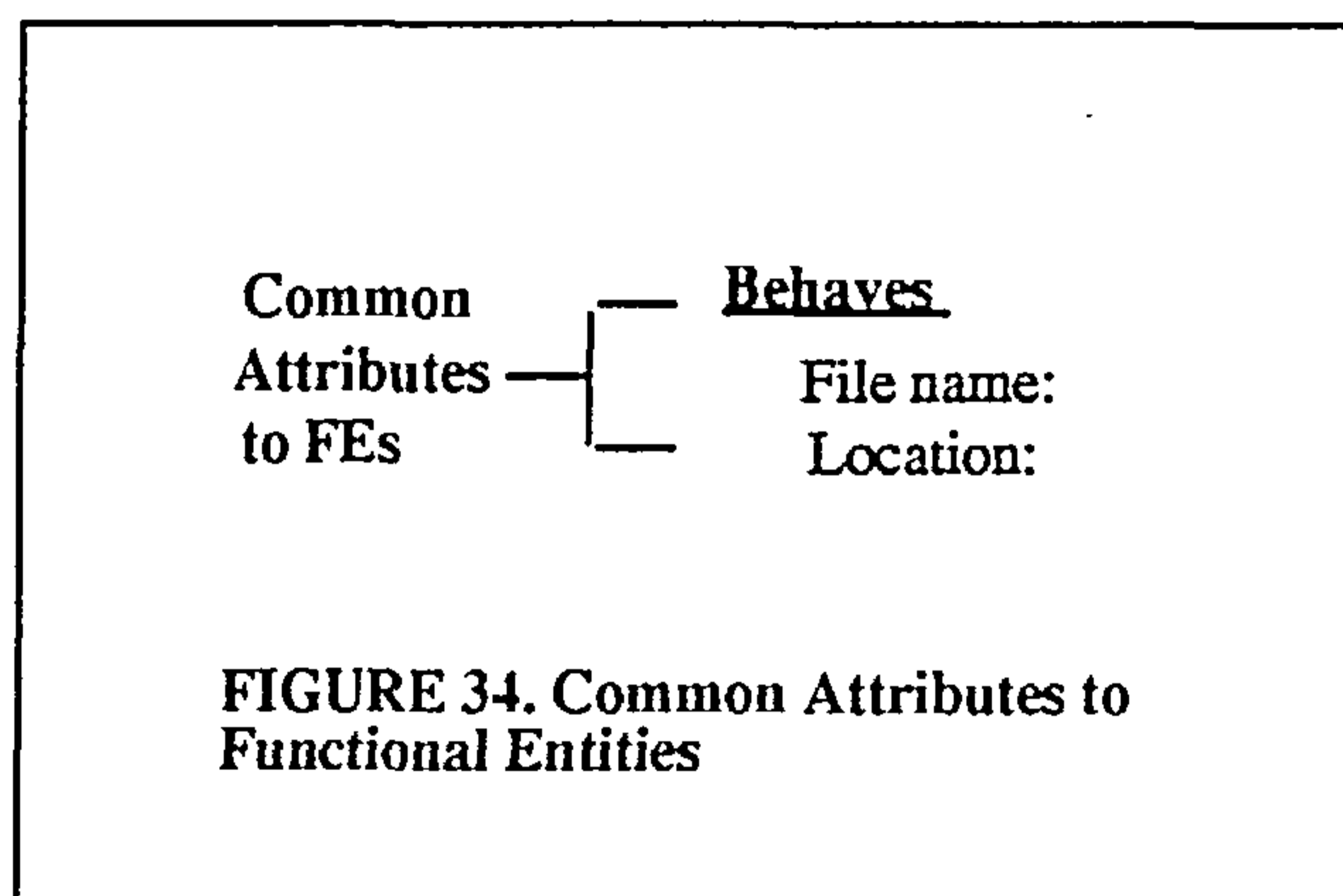
On-line status: (busy/ideal/ready/break down)

Cost:

(list of parameters)

Linkage to the cost model. This definition is not complete. However the link can be user defined.

- *Common Attributes of FEs (Figure 34)*



Behaves:

This dynamic characteristic of a resource is attributed only “active resources” (e.g. Function Entities of CIMOSA). This information is used to support system design, and system simulation.

File name: behaviour description file name

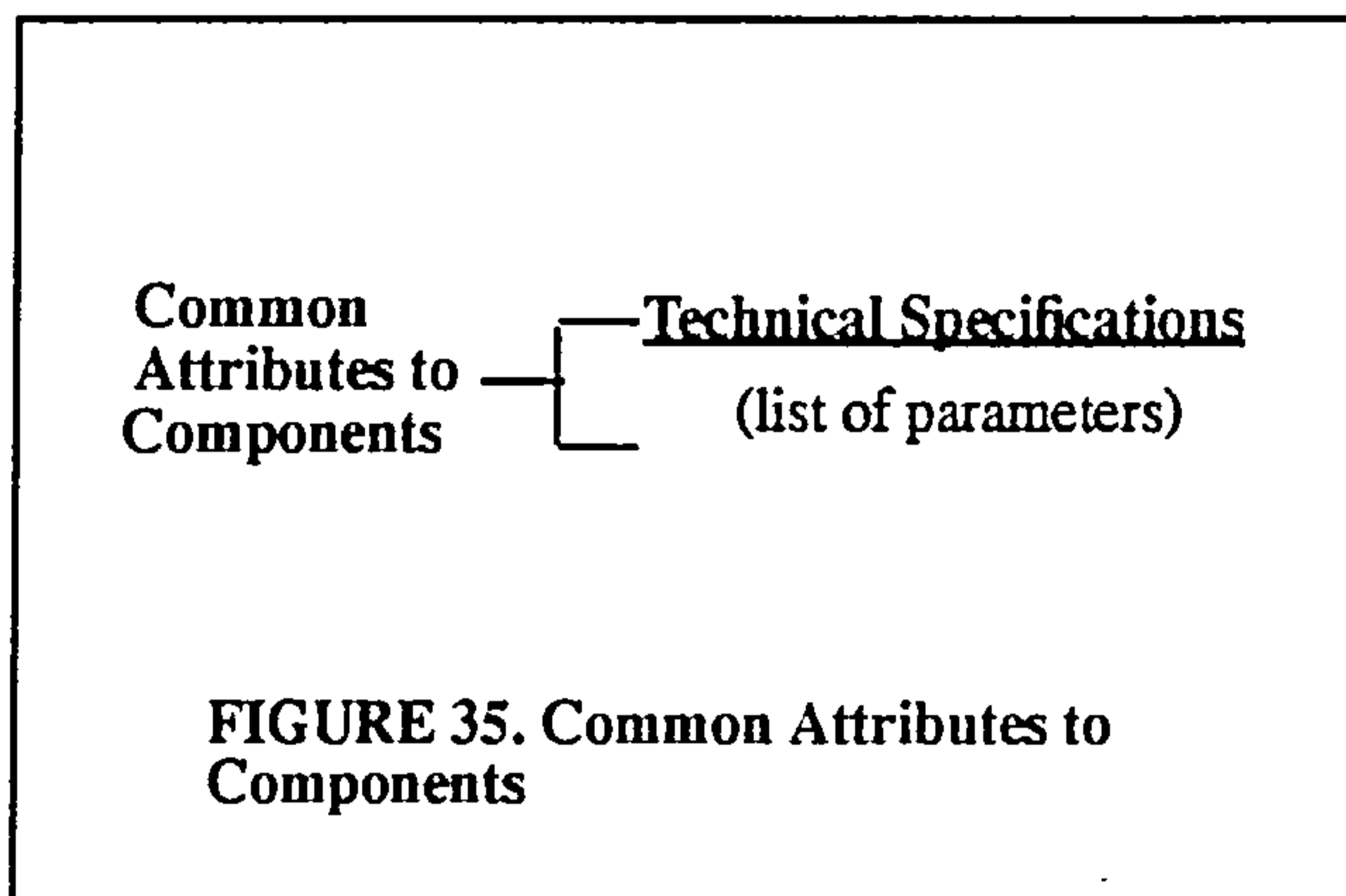
Location: the path to the file

- *Common Attributes of Components (Figure 35)*

Technical Specifications:

(list of parameters)

As passive resources these can take various forms, hence no fixed parameters are defined. Definition is left to the user.



- *Human (Figure 36)*

Discussed in the next chapter.

- *Machine (Figure 37)*

Technical Specification

(list of parameters)

Definition of a generic classification is not possible. The author leaves further classification to users. However this could well comprise a partial classification for machines used in specific industrial sectors.

Environment Support

Human: operator of the machine

Power: power needed to run the machine

Other equipment: any other equipment needed to run this machine

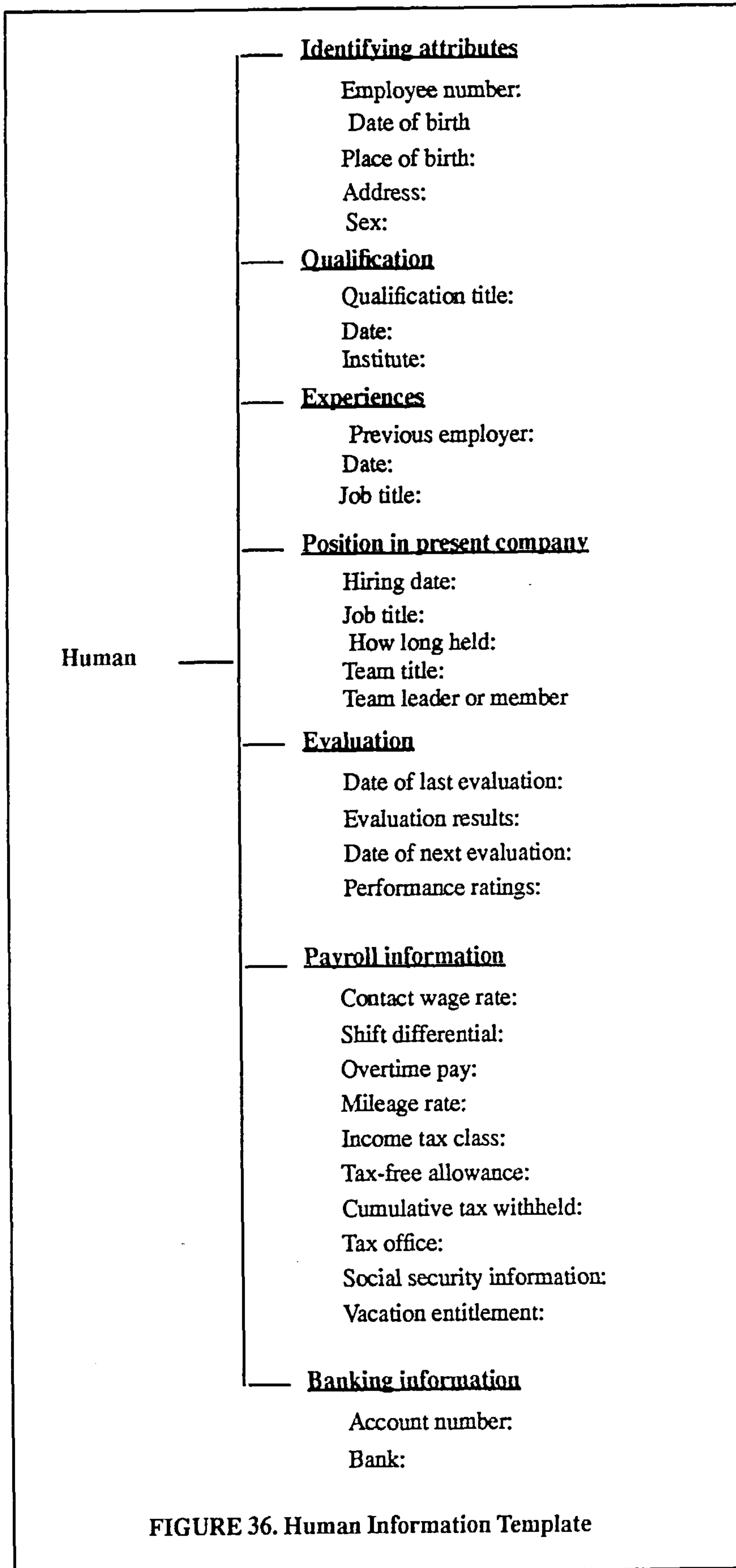
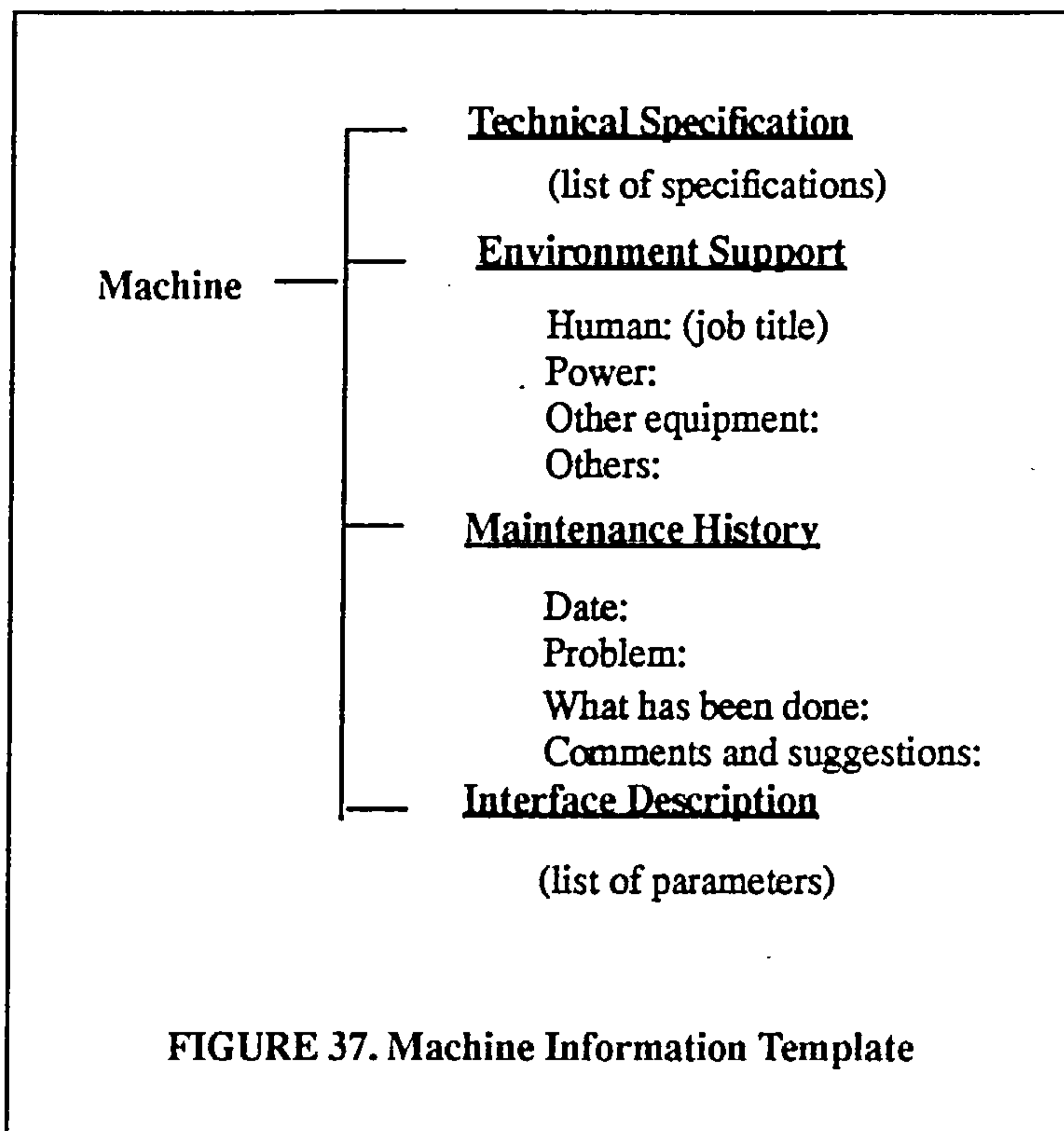


FIGURE 36. Human Information Template



Others: any other information needed for integration and implementation

Maintenance History

This information is required to support the life cycle of systems in terms of their maintenance.

Date: latest date of maintenance carried out

Problem: problem diagnosed

What has been done: repair work record

Comments and suggestions:

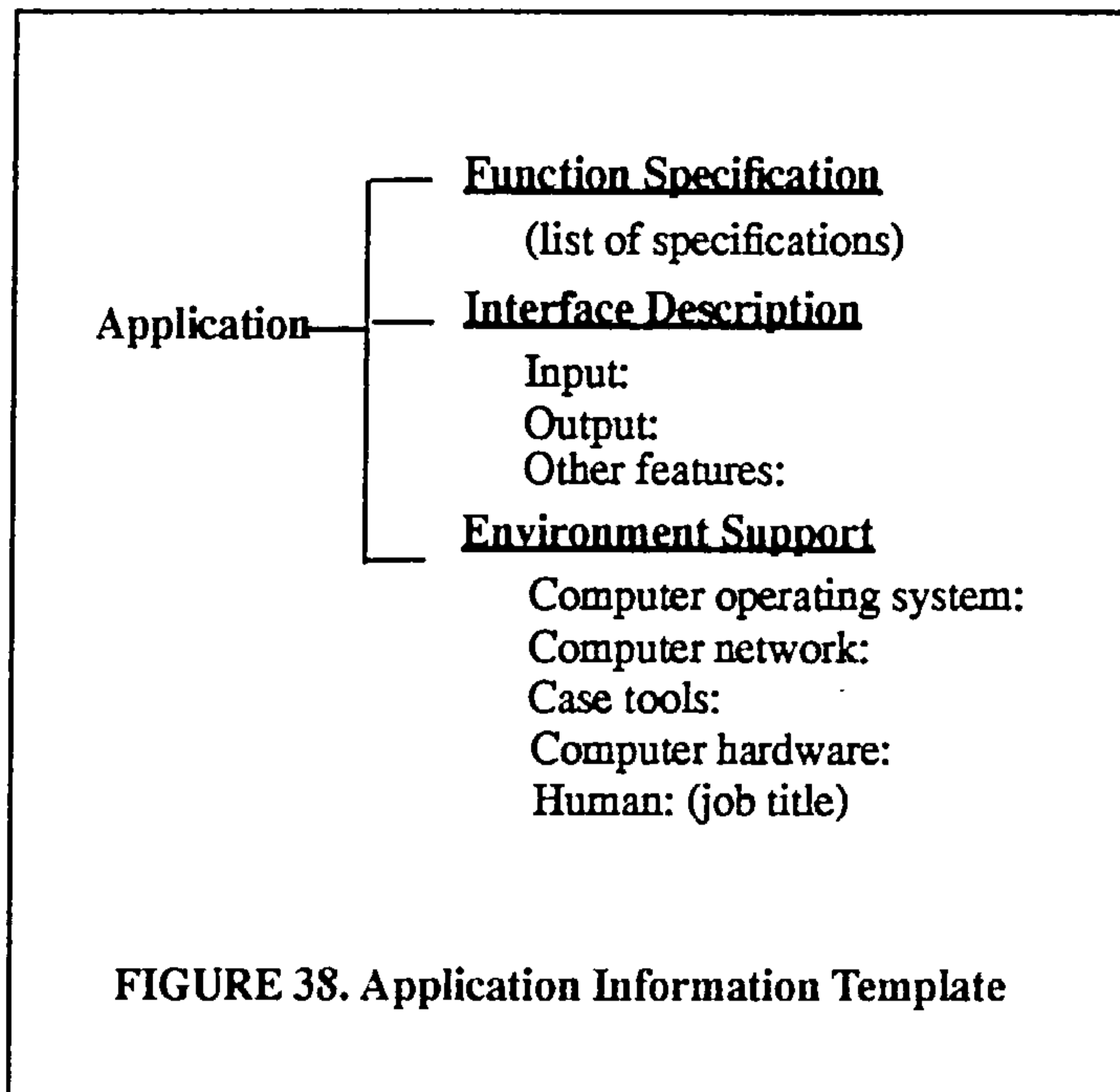
Interface Description

(list of parameters)

Apparently a generic classification is not possible. Hence the author leaves this

open for further classification. It could have a partial classification for the machines used in specific industrial sectors.

- *Application (Figure 38)*



Function Specification

(list of parameters)

This is further information required about the capability of an application.

Interface Description

Input: description of input information, such as data format, file format etc.

Output: description of output information

Other features: any other information needed to describe the interface

Environment Support

Computer operating system: name of the computer operating system required

Computer network: name of the computer network required

Case tools: name(s) of the case tool(s) required

Computer hardware: name of the computer type needed

Human: title of human operator needed

5.6 Summary

The foregoing provides the basis of a framework for resource modelling. This framework encompasses the following:

- the role of resource models in relation to other enterprise models has been considered. Hence resource models should:
 - (1) support process modelling;
 - (2) cooperate with organization, cost and information modelling in support of process modelling;
 - (3) provide consistent support for different life phases of an enterprise.
- the relationship between enterprise activity and resource capability was investigated and the important role of a classification of resource capabilities was recognised and developed. Example classifications of resource capabilities have been produced
- the nature of interrelationships between models has been classified and means of establishing linkages to other models has been suggested
- a methodology for resource information capture has been defined which comprises the following.
 - (1) definition of *resource type* and *resource architecture*;

- (2) mappings between *resource architecture* and *enterprise organization structure*;
- (3) a classification of resource types;
- (4) information capture guidelines;
- (5) information templates.

6.0 Human Resource Modelling and Organisation Issues

6.1 Introduction

Inherently resource models will have a close relationship with organisation models. This is evident as humans (as basic “components” of an organisation) are key manufacturing resources which must have defined relationships with other resources in an organisation. In order to develop a practical classification of human resources and to establish a flexible and open linkage between resource and organisation models, the fundamentals of organisation issues were studied by the author. This chapter reports study findings on alternative organisation structures and team work. It also develops the notion of information templates for human resources.

6.2 Brief Review of Literature on Organisational Structures and Team Work

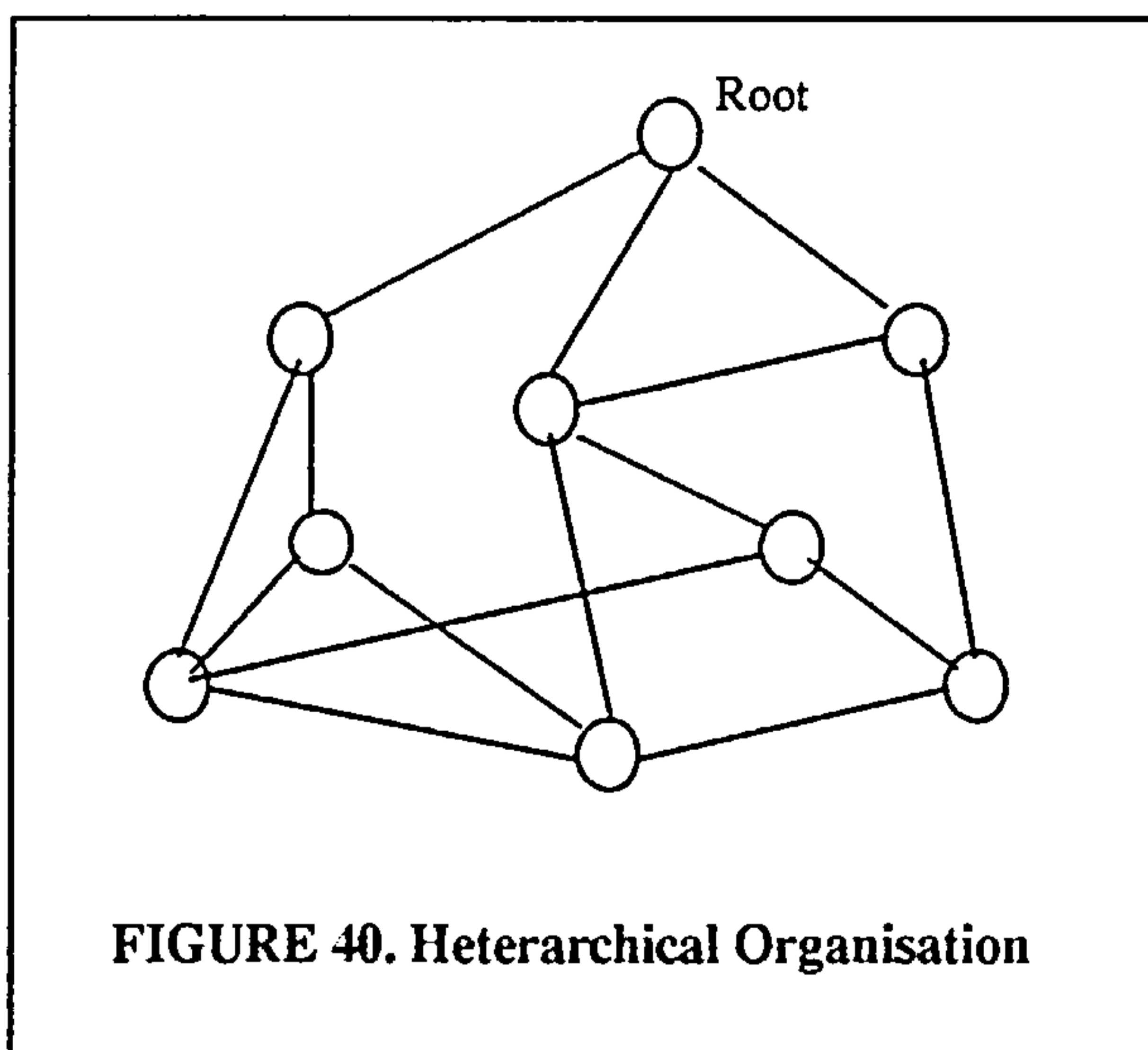
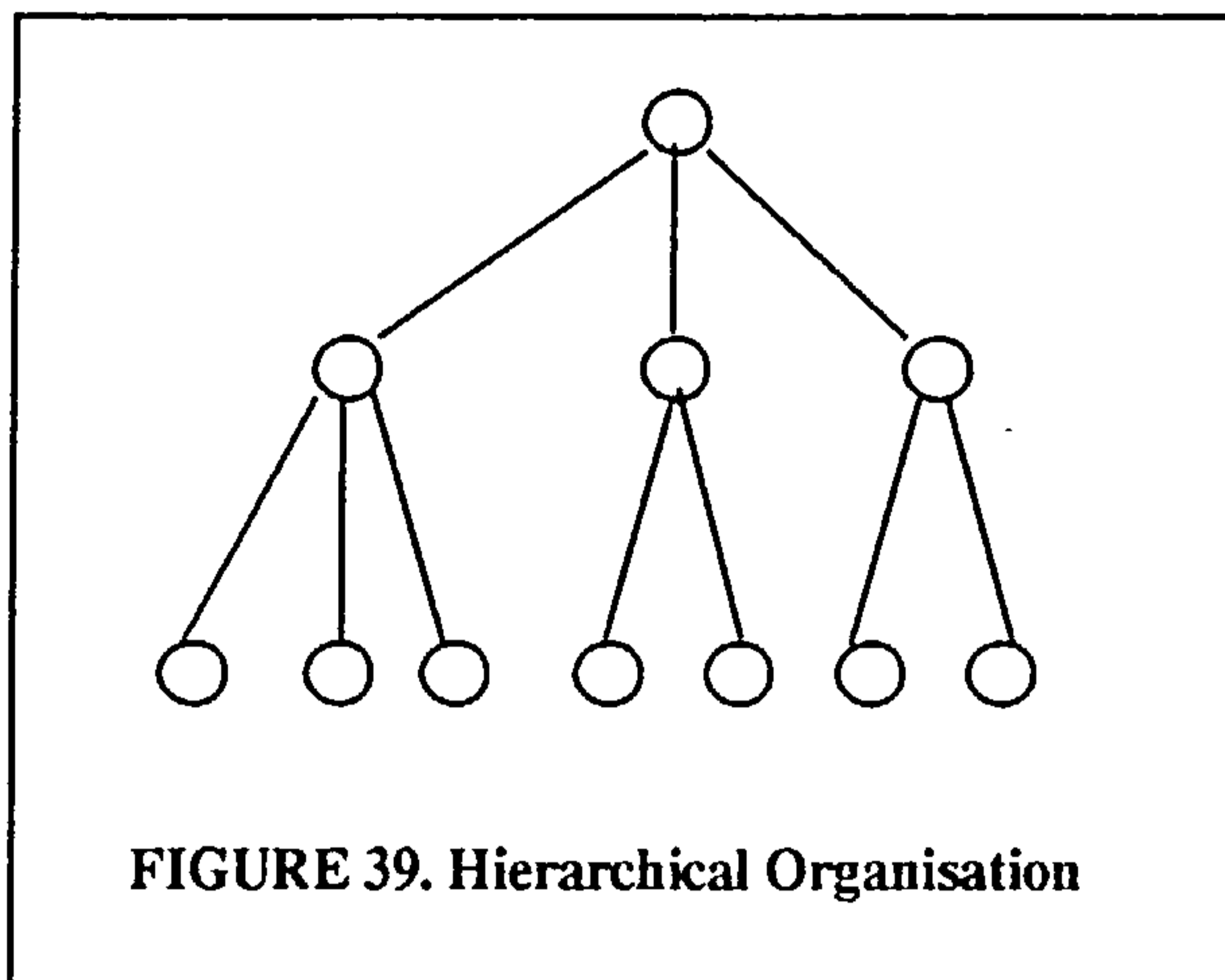
6.2.1 Organisational Structures

6.2.1.1 Classification of Organisational Structures

Organisation structures are an important aspect of organisation study. The organisation structures adopted can be influenced by technology developments and change in socio-political economic situations. Also the choice of organisation structure will effect the way in which people work. These relationships have been studied by both practitioners and research professionals working in business, economic, social and political fields.

A number of organisation structures are described in the literature. The following draws distinction between the alternative described.

1. Common descriptions differentiate between 'hierarchical' and 'heterarchical' organisational structures, see Figures 39 and 40 respectively. Most organisations adopt one (or even both) of these structures.



2. Handy reported on four types of organisational structure (Figure 41)[Handy, 93].

They include:

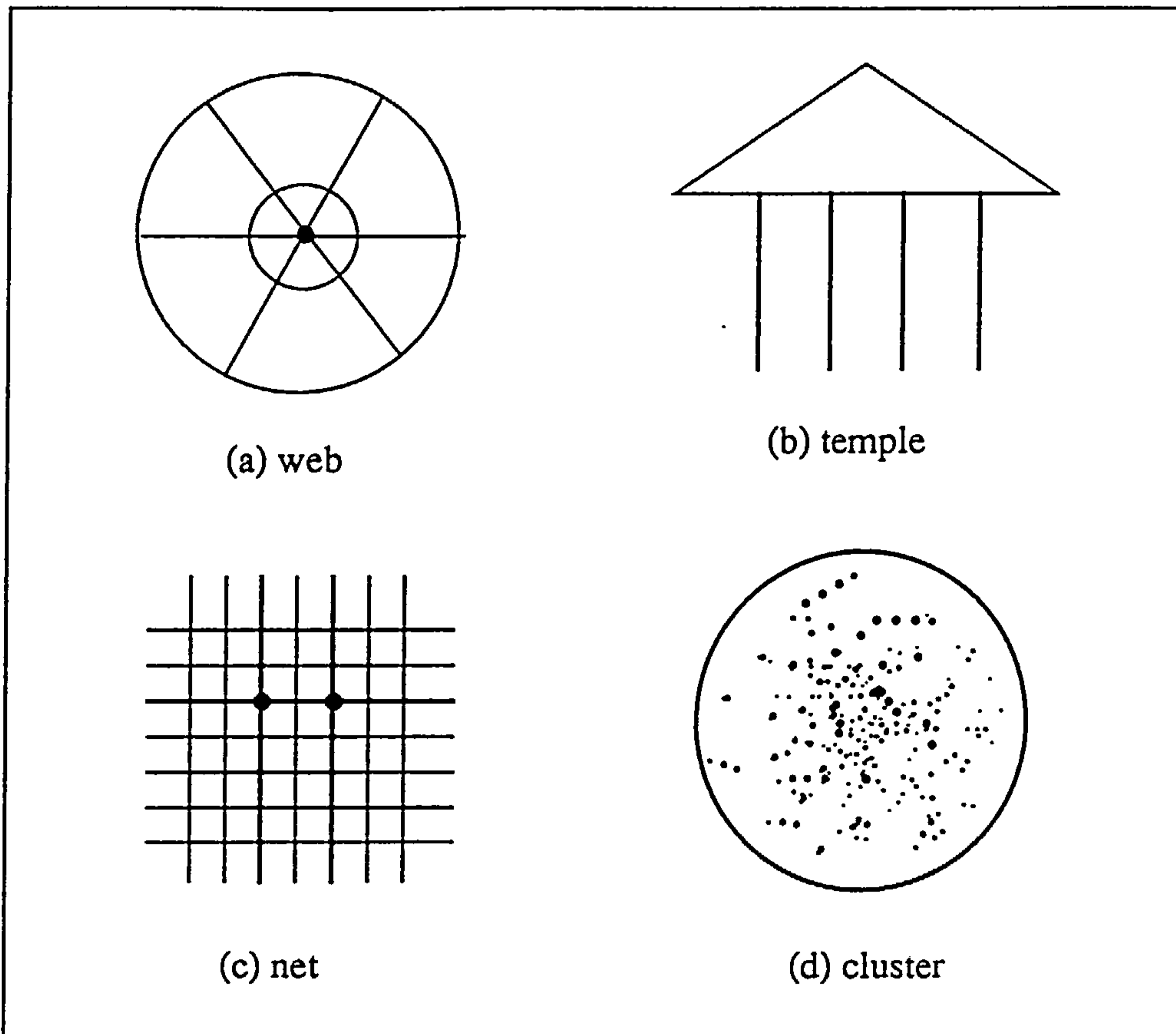


FIGURE 41. A Classification of Organisation Structures by Handy

(a) the web (power-based); applicable to small entrepreneurial organisations; depends on central power; trust and empathy; communication by conversation.

(b) the temple (role-based); works by logic and rationality; rests its strength on its functional capabilities or specialities; the interaction of these “functional departments” is controlled by rules and procedures and coordinated by senior management.

(c) the net (task-based); emphasis on getting the job done; enabling the right people at the right level in an organisation; based on expert power rather than position or personal power; unifies power of the group and identifies and links the individual to the objective of the organisation; control in this type of organisation is accepted to be difficult.

(d) the cluster (person-based); not found in the majority of organisations; individual is the central point, all other parts of an organisation serve and assist the individuals within it; examples are barristers' chambers, architects' partnerships, some small consultancy firms, families etc.

This classification provided by Handy can cover most structures used during the 19th and 20th centuries and by different types of organisation (i.e. manufacturing, government departments, legal services etc.) and for organisations of different sizes (i.e. small, medium, or big).

3. A further classification of organisational structures was summarised by Huczynski & Buchanan's [Huczynski & Buchanan, 91]. This includes three different structures described below, each of which can be organised into a hierarchy or heterarchy (see Figure 42):

(a) function-based organisational structure; (formal, centralised)

(b) product-based organisational structure; (formal, decentralised)

(c) geography-based organisational structure. (formal, decentralised)

4. Organisational structures observed by Mintzberg included seven types of organisational structure [Mintzberg, 89], namely: (a) the entrepreneurial; (b) the machine; (c) the professional; (d) the innovative; (e) the missionary; (f) the diversified; (g) the political.

5. Other structures reported include the matrix organisation as described by Galbraith and Kingdon [Galbraith, 73] [Kingdon, 73]; loosely-coupled organisation as described by Weick [Weick,79]; and the network organisation described by Foy [Foy,80].

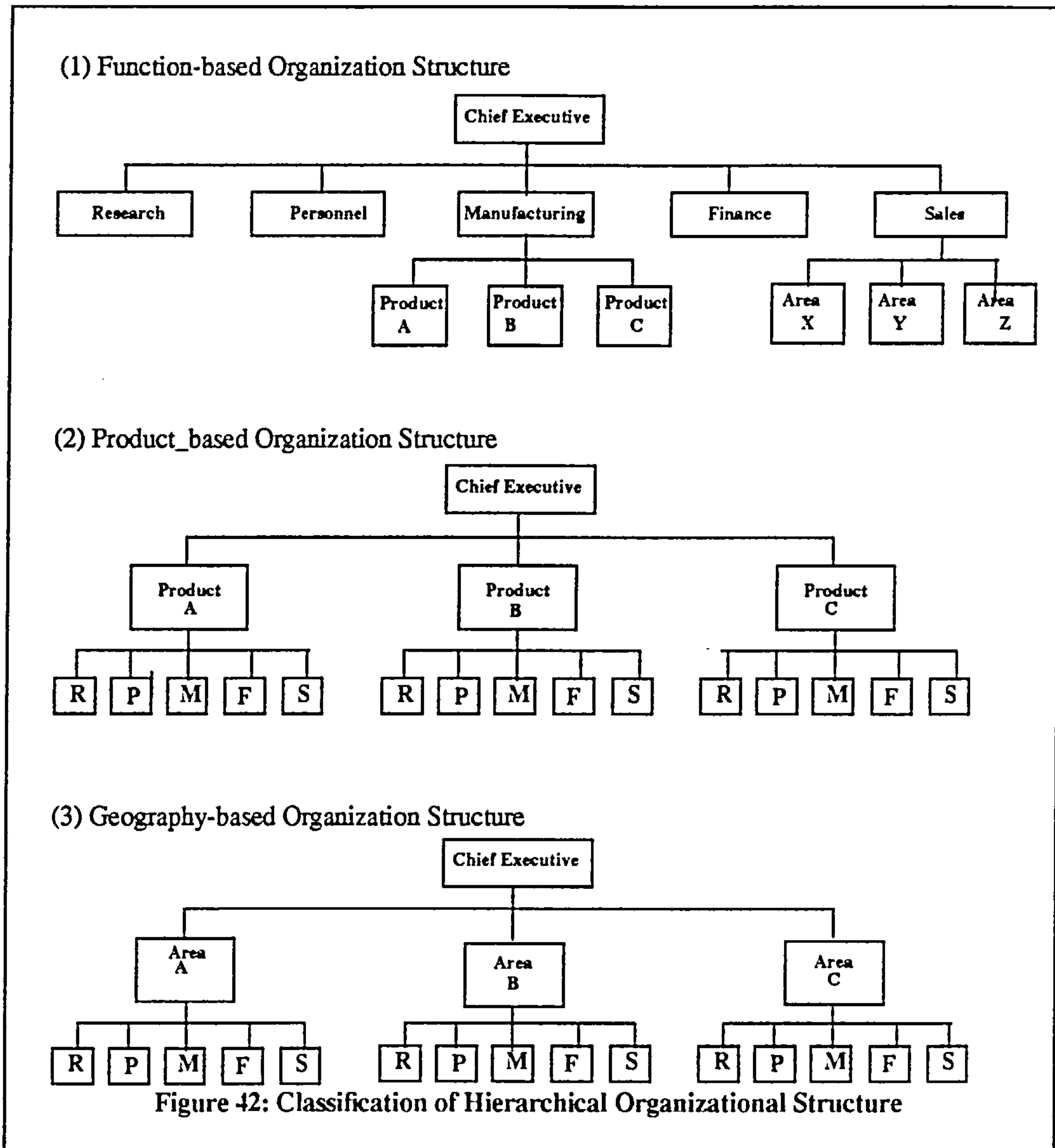


FIGURE 42. Classification of Hierarchical Organisational Structure
(source: [Huczynski & Buchanan,91])

6. Further organisation structures, classified as 'holonic approaches' were reported by Suda and Valckenaers [Suda, 89] [Suda, 90] [Valckenaers et al, 94] [Mathews, 95]. This is claimed to characterise heterachic organisations in which an enterprise comprises networks of organisation units. Each unit has its own autonomy and intelligence to enable it to handle problems in its area of competence. In so doing it communicates and negotiates with other organisation units.

6.2.1.2 Some important issues related to organisational structures which need to be considered in the context of resource modelling

In the context of this thesis the author has drawn the following conclusions about organisational structure:

1. Essentially any organisational structure comprises two elements. One of these elements concerns the *basic structure* which determines in terms of functional responsibility; which commonly can be depicted by an organisation chart. The other is the *operating mechanisms* (i.e. regulations, rules, constraints, etc.) that it deploys [Lorsch, 70] [Child, 84] [Handy, 93]. Hence two companies may adopt the same basic structures but may use very different operating mechanisms, i.e. rules and control constraints, mechanisms to implement the structure adopted;
2. Organisations with different organisational structures can achieve the same business goal [Pugh & Hickson, 68];
3. The quality of an organisation's structure can affect its operational result [Child, 84];
4. The quality of an organisational structure can effect its ability to respond to changing requirements, i.e. restrict its agility [Li, 95]. Conversely it may be of significant advantage for a company to be able to rapidly change its organisational structure in line with new business opportunities;
5. The organisational structure adopted will partly determine the behaviour of humans at work [Fox, 66] [Lorsch, 70];
6. Choice of organisational structure can be influenced by a number of factors, such as

the history and ownership of the company, the type of products it produces, the size of the company, the technology it deploys and characteristic properties of the people and the culture they develop, both within the company and within its environment [Handy, 93].

7. The use of hierarchical organisational structures has played an important role in organisation history. It is still a dominant structure in different countries, industrial sectors and types of company. However following technology advanced and changes in socio-political economic systems generally speaking more people are involved in decision making processes. Hence organisation structures tend to be flattening out and moving towards the adoption of heterarchical [Huczynski & Buchanan, 91].

6.2.2 Team Work in an Organisation

The study of team work is not a new topic. Historical study about group working in Britain dates back to 1917 and in America to 1920 [Huczynski & Buchanan, 91]. In China team work practice might date back for more than thousand years. It has gained prominence following development of team working methods by competitive Japanese industries [Kidd, 94] [Womack, 90] [Harrison, 94], which provoked new interest in it.

In the context of this thesis, the author's literature study identified the following essential points about team work.

6.2.2.1 Human nature in support of team work

1. Wanting to belong to a group is a typical characteristic of most humans. This is

manifest in people's private and social lives [Huczynski & Buchanan, 91]. A working team is a psychological home for an individual [Handy, 93], in which the individual feels safe and secure [Likert, 61].

2. Often people like to perceive themselves as being part of a group [Handy, 93].

People like to work in groups when learning skills, acquiring knowledge and developing a positive way of thinking towards work. People like to improve themselves in terms of social behaviour and work efficiency when they are with other people.

3. Often groups of people can make better decisions [Handy, 93].

4. Often groups of people can take greater risks [Handy, 93].

5. People working together can be more productive and produce better quality outputs [Deutsch, 69].

6. People like to work together to achieve bigger and better goals, to invent new technology, to produce more products that humans require, and to improve the quality of human life.

6.2.2.2 Organisations need team work support

1. Industrialization, automation and information technology are all the outcome of humans working together. Even so, arguably to make further advances people, organisations and new technology need to work more efficiently as a whole.

2. A working team is a basic building block of an organisation [Likert, 61] [Leavitt, 75] [Peters, 87] [Li, 95]. An organisation can achieve business targets by deploying teams to manage and control the distribution and completion of work to achieve

problem solving and decision making and to generally improve co-ordination, liaison and communication within an organisation [Handy, 93].

3. Japanese industries have demonstrated that team work is a technique which can help build a successfully world class enterprise [Womack, 90] [Kidd, 94].

6.2.2.3 Some important points which need to be considered with respect to resource modelling

1. Working teams, should be adopted as a basic building block of organisational structures [Likert, 61] .
2. Human resource models should be designed to support various organisation structures (hierarchical or heterachic, tall or flat, role-based or task-based), and should support team work.

6.3 Classification of Human Resources

Humans are the initiator, designer, producer and operator of machines and manufacturing systems. Some people are good at innovating and inventing, whilst others will be good at putting ideas into practice. In some companies, people have the opportunity to play different roles. However, in other companies people may do one kind of job only. Whatever there must be some general rules adopted in companies to organise their deployment of human resources.

In all manufacturing companies there is a division between the functions¹ that directly

1. Function has a special meaning when applied to jobs carried out by people. It describes what they do or their role. A manufacturing director, an accountant or system designer are all functions.

support the manufacturing process (that is to say that part of the company that provides its engineering or technology base) and which manage and support manufacture and its interfaces with the outside world.

The functions that support the technological base include engineers, planners, process operatives. The functions found at the organisational level include managing director, assistant manager, accountant, personnel and so on.

With increased use of information technology new roles have emerged [Storey, 94], such as: information systems designer, system analysis,... etc. Such functions cross conventional boundaries between a manufacturing base and its executive support roles. Such functions help organise and plan manufacture, increasing its efficiency whilst also providing managers with increased knowledge of what is happening in the company so that better quality decisions can be taken.

Based on an understanding of typical functions carried out by human resources in enterprise systems, a classification of human resources is suggested by the author. Generally, there are two “clusters” of functions which concern organisational aspects and functional aspects. Hence human resources have been classified from these two aspects.

6.3.1 Human Resource Architecture - Organisational Aspect

6.3.1.1 Team leader or team member

From a management view point, each human being can be classified as a team member or a team leader (or both), see Figure 43.

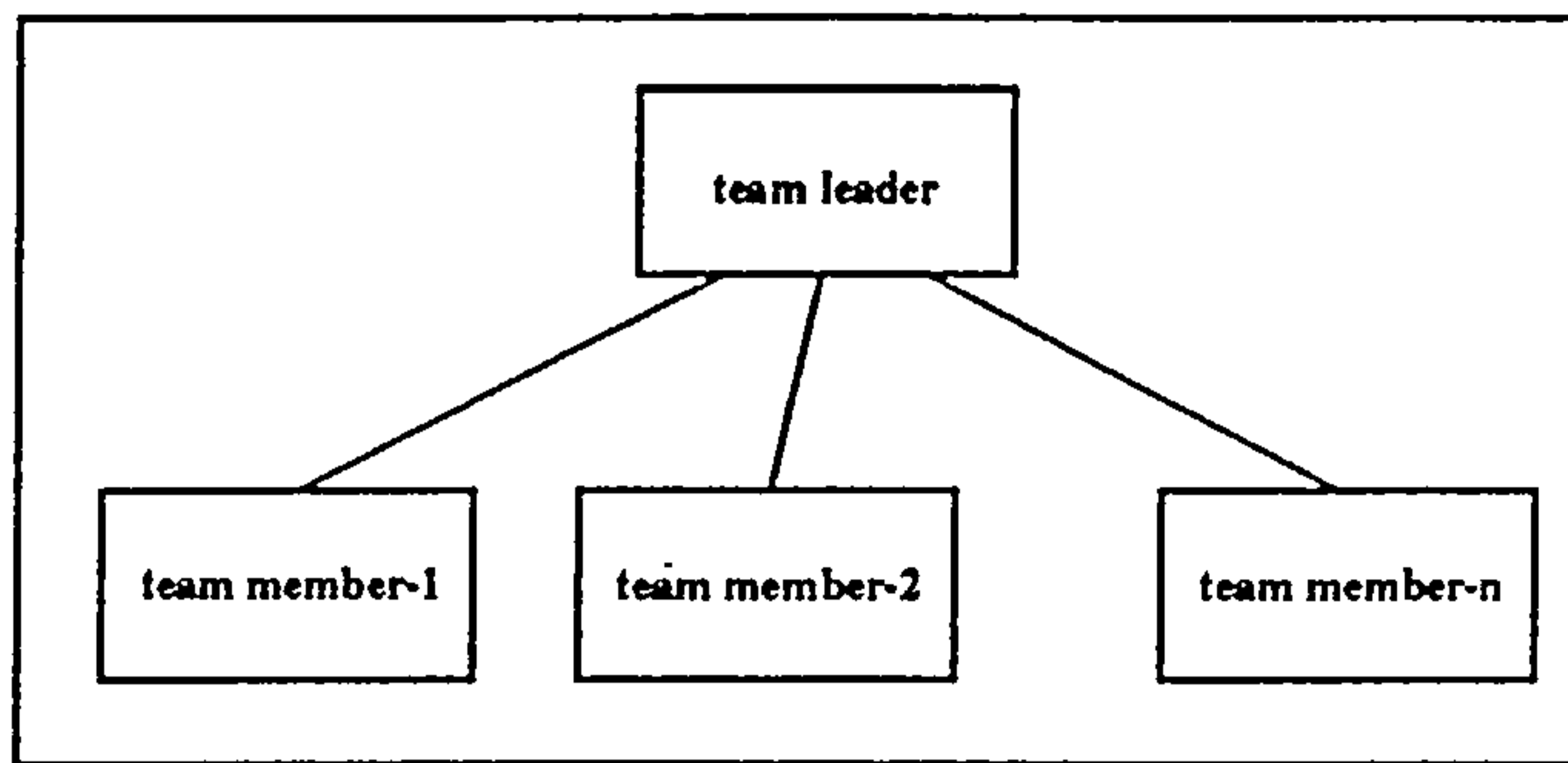


FIGURE 43. Human Resource Type and Relationship

On its own such a definition can reflect only one characteristic of a human resource, i.e. he or she is a team leader or a team member. Stated another way, he/she is an organiser or an individual worker. This concerns the organisational aspect of human resources.

6.3.1.2 Human resource architecture

Since team work occurs at all levels of an enterprise, team leaders and the team members can exist at different levels. This nature of human resources can be viewed as a human resource architecture. A human resource architecture can be expected typically to reflect hierarchical characteristics of an organisation. See Figure 44.

It is probable that the definitions of team member, team leader and human resource architecture reflect organisational characteristics which can apply to all kinds of industry.

6.3.2 Human Resources Types -Functional Aspect

Another nature of human resources is that each human should have a functional role in an enterprise system. Functional role may typically include the skills necessary to

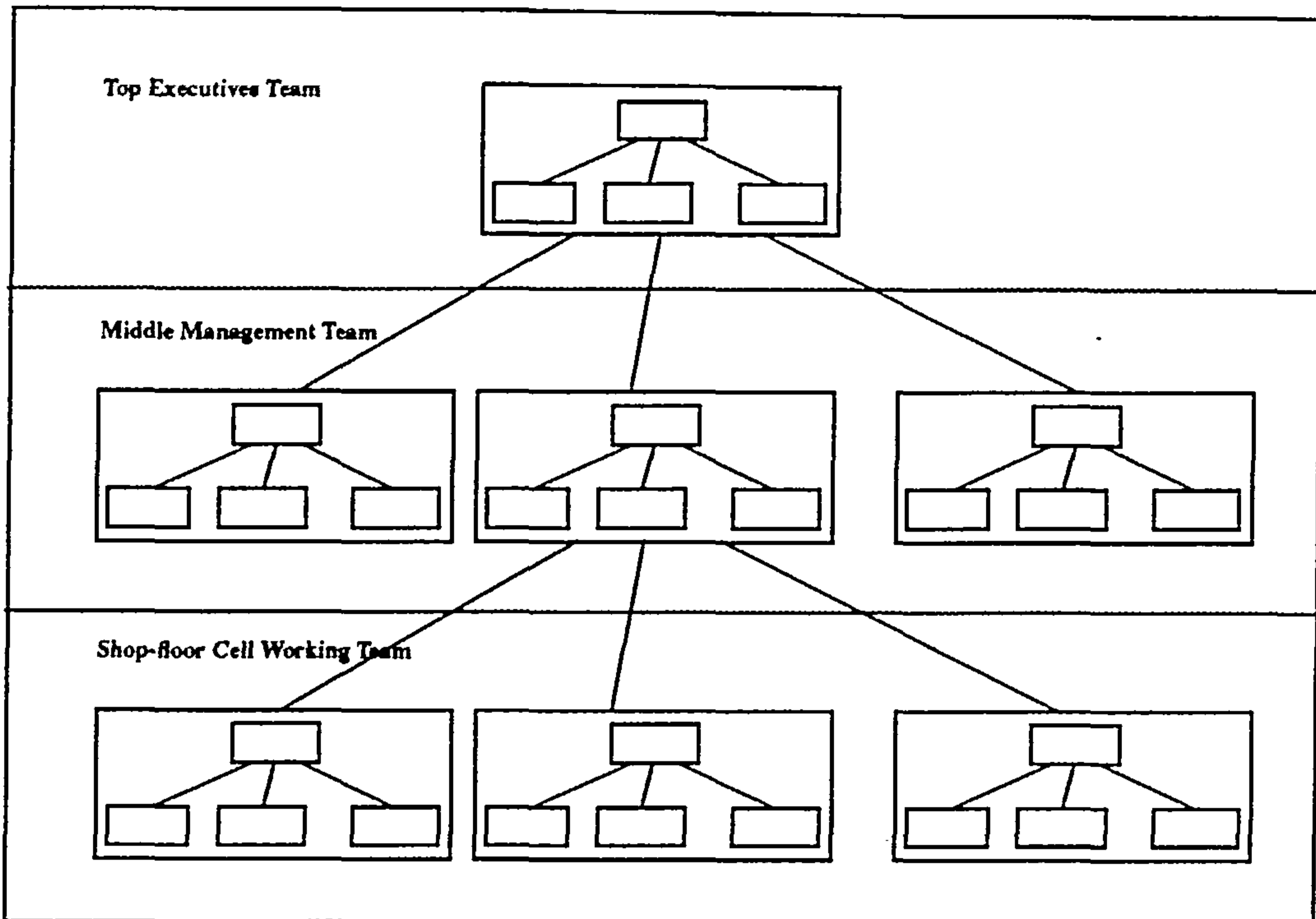


FIGURE 44. Human Resource Type Mapping to Organisation Structure

carry out the business process and manufacturing process of an enterprise (for example, product design, product introduction, machine operation, etc.) and skills related to its management and infrastructure process (such as accountants, marketing, etc.)

6.3.3 Classification of Human Resources

Based on the discussion and definitions contained in sections 6.3.1 and 6.3.2, a generic classification of human resources was attempted. The design of this classification led to the collection of a Common Job Tile list² as depicted by Table 7. The reasons for this outcome are summarised below.

2. It has to be noted that this collection is not a comprehensive one at all. Further classification needs to be carried out.

Common Job Titles in Manufacturing Enterprises																											
Top Level Executive Team	Chief executive Managing director Chairperson of board of directors Marketing & sales director Production director R & D director Finance director Company secretary NonExec. director Manufacturing director																										
Middle Level Management Team	<table border="0" style="width: 100%;"> <tr> <td style="width: 50%;">Marketing manager</td> <td style="width: 50%;">Marketing assistant</td> </tr> <tr> <td>Product design manager</td> <td>Production design assistant</td> </tr> <tr> <td>Production planning manager</td> <td>Production planning assistant</td> </tr> <tr> <td>R & D manager</td> <td>R & D assistant</td> </tr> <tr> <td>Quality control manager</td> <td>Quality control assistant</td> </tr> <tr> <td>Sales manager</td> <td>Sales assistant</td> </tr> <tr> <td>Product support manager</td> <td>Product support assistant</td> </tr> <tr> <td>Financing manager</td> <td>Financing assistant</td> </tr> <tr> <td>Personnel manager</td> <td>Personnel assistant</td> </tr> <tr> <td>Equipment manager</td> <td>Equipment assistant</td> </tr> <tr> <td>Information system manager</td> <td>Information system assistant</td> </tr> <tr> <td>Site manager</td> <td>Site assistant</td> </tr> <tr> <td>Shop-floor manager</td> <td>Shop floor assistant</td> </tr> </table>	Marketing manager	Marketing assistant	Product design manager	Production design assistant	Production planning manager	Production planning assistant	R & D manager	R & D assistant	Quality control manager	Quality control assistant	Sales manager	Sales assistant	Product support manager	Product support assistant	Financing manager	Financing assistant	Personnel manager	Personnel assistant	Equipment manager	Equipment assistant	Information system manager	Information system assistant	Site manager	Site assistant	Shop-floor manager	Shop floor assistant
Marketing manager	Marketing assistant																										
Product design manager	Production design assistant																										
Production planning manager	Production planning assistant																										
R & D manager	R & D assistant																										
Quality control manager	Quality control assistant																										
Sales manager	Sales assistant																										
Product support manager	Product support assistant																										
Financing manager	Financing assistant																										
Personnel manager	Personnel assistant																										
Equipment manager	Equipment assistant																										
Information system manager	Information system assistant																										
Site manager	Site assistant																										
Shop-floor manager	Shop floor assistant																										
Lowest Level Operational Teams	Production engineer Engineering designer Production planner / analyser Salesperson Quality inspector Accountant Information system designer / analyser Machine operator Technician Store room keeper Cashier Secretary Driver Cleaner Supervisor Foreman																										

TABLE 7. Common Job Titles in Manufacturing Enterprises

- As mentioned at the beginning of this chapter, humans are the initiator, designer, producer and operator of machines and manufacturing systems. Some people can be good at innovating and inventing, whilst others are good at putting ideas into practice. In some companies people play different roles. Therefore, establishing an universally acceptable classification of human's function in manufacturing

enterprises is extremely difficult if not impossible.

- The two important aspects of human resources discussed in section 6.3.1 and 6.3.2 can be reflected by an appropriate choice of a common job title. For example, titles like 'Product Engineer', 'Accountant', 'Technician' etc. show clearly the functional aspect of human resources. Furthermore, organisational aspects of human resources (i.e. team leader, team member and architecture) are also reflected by commonly used job titles. For instance, 'managing director', 'R & D manager' 'Supervisor' etc. show that the person concerned is a team leader at different levels in an organisation. The previous example implies that the persons who take that jobs are the team members only. Mainly the job titles could show both the functional aspect and organisational aspect of human resources. Hence only a list of common job titles was produced.

Since the skills needed in each enterprise can be different (especially those related to manufacturing processes) and the organisational structure adopted in each enterprise can be different, this classification can only serve as a reference. Also the human resource classification defined in this thesis matches typical job titles used by the UK business community, which will different from that used in other countries.

- The author believes that from an enterprise modelling viewpoint it is essential to classify the 'capabilities' of each kind of resource, including human resources. A classification of human resources in terms of job titles can be treated as a first step towards a classification of human capability. A further and more detailed and consistent classification of human resource capabilities (in respect to different model views and life phases) needs to be studied thoroughly; Chapter 5 gives

examples which could provide a foundation for such a study.

6.4 Information Templates for Human Resources

Based on the considerations discussed above, a human resource information template was designed by the author. See Figures 32, 33 and 35. This model has the following characteristics:

- Support for different types of organisation structure

The attribute Organisation Unit under the heading Common Attributes (Figure 32) is responsible for linking the organisation and resource models. Potentially it can support different types of organisational structure as discussed in detail in the Chapter 7.

- Support for team working

Two attributes, namely Team title and Team leader or member have been introduced within the 'human' resource category (see Figure 35) as part of the construct Position in present company. These two attributes can be used to support the modelling of team working in an organisation.

- Support for further classification of human resource capabilities

As discussed before, the classification of resource capabilities is essential to realise formal enterprise modelling. The classification of human resource capabilities should bear this requirement in mind. The classification of human resource type, which led onto a classification of common job titles used in manufacturing enterprises, is a start. Flexibility to further extend this classification is required in

the design of information templates of human resources. This is realised by developing extendable lists of resource capabilities within the human resource templates.

The attributes shown in figure 35 are modelled on, but represent an extension of, extended definitions contained in the ARIS human resource model [ARIS, 94]. As most attributes have a clear meaning, no further explanation is given here.

6.5 Summary

Thus we may conclude that:

- human resource models should have the capacity to support various forms of organisational structure, including hierarchical / heterarchic, tall / flat, role-based / task-based etc.
- human resource modelling should have the capacity to support team working. This may be implicit within the organisation structure.

On considering general human resource information requirements, a human resource information model was defined with an emphasis on the classification of human resource capabilities.

7.0 Function Specification of a Resource Modelling Toolset

7.1 Introduction

Chapters 4 to 6 described the formulation of a framework for resource modelling. In this chapter the functional specification of a resource modelling toolset is reported which conforms to that framework. Initial discussion is based on a consideration of CIMOSA enterprise modelling concepts. This provides the basis of an new approach to resource modelling and has identified generic functional requirements of resource modelling toolsets.

7.2 Assessment of CIMOSA Concepts from a Resource Modelling

Perspective

By studying aspects of other enterprise modelling reported in the literature and gaining practical experience of resource modelling the author formed a conceptual view of necessary advances which could be accrued within the scope of a single Ph.D study. To maintain as broad a scope as possible it was decided that where possible and practical this project should build on and provide means of unifying the use of existing enterprise modelling tools. Indeed this set of considerations led to the conceptual design of a toolset which could be implemented and tested by the end of the project. The new approach is illustrated by Figure 45 and is based upon the following principles and observations:

- The new approach is essentially a development of CIMOSA principles and methods as it embodies: CIMOSA 'views', use of a CIMOSA conformant 'integrating infrastructure' (including common services, the business entity, the

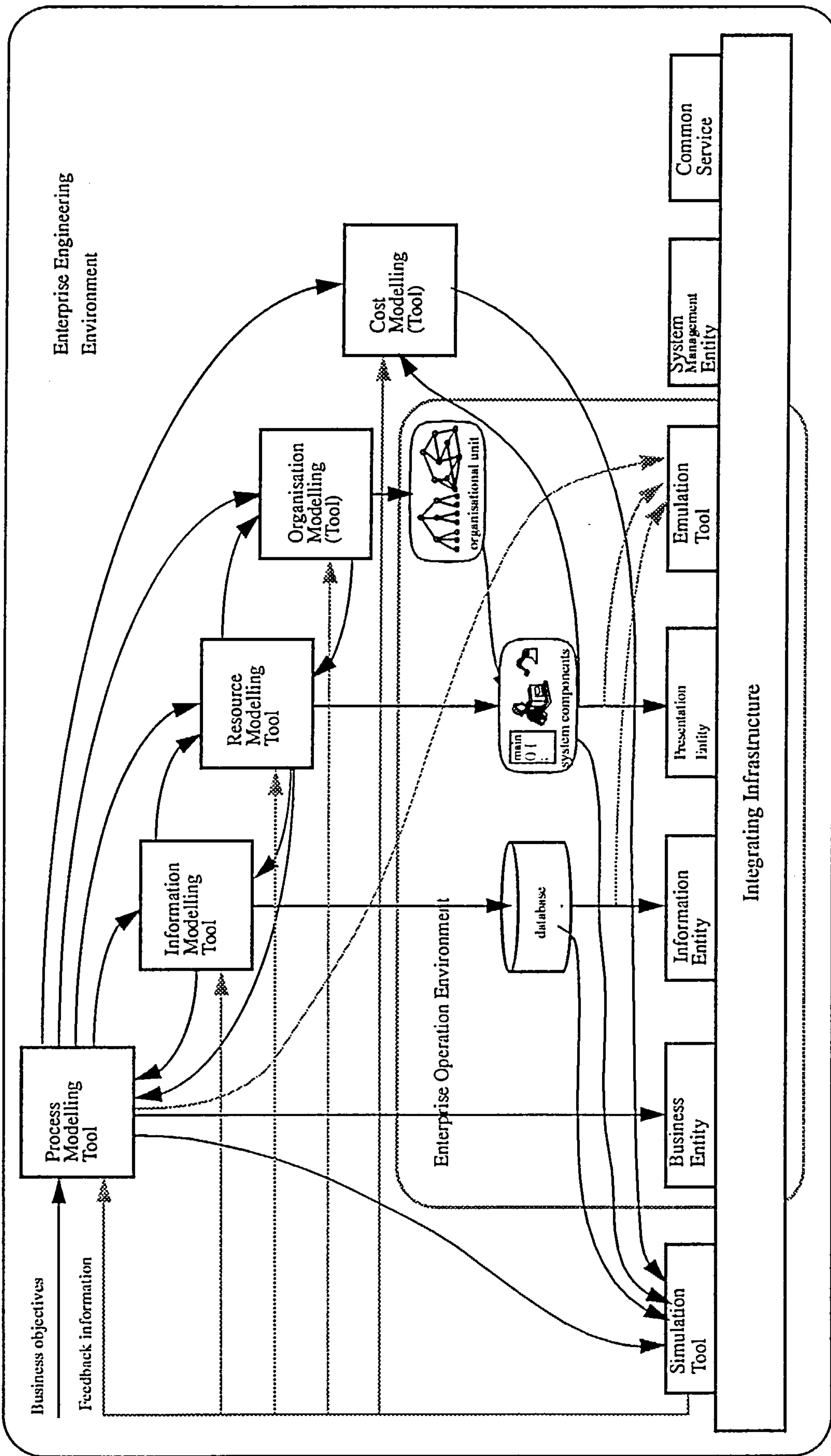


FIGURE 45. A New Approach to Enterprise Modelling Centred on the Use of the CIMOSA Framework - A Physical View

information entity, the presentation entity, the system management entity), use of a conformant CIMOSA 'enterprise engineering environment' and the use of a CIMOSA conformant 'enterprise operation environment'. This was seen to be a pragmatic and a practical way forward which builds upon ISO standard definitions.

The need to encompass the CIMOSA 'system life cycle' and its 'modelling levels' was also accepted. However it was understood that not all of the relevant CIMOSA principles and concepts have been used successfully to date and that in some areas specifications are incomplete;

- Relationships among different modelling views, and the capabilities of the services (entities) provided by the integrating infrastructure are more complex than indicated by Figure 45. In fact clarifying aspects of those relationships needed to be open research issues in the context of this study;
- The fact that different modelling views are required doesn't imply that each modelling view needs a separate modelling tool. Initially the author believed that it would be necessary to include tool support (whether it be in one or more tools) to cover process modelling, information modelling and resource modelling. It was also understood that ideally resource modelling needs tool support for organisation and cost modelling views, otherwise resource modelling activities will necessarily remain incomplete. However, within the scope of this study, it did not prove to be practical to implement organisation modelling and cost modelling in a generalised way.

7.3 Basic Toolset Support Required to Implement a Resource Modelling Capability

A general purpose resource modelling tool cannot be designed and implemented in isolation. Indeed its prime function is one of supporting design decision making, hence it cannot function fully in isolation. Thus it must be designed and implemented in a way which enables it to interoperate with other modelling tools. To demonstrate use of a resource modelling capability (based on the framework defined by this research) it was therefore concluded that the capability should be tested in respect of its ability to interoperate with the following related elements:

- process modelling tool(s);
- information modelling tool(s);
- organisation models (and if possible an organisation modelling tool);
- cost models (and if possible a cost modelling tool);
- a simulation tool;
- an integration infrastructure;
- an operation environment.

Clearly within a single PhD research project it would not be practical or sensible for the author to design and implement from scratch all such environmental capabilities and tools. Hence the need to select and use existing tools and working environment where possible; thereby to allow sufficient effort to be expended on key issues connected with the design and implementation of resource modelling tools. Even this approach implied the need to implement 'IT glue' to connect the tools within the environment implemented in the manner defined by the framework of chapters 4 to 6.

Among the tools and environmental services listed above, the need to include a process modelling tool and a minimum operation environment were considered to be

essential and critical.

7.4 General Functions which Need to Be Provided by the Resource

Modelling Toolset

On decomposing functional requirements of resource modelling in support of the different life phases of enterprise systems, it was found that few distinct classes of resource modelling entity are required. The purpose of each of class of functional entity is to provide the following functional capabilities: (1) resource information management; (2) system analysis and design support; (3) support for system implementation and release as part or all of run time systems and (4) system operation support. Each class of functional entity needs to form part of a consistent resource modelling environment. This requires a means of realising appropriate interconnections between function entity, as depicted in Figure 46.

7.4.1 Resource Information Management Capability

The function of resource information management is to:

- create a resource information library, to implement this in a database and to link it to a suitable information modelling tool;
- provide the facilities for resource information management (i.e. provide input, insert, update, read and delete capabilities for resource information);
- provide suitable interfaces to users of resource modelling tools.

The users of the resource information management capability were expected to be personnel responsible for managing resources, system analysts and designers,

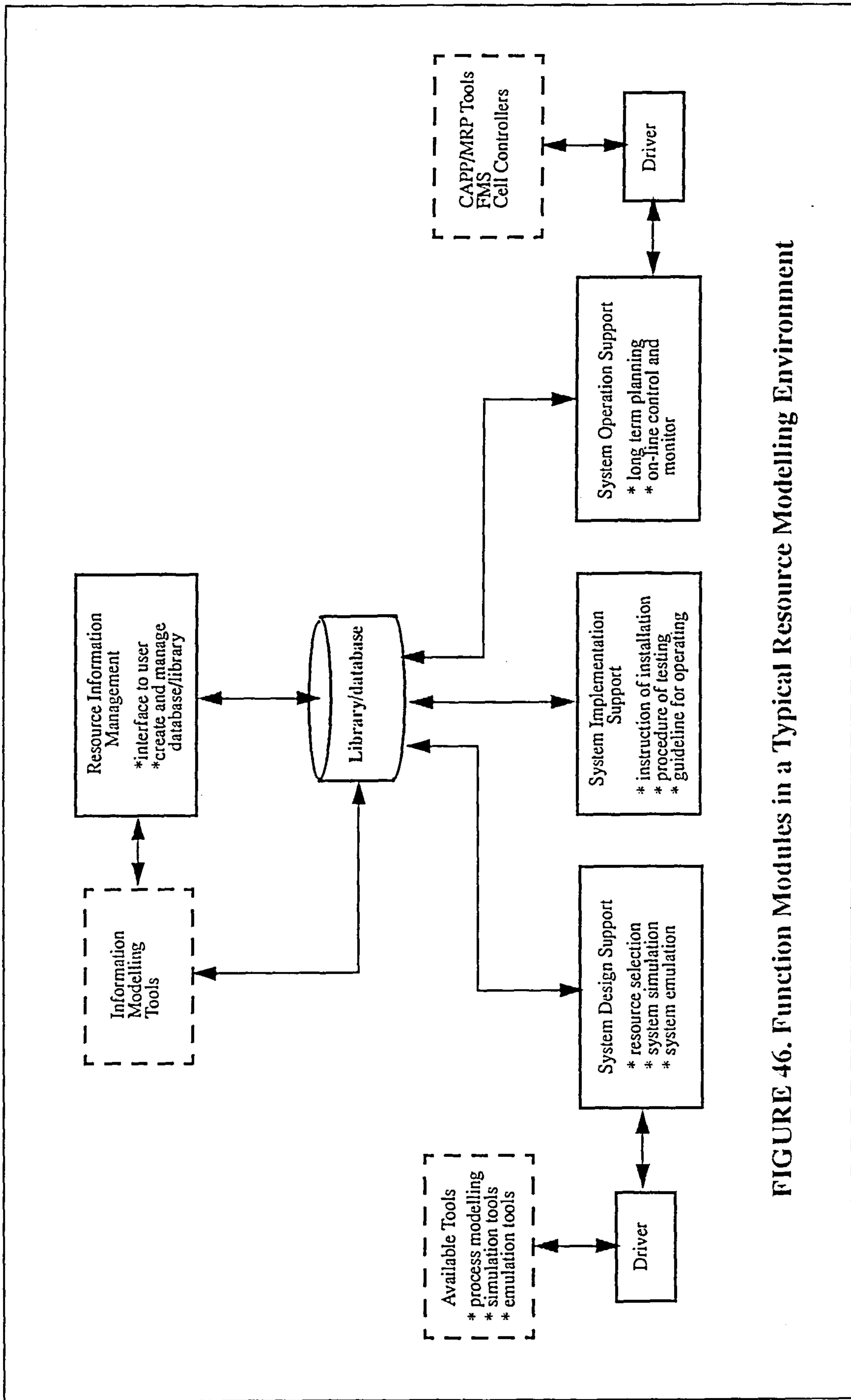


FIGURE 46. Function Modules in a Typical Resource Modelling Environment

production planning and scheduling personnel and resource suppliers.

7.4.2 System Design Support Capability

The system design support capability should facilitate: (1) resource selection; (2) system simulation; and (3) system emulation.

7.4.2.1 Resource selection

The selection of resources to meet the requirement of a particular design specification can involve complex decision processes. If a top-down approach to system design is followed it will be necessary to establish which candidate resources have a set of capabilities previously established as being necessary at the system definition level. Subsequently it will be necessary to refine any selection following analysis in respect to: detailed performance criteria (such as quality, speed, physical size, manpower needed); cost information (such as capital, running and overhead costs); characteristics of interfaces; and so on.

Thus, apart from providing access to information about resources, a resource modelling tool requires a function module which supports design activities, and particularly 'resource selection'. Thus such a function module should be designed:

(1) based on a good understanding of general processes and procedures involved in 'resource selection'. Normally this is carried out by humans but it is possible to formalise some aspects of the knowledge they bring to bear on such problems within a computer program;

(2) so that it can access well defined information about candidate resources which is sufficiently precise and complete to support the processes and procedures

involved in selection.

Thus realising (1) is a prime concern when designing the system design support capability, whereas (2) will be of prime concern when designing a resource information capture capability, such as that discussed in section 5.5. If resource selection is to be semi or fully automated this implies the need to describe resources more precisely.

7.4.2.2 System simulation

Having selected resources and assigned activities to them, performance analysis can be carried out, including an appraisal of the use of alternative candidate systems or sub-systems. It is evident that computer-based system simulation can be used to support system design at this stage.

In the context of this Ph.D study it was clear that a resource modelling tool could support system simulation by either:

- (1) developing a simulation tool as an integral part of a resource modelling tool or
- (2) incorporating an existing simulation tool into the author's enterprise modelling environment.

7.4.2.3 System emulation

Computer technology has developed to such a stage that it is now possible to emulate manufacturing systems, i.e. to build and test integrated systems in which simulated and real components interoperate to facilitate life cycle engineering. Exploring the use of such approaches and providing emulation tools within support resource modelling tools was also of interest to the author in establishing an integrated *design* and

operation support capability.

There may be various users of a system emulation capability including system designers, system analysts, system builders and system operators.

7.4.3 Functional Capabilities to Support System Implementation and Release

As defined by CIMOSA [CIMOSA, 93] the system implementation and release life phase includes the following:

- Build and buy tasks (where physical components are integrated into an existing system and their underlying implementation description models are *installed*);
- Verify implementation tasks (where system functions and behaviour are *verified*);
- Transfer to operation (when operator training and customer testing leads onto systems being *accepted*);
- Release for operation (when systems are *released* for operation).

With respect to contemporary approaches to engineering systems this phase is least well supported by information technology. Generally the level of automation used in respect of system implementation and release is still low. Indeed significant research and development work needs to be done before this situation can be expected to change appreciably.

In the context of enterprise modelling, it is important to ask the following questions: 3.

How can the level of automation be enhanced, so that structured support can be given to people responsible for installing systems? How can they test systems more easily through the provision of automated support? Also, how can we train system operators more quickly and efficiently? Thus the following work was identified as being part of

the functional requirements of resource modelling tools:

- the provision of structure and instructions during installation (of components, sub-systems, and systems).

To automatically (or semi-automatically) generate 'installation instructions' by processing information described as part of resource models or system models;

- the definition of testing procedures (for components, sub-systems and system levels).

To automatically (or semi-automatically) produce test procedures based on system and resource modelling information;

- the provision of guidelines (or computer software training programs) to facilitate operator training (on the operation of machines, systems etc.).

To automatically (or semi-automatically) produce guidelines (training software) to support operator training by processing information described in system and resource models;

The prime users of this functional capability will be system builders and system operators.

7.4.4 Functional Capabilities to Support System Operation

Generally system operation will require two kinds of activity. One will be concerned with 'off line' forward planning, whereas the other will concern the 'on line' production control and monitor use of system operations. Resource modelling tools should have the capability to support both types of activity.

Thus it was assumed that the main requirement of such a functional block is to provide

- long term production planning support (i.e. planning, scheduling);
- on-line production control and monitor support (i.e. dispatching and monitoring).

Normally the operation of a specific manufacturing system is relatively well understood and often this will have facilitated the development of methods and tools which support planning, control and monitoring. Examples of generic methods and tools used in this area include Computer Aided Production Management (CAPM), Material Requirement Planning (MRP and MRPII), Flexible Manufacturing Systems (FMS), and Cell Controllers - each of which are used industrially to provide operational support function. Therefore, an operation support module of a resource modelling toolset could either provide loosely coupled links to existing application packages (i.e. CAPM, MRP II) or be specially developed to incorporate a suitable selection of such methods as an integral part of a modelling current. The prime users will be production planners and system supervisors and operators.

7.5 Summary and Discussion

This chapter has further clarified the position of resource modelling with respect to other enterprise modelling and integration requirements, with emphasis on a physical point of view. Indeed physical relationships with other modelling tools and system integration services in common industrial use have been identified.

Based on this functional specification, a resource modelling demonstration tool was specified in detail and implemented by the author. As resource modelling tool needs to work together with other tools, such as process modelling tool, information modelling tool etc., system simulation tool and even integrating infrastructure, the issues on integration of tools become important, these all being the topic of the next chapter.

8.0 Design and Implementation of a Proof-of-Concept Resource Modelling Capability

As described in chapter 7 and illustrated by Figure 45, this study has emphasised the need to investigate ways in which a selection of enterprise modelling tools can interoperate to provide a comprehensive enterprise modelling environment. Hence the remainder of this thesis will be concerned with explaining how the author conceived, developed and tested an approach to toolset interoperation. Naturally this investigation focused on illustrating the role of resource modelling, as defined in sections 4.3.

8.1 The Role of a Conceptual Integration Schema in Toolset Integration

Figure 47 illustrates conceptually an approach to toolset integration.

The approach deploys the following elements:

(i) A set of enterprise modelling tools. Individually these tools facilitate enterprise modelling thereby allowing their users to model enterprises from one or more viewpoints. In so doing a tool will support personnel concerned with some aspects of the life-cycle engineering of enterprises. Alternative tools may be selected and included in the toolset (such as existing proprietary tools or specially developed ones).

Normally their coverage will be complementary, albeit that there may be overlap in their coverage;

(ii) A conceptual integration schema. This is a global conceptual model (or meta

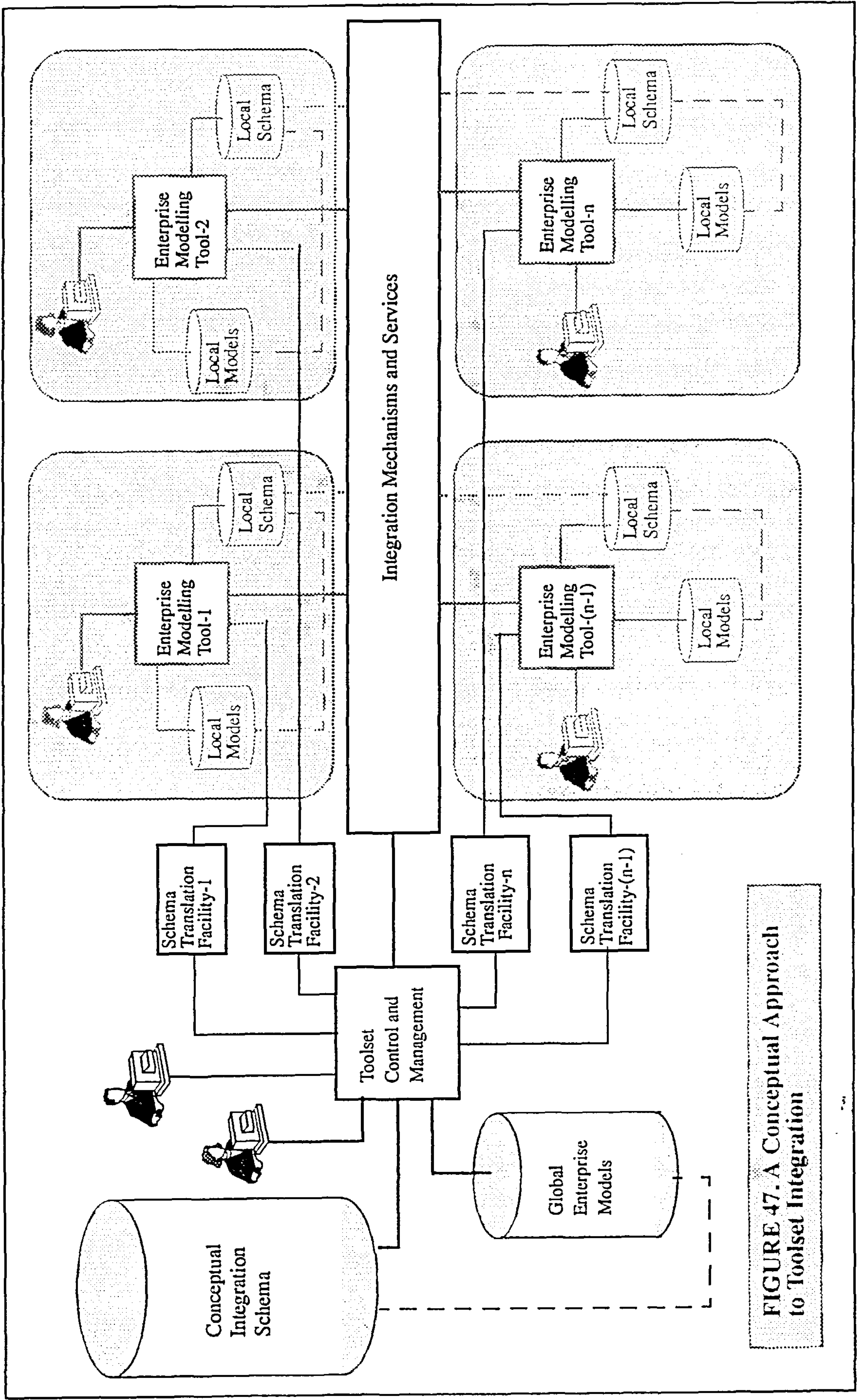


FIGURE 47. A Conceptual Approach to Toolset Integration

model), the purpose of which is to structure the use of modelling constructs (utilised within individual tools) so that a consistent set of enterprise model fragments is produced by the various personnel who use the tools during an enterprise engineering project;

(iii) Schema translation facilities. Modelling constructs used within an individual tool may or may not conform to global constructs defined by the conceptual integration schema. Where local models are to be utilised as part of a more global enterprise model it may be necessary to translate or transform them into an equivalent global form. In some enterprise modelling environments it may be necessary to facilitate a two way translation and transfer of models, from local to global form and from global to local form;

(iv) Integration Mechanisms and Services. Having decided what model fragments need to be ported to or from individual tools and the schema conversion processes involved in a given enterprise modelling environment, it will be necessary to specify and deploy appropriate integration mechanisms which realise that need. For example, this could be achieved by using the services of an integration infrastructure (such as CIM-BIOSYS) or more simply a suitable database management system;

(v) Toolset Control and Management. Global control and management facilities will be required which meet specified requirements of a given enterprise modelling environment and the type of enterprise engineering projects it is designed to support. A control capability will typically be required to help co-ordinate enterprise model generation processes, including the unification, release and storage of model fragments. Also management capabilities may be required to manage and change the

enterprise modelling environment such as the inclusion of a different or a new release of a modelling tool.

In this study it was not practical to build a proof-of-concept system which includes all the elements of the enterprise modelling environment characterised by Figure 45 and 47. Hence in this study attention was focused on the design, realisation and use of a meta model to illustrate its use in underpinning toolset interoperation. Also to maximise the use of other research outputs and minimise the amount of “run-of-the-mill” implementation work a decision was taken to use the CIMOSA enterprise modelling framework as the basis of the conceptual integration schema but to extend and enhance this definition particularly with respect to resource modelling aspects and related organisation and cost views. It was also decided to focus the schema extension on building and integrating a resource modelling tool capable of operating as part of a wider enterprise modelling environment. Furthermore it was decided that the schema extension and choice of other enterprise modelling tools should allow the use of capability modelling constructs and information templates proposed by Table 6 of Section 5.4 to be studied as part of a generic approach to connecting process, resource, information, organisation and cost modelling perspectives.

8.2 Specification, Development and Implementation of a Conceptual Integration Schema

Before specifying a proof-of-concept version of the conceptual integration schema it was necessary to decide which tools to include into the proof-of-concept enterprise modelling environment. In making this decision it was considered important that the

choice of tools should not duplicate research effort elsewhere. Indeed significant previous effort has already centred on the link between process, function and information modelling perspectives. For example, earlier MSI research had contributed to the body of available knowledge in this area through (a) the development and use of the SEWOSA workbench [Aguiar, 95] and (b) the use of this tool in combination with MSI's Information Systems Modelling toolset [Clements et al, 96] and the GSTPN Petri Net Simulator tool [Aguiar,95]. However as explained in earlier thesis sections a more detailed investigation of the process modelling - resource modelling boundary could generate and demonstrate new research findings and yield relevant and timely methods which could be employed industrially. Hence the author decided to redeploy and extend use of the SEWOSA process modelling capability. This decision also allowed reuse of the CIMOSA conformant meta model, which was implemented by Aguiar using the IPSYS CASE tool¹. The aim therefore was to specify and develop a conceptual integration schema by extending the SEWOSA (CIMOSA conformant) meta model so that it is capable of supporting (a) an integration of tools which support resource and process modelling perspectives and (b) a more rudimentary support capability which facilitates the integration of process, resource, information, organisation and cost models, by including organisation, information and cost models within the definition of resource models.

In specifying necessary extensions to the SEWOSA meta model in a way which promoted the development of a proof-of-concept integration schema and toolset, the

1. A meta CASE tool is a Computer Aided Software Engineering tool designed to produce Computer Aided Software Engineering tools.

author utilised practical experience and knowledge gained from using MSI's information systems modelling toolset.

Implicit in the decision to redeploy and extend use of the SEWOSA workbench, was the need to reuse the IPSYS Meta CASE tool and its toolbuilder facilities [IPSYS, 92]. Thus the extended meta model was specified using the Information Modelling Tool (see Figure 49) and implemented by IPSYS Meta CASE ToolBuilder. Detailed description of the Extended SEWOSA Enterprise Engineering Environment including tools deployed and newly implemented and meta models inherited and newly designed and implemented are represented by Table 8. A physical view of original SEWOSA system engineering environment and extended system engineering environment is depicted by Figure 50.

The decision to redeploy SEWOSA, which has integrated several tools (such as process and information modelling tools, simulation tool and CIM-BIOSYS integration services) and to extend its scope by building a completely new resource modelling tool meant that it was not necessary for the author to investigate the use of translators (for schema mapping), nor to utilise general purpose (open) integration mechanisms and services. Also for this reason it was not necessary to develop generalised control and management capabilities for the modelling environment. However, a study of such issues will be necessary if the concepts illustrated by Figure 47 are to be realised in a way which can be widely exploited within industry.

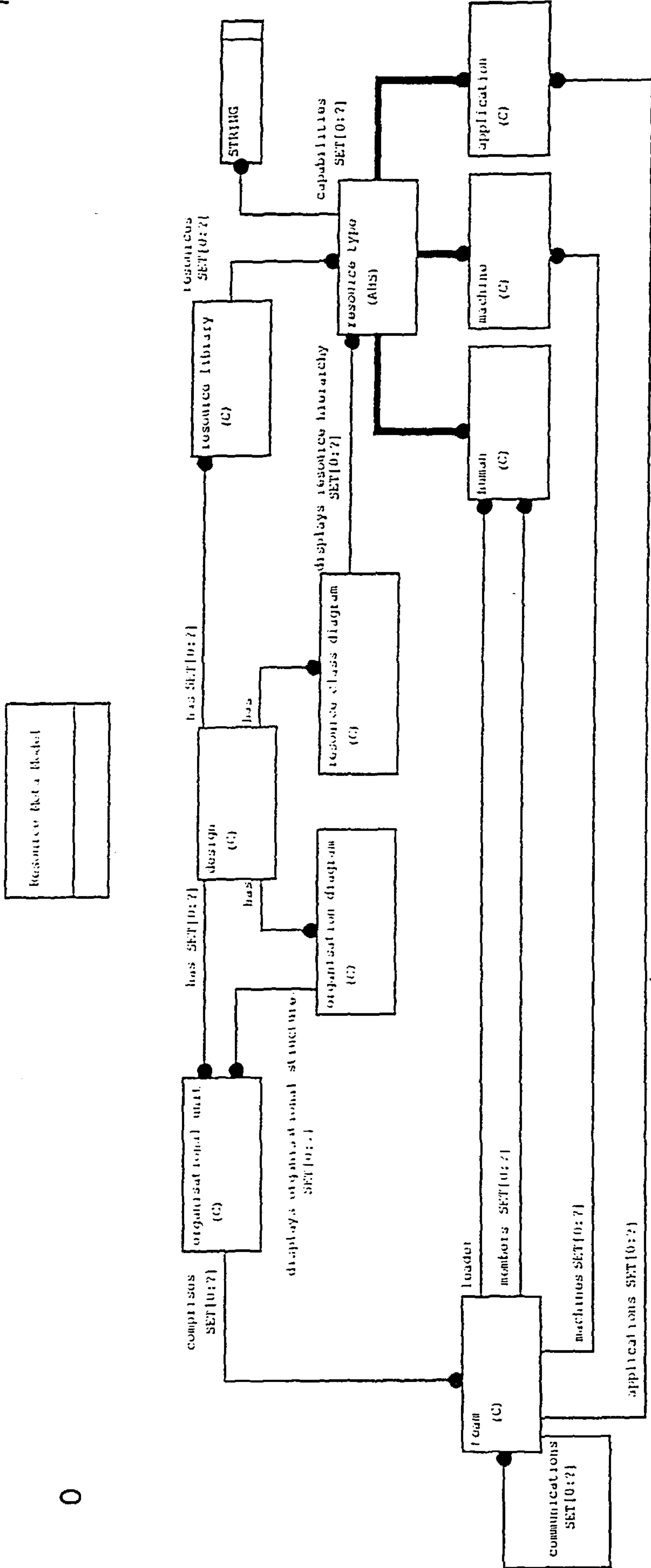
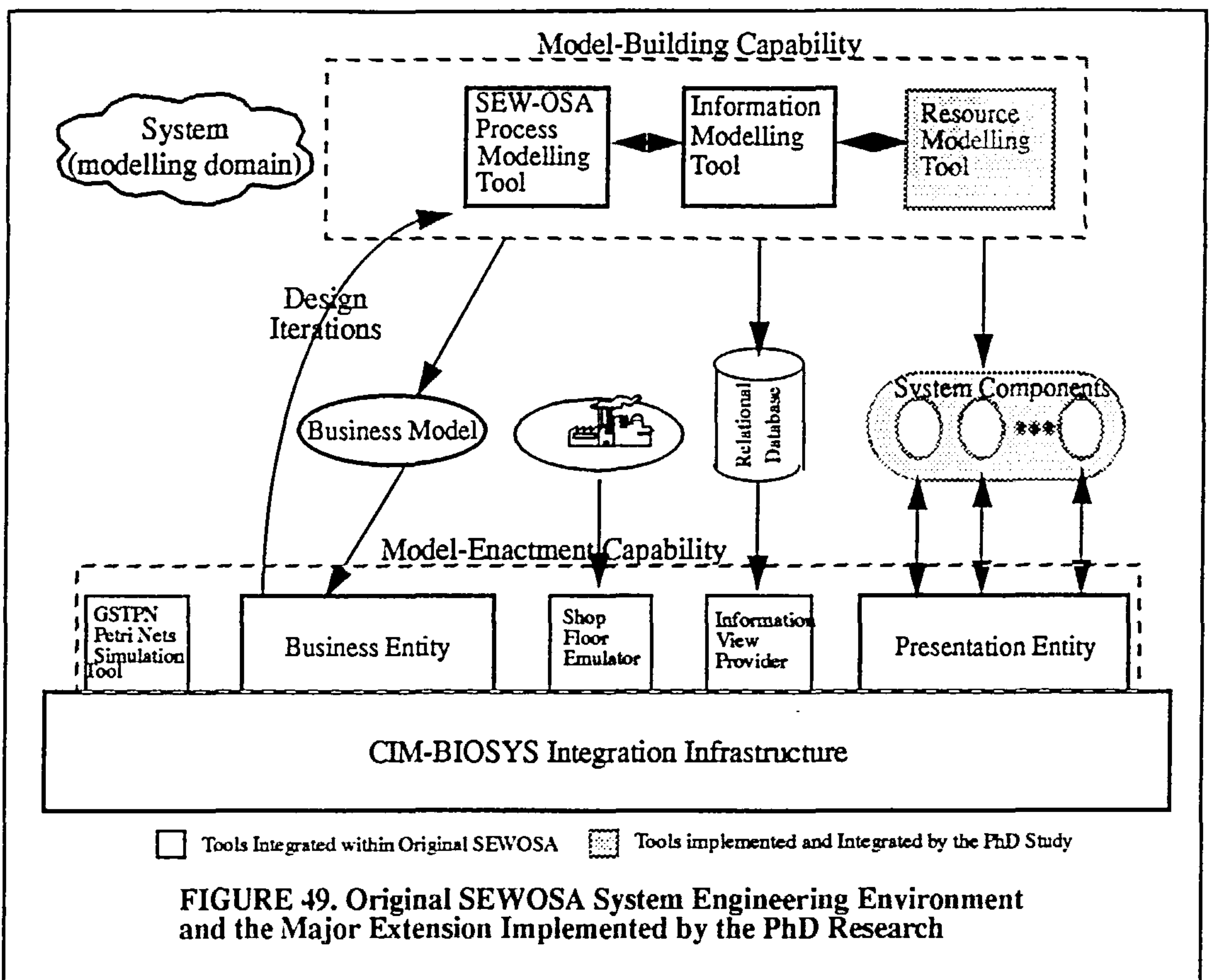


FIGURE 48. Resource Meta-Model Built by IPSYS CASE ToolBuilder

Process Modelling Tool	Information Modelling Tool	Resource Modelling Tool	Organisation Modelling Tool	Cost Modelling Tool
SEWOSA process modelling tool - CIMOSA conformant meta model	Information modelling tool designed and integrated by model-driven CIM project	Designed and implemented by this PhD study	Part of organisation models designed and implemented within this PhD study	Part of cost models designed and implemented within this PhD study
System Requirements Definition	<p>analysis of information req.</p> <p>identity object class object views information elements</p> <p>mapping object views into information elements</p>	<p>resource capability</p> <p>(This model building ability is achieved by using IPSYS meta CASE: ToolBuilder)</p>	<p>organisational structure team decomposition team-based org. structure</p> <p>(This model building ability is achieved by using IPSYS meta CASE: ToolBuilder)</p>	<p>cost constraints costing rules</p> <p>(identified, but no implementation within the tool)</p>
System Design Specification	<p>entity relationship model; structure determined for information elements.</p> <p>(This is realised by using EXPRESS-G)</p>	<p>resource information templates human machine application resource organisation unit code resource cost information resource interface/integration resource behaviour</p> <p>(This model building ability is achieved by using IPSYS meta CASE: ToolBuilder)</p>	<p>organisation structure selection team composition organisation unit code</p> <p>(This model building ability is achieved by using IPSYS meta CASE: ToolBuilder)</p>	<p>cost construct: fixed cost capital cost maintenance cost overheads activity-based cost resource selection based on cost constrains</p> <p>(This model building ability is achieved by using IPSYS meta CASE: ToolBuilder)</p>
System Implementation Description	<p>information in form of database, file etc</p> <p>View Provider: information access aggregation presentation</p> <p>(Implementation is realised by using SQL, Oracle, STEP, C, X Windows)</p>	<p>resource code - as the entry in support of any access to the resource either off-line management or on-line manufacturing control</p> <p>(Implementation is achieved by using Petri Nets, Prolog, CIM-BIOSYS integration services)</p>		

TABLE 8. Extended SEWOSA Enterprise Engineering Environment - tools deployed and implemented; meta CASE models inherited and implemented



8.3 Functions Realised by The Resource Modelling Toolset

8.3.1 Introduction

Using IPSYS ToolBuilder, functions included within the original version of SEWOSA workbench was extended to cover resource modelling aspects. As explained below the original SEWOSA functions extended by this study included the rapid prototyping² of systems and a Petri-net generation and execution facility. Also a resource information library was built into the internal database of the IPSYS Tool.

2. Rapid prototyping characterises the engineering process by which a design description is rapidly realised in order for it to be tested [Aguiar, 95].

The combination of process modelling and resource modelling tools so created use common modelling constructs to describe resource capabilities. This provides flexible means by which use of the resource modelling and process modelling tools (and the models they help generate) can be linked together. Part of the organisation model defined by this research was also built into the meta model and database of the IPSYS ToolBuilder. The modelling constructs used to define resources and their relationships within an organisation (such as which resource belongs to which organisation unit, for example, a business unit or team) also provide a link between resource and organisation models. The cost modelling constructs of a resource were built into the resource modelling tool in a way which can readily realise “connections” to different cost models, if such a model exists. Once again relationships between constructs (in this case cost modelling constructs) were defined and implemented by the IPSYS meta model and database. In this way simple cost calculations can be supported.

In cases where a significant amount of resource information needs to be managed, the information modelling tool can be linked to one or more separate database management systems (such as database management systems incorporated into Oracle or Ingres databases) using software tools provided by other researchers in MSI.

Figure 50 illustrates a more detailed physical view of the resource modelling capabilities implemented along with its working environment.

8.3.2 Resource Information Management

Resource Information Management was implemented by extending the SEWOSA Tool primarily by modifying the IPSYS ToolBuilder meta model.

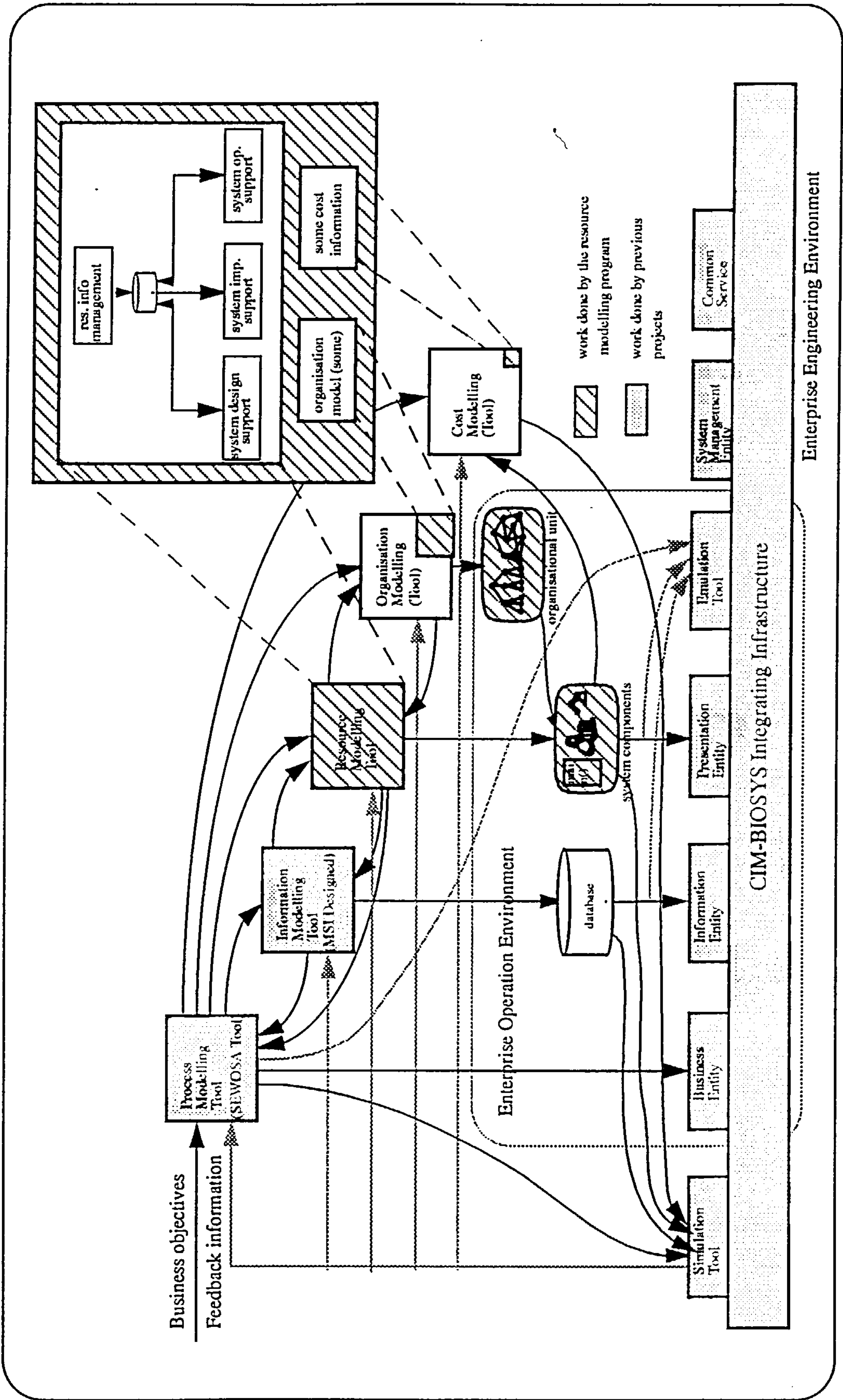


FIGURE 50. Illustration of Resource Modelling Toolset and Its Environment

The classification of resource types (Figures 23 and 24), the organisational chart (Figure 25) and resource information constructs (Figures 32 to 37) were all built into the toolset. In this way the user can readily create, input and delete resource information using services provided by the resource management system.

Unfortunately a general purpose organisation modelling tool was not available to the author. However based on the research on organisation issues reported in chapter 6, an organisational chart was defined which it is believed can accommodate most of the organisational structures currently used in contemporary enterprises. This model was used to help structure and support the capture and use of models from an organisation perspective. In this way resource models and information assigned to an organisation unit can be easily created.

8.3.3 Support for System Design

As a prime focus of resource modelling, support for system design has been realised by offering: (1) support for resource selection and (2) candidate system analysis and simulation.

8.3.3.1 Support for resource selection

Based on the author's understanding and experience of resource selection, support for this design activity has been integrated into the resource modelling toolset. The basic resource selection processes and procedures supported are depicted by Figure 51.

General processes and procedures of resource selection are thereby formalised into the following four stages:

The first selection is carried out with reference to a definition of 'capability'

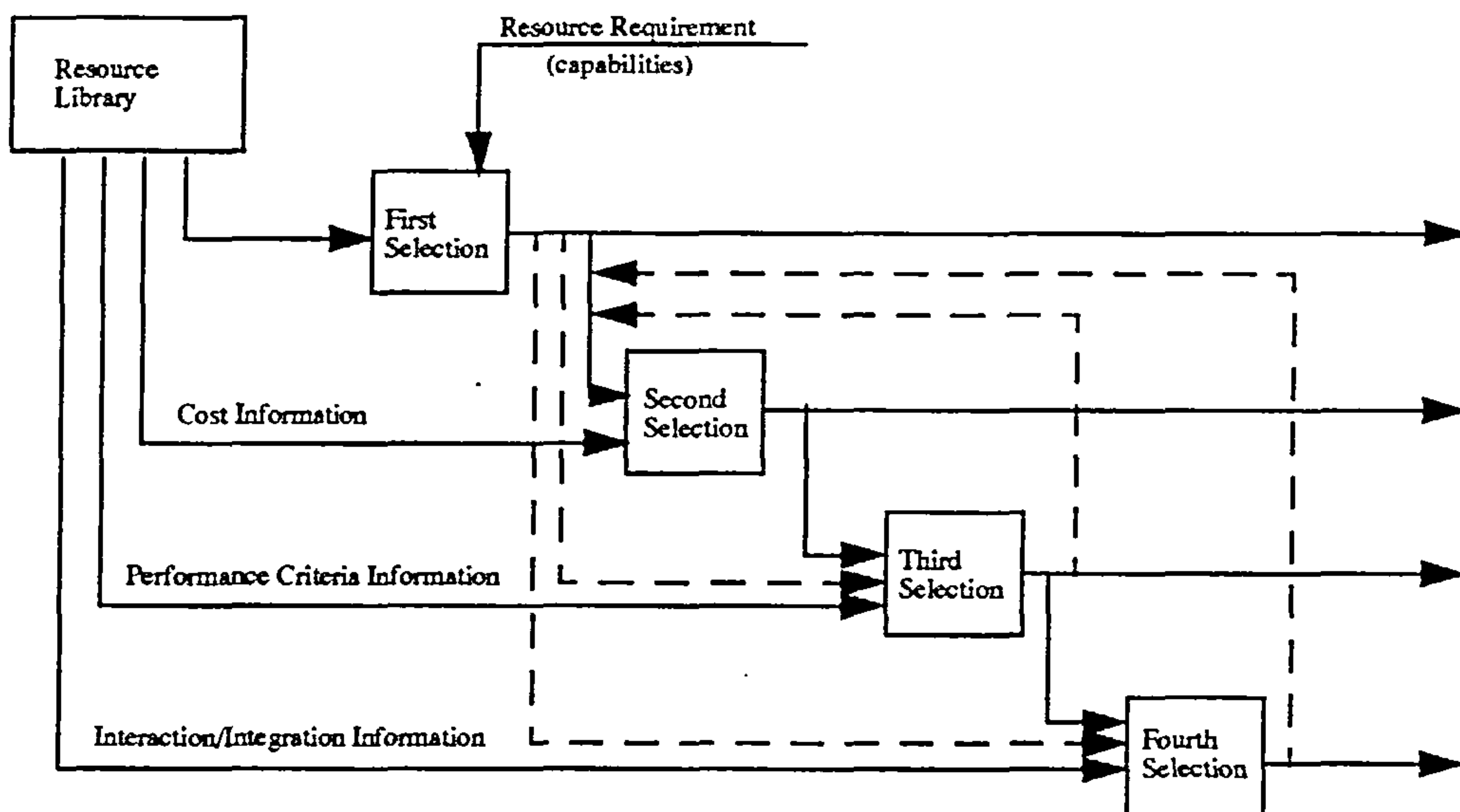


FIGURE 51. General Procedures for Selecting Resources

requirements, this being attached to process models created during the requirements definition life phase. Hence during this stage the designer can select resource models from the resource library and find which resources can meet the 'capability' requirement. The selection can be done resource by resource or by selecting and appraising the capabilities of a group of resources (or candidate system). A list of candidate resources is presented in the form of textual files as an output from the resource modelling toolset. See Figure 59 which illustrates example outputs generated.

After the first selection, a second stage of selection can be carried out by differentiating between resources in terms of their ability to meet the 'cost' requirement.

A third selection stage will be carried out by selecting resources which satisfy more detailed performance criteria requirement, such as speed, physical size etc. Detailed and well defined information about resource capabilities is typically needed to carry

out this type of selection. Although supporting information can be made available the author believes that human involvement is necessary during this step.

The fourth selection stage concerns the selection of resources which can readily be integrated together within a target environment. It is also difficult to automate this step, hence human involvement is needed.

Thus although it proved to be practical to seek to automate the first and second stages of resource selection, the third and fourth stages were found to require human intervention. Having completed all four stages, system resources will have been selected from a library of candidates of resource models. Final selection can be presented in the form of a textual file.

8.3.3.2 System analysis and simulation

Use of the SEWOSA tool can lead to the generation of Petri-net descriptions of system behaviour, where the systems comprise a selection of candidate resources. These Petri-net descriptions can be input to a GSTPN simulation tool [Aguilar, 95]. Thereby system behaviour can be simulated and selection made with respect to defined criteria between alternative candidate systems, comprising alternative combinations of candidate resource elements. By allowing access and input of detailed resource information to this model, behaviour simulation can lead to accurate analysis thereby avoiding making inappropriate and time-consuming investment in building real enterprise systems. In seeking to support such activities the author recognises the need to model and capture resource behaviour information in a way which enables resource modelling using different situation tools.

8.3.4 Support for System Operation based on Emulation

Support for on-line control and monitoring is also provided by the resource modelling toolset. The combination of SEWOSA and resource modelling tools generates a model which can be executed by a CIMOSA conformant business entity. As explained by Aguiar, the SEWOSA business entity comprises an event handler, process controller, activity controller and resource manager which collectively execute SEWOSA behaviour models. Also a CIMOSA conformant presentation entity can be assigned to resource components and flexibly linked via CIM-BIOSYS integration services to selected resources by accessing the resource information database. In this way control information and actual plant data can be processed in a flexible and reconfigurable way. This approach facilitates on-line process monitoring, statistical process control and system analysis by allowing both modelled and real components to interoperate using CIM-BIOSYS integration services, in a manner defined by the business model. Here the business model is automatically derived by the SEWOSA tool by transforming information defined by models of system behaviour.

8.4 Discussion

To realise various elements of the resource modelling toolset, general purpose computational tools were chosen and deployed by the author. This included use of C++, X window and Motif window manager, an Oracle Database, and Pro-C.

There were benefits obtained from building the process modelling and resource modelling capabilities within a single tool. By so doing it was a relatively simple matter to use common modelling constructs and to support their use via the meta

model and database facilitate of the IPSYS tool. This allowed changes to models and the modelling tools to be managed efficiently and readily. It also facilitated experimentation and extension, such as the development and use of organisation and cost models. However, to promote the wider use of the concepts developed in this thesis, it may be better to pursue the second approach based on the use of common computer languages and tools such as C++, X Windows and Motif Window manager, Oracle Database, Pro-C instead of the IPSYS ToolBuilder. Generally it may be more effective to provide a means of realising a looser (but sufficiently effective and flexible) to integration between different proprietary process, information, organisation and resource modelling tools. This would allow system designers and builders to use their preferred tools. It would also allow access to wider information sources, possibly by supporting the use of an WWW infrastructure service to realise remote browsing of resource/ component catalogues etc.

The benefits gained from the methods used to build the resource modelling toolset are:

- (1) that process modelling, resource modelling and organisation modelling tools can work together in a holistic way (because all of them utilise modelling constructs which conform to the conceptual integration schema implemented within the CASE tool) and
- (2) different modelling tools (or modified versions of the current tools) can be substituted into the environment provided that they generate models which conform to the conceptual integration schema defined by this research.

Note: The programming of the demonstration toolset related with IPSYS ToolBuilder has been fully realised by I. S. Murgatroyd in MSI Research Institute. Great thanks to him.

9.0 Case Studies¹

9.1 Case Study One - A Typical Manufacturing Process in a Machine Tool Laboratory

9.1.1 Introduction

This study considered a typical manufacturing process carried out in a general purpose machine tool laboratory. In this laboratory, conventional metal cutting machines are deployed (including lathes, mills, drills and grinding machines) along with computer controlled machines (including a CNC vertical machining centre and a four axis CNC horizontal machining centre). Six technical staff and machine operators work in this laboratory. To support their activities common application software tools are used which include Unigraphics and PEPS CAD/CAM software.

Information was collected about the human, machine and software application resources deployed using the extended enterprise modelling environment, and particularly the resource modelling tools produced as part of this research study. Here resource models were populated using the resource information management system. Appendix 3 details example information templates generated for the classes of human, machine and application resource utilised.

9.1.2 Model Building for an Example Manufacturing Process

An example wheel coupling manufacturing process was modelled using the extended enterprise modelling environment and particularly the SEWOSA process modelling

1. Note: all of the figures and tables in this chapter are arranged at the end of the chapter.

tool. The full set of models captured to describe the wheel coupling manufacturing process are included in Appendix 3. Those models were captured in the form of CIMOSA conformant diagrams and templates and correspond to the requirements definition and system design specification life phases.

Figure 52 illustrates the method used when building process and resource models and relationships between the different model fragments produced. The full range of model fragments generated can be found in Appendix 3. However the main diagrams (and model fragments) created during the case study are reproduced here (Figures 53 to 58) to illustrate the way in which the wheel coupling manufacturing process was decomposed into well defined process and resource descriptions.

Figures 53 to 58 and Figures 63 to 68 are input as indicated by input requirement of extended SEWOSA system. Figure 59 to 61 are the output of the extended SEWOSA. The diagrams collected in appendix 3 including context, domain, structure, functional and behaviour diagrams are all input as required by SEWOSA system, and all the rest including object, resource and configuration diagrams are the output from the SEWOSA system.

9.1.3 Characteristics of This Case Study

The system requirement definition modelling phase was initiated following a consideration of resource information, especially resource capabilities. Here the classification of shop floor resource capabilities developed in chapter 5 and represented by Figure 27 was deployed in this case study.

Previously when using the original, stand-alone version of the SEWOSA Workbench

to model the case study system and analyse manufacturing system requirements, it was evident that the method used to decompose the functional elements of the system was left to the individual model builder and hence the quality of the decomposition will depend on the experience of the designer and their understanding of the system being modelled. No formal rules or guidelines are provided to structure system analysis. Therefore the model can be built in many different ways and at variety of levels of granularity. The level of decomposition chosen will influence the quality and solutions. Hence there is a need for a common understanding of the system and general rules to guide system decomposition. Conversely when using the extended modelling environment, the embedded classification of resources specified during this research provides a foundation for an organised approach to the functional decomposition of shop floor manufacturing systems. By deploying this classification of resources, system analysis and functional decomposition can be carried out by designers who have less experience of the design and construction of manufacturing systems and with more consistent results.

In this case study, use of the resource capability modelling construct successfully maintained consistency between process models captured during the system requirements definition phase and resource models produced during the conceptual design phase, yet allowed the models describing process requirements and system solutions to be developed separately.

The resource capabilities (RC) used in the case study scenario were as follows:

RC-1: prepare manuf info (prepare manufacturing information)

RC-2: cutting

RC-3: turning

RC-4: drilling1 (centre position)

RC-5: milling

RC-6: drilling2 (none-centre position).

By using the resource selection support facilities provided by the extended modelling environment it was found that the transformation of a given process model (captured during the system requirements definition phase) into a corresponding process model (which can be analysed during the system design specification phase) can be semi or even fully automated. In practice this can be achieved as sufficient information is captured in a computer executable form, about process requirements and alternative resource capabilities to allow the transformation to be automated. It should be noted that previously using the SEWOSA workbench both of these models (resource and system configuration diagrams) had to be generated manually.

For this case study, Figure 61 shows the output of the first stage, fully automatic selection of resources, realised by the extended modelling environment. This automatically selected set of resources were subsequently found to satisfy capability requirements defined within the system requirements definition model. This automated selection was made by seeking to minimise the “cost” of realising individual enterprise activities. However it was found that this is not an ideal selection of resources as a further consideration of other factors such as set-up time, performance criteria, etc. can generate an improved selection. Two alternative (semi-automated) selections of resources realised using the new enterprise modelling environment are presented by Figures 62 and 63. The choice characterised by Figure

62 can meet an operational requirement that conventional machines can only be used to achieve the manufacture of a wheel couplings, whereas hypothetically the choice represented by Figure 63 can lead to higher quality production as a result of deploying the CNC machining centre. For these last two selections it was necessary to complement the knowledge captured within the auto selection capability with the experience of the system designer.

More comprehensive automated support of resource selection processes would have been possible in this and similar metal cutting processes. For example, knowledge about manufacturing process planning could be integrated into the function module of the enterprise modelling environment by extending the type of resource selection support facilities provided. However because of time constraints, this line of study could not be pursued further. Hence it is recommended that further work should be carried out in this area, as such an approach could lead to an improved utilisation of resources in various types of enterprise.

In addition, this first case study served to illustrate that the rapid system prototyping utility provided by the original SEWOSA modelling tool could be enhanced by the inclusion of a resource modelling capability. To illustrate this point, the CIMOSA conformant models of the processes and resources needed to produce a wheel coupling can be input into a system prototyping environment which has the ability to emulate wheel coupling production activities. The business and presentation entities realised by SEWOSA prototyping environment communicate by using services of the CIM-BIOSYS integration infrastructure. Models built using the SEWOSA modelling tool can be automatically transformed into code which can be interpreted and executed by

the business and presentation entities using CIM-BIOSYS integration services.

9.1.4 Discussion

Thus use of the extended enterprise modelling environment to tackle case study one demonstrated the following advances over and above the original SEWOSA workbench:

- Use of the classification of resource capabilities proved beneficial in structuring and supporting model building activities;
- Automated and semi-automated support of decision making was achieved during resource selection. This can deskill the design and construction activities involved and lead to better solutions. Ultimately it can automatically generate some software elements of physical systems;
- The classification of resource capabilities classified was found to satisfactorily support resource allocation and system reconfiguration. Theoretically therefore a similar approach can be applied in different manufacturing environments to reconfigure systems in a way which improves the utilisation of resources. Thereby the approach has the potential to improve the responsiveness (or agility) of systems.

9.2 Case Study Two - the Design and Construction of Cell Control Systems Used in Electronic Product Manufacture

9.2.1 Introduction

A similar approach was used to study the operation of a PCB (Printed Circuit Board) assembly line at a plant of a major UK manufacturer of electronic products. This PCB assembly line had been studied previously by other researchers in MSI Research Institute. In particular the original SEWOSA systems engineering workbench was used to design and construct such a cell in a proof-of-concept demonstration form [Aguiar, 95]. Thus the same production line was studied to:

1. investigate what benefits and differences can be realised by providing an integrated resource and process modelling environment, when compared with the previous SEWOSA environment which primarily is based on process modelling;
2. illustrate that the methodologies provided by the extended enterprise modelling environment can be applied to a different industrial domain than that studied in case study one.

The machine resources deployed by the PCB assembly line are different from those used in the machine tool manufacturing environment. They include: a solder printer, placement machine, a reflow solder machine, a conveyor and a PCB board testing machine.

A more generalised classification of resource capabilities required by PCB assembly lines was developed by the author and is shown in Figure 64. No claim is made that the classification is comprehensive. However, the capabilities classified are generic in

the sense that they are known to be required by different types of PCB production line and cell.

9.2.2 Model Building

Once again the process model of the PCB assembly line was captured using the SEWOSA model building capability. The main diagrams captured, which collectively describe this model, are shown in Figures 63 to 68.

The author sought to reuse the generic relationship between resource capabilities and enterprise activities considered in section 5.3 to structure the functional decomposition of this manufacturing process. In so doing a further enquiry sought to compare the outcome of using this more structured approach to that realised previously by Aguiar when using SEWOSA to model the same assembly line but in an unstructured way. The output is interesting in that the decompositions produced by the author and Aguiar are essentially the same. One difference is that the author defined the resource capabilities formally, so the resource capability required to perform the enterprise activity can be selected from the list defined. This observation indicates that the model building process with resource modelling support can generate models more automatically and therefore require less human input.

9.2.3 Discussion

1. A benefit from using resource modelling support confirmed by this case study is that it leads to a formal classification of resource capabilities. This facilitates model capture and system analysis. Essentially the resource modelling support provides a common language which traverses the system modelling and system building.

Hence we may conclude that a proper classification of resource capabilities can be used generally to guide model building.

2. The fact that the same decomposition of a PCB assembly process was generated semi-automatically as that previously generated by an experienced system designer, proves that the classification of resource capabilities for this class of cell was an appropriate one capable of modelling the requirements of a real situation.
3. Nearly all of the benefits realised during case study one were also achieved in this second case study. However one such benefit could not be achieved during case study two. Normally the configuration of this type of PCB assembly line will remain unchanged until more advanced assembly production processes are deployed, more advanced machines become available or there is major production design change. Hence the ability to realise flexible (and hence reconfigurable) manufacturing processes and systems, which was a key benefit in case study one, was of lesser benefit in the second study.
4. Essentially the methodologies provided by this research equally apply in both metal cutting and electronic manufacturing domains.

9.3 Summary and Discussion

The two case studies have shown that the resource modelling toolset designed and implemented as part of this research project has promising potential. This conclusion is based on the following observations:

1. The extended enterprise modelling helps to structure and formalise the modelling

building process. This allows the degree to which process model generation and deployment can be increased. Furthermore it can also lead to improved on line planning and control, and thereby better utilisation of enterprise resources within an existing enterprise. Indeed this has shown that realising enterprise integration in a holistic way, by deploying enterprise modelling technology, is a practical proposition;

2. The classifications of resource types and resource capabilities developed in these studies can be reused in different industrial domains. Some parts of these classifications are generic, whereas others need to be particularised for use in different industrial domains. The study of resource selection processes showed that further detailed classification of resource capabilities is required to enable the automatic allocation of tasks to suitable resources and the flexible reconfiguration of manufacturing systems (comprising a configured set of such resources) to be achieved in an effective way.

Unfortunately, due to time constraints, it was not possible to fully evaluate the use of the extended enterprise environment because:

1. It was not possible to carry out a comprehensive performance analysis of alternative candidate systems during the conceptual design stage as the simulator tool used by Aguiar was no longer available;
2. The suitability of the organisation modelling capability, which was designed and implemented as an integral part of the resource modelling toolset, could not be evaluated effectively in respect of the two case study examples;

3. Large scale experiments based on these methods and tools need to be carried out to investigate the scalability of the approach.

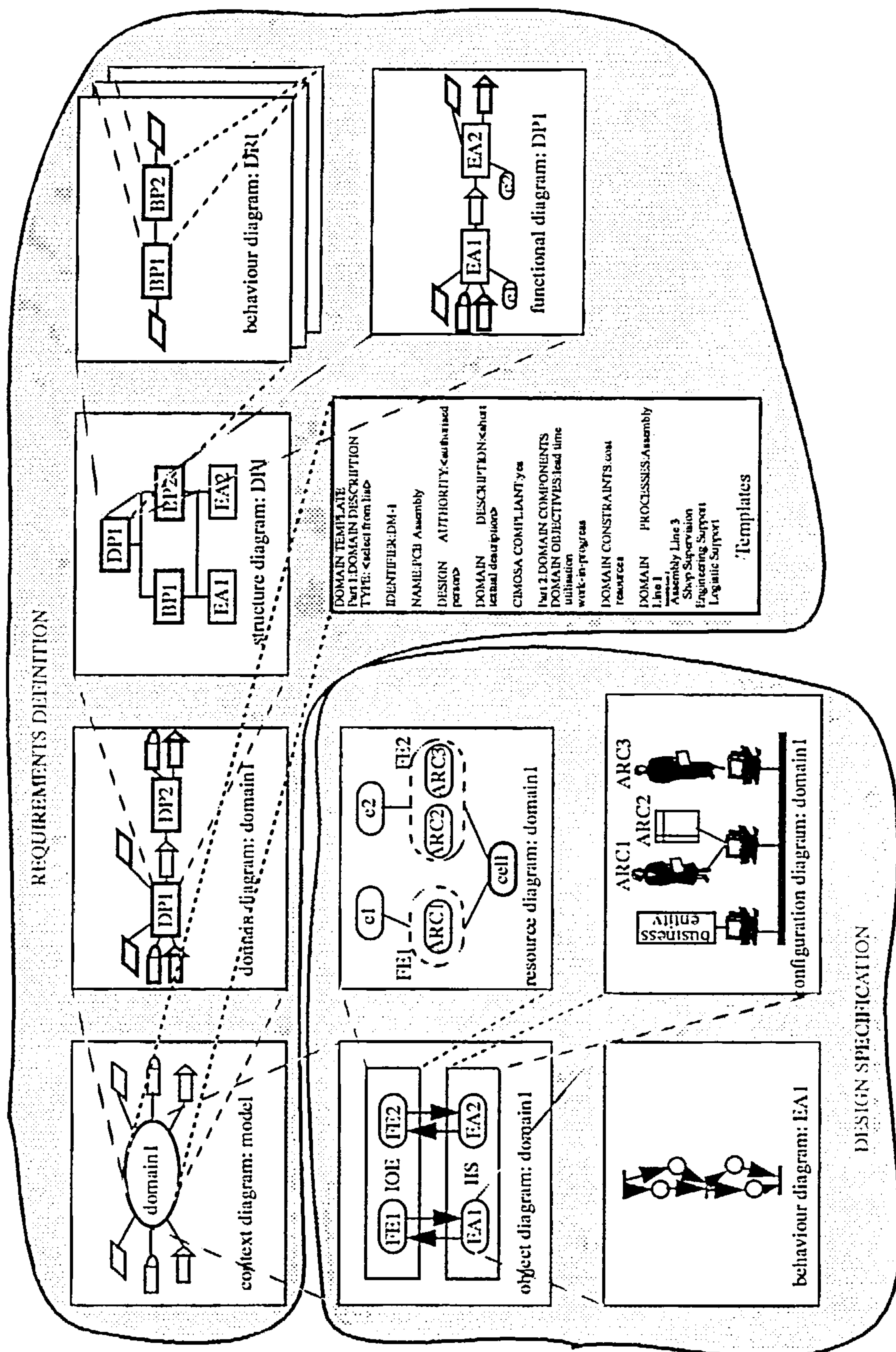


FIGURE 52. SEW-OSA Model-building Capability (source [Aguilar, 95])

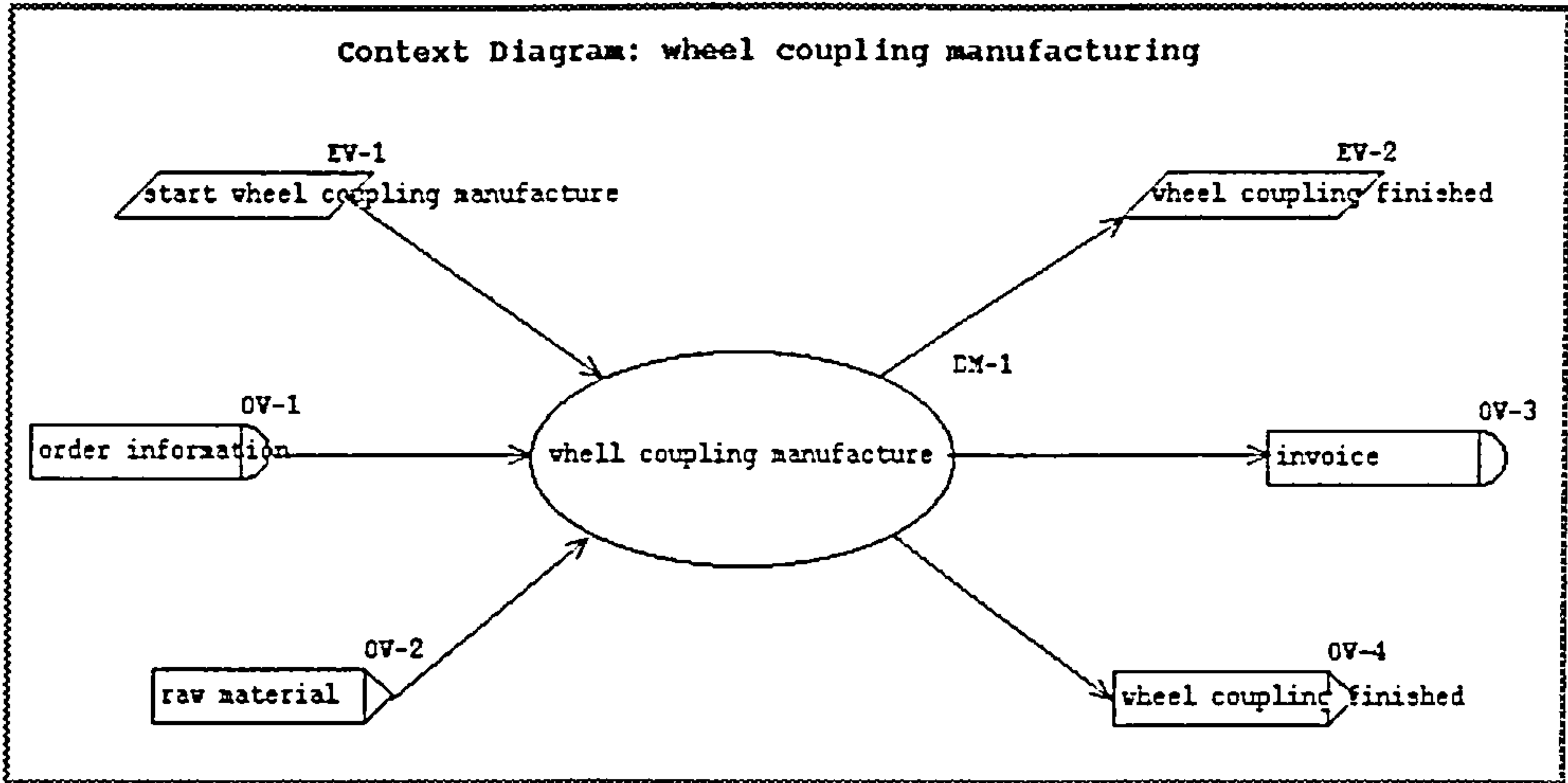


FIGURE 53. Context Diagram for Case Study One

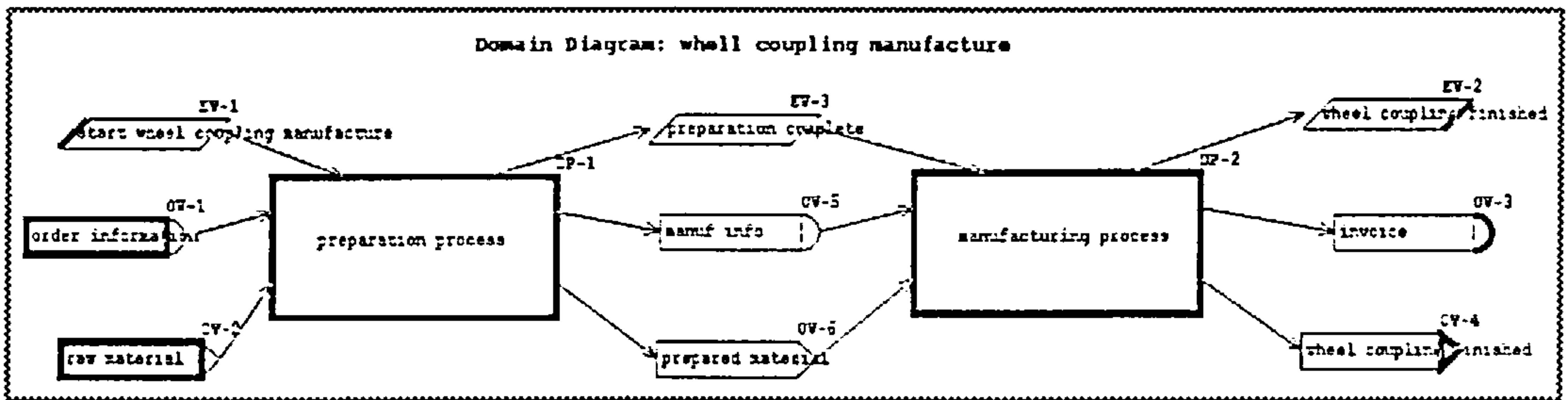


FIGURE 54. Domain Diagram for Case Study One

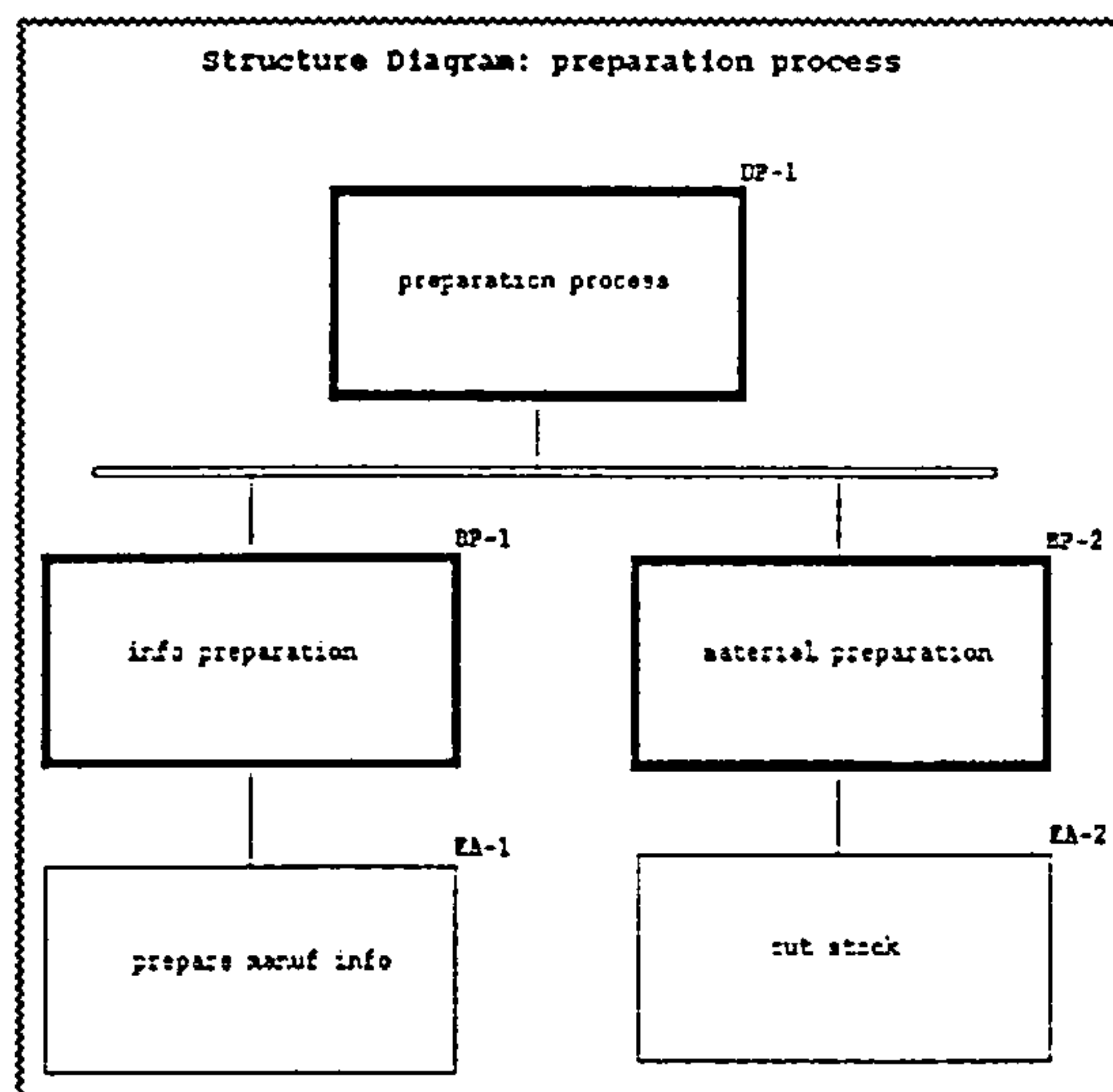


FIGURE 55. Structure Diagram-1 for Case Study One

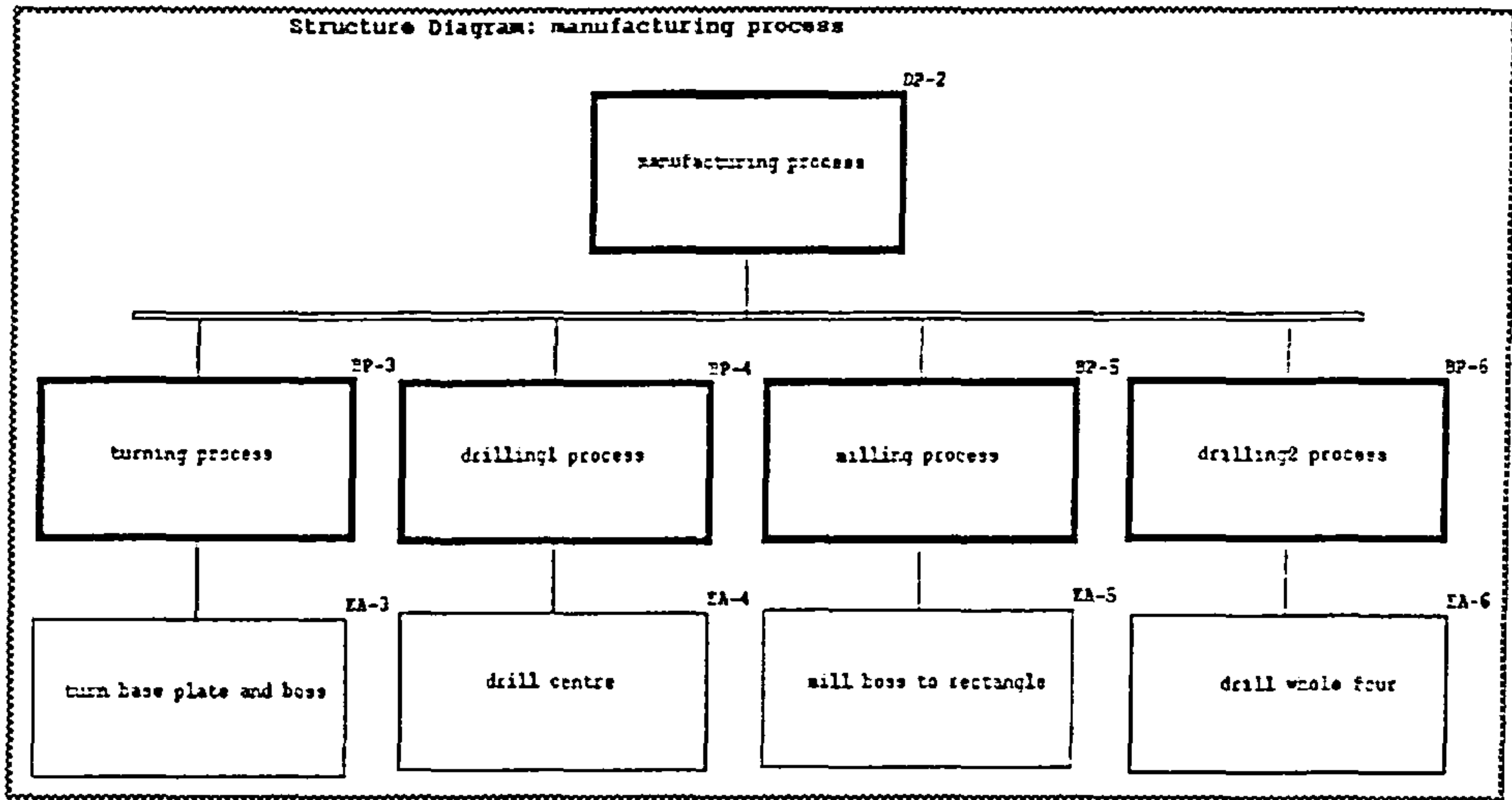


FIGURE 56. Structure Diagram-2 for Case Study One

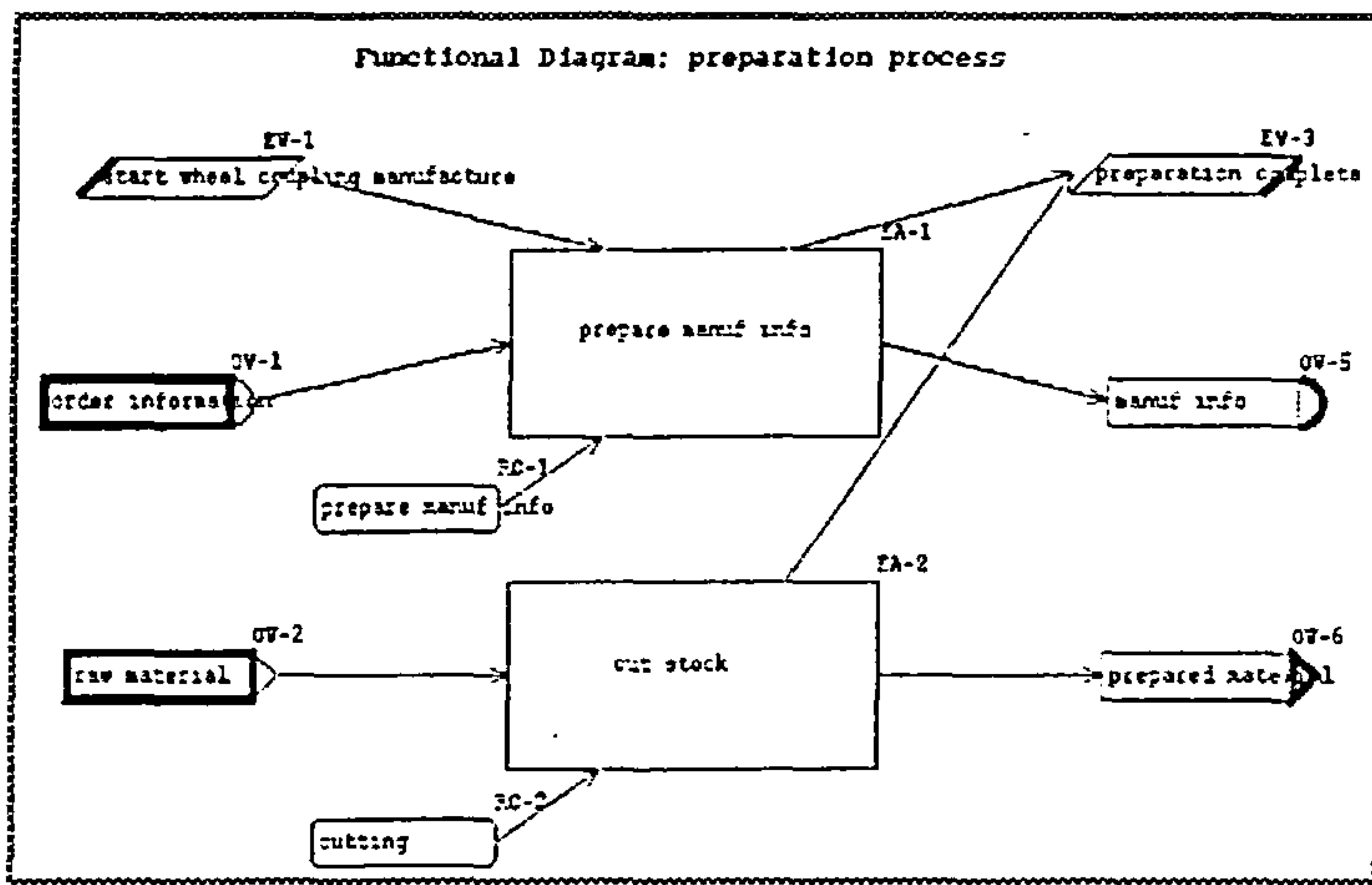


FIGURE 57. Functional Diagram-1 for Case Study One

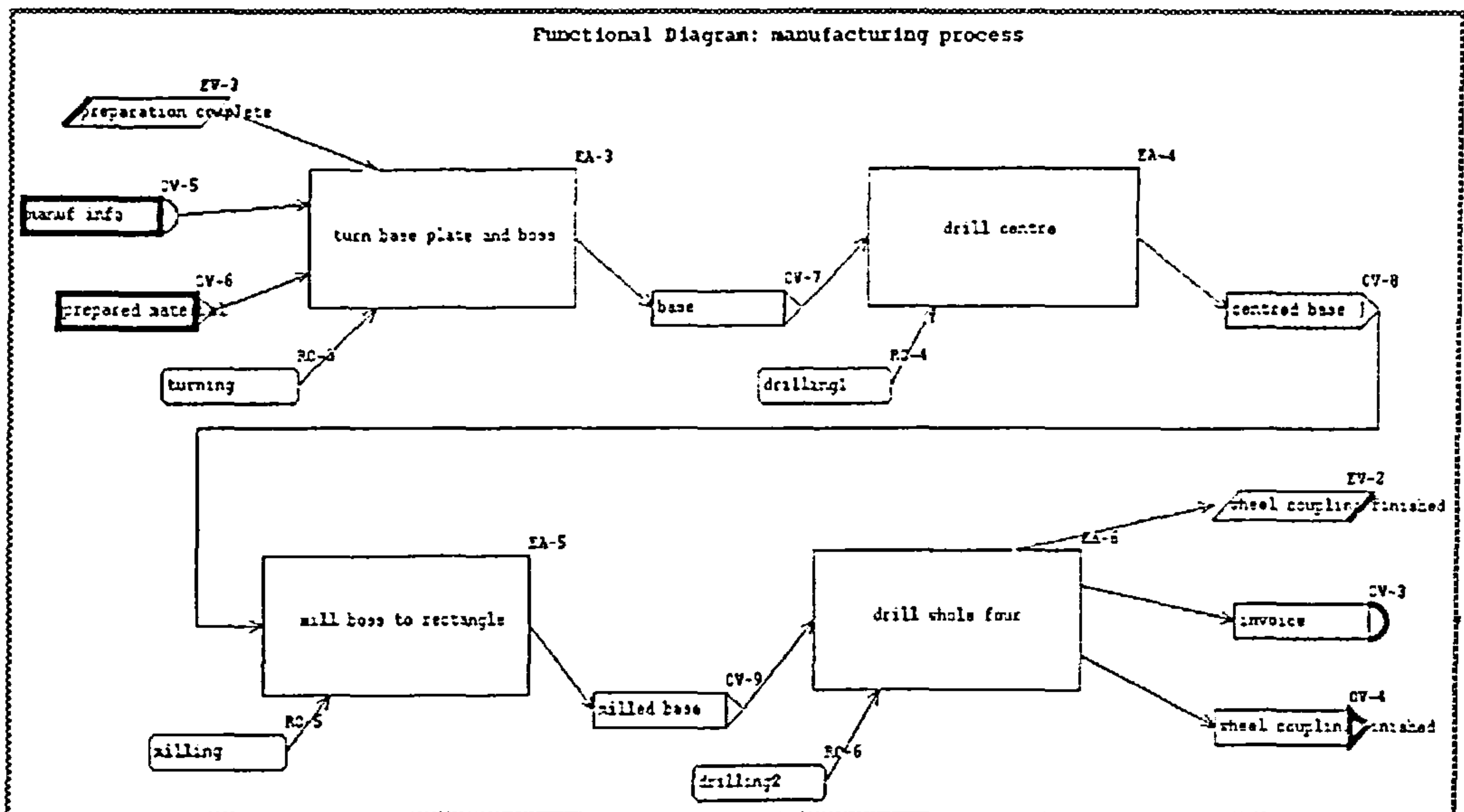


FIGURE 58. Functional Diagram-2 for Case Study One

```

Total Resource Allocation
=====
Domain: preparation process
-----
Capability Identifier: RC-1
-----
Peter

Capability Identifier: RC-2
-----
BANDSAW
Domain: manufacturing process
-----
Capability Identifier: RC-3
-----
CENTRE LATHE

Capability Identifier: RC-4
-----
VERTICAL DRILLING MACHINE

Capability Identifier: RC-5
-----
UNIVERSAL MILL

Capability Identifier: RC-6
-----
3 AXIS CNC MILLING MACHINE
    
```

FIGURE 59. Resource Selection (1)

```

Total Resource Allocation
=====
Domain: preparation process
-----
Capability Identifier: RC-1
-----
Peter

Capability Identifier: RC-2
-----
BANDSAW
Domain: manufacturing process
-----
Capability Identifier: RC-3
-----
CENTRE LATHE

Capability Identifier: RC-4
-----
CENTRE LATHE

Capability Identifier: RC-5
-----
UNIVERSAL MILL

Capability Identifier: RC-6
-----
VERTICAL DRILLING MACHINE
    
```

FIGURE 60. Resource Selection (2)

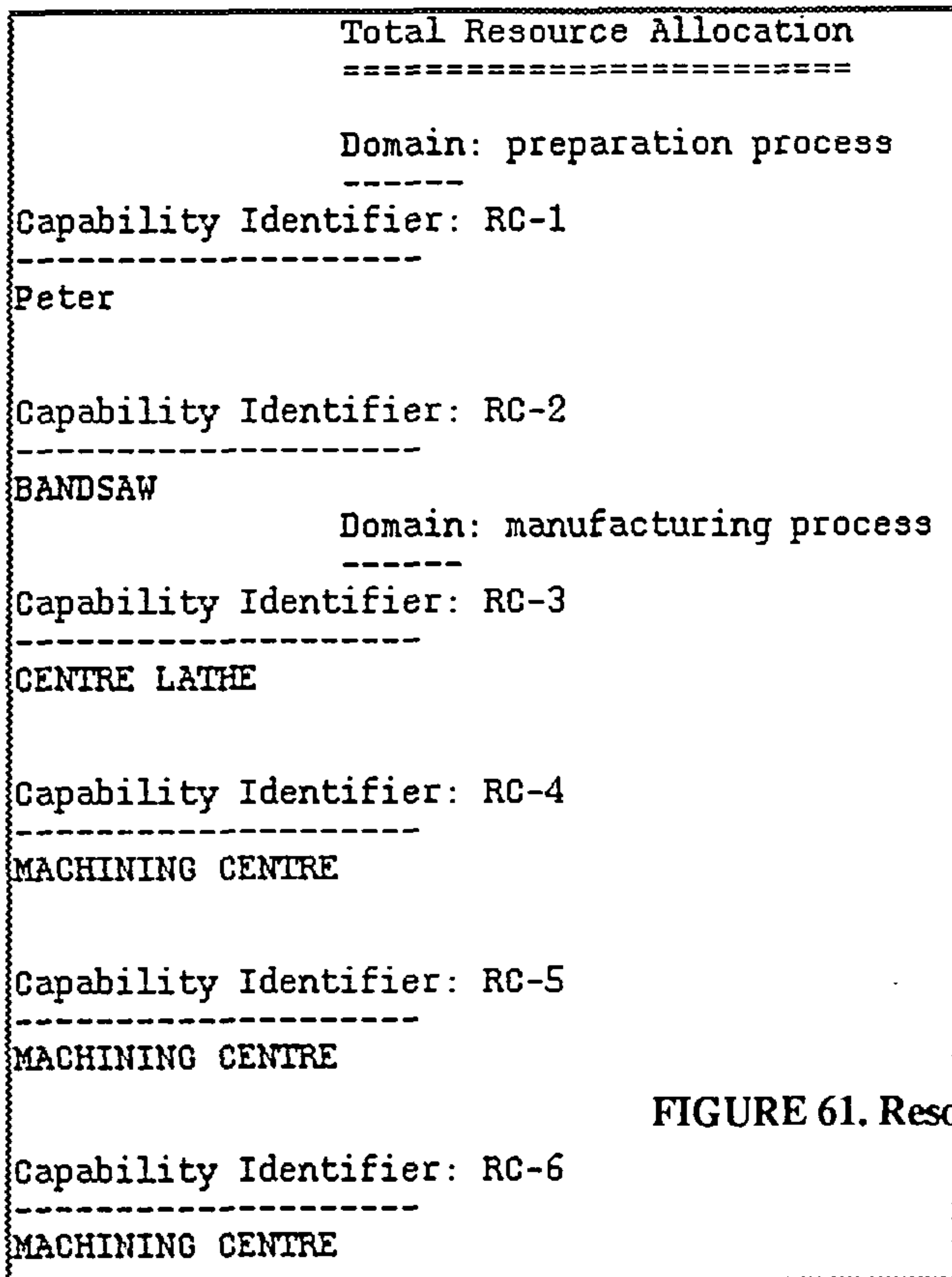
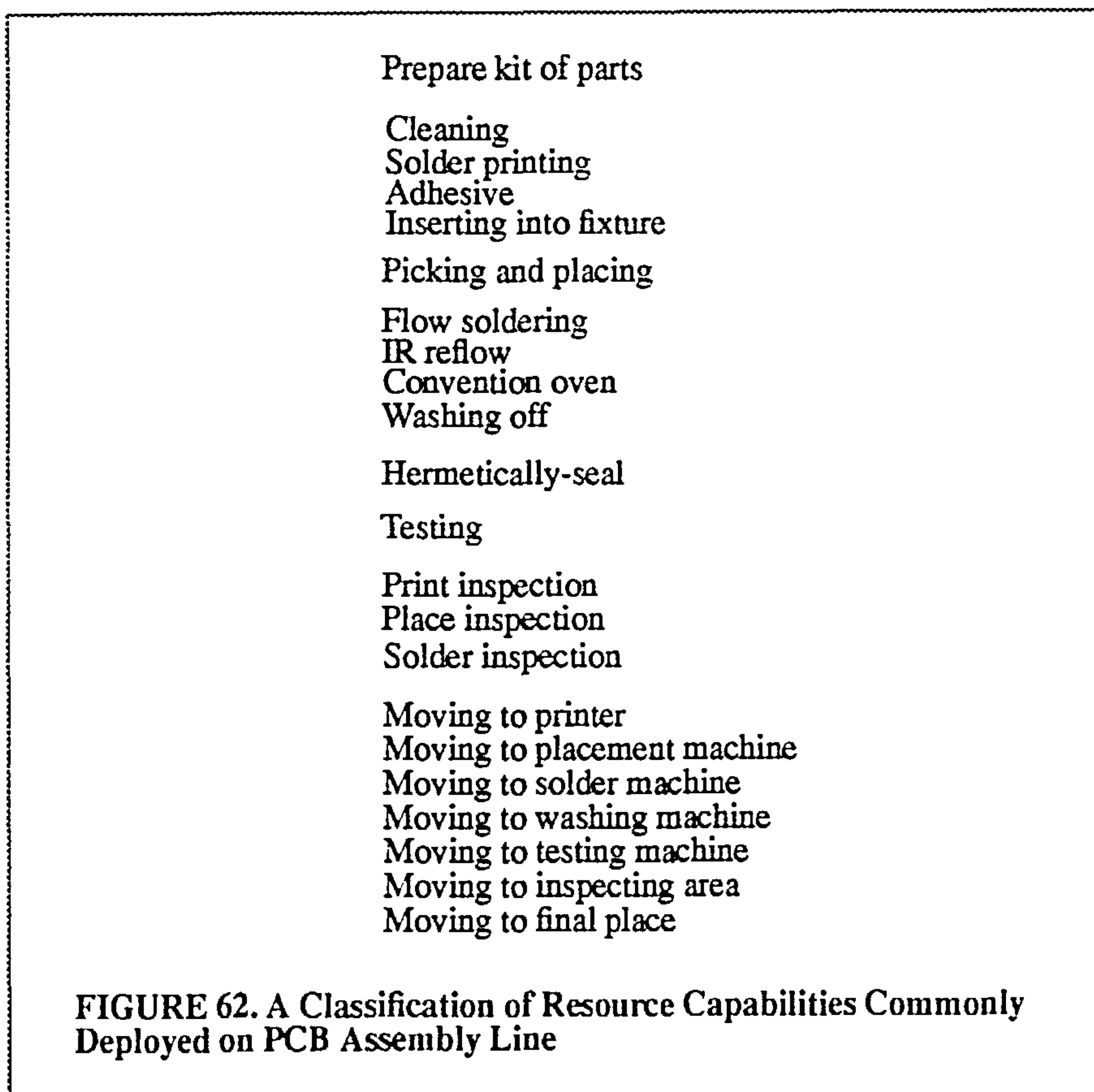


FIGURE 61. Resource Selection (3)



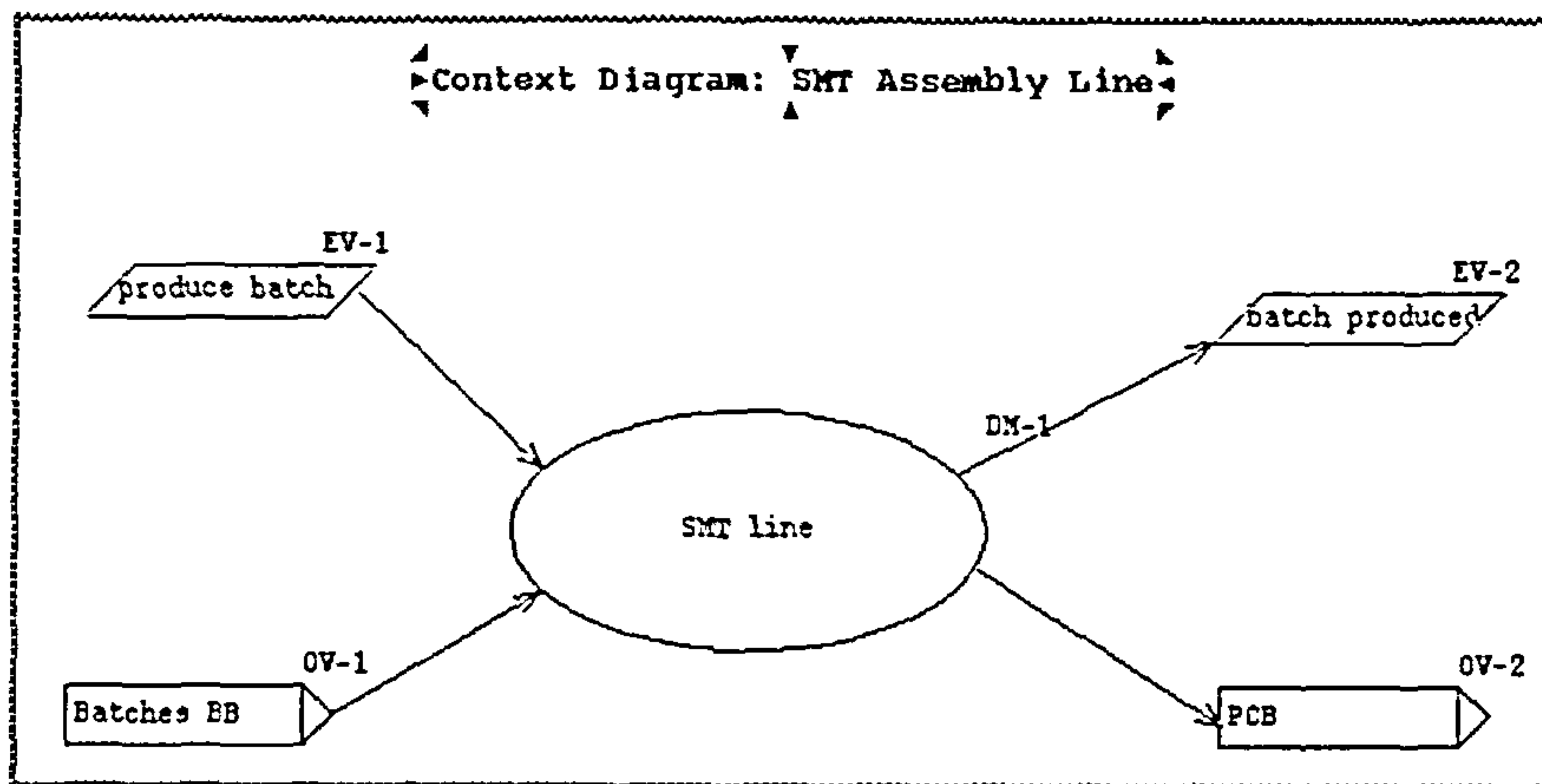


FIGURE 63. Context Diagram for Case Study Two

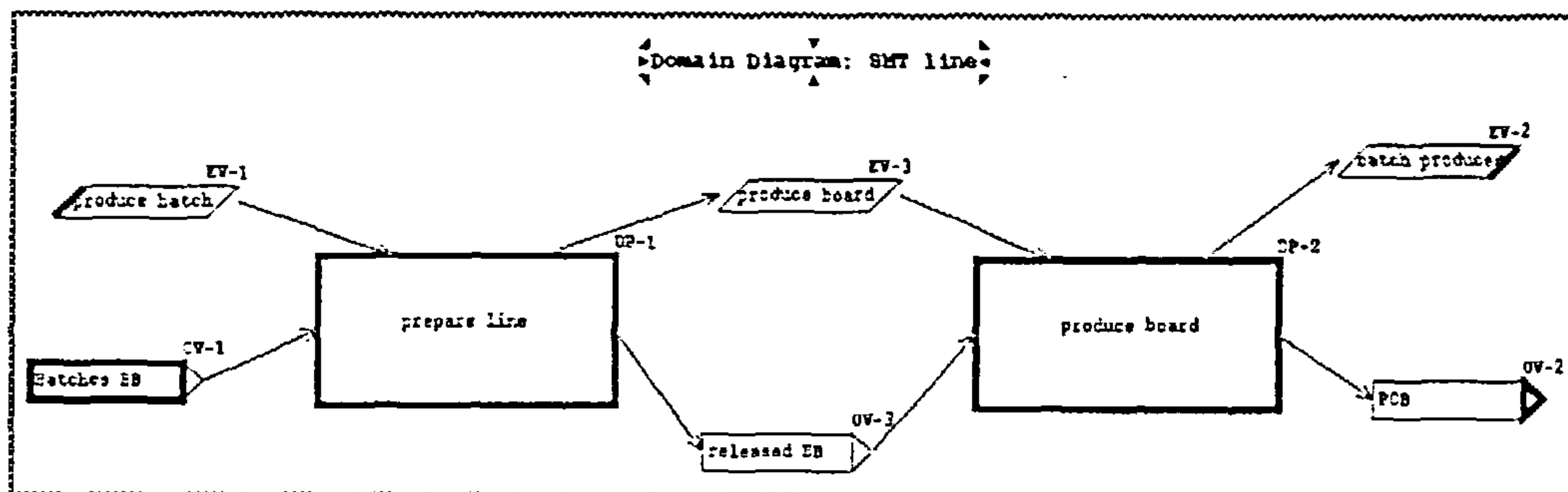


FIGURE 64. Domain Diagram for Case Study Two

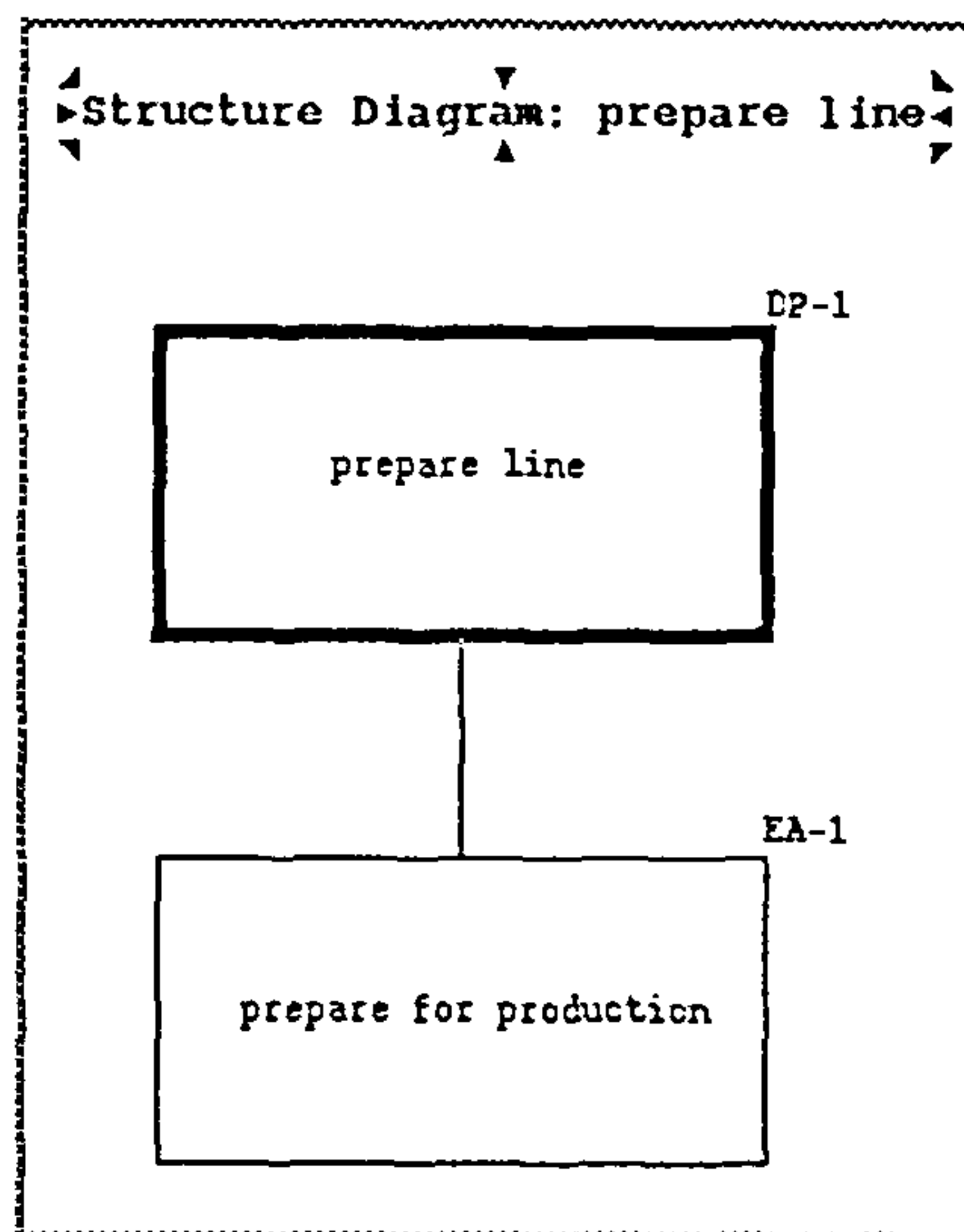


FIGURE 65. Structure Diagram-1 for Case Study Two

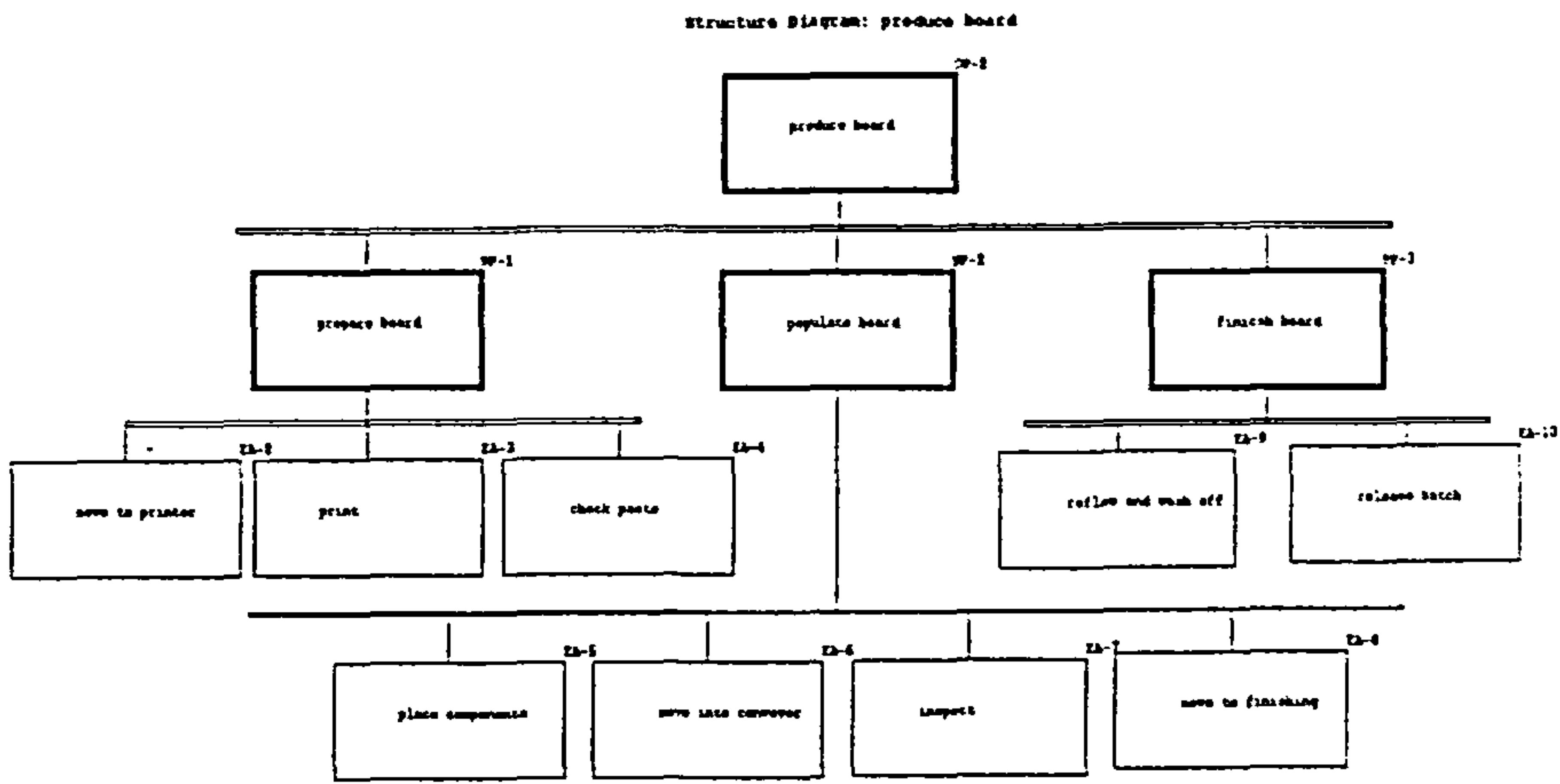


FIGURE 66. Structure Diagram 2 for Case Study Two

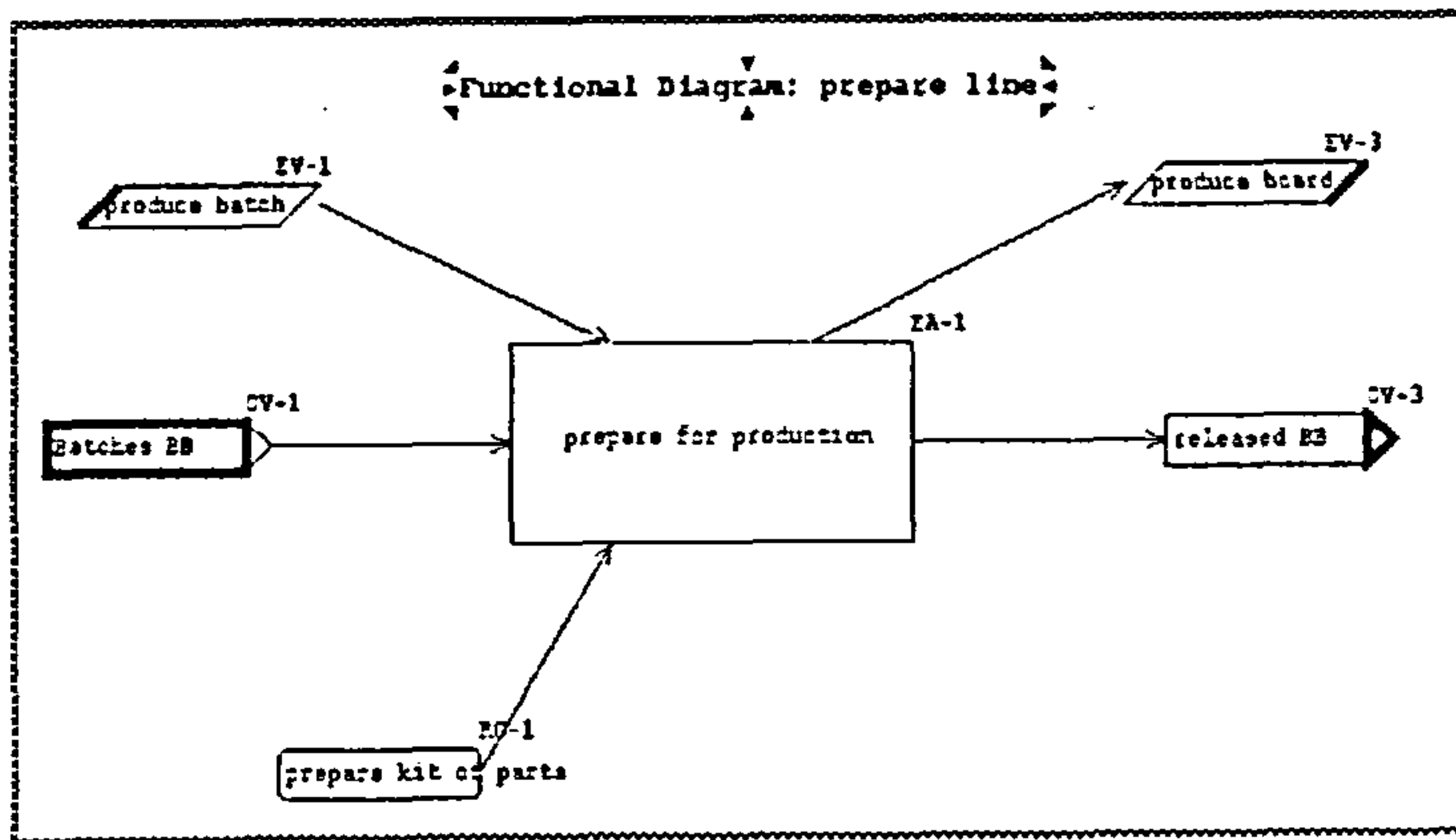


FIGURE 67. Functional Diagram 1 for Case Study Two

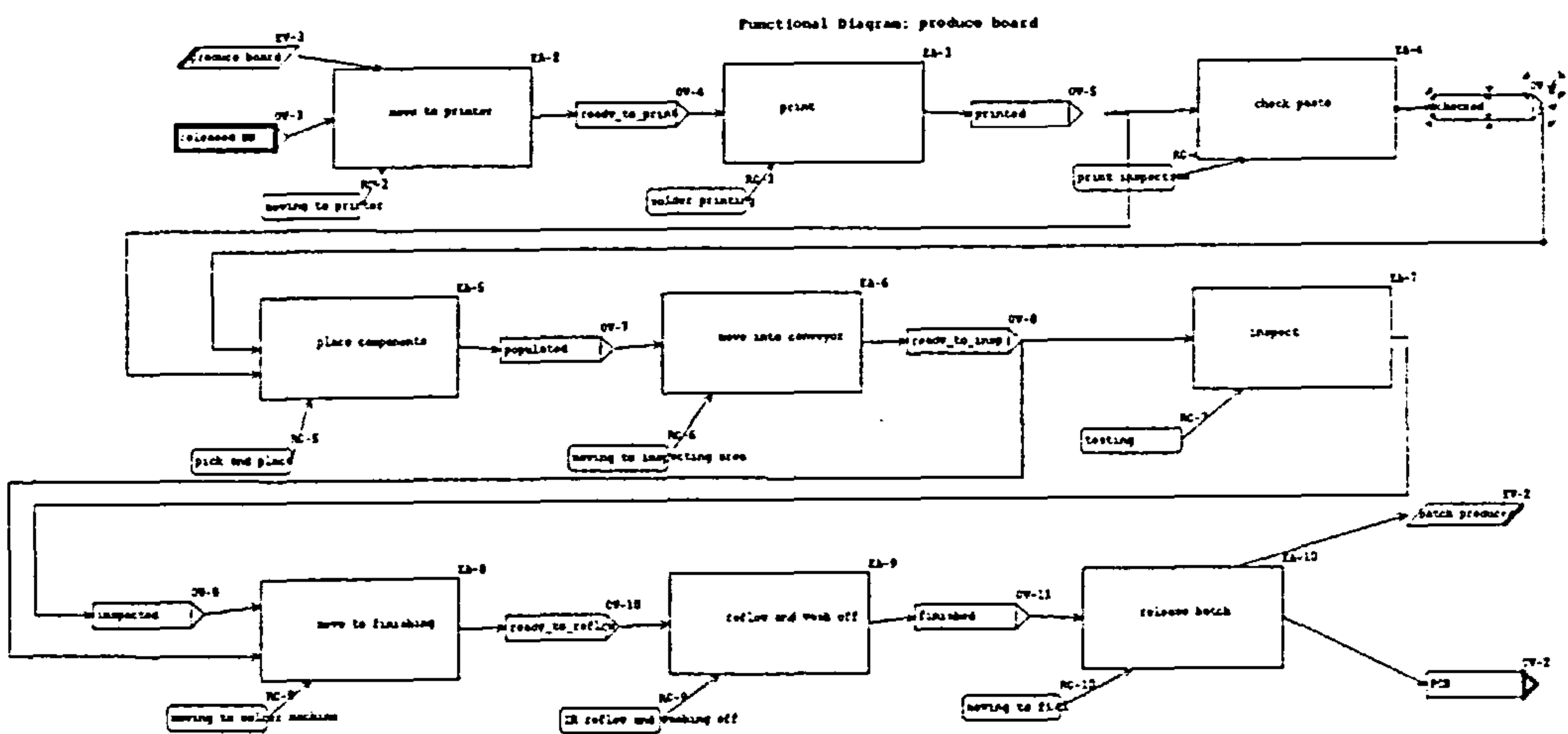


FIGURE 68. Functional Diagram 2 for Case Study Two

10.0 Discussion and Conclusions

10.1 Contribution to Knowledge Made by the Research

This research has produced a number of outputs as described in the main text and summarised by Figure 69. A comparison between this approach and other methods surveyed in chapter 4 are also represented in Table 9. The main contributions to knowledge made by this research are outlined below.

1. A framework for resource modelling was conceived and developed. This is the first systematic study of resource modelling reported in the literature which covers all primary life phases of enterprise engineering projects. The framework was designed and developed based on (a) previously established enterprise modelling principles and methodologies and (b) a new understanding of outstanding problems, which may be alleviated by deploying resource modelling;
2. In developing the resource modelling framework it was necessary to define new ways in which model fragments, generated during different life phases and from different perspectives, can be unified in an organised way to produce a consistent enterprise model;
3. In seeking ways of unifying model fragments generated from different modelling perspectives, this study examined generic relationships between process, resource, organisation and cost models. This understanding led to the definition of connecting mechanisms in the form of modelling constructs, which can link together different model fragments. Use of these mechanisms can help system designers and builders cope with high levels of modelling complexity;

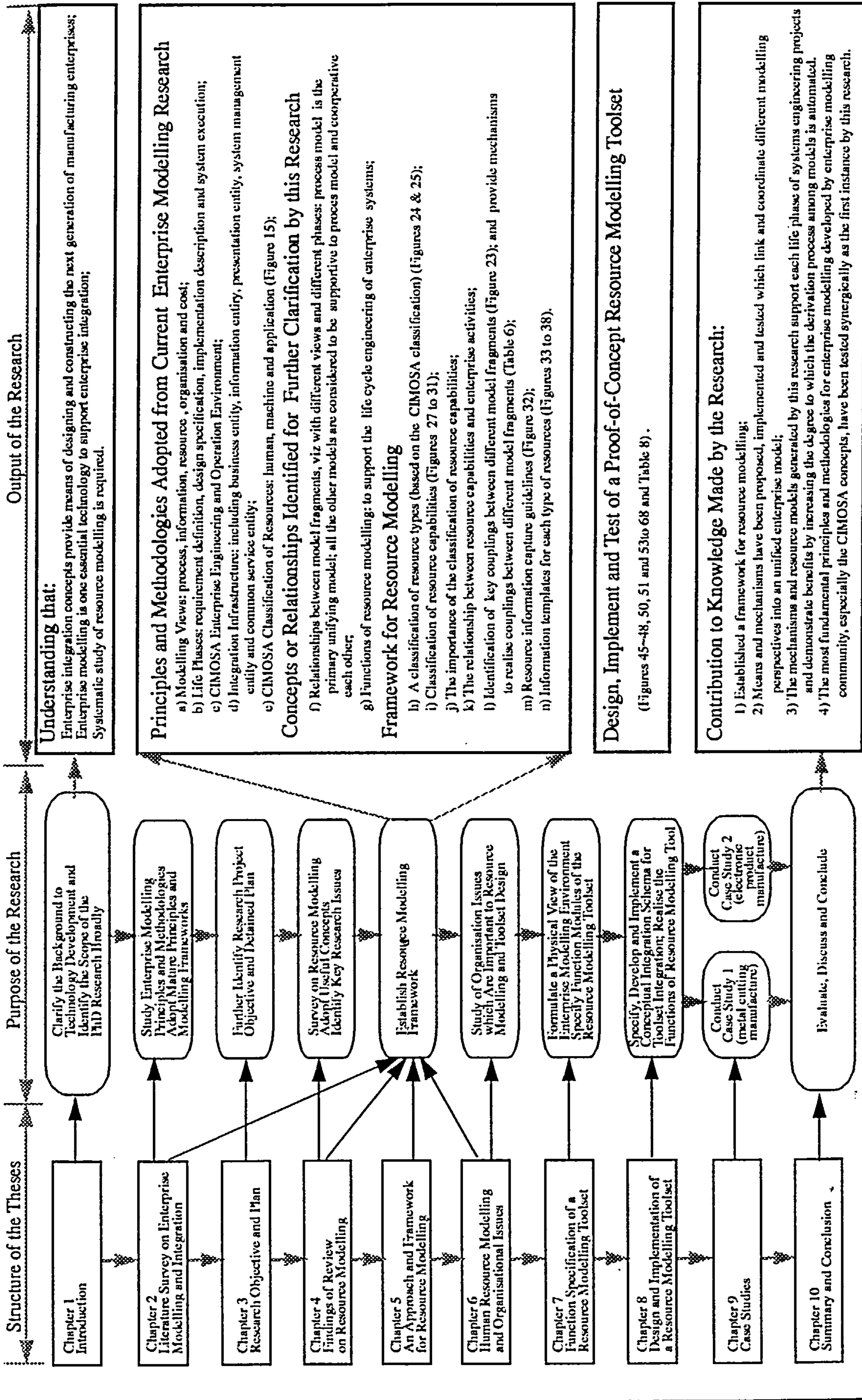


FIGURE 69. Summary of the Research Project of Resource Modelling

	Purpose & Focus	Resource Classification		Relationships with Other Aspects Models		Characteristic of Resource Capture Methods	Resource Modelling Tools	
		General Classification	Hierarchy (Grouping)	Principle	Mechanisms		Environment	Function Achieved
CIMOSA	support: system operation (management (control & monitor) resources)	It is human machine application Components: (no further classifications)	<i>Resource Cell</i> <i>Resource Set</i>	decoupling resource model from other aspects models	1. <i>Capability Set</i> is offered to decouple process and resource models; 2. <i>Capability Set</i> and <i>Resource</i> object class are used to link to other aspects models	not complete, but open flexible extendable generic	—	—
IEM	focus on: describing all things which support enterprise functions support: system operation & system analysis	employees resources materials information space time	<i>ClassHierarchy</i> <i>-SuperClass</i> <i>-SubClass</i>	holistic way of modelling: resource, process, function and order are bound together	—	specific machine-oriented not flexible not generic	C/C++; OODB; SQL; IBM-PC 386/486; MS-Windows.	IEM Tool (no separate resource tool) Presentation of business process; Analyse system static; and dynamic with Petri-net support. (Prototype tool)
TOVE	support: system operation planning scheduling	machine electricity raw materials equipment tools capital human skill information	<i>Division of:</i> <i>physical</i> <i>functional</i> <i>Component of:</i> <i>physical</i> <i>functional</i>	support different views	<i>Relation between Resource</i> <i>Ontology and Activity-State</i> <i>Ontology</i> has been defined to decouple from Activity-State Ontology	not complete, but open, extendable	C++; Carnegie Group's ROCK knowledge representation tool; Quintus Prolog.	TOVE Testbed: 1. a model of an enterprise; 2. tools for browsing, visualization, simulation, deductive queries (Prototype tool)
MOSES	focus on: describing manuf. capabilities support: product life cycle design manufacture assembly	furniture & fittings human info. processing equip. production equip. material handling equip. measuring & testing storage equip.	factory shop cell station	resource, process & strategies strongly coupled together	—	specific	C++; DEC Object/DB; STEP/EXPRESS Modelling Kit: SF-DEVELOPER; Booch Modelling Tool; RATIONAL ROSE. (Prototype tool)	MOSES System (no separate resource tool) Manufacturing process presentation (Prototype tool)
New Approach to Resource Modelling	support: life cycle engineering 1. system requirement definition; 2. system design specification; 3. system implementation description; 4. system execution.	CIMOSA classification was extended in more detail. see figure 24.	Resource Architecture <i>Structure:</i> <i>part of</i> <i>consist of</i>	providing flexible coupling constructs to couple resource models and other modelling perspectives	1. <i>Resource Capability</i> ; 2. <i>Resource Information</i> <i>Templates</i> ; 3. <i>Organisation Unit Code</i> ; 4. <i>Cost Information</i> <i>Construct</i> ; 5. <i>Resource Behaviour</i> <i>Construct</i> ; 6. <i>Resource Integration</i> <i>Construct</i> ;	open flexible extendable generic	IPSYS Meta CASE ToolBuilder; SUN workstation; incorporate with process, information, and organisation modelling tools and CIM-BIOSYS integration infrastructure	SEWOSA Resource Modelling Toolset 1. resource information management; 2. resource selection support; 3. potential system simulation support; 4. potential system operation support by prototyping

TABLE 9. Summary of New Approach to Resource Modelling Comparatively with Other Methods

4. This study also investigated ways of flexibly connecting model fragments generated and deployed during different life phases. It also defined and developed modelling constructs which provide appropriate connecting mechanisms which traverse life phases. This was understood as being necessary as a clear separation of certain life cycle enterprise engineering activities needs to be maintained to enable changing requirements to be reflected rapidly and effectively in changes to solutions (i.e. to enable systems to be configured rapidly from reusable systems and resource elements). Use of the type of connecting mechanisms (i.e. modelling constructs) designed and developed in this study was shown to maintain flexible couplings between model fragments produced during different life phases, yet allowed their separate engineering development;
5. The connecting mechanisms and resource modelling concepts generated by this research cover primary life phases and modelling perspectives involved in the engineering of enterprise systems. Furthermore as the resource models and the connecting mechanisms are described in a computer executable form they can be deployed to allow some enterprise model fragments to be generated automatically. The automatic model generation capability realised in this study could be developed further than proved possible during this study. However it did prove possible to automate some and semi-automate other resource selection and allocation activities involved in the design and appraisal of alternative candidate systems which were shown to have capabilities which matched process requirements;
6. The findings of this study show that process modelling can be used effectively to support system analysis and definition. However, when deploying process models

during each life phase it is also necessary to access relevant resource information (or models). Use of the extended enterprise modelling environment in the case study scenarios has demonstrated the effectiveness of combining the use of resource information, in the form of object oriented descriptions of candidate resources, with that of process oriented models describing enterprise activities to:

(i) develop and analyse conceptual models of manufacturing processes which are capable of both being aligned with defined business requirements and being physically realisable by deploying known system and resource elements;

(ii) develop and analyse conceptual models of candidate systems capable of realising defined business requirements. These models comprise descriptions of collective (system-wide) behaviour (including component interactions) and individual component behaviour (including enterprise activity assignments);

(iii) generate “control” and “presentation” models which can be executed using the services of an integration infrastructure (including CIMOSA conformant “business” and “presentation” entities) to realise the model driven configuration and operation of systems built from real components, which conform to the resource models selected during system design and construction;

7. Thus it is believed that this study has extended previous understanding about the way in which process and resource (and hence process oriented and object oriented system descriptions) can be deployed harmoniously to realise systems which

(i) are aligned to high level (even business oriented) goals, and

(ii) can be realigned (i.e. reconfigured and even re-engineered) to meet changes in high level goals;

8. Furthermore the case study scenarios have shown that the use of resource classifications can help to structure the way in which system decomposition is

carried out, and thereby can help to de-skill an important aspect of enterprise engineering projects. It is evident that experienced system designers and builders will generate better systems than inexperienced ones; and that the key to those improvements will be the architectural decomposition they deploy. However, except in well defined circumstances, it will be better to advise system designers and builders (by providing such classifications) rather than seek to replace them and automate their decision making activities. Good advice should simplify their task, allow intellectual capital to be stored and reused, lead to better results or even allow less skilled personnel to be deployed;

9. The study has sought to test and as appropriate extend fundamental principles and methodologies previously developed by the enterprise modelling community, especially CIMOSA concepts. It has shown that it is possible to model enterprises from different perspectives and during different life phases yet maintain consistency through the use of modelling constructs and connected model fragments. The ability to think holistically about complex enterprise systems and to change them incrementally targeted on business goals is a key requirement of a world class business;

10. It is also evident that the use of resource models can help to define end user needs in a way which could guide future developments made by their system and component suppliers; and thereby contribute to ongoing research development initiatives under the banner of “component technology” [Weston, 97].

10.2 Problems and Difficulties Faced during the Research Study

1. It only proved to be practical to classify in detail a small number of common manufacturing resources deployed in different industrial sectors. Hence to develop further the concepts and approaches advocated in this thesis such a task would need to be carried out on a wider scale. However, as indicated by benefit 10 above, there may well be a future impetus for some end users and their IT vendors to participate in such a venture.
2. Resource selection support could be realised more automatically. However time did not permit the development of all but simple algorithms to support this nor was it possible to consider any cost/benefit analysis of such opportunities.
3. A system simulation facility was not deployed in the case study due to time constraints. This was disappointing as it could have shed more light on key issues.
4. Multi-disciplinary knowledge is needed to carry out more complete resource modelling. For example, a classification of manufacturing resources needs knowledge of a broad variety of resource elements, including machines and different level software applications (e.g. cell controllers, FMS systems, CAD/CAE/CAM packages, production planning and control systems, financial systems, business strategy support systems, etc.). Resource selection support needs knowledge of manufacturing process planning, group technology, etc. These facts highlight just some of the difficult issues considered in this research, many of which could not be tackled in detail.

10.3 Further Research

There are many possible avenues of future research which could be followed to develop the study findings, including:

1. Large scale experiments should be carried out to test the scalability of methodologies provided by this research;
2. The resource classifications and models should be developed and their use evaluated. This could for example for the purpose of standardising manufacturing resource descriptions and/or developing a taxonomy of manufacturing resources.
3. It is necessary to identify and develop reusable resource components of next generation manufacturing systems. Relationships between self standing resource capabilities, which in practical terms can be separated out and classified, need to be mapped onto generic and formal descriptions of business process requirements.

10.4 Reusable Components for Next Generation of Manufacturing Enterprises

The next generation of manufacturing enterprise will be characterised by rapid change and growing competition. The agility of systems, i.e. their ability to cope with change, will be of strategic importance.

From a macro point of view, a systems approach and enterprise level integration is necessary to cope with such changes. On the other hand, when viewing the problems from a micro point of view, robust and reusable components which vendors can sell

will be required to build enterprise systems.

So called “components technology” has originated from advances in software development and the availability of distributed object technology [Orfali et al, 96].

The underlying principles can be applied more generally to define generic and reusable manufacturing resources including application software, machine and human resources. Applied more widely the approach should lead to the availability of reusable components to readily configure and build a new generation of agile manufacturing enterprises.

The resource classifications, resource models and modelling constructs designed and developed in this study could provide useful foundation research which can help map generic business and manufacturing process requirements onto new forms of reusable component. Such developments, merged with ongoing component technology developments, could bring closer together the top-down, holistically defined specific needs of end users with business requirements of IT vendors for system and components which can be applied generally.

Appendix 1: References

- [AGILE, 96] Agility Overview, from WWW: <http://elib.cme.nist.gov/agile/agile.html>, 1996.
- [Aguiar & Weston, 93] M. W. C. Aguiar and R. H. Weston, CIMOSA and Stochastic Time Petri Nets for Behavioural Modelling and Model Handling in CIM Systems Design and Building, in *Proc. I.MechE. Vol. 207. Part B: Journal of Engineering Manufacturing*, pp147-158. -Awarded Donald Julius Groen Prize, 1993.
- [Aguiar & Weston, 94] M. W. C. Aguiar and R. H. Weston, SEW-OSA: Systems Engineering and Workbench Centred on CIMOSA. in *Proc. of 10th ISPE/IFAC International Conference on CAD/CAM, Robotics and Factories of the Future (CARs & FOF'94)*, pp289-94, Ottawa, Canada, 21-24 August, 1994.
- [Aguiar, 95] Marcos Wilson Costa de Aguiar, *An Approach to Enacting Business Models in Support of the Life Cycle of Integrated Manufacturing Systems*, PhD thesis, Loughborough University of Technology, 1995.
- [Aguiar et al, 96] Marcos Wilson Costa de Aguiar, Shaun Murgatroyd and John M. Edwards, Object-oriented Resource Models: Their Role in Specifying Components of Integrated Manufacturing Systems, in *Computer Integrated Manufacturing Systems*, Vol. 9, No. 1, 1996.
- [Aravindan & Hiregoudar, 95] P. Aravindan and N. L. Hiregoudar, Design of Network Information System for Management of Enterprises Through Teams, in *The 11th ISPE/IEEE/IFAC International Conference on CAD/CAM Robotics and Factories of the Future'95*.
- [Ariffin, 96] S. Ariffin, *Modelling and Simulation in Support of the Design and Construction of Modular Machine Control System*, PhD Theses, Loughborough University, UK, 1996.
- [ARIS, 94] A.-W. Scheer, *Business Process Engineering - Reference Models for Industrial Enterprises*, Springer-Verlag, 1994.
- [Badham & Schallock, 91] R. Badham and B. Schallock, Human Factors in CIM: A Human Centred Perspective from Europe, in *International Journal of Human Factor in Manufacturing*, vol.1, no.2 pp121-41, 1991.
- [Baecker, 93] Ronald M. Baecker, Part I: Introduction, in *Readings in Groupware and Computer-Supported Cooperative Work - Assisting HUMAN-HUMAN Collaboration*, Written and Edited by Ronald M. Baecker, Morgan Kaufmann Publishers, Inc., 1993.
- [Bailey, 82] Robert W Bailey, *Human Performance Engineering: A Guide for System Designers*, Prentice-Hall, 1982.
- [Balint, 95] Lajos Balint, Adaptive Human-computer Interfaces for Man-machine Integration in Computer-integrated Systems, in *Computer Integrated Manufacturing Systems*, Vol 8 No 2 pp133-142, 1995.
- [Bannon & Schmidt, 91] Liam J. Bannon and Kjeld Schmidt, CSCW: Four

Characters in Search of a Context, in *Studies in Computer Supported Cooperative Work*, Edited by J. M. Bowers and S. D. Benford, Elsevier Science Publishers, 1991.

- [Barber & Weston, 96] M. I. Barber and R. H. Weston, Scoping Study of Business Process Reengineering: Towards Successful IT Application, Internal Report of MSI Research Institute, Loughborough University, 1996.
- [Bendell et al, 89] A. Bendell, J. Disney and W. A. Pridmore (Ed), *Taguchi methods: Application in World Industry*, London: IFS, 1989.
- [Benson et al, 92] Charlene R. Benson, T. Govindaraj, Christine M. Mitchell and Stephen M. Krosner, Effectiveness of Direct Manipulation Interaction in the Supervisory Control of Flexible Manufacturing Systems, in *Information and Decision Technologies* 18 (1992) 33-53, Elsevier Science Publishers.
- [Bernus & Nemes, 94] Peter Bernus and Laszlo Nemes, A Framework to Define a Generic Enterprise Reference Architecture and Methodology (GERAM), in *Proc. Third International Conference on Automation, Robotics and Computer Vision (ICARCV'94)*, Singapore, 8-11 November, 1994 99. 88-92.
- [Bernus & Nemes, 96] Peter Bernus and Laszlo Nemes, Enterprise Integration - Engineering Tools for Designing Enterprises, in *Modelling and Methodologies for Enterprise Integration*, Edited by Peter Bernus and Laszlo Nemes, Chapman & Hall, 1996.
- [Bernus et al, 96] P. Bernus, L. Nemes and R. Orris, The Meaning of Enterprise Model, in *Modelling and Methodologies for Enterprise Integration*, Edited by Peter Bernus and Laszlo Nemes, Chapman & Hall, 1996.
- [Bessant, 92] J. Bessant, *Trends and Perspectives in the Development and Diffusion of CIM, CIM Computer-Integrated Manufacturing*, UNIDO Publication, Vienna, 1992.
- [Blumberg, 88] M. Blumberg, Towards a New Theory of Job Design, in *Ergonomics of Hybrid Automated Systems I*, Edited by W. Karwowski, H. R. Parsaei and M. R. Wilhelm, Elsevier Science Publishers, 1988.
- [Borusan, 94] Alexander Borusan, An Integrated Formal Approach to Concurrent Engineering Using Petri Nets, in *Concurrent Engineering: Research and Applications, 1994 Conference*.
- [BPRAG, 96] Business Process Reengineering Tool Repository, by Business Process Reengineering Advisory Group, Enterprise Integration Laboratory, University of Toronto, <http://www.ie.utoronto.ca/EIL/eil.html>. 1996.
- [Bracegirdle et al, 93] Brian Bracegirdle, Brian Bowers, Neil Cossons, W.K.V. Gale, Charles E. Lee, A. Ridley, L.T. C. Rolt, Will Slatcher, Jennifer Tann, Rex Wailes, Stanley Paine and Patricia H. Miles, *The Archaeology of the Industrial Revolution*, Heinemann London, 1973.
- [Bradley et al, 95] P. Bradley, J. Browne, S. Jackson and H. Jagdev, Business Process Re-engineering (BPR) - A Study of the Software Tools Currently

Available, in *Computers in Industry*, 25 (1995) 309-330.

- [Braveman, 74] H. Braveman, *Labour and Monopoly Capital*, Monthly Review Press, New York, 1974.
- [Bright, 58] James R. Bright, *Automation and Management*, Maxwell Reprint Company, 1958.
- [Brookes & Backhouse, 96] Naomi J. Brookes and Christopher J. Backhouse, Concurrent Engineering: Where It Has Come from and Where It Is Now, in *Concurrent Engineering: What's Working Where*, Edited by Christopher J. Backhouse and Naomi J. Brookes, The Design Council: Gower, 1996.
- [Broughton, 90] T. Broughton, Simultaneous Engineering in Aero Gas Turbine Design and Manufacture, in *Proc.1st Int. Conf. on Simultaneous Engineering*, London, 4-5 December 1990, Status Meetings Ltd. pp25-36.
- [Browne et al, 95] Jim Browne, Peter Sackett and Hans Wortman, Industry Requirements and Associated Research Issues in the Extended Enterprise, in *Integrated Manufacturing Systems Engineering*, Edited by Pierre Ladet and Francois Vernadat, Chapman & Hall, 1995.
- [Bruno et al, 95] G. Bruno, R. Agarwal, C. Reyneri, B. Chiavola and M. Varani, Making CIMOSA Operational, in *Integrated Manufacturing Systems Engineering*, Edited by P. Ladet and F. Vernadat, 1995
- [BSI, 90] BSI PD 6526:1990, CEN/CENELEC Report R-IT-01, *Evaluation on CIM Architectures*, British Standard Institute.
- [Burkhart, 92] Roger Burkhart, Process-based Definition of Enterprise Models, in *Enterprise Integration Modelling: Proceedings of the First International Conference of Enterprise Integration Modelling Technology (ICEIMT)*, Edited by Charles J. Petrie, Jr. The MIT Press, 1992.
- [Burnes et al, 89] B. Burnes and B. Weekes, Success and failure with Advanced Manufacturing Technology: The Need for a Broader Perspective, in *Adv. Manuf. Eng.* Vol. 1 January 1989.
- [Champy, 95] James Champy, *Reengineering Management: The Mandate for New Leadership*, HarperCollinsPublishers, 1995.
- [Chant, 89] *Science Technology and Everyday Life 1870-1950*, Ed C. Chant, Routledge and Open University Press, 1989, ISBN: 0-415-00037-8.
- [Child, 84] John Child, *Organization: A Guide to Problems and Practice* (second edition), Harper & Row, London, 1984.
- [CIMOSA, 89] ESPRIT/AMICE Project 688/5288 Research Report, *CIMOSA: Open System Architecture for CIM*, 1989.
- [CIMOSA, 91] ESPRIT/AMICE Project 688/5288 Research Report: *CIMOSA: Open System Architecture for CIM*, 2nd Edition, Springer-Verlag, 1991.
- [CIMOSA, 93] ESPRIT/AMICE *CIM-OSA: Open System Architecture for CIM*, Springer-Verlag, 1993.
- [CIMOSA, 96] ESPRIT/AMICE, *CIMOSA: Open System Architecture for CIM*,

- *Technical Baseline -PART I: Sections on Business Modelling*, Version 3.2, 1996.
- [Clark, 85] Ronald W. Clark, *Works of Man*, Century Publishing Co Ltd., London, 1985.
- [Clarke, 86] A.A. Clarke, A Three-level Human-computer Interface Model, in *Int. J. Man-Machine Studies* (1986) 24, 503-517.
- [Clements et al, 96] P. E. Clements, I. A. Coutts and J. M. Edwards, A Model Based Approach to Enterprise Wide Information Support, in *DIISM'96*, Eindhoven, Holland.
- [Cobb et al, 96] C. Kim Cobb, W. Harvey Gray, Robert E. Hewgley, Edward J. Klages and Richard E. Neal, Integrating a Distributed, Agile, Virtual Enterprise in the TEAM Program, in *Plug and Play Software for Agile Manufacturing - Proceedings of SPIE - The International Society for Optical Engineering*, Edited by Barbara L. Maia Goldstein, Boston, Massachusetts, 1996.
- [Combacau & Courvoiser, 90] M. Combacau and M. Courvoiser, A Hierarchical and Modular Structure for FMS Control and Monitoring, in *IEEE*, 80-88, 1990.
- [Cooley, 84] M. J. E. Cooley, Problems of Automation, in *Human Factors in Manufacturing*, 1st Annual Conf. 1984
- [Cooper, 89] R. Cooper, The Rise of Activity-based Costing - Part Two: How Many Cost Drivers Do you Need and How Do You Select Them? in *J. of Cost Management*, pp34-36, Winter 1989.
- [Cossons, 75] Neil Cossons, *The BP Book of Industrial Archaeology*, David & Charles Newton Abbot Devon, 1975.
- [Coutts et al, 92] I. A. Coutts, R. H. Weston, I. S. Murgatroyd and J. D. Gascoigne, Open Applications within Soft Integrated Manufacturing Systems, in *ICMA92*, Hong Kong.
- [Dawson, 94] Patrick Dawson, Total Quality Management, in *New Wave Manufacturing Strategies-organizational and Human Resource Management Dimensions*, Edited by John Storey, Paul Chapman Publishing Ltd, 1994
- [Deutsch, 69] M. Deutsch, Conflicts: Productive and Destructive, in *Journal of Social Issues*, 1969.
- [Devor et al, 92] Richard E Devor, Tsong-how Chang and John W. Sutherland, *Statistical Quality Design and Control: Contemporary Concepts and Methods*, Macmillan: Maxwell, 1992.
- [Didic, 94] Milena Didic, CIMOSA Model Creation and Execution for a Casting Process and a Manufacturing Cell, in *Computers in Industry* 14 (1994) 237-247, Elsevier.
- [Doumeingts et al, 93] G. Doumeingts, D. Chen, B. Vallespir and P. Fenie, GIM (GRAI Integrated Methodology) and Its Evolutions: A Methodology to Design and Specify Advanced Manufacturing Systems, in *Information*

Infrastructure Systems for Manufacturing (B-14), Edited by H. Yoshikawa and J. Goossenarts, Elsevier Science B. V. (North-Holland) 1993.

- [DTI, 93] *Manufacturing Into The Late 1990s*, DTI HMSO: London, 1993.
- [Ellis et al, 95] T.I.A.Ellis, A. Molina, R.I. M Young and R. Bell, An Information Sharing Platform for Concurrent Engineering, in *Integrated Manufacturing Systems Engineering*, Edited by Pierre Ladet and Francois Vernadat, Chapman & Hall, 1995.
- [Evbuomwan et al, 94] N.F.O. Evbuomwan, S.Sivaloganathan and A. Jebb, A State of the Art Report on Concurrent Engineering, in *Proceedings of Concurrent Engineering: Research and Applications - CE94*, Pittsburgh, Pennsylvania.
- [Eversheim, 90] W. Eversheim, Trends and Experience in Applying Simultaneous Engineering in Germany, in *Proc. 1st Int. Conf. on Simultaneous Engineering*, Status Meetings Ltd. pp5-23, 1990,
- [Eversheim & Heuser, 95] W. Eversheim and T. Heuser, Process-oriented Order Processing - a New Method for Business Process Reengineering, in *Integrated Manufacturing Systems Engineering*, Edited by P. Ladet and F. Vernadat, Chapman & Hall, 95.
- [EXPRESS, 92] ISO DIS 10303-11, The EXPRESS Language Reference Manual, IOS TC 184/SC4/WG5, N35, 1992.
- [Fadel et al, 94] Fadi George Fadel, Mark S. Fox and Michael Guninger, A Generic Enterprise Resource Ontology, in *3rd Workshop on Enabling Technology: Infrastructure for Collaborative Enterprises*, Morgauston W, Virginia, USA, April 1994.
- [Fahnrich & Hanne, 93] K.-P. Fahnrich and K.-H. Hanne, Aspects of Multimodal and Multimedia Human-Computer Interaction, in *Advances in Human Factors / Ergonomics, 19B: Human-Computer Interaction: Software and Hardware Interfaces*, Edited By G. Salvendy and M. J. Smith, Elsevier, 1993.
- [Favrel et al, 85] J. Favrel et al, Modelling, Analysing, Scheduling and Control of Flexible Manufacturing Systems by Petri Nets, in *Modelling Production Management Systems*, IFIP 1985.
- [Fitts & Posner, 67] Paul M. Fitts and Michael I. Posner, *Human Performance*, Greenwood Press, Publishers, 1967
- [Fox, 66] Alan Fox, *Industrial Sociology and Industrial Relations*, Royal Commission on Trade Unions and Employers Associations, Research Paper 3, HMSO, LONDON, 1966.
- [Fox, 92] Mark S. Fox, The TOVE Project: Towards a Common Sense Model of the Enterprise, in *Enterprise Integration Modelling: Proceedings of the First International Conference of Enterprise Integration Modelling Technology (ICEIMT)*, Edited by Charles J. Petrie, Jr. The MIT Press, 1992.
- [Foy, 80] N. Foy, *The Yin and Yang Organizations*, Grant GcIntyre, 1980.

- [Fraser, 94] John Fraser, Managing Change through Enterprise Models, in *Proceedings: Applications and Innovations in Expert Systems II*, Edited by R. Milne and A Montgomery, SGEN Publications, 1994.
- [Galbraith, 73] J. R. Galbraith, *Designing Complex Organisations*, Addison-Wesley, Reading, MA, 1993.
- [Gascoigne, 94] J. D. Gascoigne, CIM-BIOSYS Integrated System Implementation Toolset, Internal Report, MSI Research Institute, Loughborough University, UK, 1994.
- [Genrich, 87] H. J. Genrich, Predicate/Transition Nets, in *Petri Nets: Central Models and Their Properties, Advances in Petri Nets 1986-Part I, Lecture Notes in Computer Science*, Vol. 254, pp207-247, Springer-Verlag 1987.
- [GERAM, 94] P. Bernus and L. Nemes, A Framework to Define a Generic Enterprise Reference Architecture and Methodology (GERAM), Divisional Report No.: MTM 366, CSIRO Division of Manufacturing Technology, 1994.
- [Gilbert & Siong, 94] A. Lee Gilbert and Neo Boon Siong, A Contingency for Selecting a BPR Planning Approach, in *TENCON'94*, IEEE Region 10's 9th Annual Int. Conf. Singapore, Aug. 1994.
- [Gilders, 95] Paul Gilders, Internal Report on ARIS Toolset, MSI Research Institute, Loughborough University, UK, 1995.
- [Goldman et al, 95] S L Goldman, R N Nagel and K Preiss, *Agile Competitors and Virtual Organisations*, Van Nostrand Reinhold Publishing Inc., 1995.
- [Golhar & Stamm, 91] D. Y. Golhar and C.L. Stamm, The Just-In-Time Philosophy: A Literature Review, in *Int. J. Prod. Res.*, 29:657-676, 1991.
- [Goodman, 56] L. Landon Goodman, *Man and Automation*, Pelican Books, 1956.
- [Goossenaerts & Yoshikawa, 93] J. Goossenaerts and H. Yoshikawa, Refining the Functions and Attributes of Manufacturing Systems, in *MAPLE'93, Proceedings Symposium on Manufacturing Application Programming Language Environments*, Ottawa, Ontario, October 4-5, 1993.
- [Goranson, 92] H. T. Goranson, Dimensions of Enterprise Integration, in *Enterprise Integration Modelling: Proceedings of the First International Conference of Enterprise Integration Modelling Technology (ICEIMT)*, Edited by Charles J. Petrie, Jr. The MIT Press, 1992.
- [Goulette, 89] Reger Goulette, The Impact of Interorganizational CIM, in *Autofact'89*. Detroit, Michigan, USA, October 30-November 2, 1989.
- [Grant, 92] C R Grant, MMS and Time-Critical Communications in CIM, in *Proceedings of the Eighth CIM-Europe Annual Conferences*, 1992.
- [Greenwood, 88] N. Greenwood, *Implementing Flexible Manufacturing System*, Macmillan Education Ltd., 1988.
- [Groover, 94] Mikell P. Groover, Automation, in *Handbook of Design, Manufacturing and Automation*, Edited by R. C. Dorf and A. Kusiak, John Wiley & Sons, New York, 1994.

- [Gruninger & Fox, 96] M. Gruninger and M. S. Fox, The Logic of Enterprise Modelling, in *Modelling and Methodologies for Enterprise Integration*, Edited by Peter Bernus and Laszlo Nemes, Chapman & Hall, 1996.
- [Gunasekaran et al, 93] A. Gunasekaran, S. K. Goyal, T. Partikainen and P. Yli-Olli, Modelling and Analysis of Just-In-Time Manufacturing Systems, in *Int. J. of Production Economics*, 32 (1993) 23-37, Elsevier.
- [Gutierrez, 95] A. Molina Gutierrez, *A Manufacturing Model to Support Data-Driven Application for Design and Manufacture*, PhD Thesis, Loughborough University of Technology, 1995.
- [Hallihan et al, 97] JIT Manufacturing: the Evolution to an Implementation Model Founded in Current Practice, in *Int. J. Prod. Res.*, Vol.35, No.4, 901-920., 1997.
- [Hammer & Champy, 93] Michael Hammer and James Champy, *Reengineering the Corporation - A Manifesto For Business Revolution*, Nicholas Brealey Publishing, London, 1993.
- [Handy, 93] Charles Handy, *Understanding Organizations*, Penguin Books, 1993.
- [Harrison, 94] Alan Harrison, Just-In-Time Manufacturing, in *New Wave Manufacturing Strategies-organizational and Human Resource Management Dimensions*, Edited by John Storey, Paul Chapman Publishing Ltd, 1994.
- [Hayakawa, 95] Iwao Hayakawa, Self-Defence Strategy under Activity Based Cost Management and Business Process Innovation, in *The 11th ISPE/IEEE/IFAC International Conferences on CAD/CAM Robotics and Factories of the Future'95*.
- [Henderson, 69] W. O. Henderson, *Industrialisation of Europe 1780-1814*, Jarrold & Sons Ltd., Norwich, 1969.
- [Herman et al, 96] P. Herman, C. Good, T. J. Hahn, D. Wierbowski, Creating the Virtual Enterprise with VE Gateways, in *Plug and Play Software for Agile Manufacturing - Proceedings of SPIE - The International Society for Optical Engineering*, Edited by Barbara L. Maia Goldstein, Boston, Massachusetts, 1996.
- [Hiromoto, 88] T. Hiromoto, Another Hidden Edge: Japanese Management Accounting, in *Harvard Business Review*, July-August, 1988.
- [Hitomi, 90] Katsundo Hitomi, Manufacturing Systems Engineering: the Concept, Its Context and the State of the Art, in *Int. J. Computer Integrated Manufacturing*, 1990, Vol. 3, No. 5, 275-288.
- [Horstmann et al, 96] Paul Horstmann, Richard Bolton, Allen Dewey, Art Goldschmidt and Anthony Blazej, Manufacturing Virtual Enterprises Through the Use of the National Information Infrastructure Protocols (NIIP), in *Plug and Play Software for Agile Manufacturing - Proceedings of SPIE - The International Society for Optical Engineering*, Edited by Barbara L. Maia Goldstein, Boston, Massachusetts, 1996.

- [Huczynski & Buchanan, 91] Andrzej A. Huczynski and David A. Buchanan, *Organizational Behaviour*, Second Edition, Prentice Hall, 1991.
- [Iacocca Institute, 91a] Iacocca Institute, Lehigh University, *21st Century Manufacturing Enterprise Strategy*, Volume 1: An Industry-Led View, 1991
- [Iacocca Institute, 91b] Iacocca Institute, Lehigh University, *21st Century Manufacturing Enterprise Strategy*, Volume 2: Infrastructure, 1991.
- [ICAM, 81] *Integrated Computer Aided Manufacturing (ICAM) Architecture Part II, Volume IV - Functional Modelling Manual (IDEF0)*, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio 45433, AFWAL-TR-81-4023.
- [ICEIMT WSIII WG1, 92] The Integration Domain and the Execution Environment: Report of Workgroup 1 of ICEIMT Workshop III, in *Enterprise Integration Modelling: Proceedings of the First International Conference of Enterprise Integration Modelling Technology (ICEIMT)*, Edited by Charles J. Petrie, Jr. The MIT Press, 1992.
- [IEE/PGC5, 95] *Colloquium on Human Centred Automation*, Computer and Control Division, Professional Group C5, IEE, 1995.
- [IEM, 96] G. Spur, K. Mertins and R. Jochem, *Integrated Enterprise Modelling*, Beuth, 1996.
- [IMPACT, 91] IMPACT, ESPRIT No.2165, in *Proceedings of Workshop Integrated Modelling of Products and Process Using Advanced Computer Technologies*. Feb. 1991.
- [IPSYS, 92] IPSYS SOFTWARE P.C., *IPSYS ToolBuilder Version 1.3 - Methods and Concepts Manual*, 1992.
- [ISO, 90] *Reference Model for Shop Floor Production Standards*. Technical Report 10314, Part 1.(ISO TC 184/SC5/WG1 N126) and Part 2 (ISO TC 84/SC5/WG1 N160), 1990.
- [ITHINK, 94] *Introduction to Systems Thinking and Ithink*, High Performance Systems Inc., 1994.
- [Jeffers, 82] John N. R. Jeffers, *Modelling*, Chapman and Hall, 1982.
- [Jensen, 87] K. Jensen, Coloured Petri Nets: A Way to Describe and Analyse Real World Systems - Without Drowning in Unnecessary Details, in *Proceedings of the 5th International Conference on Systems Engineering*, New York: IEEE, 395-401, Dayton 1987.
- [Johannsen, 86] Gunnar Johannsen, Architecture of Man-machine Decision Making Systems, in NATO ASI Series. Vol. F21: *Intelligent Decision Support in Process Environments* Edited By E. Hollnagel et al. Springer-Verlag, 1986.
- [Karangelen et al, 94] Nicholas E. Karangelen, NgocDung T. Hoang and Steven Howell, Representing System Resources in Design and Analysis of Complex Systems, in PD-Vol. 59, *Software System Engineering*, ASME

1994.

- [Katzy, 96] B. Katzy, Case Study Examples of Enacting CIMOSA Models, in *Workshop of Process Modelling for Enterprise Integration with CIMOSA* at Loughborough University, March 27/28 1996.
- [Kidd, 90] Paul T. Kidd, Human Factor in CIM: An European Perspective, in *IEE Colloquium (digest) n007*. p2/1-2/7, 1990.
- [Kidd, 92] Paul. T. Kidd, *Organisation, People and Technology in European Manufacturing*, Published by Commission of the European Communities, ISBN 92-826-3819-7, 1992.
- [Kidd, 94] Paul T. Kidd, *Agile Manufacturing*, Addison-Wesley Publishing Company, 1994.
- [Kingdon, 73] D. R. Kingdon, *Matrix Organisations: Managing Information Technologies*, Tavistock Publications, London.
- [Knapp & Wang, 92] G. M. Knapp and H. P. Wang, Modelling of Automated Storage/retrieval Systems Using Petri Nets, in *Journal of Manufacturing Systems*, Vol 11, No 1, 20-29, 1992.
- [Koenig, 90] Daniel T. Koenig, *Computer Integrated Manufacturing*, London:Hemisphere, 1990.
- [Kosanke et al, 95] K. Kosanke, M. Mollo, F. Naccari and C. Reyneri, Enterprise Engineering with CIMOSA - Application at FIAT, in *Integrated Manufacturing Systems Engineering*, Edited by P. Ladet and F. Vernadat, 1995.
- [Kotsiopoulos, 96] I. L. Kotsiopoulos, CIMOSA: A Basis for an Unified Theory of Enterprise Models, in *Workshop of Process Modelling for Enterprise Integration with CIMOSA* at Loughborough University, UK, 1996.
- [Ladet & Vernadat, 95] P. Ladet and F. Vernadat, The Dimensions of Integrated Manufacturing Systems Engineering, in *Integrated Manufacturing Systems Engineering*, Edited by Pierre Ladet and Francois Vernadat, Chapman & Hall, 1995.
- [Lamarsh, 89] Jeanenne Lamarsh, Manufacturing Strategies and Change Management, in *Autofact'89*.
- [Le & Geitner, 94] W. -L. Le and U. W. Geitner, Assignment of Objective Systems in Team-Based Organisations, in *Concurrent Engineering: Research and Applications 1994 Conference*.
- [Leavitt, 75] Leavitt, H. J. Suppose We Take Group Seriously... in *Man and Work in Society*, Edited by E. L. Cass and F. G. Zimmer, Van Nostrand Reinhold, London.
- [Levy et al, 93] Paul Levy, John Bessant, David Tranfield, Stuart Smith and Clive Ley, Organisation Design Implications of Computer-Integrated Technologies, in *The International Journal of Human Factors in Manufacturing*, Vol. 3 (2) 169-182 (1993), John Willey & Sons, Inc.
- [Li, 95] G. Li, Organization Structure Research, Internal Report, MSI Research

Institute, Loughborough University, UK, 1995.

- [Li, 95-1] G. Li, Requirements for Resource Modelling, Internal Report, MSI Research Institute, Loughborough University, UK, 1995.
- [Li et al, 97] G. Li, R. H. Weston, S. Murgatroyd and P. Gilders, "Unified Resource Modelling in Support of Enterprise Engineering", *CIRP International Symposium'97*, Hong Kong, August, 97.
- [Likert, 61] Rensis Likert, *New Patterns of Management*, McGraw-Hill, New York, 1961.
- [Liu & Wu, 93] C. M. Liu and F. C. Wu, Using Petri Nets to Solve FMS Problems, in *Int. J. Computer Integrated Manufacturing*, Vol.6, No 3, 175-185, 1993.
- [Liu, 94] Liwen Liu, The Changing Manufacturing Organisation With CIM, in *Computers ind. Engng* Vol. 27, Nos 104, pp.131-134, Elsevier Science Ltd, 1994.
- [Lorsch, 70] Lorsch, J. W., Introduction to the Structural Design of Organizations, in, *Organizational Structural and Design*, Edited by G. W. Dalton, P.R.Lawrence and J. W. Lorsh, Illinois, 1970.
- [Lubben, 88] Richard T. Lubben, *Just-in-time Manufacturing:- An Aggressive Manufacturing Strategy*, McGraw-Hill Book Company, 1988.
- [Luscombe, 93] Martyn Luscombe, *MRPII: Integrating the Business*, Butterworth:Heinemann, 1993.
- [Majchrzak, 88] A. Majchrzak, *The Human Side of Factory Automation*, Jossey Bass, 1988.
- [Malone, 96] Thomas W. Malone, *Inventing The Organisations of The 21st Century: Control, Empowerment, And Information Technology*, <http://www/mit.edu>, 1996.
- [Martin, 70] S. J. Martin, *Numerical Control of Machine Tools*, Hodder & Stoughton, 1970.
- [Mathews, 95] John Mathews, Organisational Foundations of Intelligent Manufacturing Systems - the Holonic Viewpoint, in *Computer Integrated Manufacturing Systems* Vol.8 No.4, pp.237-243, Elsevier Science Ltd, 1995.
- [Mayer & Painter, 91] R. J. Mayer and M. K. Painter, *IDEF Family of Methods*, College Station, TX: Knowledge Based Systems, Inc., 1991.
- [Mayer et al, 92] R. J. Mayer et al, *IDEF Family of Methods for Concurrent Engineering and Business Re-engineering Applications*, Knowledge-Based Systems, Inc., 1992.
- [Mayer et al, 96] R. J. Mayer et al, *IDEF Compendium*, WPAFB, OH:AL/HRGA, 1996.
- [McPherson & White, 94] Ronald F. McPherson, Management Control and the Manufacturing Hierarchy: Managing Integrated Manufacturing Organisations, in *The International Journal of Human Factors in*

Manufacturing, Vol. 4 (2) 121-144 (1994), John Willey & Sons, Inc.

- [Merchant, 91] M. E. Merchant, CIM - Its Evolution, Precepts, Concepts, Status and Trends, in *CIM Computer-Integrated Manufacturing: Perspectives for International Economic Development and Competitiveness*, United Nations Economic Commission for Europe, Geneva, United Nations Industrial Development Organisation, Vienna, 1991.
- [Mertins et al, 95] K. Mertins, H. Edeler, R. Jochem, J. Hofmann, Object-oriented Modelling and Analysis of Business Processes, in *Integrated Manufacturing Systems Engineering*, Edited by P. Ladet and F. Vernadat, Chapman & Hall, 1995.
- [Meshkati, 91] Najmedin Meshkati, Human Factors in Large-Scale Technological Systems' Accidents: Three Mile Island, Bhopal, Chernobyl, in *Industrial Crisis Quarterly* 5 (1991) 133-154, Elsevier.
- [Miltenburg, 97] J. Miltenburg, Comparing JIT, MRP and TOC, and Embedding TOC into MRP, in *Int. J. Prod. Res.*, 1997, Vol.35, No.4, 1147-1169.
- [Mintzberg, 83] H. Mintzberg, *Structure in Fives*, Prentice Hall, 1983.
- [Mintzberg, 89] H. Mintzberg, *Mintzberg on Management*, The Free Press, 1989.
- [Mital, 91] Anil Mital, Manual Versus Flexible Assembly: A Cross Comparison of Performance and Costs in Four Different Countries, in *Production Research: Approaching the 21st Century*, Edited by M. Pridham and C. O'Brien, Taylor & Francis, 1991.
- [Molloy, 82] M. K. Molloy, Performance Modelling Using Stochastic Petri Nets, *IEEE Transactions on Computers*, C-31, No. 9, pp913-917, Sept 1982.
- [Molloy, 89] Michael K. Molloy, Petri Net Modelling, the Past, the Present, and the Future, in *Proceedings of the 3rd International Workshop*, 1989.
- [Monfared, 96] Radmehr Pourtafreshi. Monfared, An Approach to the Definition and Construction of Manufacturing Cells Based on Extensions to CIMOSA Concept, Internal Report, MSI Research Institute, Loughborough University, 1996.
- [Monfared & Weston, 97] R. P. Monfared and R. H. Weston, The Reengineering and Reconfiguration of Manufacturing Cell Control Systems and Re-use of Their Components, Submitted to Proceedings Part B, Journal of Engineering Manufacture, Jan.1997.
- [MSI, 97] EPSRC/CDP Ground Review Report: Manufacturing Software Interoperability: Steps Towards Interoperating Distributed Objects, MSI Research Institute, Loughborough University, January 1997.
- [Munro-Faure, 92] Lesley Munro-Faure, *Implementing Total Quality Management*, London: Pitman, 1992.
- [Murgatroyd, 95] I. S. Murgatroyd, An Information Modelling Methodology and Associated Tools Applied to the SPEAR Project: A Feasibility Study, Internal Report, MSI Research Institute, Loughborough University, UK, 1995.

- [Murgatroyd, 96] I. S. Murgatroyd, Internal Seminar on ITHINK Process Modelling Tool, MSIRI, Loughborough University, UK, 1996.
- [Murrell, 65] K. F. M. Murrell, *Ergonomics- Man in His Working Environment*, Chapman and Hall, First Printed in 1965, and Reprinted in 1986.
- [Naguib & Chen, 94] Hussein Naguib and Shau-Ron Chen, Achieving High Performance Teamwork in a Semiconductor Manufacturing Operation, in *1994 IEEE/SEMI Advanced Semiconductor Manufacturing Conference*.
- [NIIP, 94] National Industrial Information Infrastructure Protocols (NIIP) (Are Being Developed in US From September 1994), Source: <http://www.niip.org>, 2/4/97.
- [NIST, 93] NIST, Federal Information Processing Standards Publication 183, December 21, 1993. Source: <http://nemo.ncsl.nist.gov/standsp>, 2/4/97.
- [Nof et al, 80] Shimon Y. Nof et al, Control and Decision Support in Automatic Manufacturing Systems, in *AIIE Transactions*. Vol 12 No 2 June 1980.
- [Norrie et al, 95] Moira C. Norrie, Martin Wunderli, Robert Montau, Uwe Leonhardt, Werner Schaad and Hans-Jorg Schek, Coordination Approaches for CIM, in *Integrated Manufacturing Systems Engineering*, Edited by Pierre Ladet and Francois Vernadat, Chapman & Hall, 1995.
- [Oakland & Porter, 95] John S. Oakland and Leslie J. Porter, *Total Quality Management: Text with Cases*, Oxford: Butterworth-Heinemann, 1995.
- [OMG'S MSIG, 96] Manufacturing Enterprise Systems, A White Paper, by the Object Management Group's Manufacturing Special Interest Group, Version 0.99, 1996.
- [O'Neil, 95] Henrigue O'Neil, *Decision Support in the Extended Enterprise - A Human Centred Model for Organisational Improvement and performance Assessment*, PhD Thesis, Cranfield University, 1995.
- [OPENframework, 93] ICL/OPENframework Division, OPENframework - Overview of Methods, Issue 1.2, England, 1993.
- [Orfali et al, 96] Robert Orfali, Dan Harkey and Jeri Edwards, *The Essential Distributed Objects Survival Guide*, John Wiley & Sons, Inc. 1996.
- [Papastavrou & Nof, 92] Jason D. Papastavrou and Shimon Y. Nof, Decision Integration Fundamentals in Distributed Manufacturing Topologies, in *IIE Transactions*, July 1992.
- [Peters, 87] T. J. Peter, *Thriving on Chaos*, Alfred Knopf, New York, 1987.
- [Peterson, 81] J. L. Peterson, *Petri Net Theory and the Modelling of Systems*, Prentice-Hall, Inc., 1981.
- [Petrie, 92] Charles J. Petrie, Jr., Introduction, in *Enterprise Integration Modelling: Proceedings of the First International Conference of Enterprise Integration Modelling Technology (ICEIMT)*, Edited by Charles J. Petrie, Jr. The MIT Press, 1992.
- [Popplewell & Bell, 94] K. Popplewell and R. Bell, A Comprehensive Methodology

for Factory Modelling, in *Proceedings: Applications and Innovations in Expert Systems II*, Edited by R. Milne and A. Montgomery, SGES Publications, 1994.

[Prasad, 96] Biren Prasad, *Concurrent Engineering Fundamentals: Integrated Product Development*, Volume II, Prentice Hall PTR, 1996.

[ProcessWise, 94] Introduction to ProcessWise, ICL, 1994.

[Pugh & Hickson, 68] Pugh, D. S and Hickson, D. J., The Comparative Study of Organizations, in *Industrial Society*, Edited by D. Pym, Penguin Books, Harmondsworth, 1968.

[Ranky, 86] P. Ranky, *Computer Integrated Manufacturing*, Prentice-Hall International UK Ltd, 1986.

[Rattner & Reid, 94] Laurie Rattner and Richard A. Reid, The Information Processing Roles for Mid-level Production Management in Agile Manufacturing, Systems, in *Man and Cybernetics, IEEE CONF 1994*, Vol 1 pp 518-524.

[Ravichandran, 86] R. Ravichandran, Decision Support in Flexible Manufacturing System Using Petri Nets, in *Journal of Manufacturing Systems*, Vol.5 No.2, 1986.

[Rehder, 94] Robert R. Rehder, Saturn, Uddevalla and Japanese Lean Systems: Paradoxical Prototype for the Twenty-first Century, in *The International Journal of Human Resource Management*, 5:1 February, 1994.

[Rembold et al, 93] U. Rembold, B.O. Nnaji and A. Storr, *Computer Integrated Manufacturing and Engineering*, Addison-Wesley, 1993.

[Rosenbrock, 89] H.H. Rosenbrock (Ed), *Design Human-Centred Technology: Across-disciplinary Project in Computer-Aided Manufacturing*, Springer-Verlag, 1989.

[Salvendy, 87] Edited by G. Salvendy, *Handbook of Human Factors*, Wiley, 1987.

[SAP, 96] *The Magazine of the SAP Group*, SAP AG, March 1996.

[Sayer, 94] P. Sayer, Environmental Management, in *Advances in Manufacturing Technology VIII- Proceedings of the Tenth National Conference on Manufacturing Research*, Edited by K. Case and S. Newman, Taylor & Francis, 1994

[Scheer, 88] A. -W. Scheer, *CIM Computer Integrated Manufacturing-Computer Steering Industry*, Springer-Verlag, Berlin Heidelberg 1988.

[Scheer, 94] A. -W. Scheer, *Business Process Engineering: Reference Models for Industrial Enterprises*, Second Edition, Springer-Verlag, 1994.

[Schlotz, 96] C. Schlotz, Production Reorganisation at the Machine Tool Manufacturer TRAUB/Germany, in *Workshop of Process Modelling for Enterprise Integration with CIMOSA*, Loughborough University, 1996.

[Schonberger, 82] R.G. Schonberger, Some Observations on the Advantages and Implementation issues of Just-In-Time Production Systems, in *J. Oper.*

Mgmt., 3:1-11, 1982.

- [SEMATECH, 94] *Computer Integrated Manufacturing (CIM) Application Framework Specification 1.2*, SEMATECH Technology Transfer 8306169D-ENG, 1994.
- [Shaharoun, 94] A M Shaharoun, *A New Approach to the life-Cycle of Costing Systems for Advanced Manufacturing Environments*, PhD thesis, Loughborough University of Technology, UK, 1994.
- [Sharit, 88] J. Sharit, Issues in Modelling Supervisory Control in Flexible Manufacturing Systems, in *Ergonomics of Hybrid Automated Systems I*, Edited by W. Karwowski, H. R. Parsaei and M. R. Wilhelm, Elsevier Science Publishers, 1988.
- [Sheridan, 87] Thomas B. Sheridan, Supervisory Control, in *Handbook of Human Factor*, Edited by G. Salvendy, Wiley, 1987.
- [Shorter, 94] David Shorter, An Evaluation of CIM Modelling Constructs: Evaluation Report of Constructs for Views According to ENV 40 003, in *Computer in Industry*, 24 (1994) 159-236, Elsevier Science B. V.
- [Siemieniuch et al, 93] C. E. Siemieniuch and M. A. Sinclair, Implications of Concurrent Engineering for Organisational Knowledge and Structure - A European, Ergonomics Perspective, in *J. of Design & Manufacturing*, 1993, 3, 189-200 - Prof. A Mital (Special Issue Editor).
- [Simpson et al, 82] J. A. Simpson, R. J. Hocken, J. S. Albus, The Automated Manufacturing Research Facility of the National Bureau of Standards, in *Journal of Manufacturing Systems*, Vol.1, No. 1, 1982.
- [Sinclair, 88] M. A. Sinclair, Future AMT and Ergonomics: Knowledge, Organisational Issues and Human Roles, in *Applied Ergonomics*, 1988, 19.1, 49-54.
- [Softwareguide, 97] World Web Site: <http://www.softwareguide.com>, June, 1997.
- [Spreadbury, 94] Alan Spreadbury, Manufacturing Resource Planning, in *New Wave Manufacturing Strategies: Organizational and Human Resource Management Dimensions*, Paul Chapman Publishing Ltd, 1994.
- [Stahre, 95] Johan Stahre, Evaluation Human/machine Interaction Problems in Advanced Manufacturing, in *Computer Integrated Manufacturing Systems*. Vol 8 No 2 pp143-150, 1995.
- [Storey, 94] John Storey, New Wave Manufacturing Strategies: An Introduction, in *New Wave Manufacturing Strategies: Organizational and Human Resource Management Dimensions*, Paul Chapman Publishing Ltd, 1993.
- [Suda, 89] Hiroharu Suda, Future Factory System Formulated in Japan - Outline, of 5th Report on FFS, in *TECHNO JAPAN*, Vol.22 - No.10, October 1989.
- [Suda, 90] Hiroharu Suda, Future Factory System Formulated in Japan (2) - Outline of 5th Report on FFS, in *TECHNO JAPAN*, Vol.23- No.3, March 1990.
- [Suri, 84] Rajan Suri, Decision Support Requirements in Flexible Manufacturing, in *Journal of Manufacturing Systems* 1984 Vol 3 pp 61-69.

- [Syan, 94] Chanan S Syan, Concurrent Engineering Practice in UK: A Survey, in *Advances in Manufacturing Technology VIII- Proceedings of the Tenth National Conference on Manufacturing Research*, Edited by K. Case and S. Newman, Taylor & Francis, 1994.
- [Temple, 86] Robert K. G. Temple, *CHINA: Land of Discovery*, Wellingborough: Stephens, 1986.
- [Toomey, 96] John W. Toomey, *MRPII: planning for manufacturing excellence*, New York: Chapman & Hall, 1996.
- [TOVE, 92] Fox, Mark S., Chionglo, John, Fadel, Fadi George, *The Toronto Virtual Enterprise Model*, Enterprise Integration Laboratory, University of Toronto, 1992.
- [Tucker, 89] Walter W Tucker, The Limits of Automation: Social-technical Engineering in Manufacturing Assembly, in *Autofact' 89*.
- [Valckenaers et al, 94] P. Valckenaers, H. Van Brussel, F. Bonneville, L. Bongaerts and J. Wyns, IMS Test Case 5: Holonic Manufacturing Systems, in *IFAC Intelligent Manufacturing Systems*, pp31-36, Conf, Vienna, 1994.
- [Vernadat, 93] F. Vernadat, CIMOSA: Enterprise Modelling and Enterprise Integration Using a Process-Based Approach, in *Information Infrastructure Systems for Manufacturing (B-14)*, H. Yoshikawa and J. Goossenarts (Editors), Elsevier Science B. V. (North-Holland) 1993.
- [Vernadat, 96] F. Vernadat, *Enterprise Modelling and Integration Principles and Applications*, Chapman & Hall, 1996.
- [Vidgen et al, 94] Richard Vidgen, Jeremy Rose, Bob Wood and Trevor Wood-Harper, Business Process Reengineering: The Need for a Methodology to Revision the Organisation, in *Business Process Re-engineering: Information Systems Opportunities and Challenges (A-54)* / B.C. Glasson et al. (Editors), Elsevier Science B. V. (North-Holland, 1994.
- [Wallace, 85] T. F. Wallace, *MRPII: Making It Happen*, Oliver Wright Co. Essex Junction, Vermont, 1985.
- [Wang & Wang, 95] H. M. Wang and H. B. Wang, Generation of Optimal Operating Strategies for Robotic Cells: a Petri Nets Approach, in *Int. J. Integrated Manufacturing*, Vol. 9, No. 1, 73-87, June, 1995.
- [Warnecke, 93] H. J. Warnecke, *The Fractal Company - Revolution in Corporate Culture*, Springer-Verlag, 1993.
- [Weick, 79] K. Weick, *The Social Psychology of Organizing*, Addison-Wesley, 1979.
- [Weston et al, 90] R. H. Weston, A. Hodgson, I. Coutts, I S Murgatroyd and J. D. Gascoigne, Highly Extendable CIM Systems Based on an Integration Platform, in *CIMCON '90*.
- [Weston, 91] R. H. Weston, CIM Enterprises of the 21st Century, in *Proceedings of ICCIM'91*, Singapore, 2-4 October, 1991.
- [Weston, 94] R. H. Weston, Requirements and Trends in Manufacturing Systems, in *Advances in Manufacturing Technology VIII- Proceedings of the Tenth*

National Conference on Manufacturing Research, Edited by K. Case and S. Newman, Taylor & Francis, 1994.

- [Weston et al, 95] R. H. Weston, J. M. Edwards, A. Hodgson, Model Driven CIM: A Framework and Toolset for the Design, Implementation and Management of Open CIM Systems, Final Project Report to EPSRC, 1995.
- [Weston & Gilders, 96] R. H. Weston and P. J. Gilders, Enterprise Engineering Methods and Tools which Facilitate Simulation, Emulation and Enactment via Formal Models, in *Modelling and Methodologies for Enterprise Integration*, Edited by Peter Bernus and Laszlo Nemes, Chapman & Hall, 1996.
- [Weston, 96] R. H. Weston, Model Driven Configuration of Manufacturing Systems in Support of the Dynamic, Virtual Enterprise, in *Advances in Concurrent Engineering - CE96*, p425-439, Canada, 1996.
- [Weston, 96-1] R. H. Weston, World Class Manufacturing Maintaining Order at the Edge of Chaos, EPSRC Senior Fellowship Application Paper, MSI Research Institute, Loughborough University, 1996.
- [Weston & Hodgson, 96] R. H. Weston and A. Hodgson, Report on Scenario Planning Exercise, MSIRI Pub, Loughborough University, UK, 1996.
- [Weston, 97] R. H. Weston, Next Generation of Manufacturing Enterprises, in *GIRP International Symposium on Advanced Design and Manufacture in the Global Manufacturing Era*, Hong Kong, 1997.
- [Williams, 94] Theodore J. Williams, The Purdue Enterprise Reference Architecture, in *Computers in Industry* 24 (1994) 141-158.
- [Williams et al, 94] T. J. Williams, P. Bernus, J. Brosvic, D. Chen, G. Doumeingts, L. Nemes, J. L. Nevins, B. Vallespir, J. Vlietstra, D. Zoetekouw, Architectures for Integrating Manufacturing Activities and Enterprises, in *Computers in Industry* 24 (1994) 111-139, Elsevier.
- [Williams, 95] T. J. Williams, Development of GERAM, A Generic Enterprise Reference Architecture and Enterprise Integration Methodology, in *Integrated Manufacturing Systems Engineering*, Edited by Pierre Ladet and Francois Vernadat, Chapman & Hall, 1995.
- [Williams et al, 96] Theodore J. Williams, Gary A. Rathwell, Hong Li, *A Handbook on Master Planning and Implementation for Enterprise Integration Programs: Based on the Purdue Enterprise Reference Architecture and the Purdue Methodology*, Report Number 160, Purdue Laboratory for Applied Industrial Control, June 1996.
- [Wilson, 92] Peter Wilson, Information Modelling and EXPRESS, *Reference Documents, Second Annual EXPRESS User's Group EUG'92*.
- [Winograd, 88] Terry Winograd, Where the Action Is, in *Byte*, December 1988.
- [Winograd et al, 91] Terry Winograd, Nancy (Tigger) Newman and Peter P. H. Yim, Including People In Computer Integrated Manufacturing Designs, in *Proceedings of ICCIM'91*, Singapore, 2-4 October, 1991.

- [Winters et al, 94] C. Winters, D. Steeple and G. Sara, Activity Based Cost Management: A Method for Analysing Strategic Options in Manufacturing Organisations, in *FACTORY 2000 - Advanced Factory Automation 4th Int. Conf.* 1994. Vol 398 pp220-226.
- [Womack, 90] J. P. Womack, D. Jones and D. Roos, *The Machine that Changes the World*, Rawson Associates, New York, 1990.
- [Woodson, 81] Wesley E. Woodson, *Human Factors Design Handbook*, McGraw-Hill Book Company, 1981.
- [Wortmann, 92] J. C. Wortmann, Enterprise Modelling: Purposes and Means, in *Enterprise Integration Modelling: Proceedings of the First International Conference of Enterprise Integration Modelling Technology (ICEIMT)*, Edited by Charles J. Petrie, Jr. The MIT Press, 1992.
- [Yim, 91] Peter Yim, CIM3-Computer Integrated Man-Machine Manufacturing Systems: An Introduction, in *Proceedings of ICCIM'91*, Singapore, 2-4 October, 1991.
- [Yim & Barta, 94] D. S. Yim and T. A. Barta, A Petri Nets Based Simulation Tool for the Design and Analysis of FMS, in *Journal of Manufacturing Systems*, Vol.13, No.4, pp251-261, 1994.
- [Young, 89] Andrew Young, Charles Slem and Daniel Levi, CIM: The Social Impact, in *Autofact'89*.
- [Zairi, 91] Mohamed Zairi, *Total Quality Management For Engineers*, Woodhead Publishing Limited, 1991.

Appendix 2: Publications

1. Papers Published during the PhD Study Years:

- [1] G. Li and R. H. Weston, "An Open Approach Enabling the Structured Integration of Shop Floor Personnel", in Proceedings of International Conference of CIM, Beijing, China, 1993.
- [2] G. Li, R. H. Weston, S. Murgatroyd and P. Gilders, "Unified Resource Modelling in Support of Enterprise Engineering", CIRP International Symposium'97, Hong Kong, August, 97.
- [3] G. Li, R. H. Weston, S. Murgatroyd and P. Gilders, "Implementation of A Resource Modelling Tool", The First International Conference of Managing Enterprises - Stakeholders, Engineering, Logistics and Achievement", UK, July 1997.
- [4] G. Li and R. H. Weston, "A Framework for Modelling Manufacturing Resources in Support of Enterprise Engineering", The First International Post-Graduate Symposium: KE-MLM'97, Loughborough, UK, July, 1997.

2. Papers Submitted

- [5] G. Li and R. H. Weston, "Manufacturing Paradigm Review and Next Generation Manufacturing Enterprises", submitted to ISOMA'98, Sixth International Symposium on Manufacturing with Applications, Alaska, USA, 1998.

Appendix 3: Models Generated for Case Study One

1.Example Information Templates for Each Type of resource

(Human, Machine and Application)(6 pages)

2.Resource Classification (1 page)

3.An Example of Organisational Chart (1 page)

4.Context Diagram (1 page)

5.Domain Diagram (1 page)

6.Structure Diagram 1 (1 page)

7.Structure Diagram 2 (1 page)

8.Functional Diagram 1 (1 page)

9.Functional Diagram 2 (1 page)

10.Behaviour Diagrams for Business Process and Enterprise

Activities (18 pages)

11.Object Diagram (1 page)

12.Resource Diagram (1 page)

13.Configuration Diagram (1 page).

=====
+ Basic Information +
=====

Name: Peter
Code HR
Unit <unit>

Behavioural Information
=====

File Name: <name>
Location: <location>

Cost Information
=====

Capital Cost: 0
Maintenance Cost: 0
Overheads: 0

Running Costs

Status Information
=====

Capac Occupied: 0
On-line Status: <status>

Structure Information
=====

Part Of: <part>
Consists Of: <consists>

Capability Information
=====

Capabilities

prepare manuf info
operating cut machine
operating drill
operating mill
shop floor manager

=====
+ Human Related Data +
=====

Identification Data
=====

Date of Birth: <date of birth>
Place of Birth: <place of birth>
Employee No: <employee number>
Address: <address>
Sex: <sex>

Present Position Data
=====

Date: <date>
Job Title: <job title>

Length of Employment: <length of employment>

Evaluation Data

=====

Result: <result>
Date: <date>
Date of Next: <next date>
Performance Ratings: <performance ratings>

Banking Data

=====

Account No: <account number>
Bank: <bank>

Payroll Data

=====

Contract Wage Rate: <wage rate>
Shift Differential: <differential>
Overtime Pay: <overtime>
Mileage Rate: <mileage>
Income Tax Class: <tax>
Tax Free Allowance: <allowance>
Cumulative Tax Withheld: <tax>
Tax Office: <office>
Social Security Information: <information>
Vacation Entitlement: <entitlement>

Experiences

Qualifications

=====
+ Basic Information +
=====

Name: 4 AXIS HORIZONTAL MACHINING CENTRE
Code MM1
Unit <unit>

Behavioural Information
=====

File Name: <name>
Location: <location>

Cost Information
=====

Capital Cost: 93295
Maintenance Cost: 30
Overheads: 40

Running Costs

Status Information
=====

Capac Occupied: 0
On-line Status: <status>

Structure Information
=====

Part Of: <part>
Consists Of: <consists>

Capability Information
=====

Capabilities

drilling1
drilling2
milling
reaming
threading1
threading2
boring

=====
+ Machine Related Data +
=====

Technical Specifications

Specification Data
=====

Specification: CINCINNATI MILACRON/SABRE 400H/ACRAMATIC 850 SX COMPUT
ER NUMERICAL CONTROL

Specification Data
=====

Specification: AXIS CAPACITY X=560MM Y=460MM Z=510MM B=ROTARY
Specification Data

=====
Specification: SPINDLE SPEED 60-8000rpm
Specification Data
=====
Specification: DRIVE MOTOR 11.2kw (15hp)
Specification Data
=====
Specification: FEED RATES 0-20m/min
Specification Data
=====
Specification: TOOL CAPACITY 60 tools
Specification Data
=====
Specification: SPINDEL TYPE ANSI-40 I.S.O.

Maintenance Histories

Environment Support Data
=====

Human Job Title: <title>
Power: <power>
Support Machine: <machine>
Others: <others>

=====
+ Basic Information +
=====

Name: PEPS
Code AP7
Unit <unit>

Behavioural Information
=====

File Name: <name>
Location: <location>

Cost Information
=====

Capital Cost: 0
Maintenance Cost: 0
Overheads: 0

Running Costs

Status Information
=====

Capac Occupied: 0
On-line Status: <status>

Structure Information
=====

Part Of: <part>
Consists Of: <consists>

Capability Information
=====

Capabilities

CAD/2D
CAD/Surface modelling
CAM/Milling
CAM/Turning
CAM/Burning
CAM/Punching and Nibbling
CAM/Cutting (laser)
CAM/EDM

=====
+ Application Related Data +
=====

Functional Description
=====

Environment Support
=====

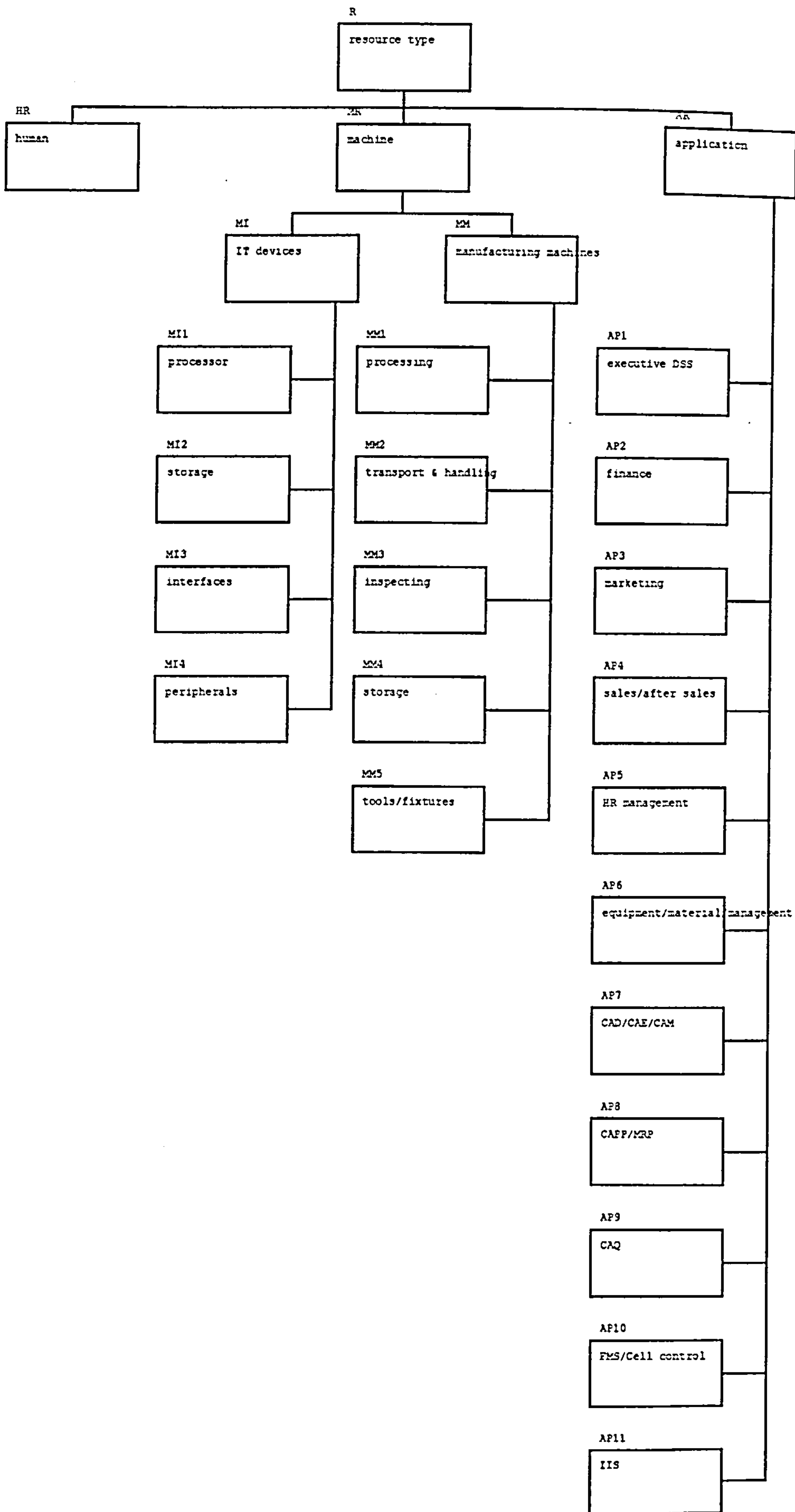
Operating System: <system>
Network: <network>

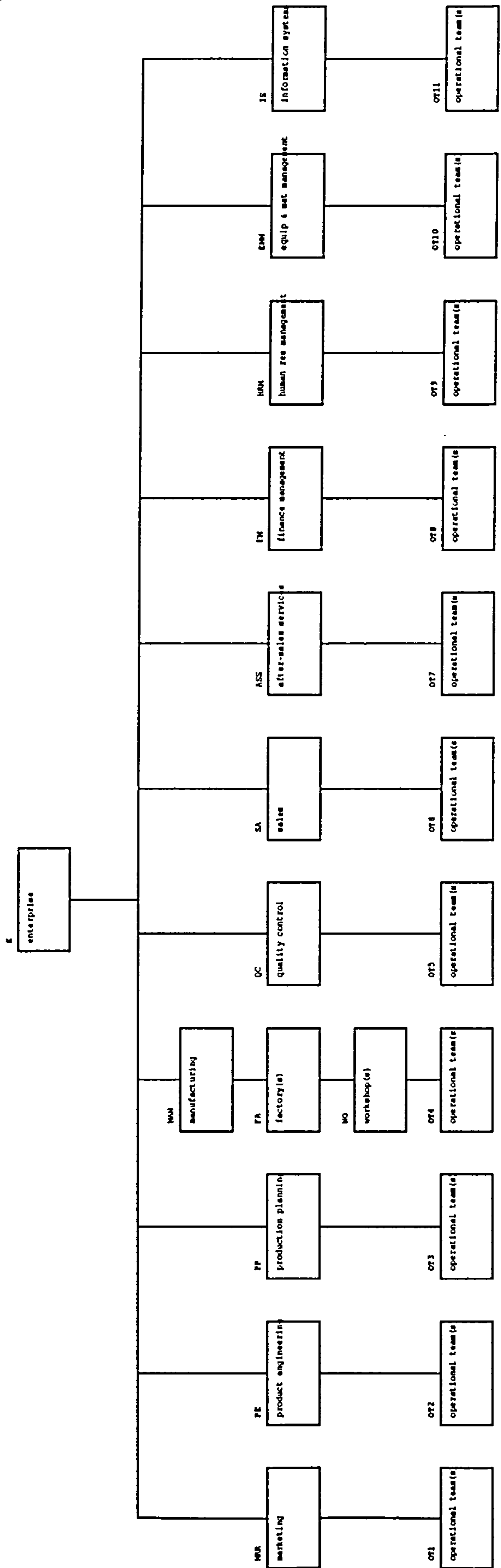
Case Tools: <tools>
Hardware: <hardware>
Human Job Title <title>

Interface Description

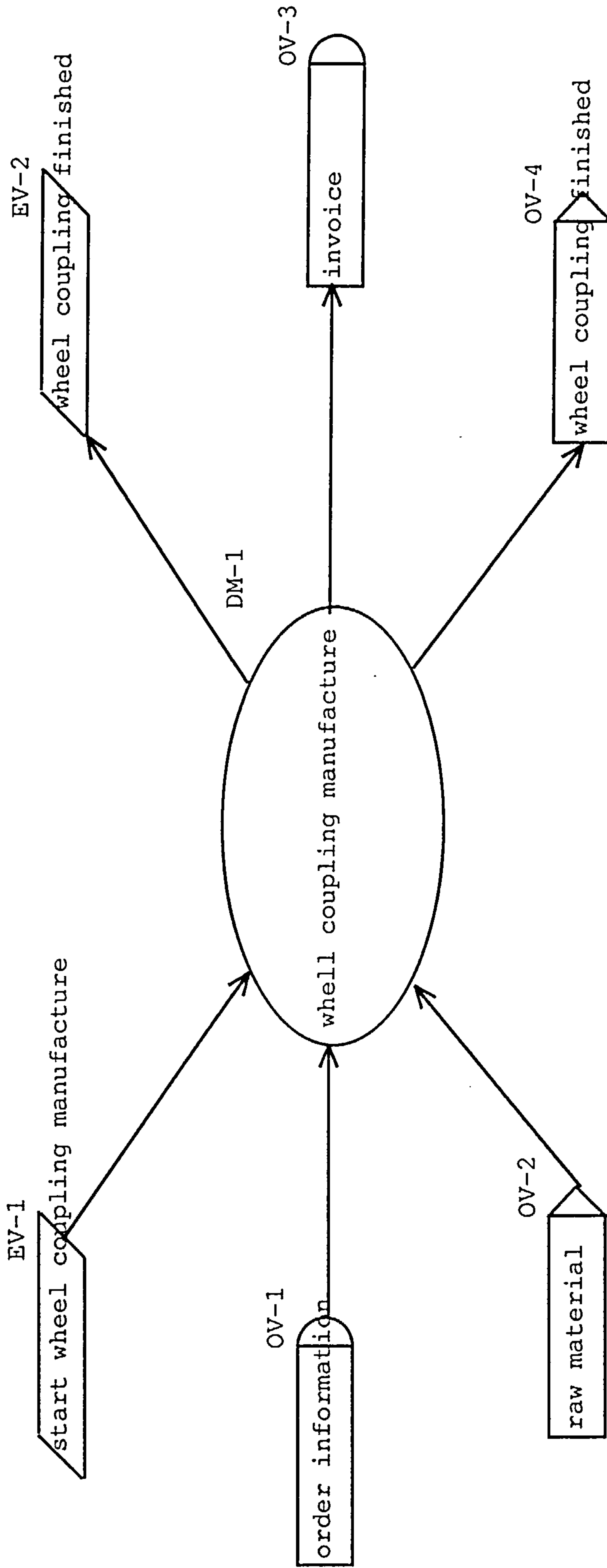
=====

Input: <input>
Output: <output>
Others: <others>

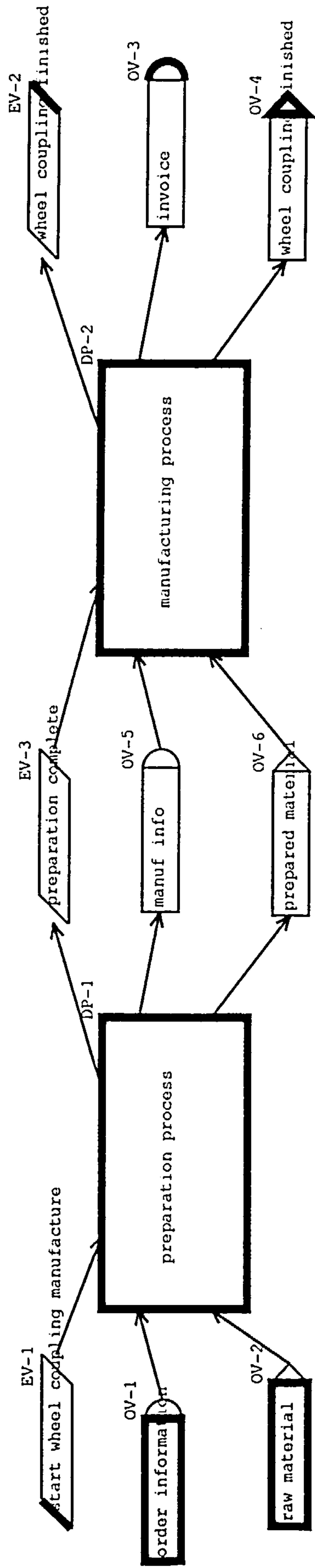




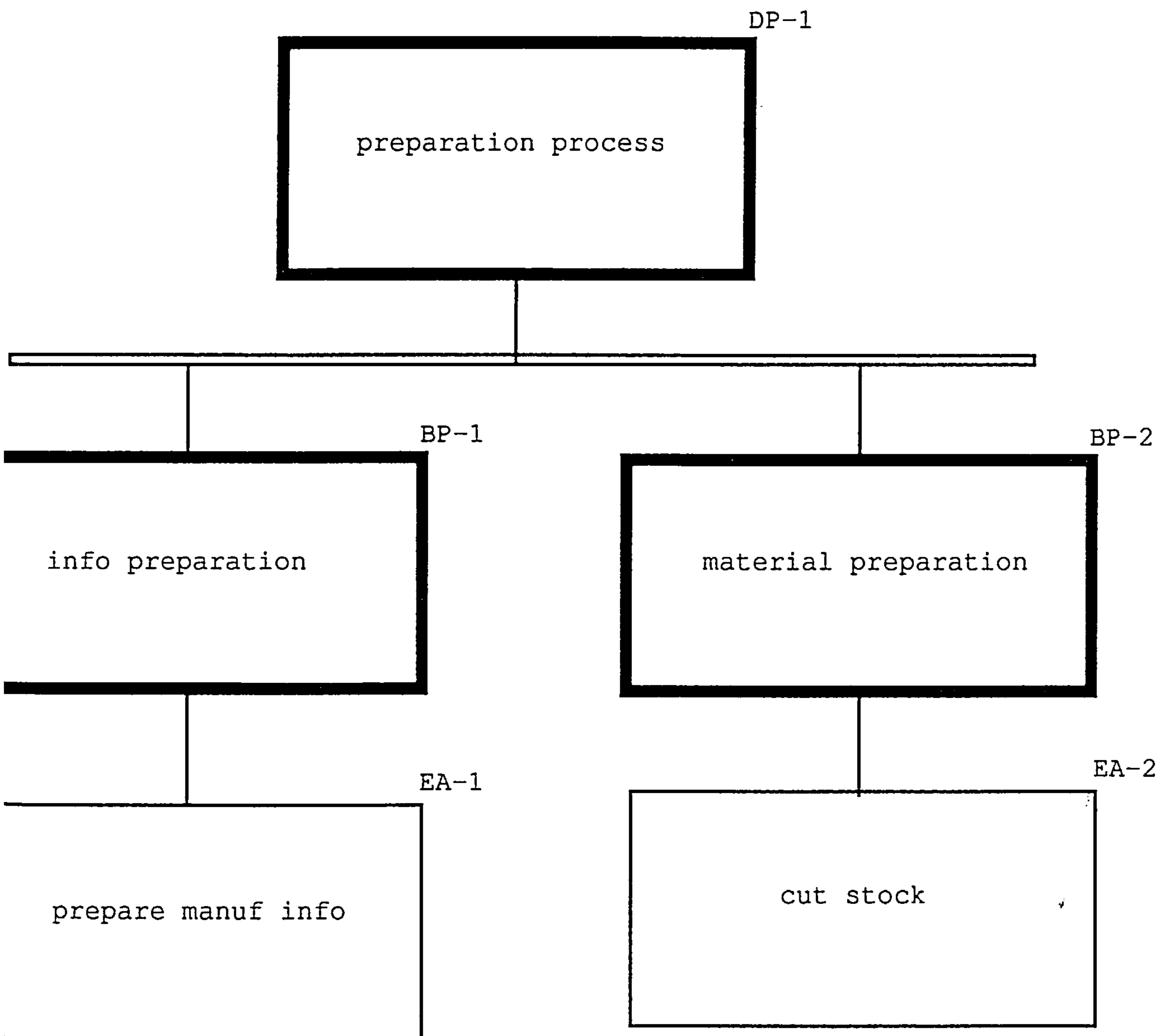
Context Diagram: wheel coupling manufacturing



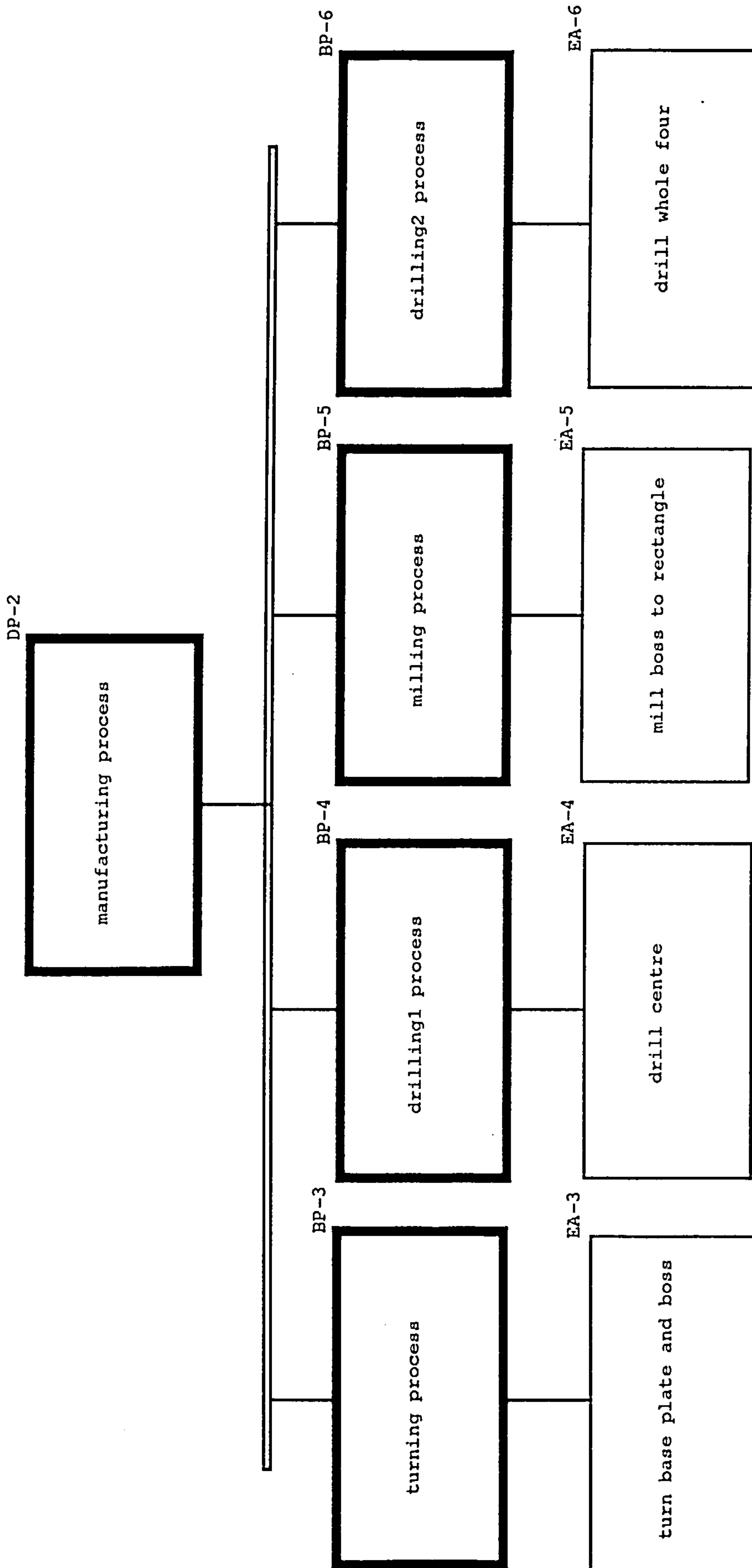
Domain Diagram: wheel coupling manufacture



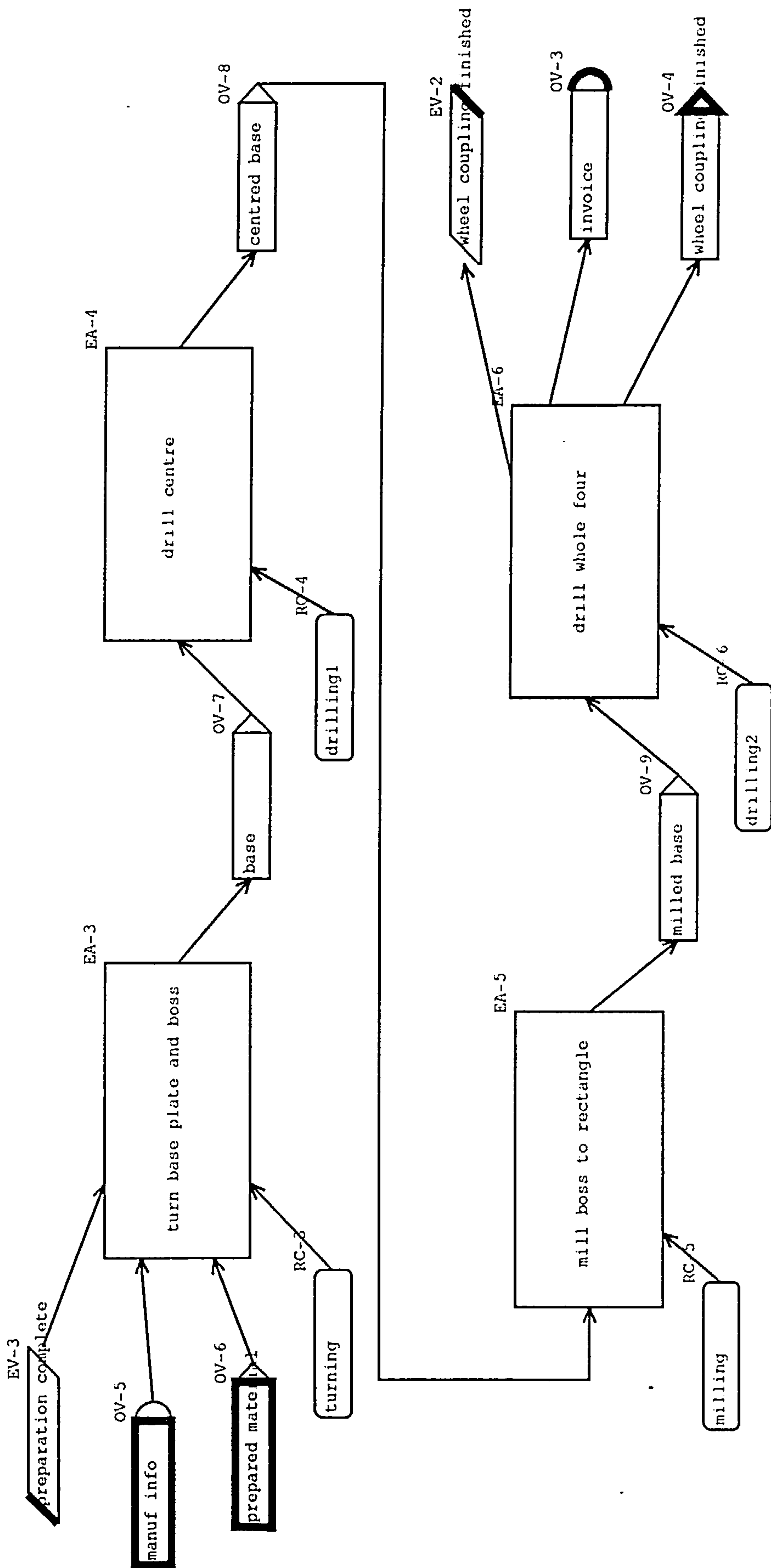
Structure Diagram: preparation process



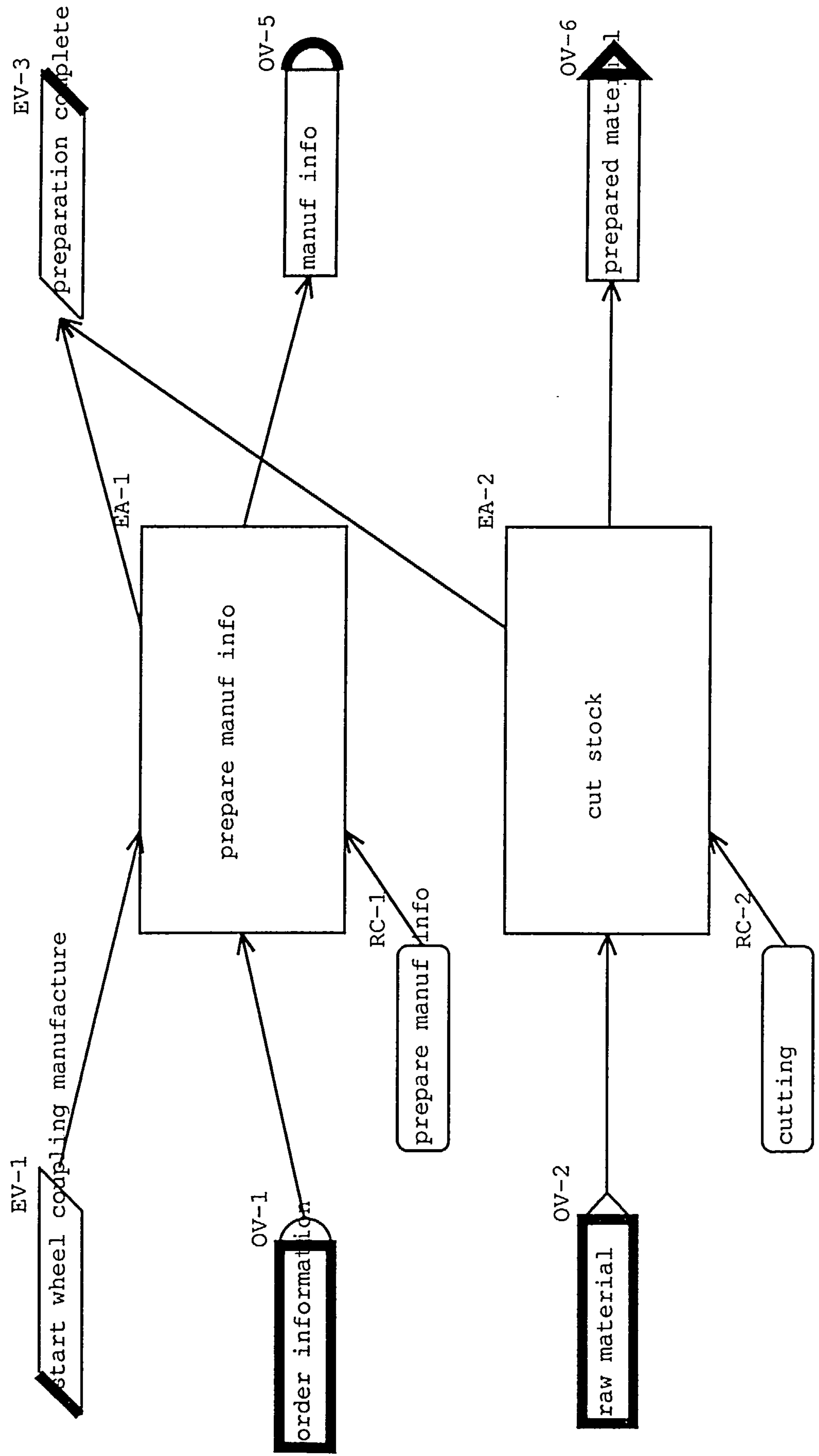
Structure Diagram: manufacturing process



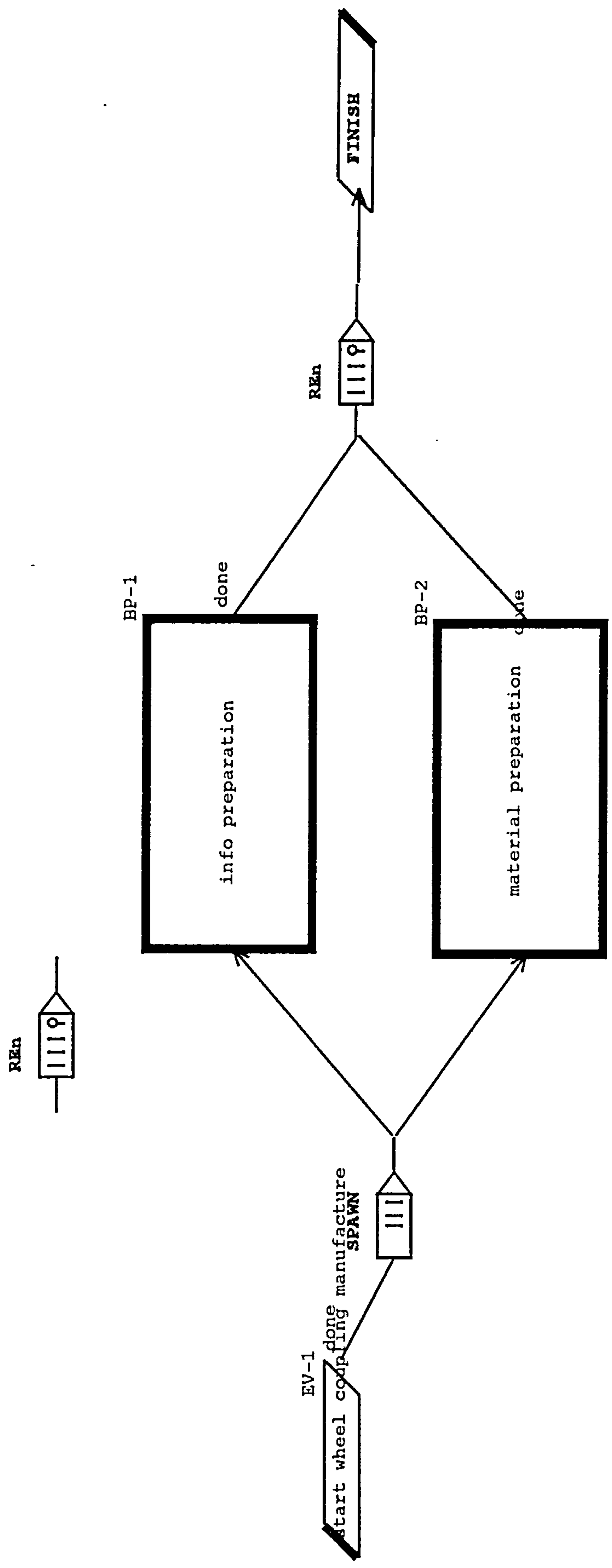
Functional Diagram: manufacturing process



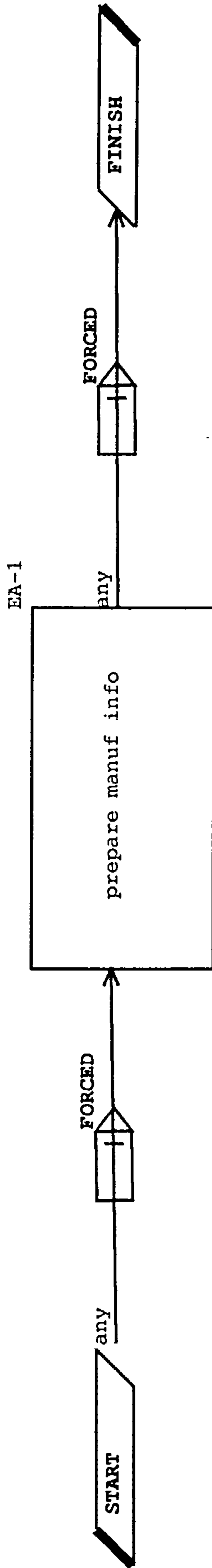
Functional Diagram: preparation process



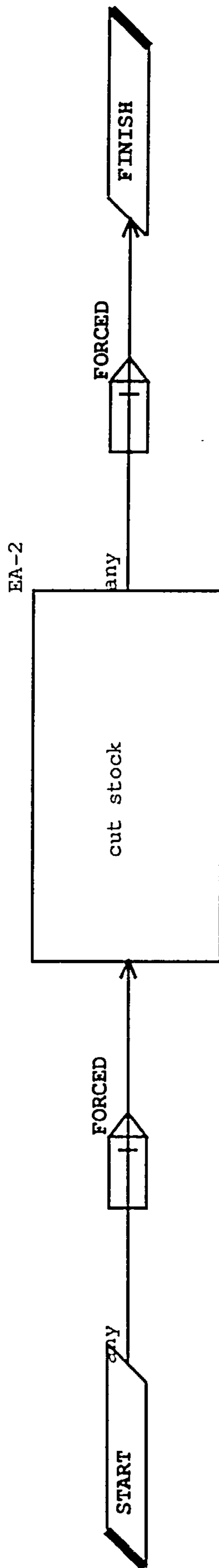
SPAWN
Behaviour Diagram: preparation process



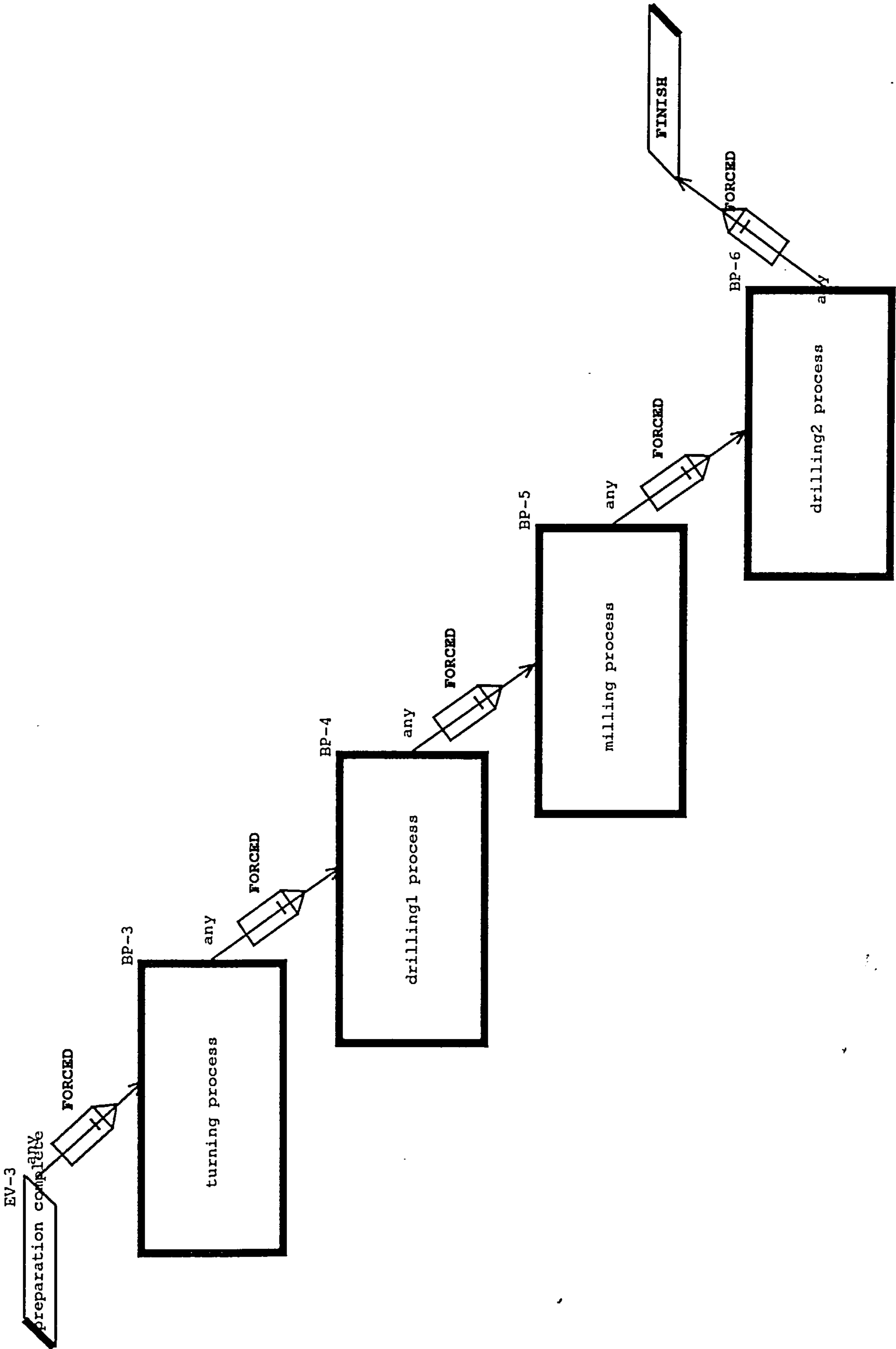
Behaviour Diagram: info preparation



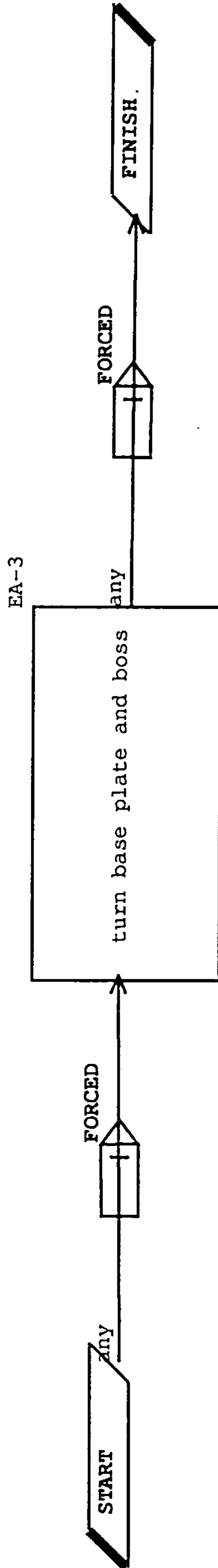
Behaviour Diagram: material preparation



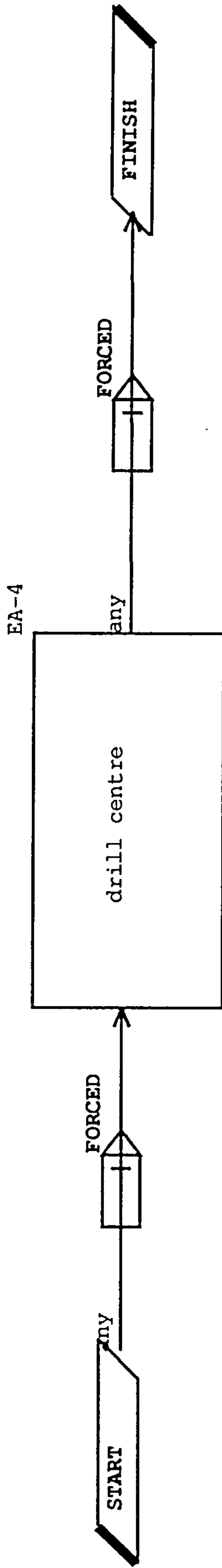
Behaviour Diagram: manufacturing process



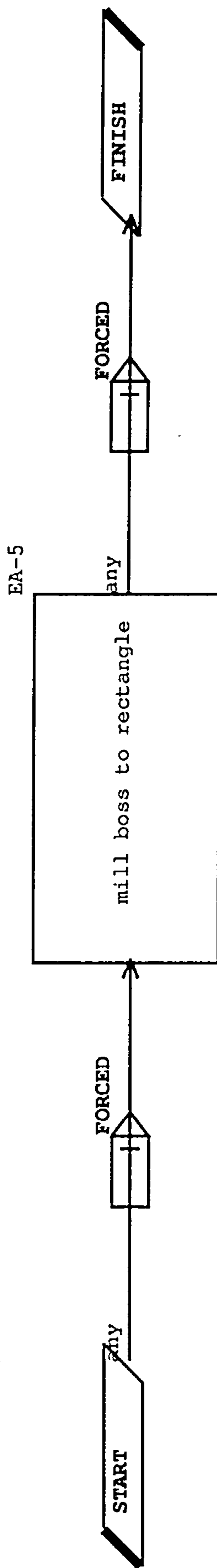
Behaviour Diagram: turning process



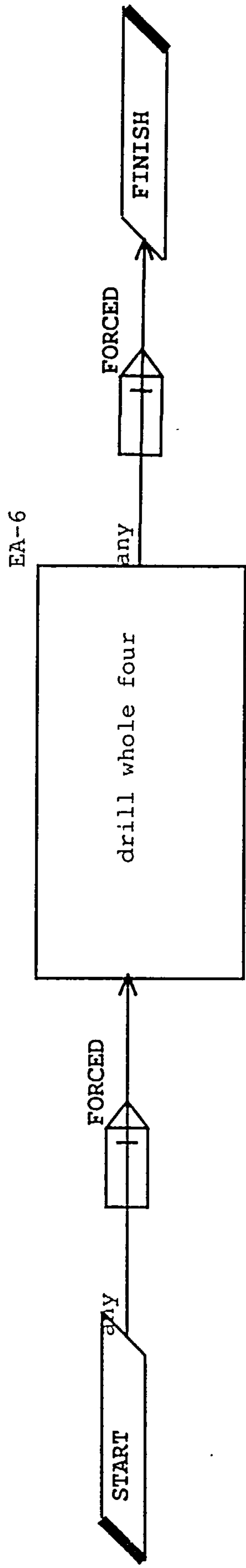
Behaviour Diagram: drilling1 process



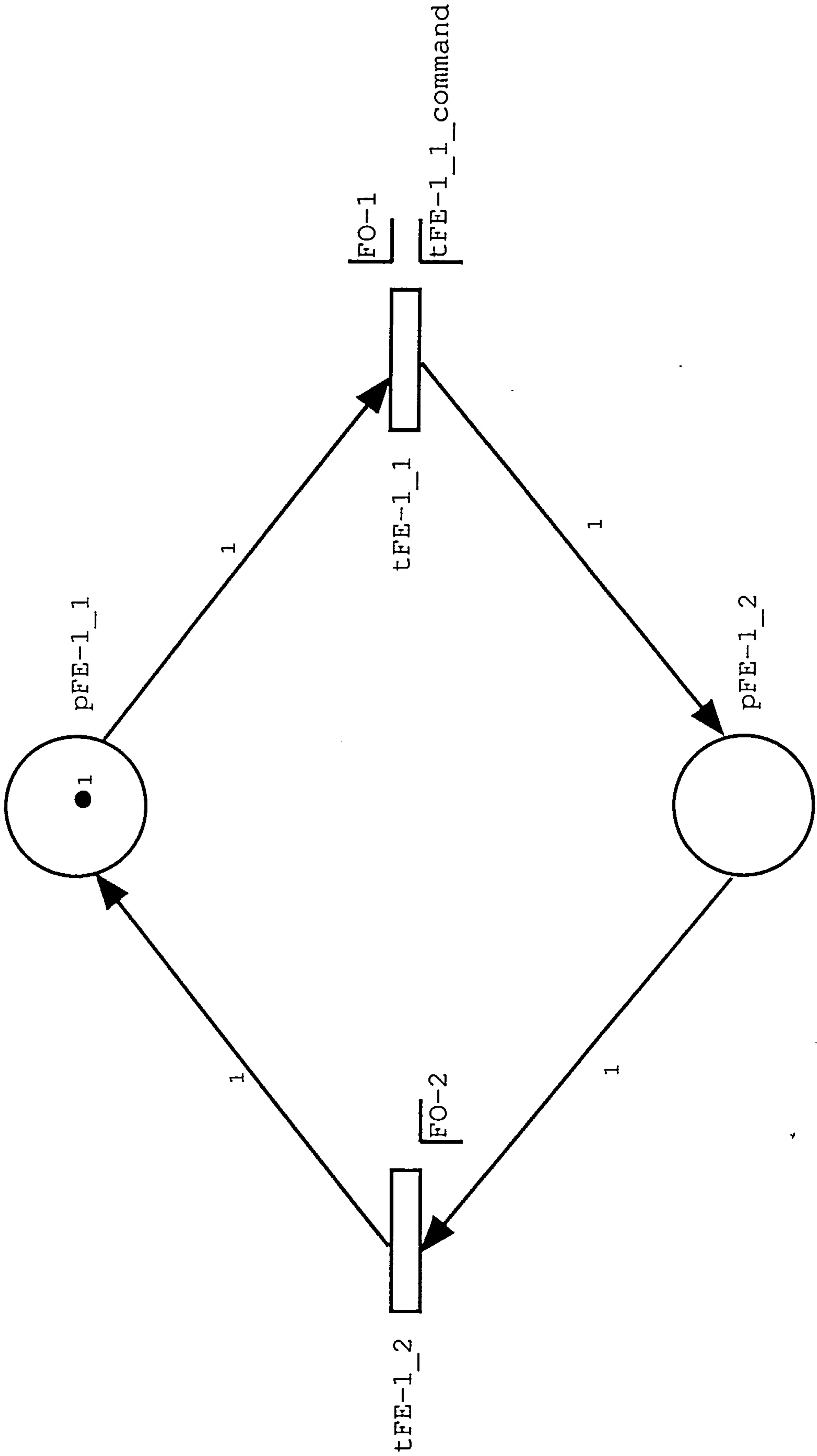
Behaviour Diagram: milling process



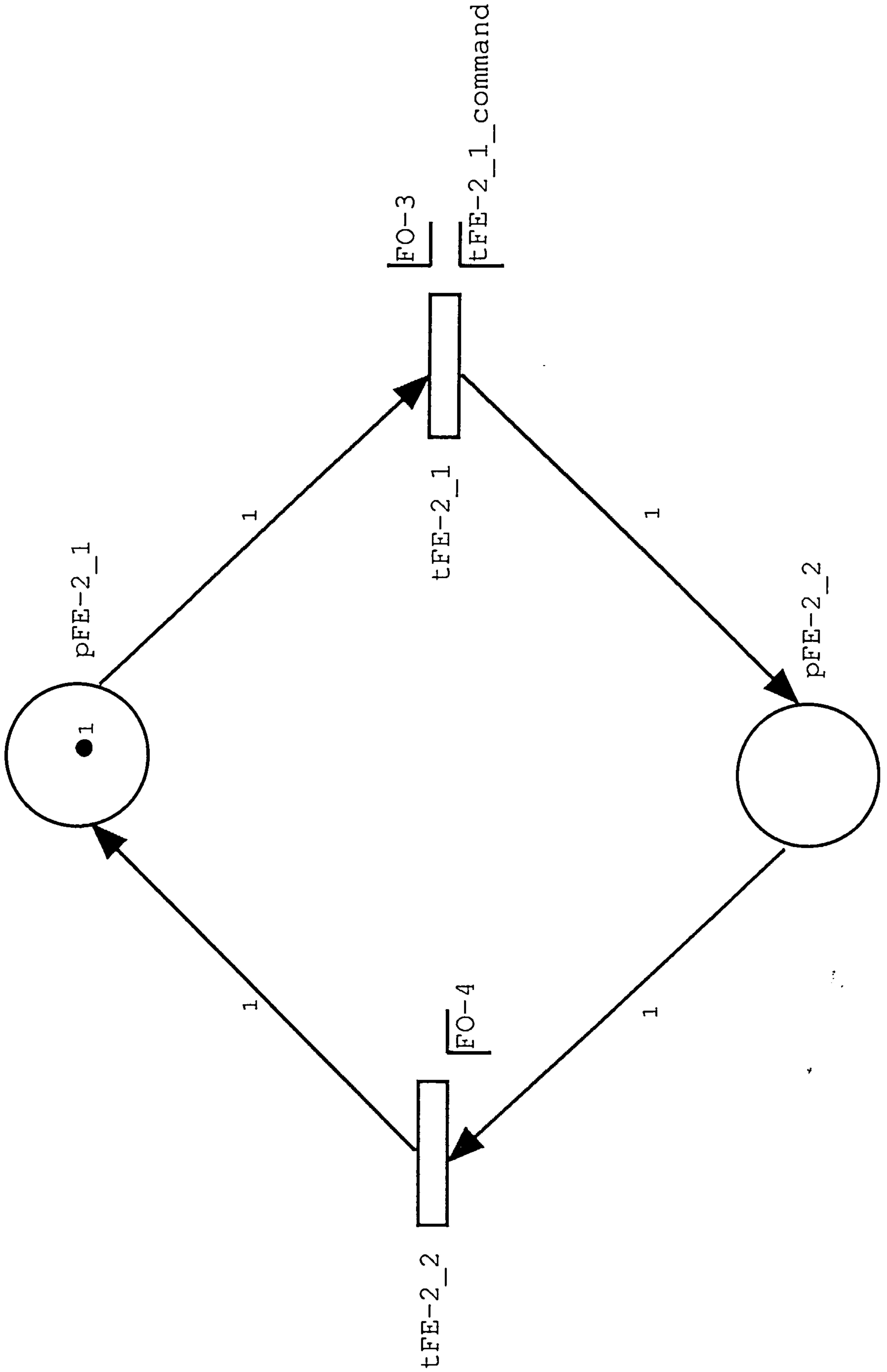
Behaviour Diagram: drilling2 process



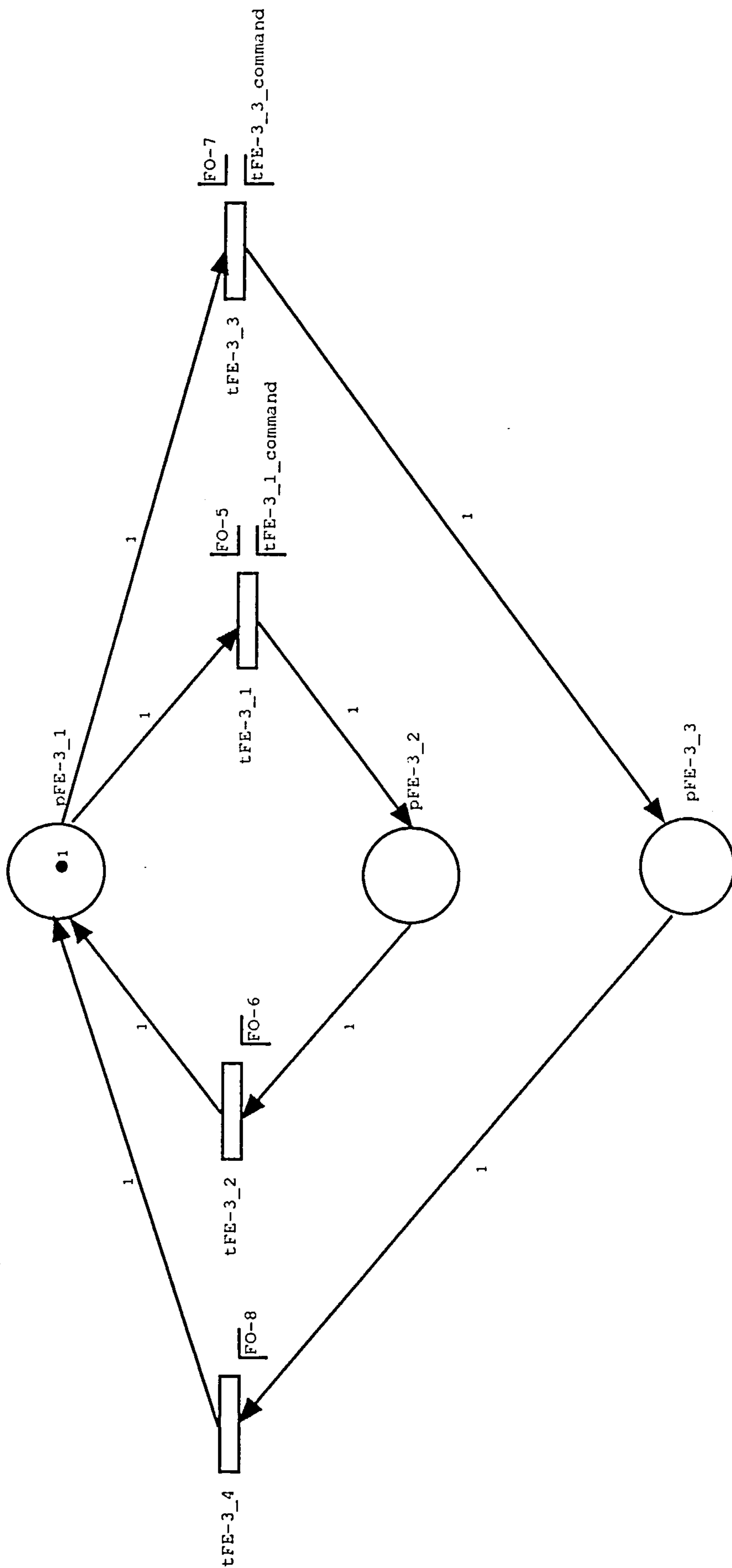
FE-1: Behaviour Diagram: info-prep_entity



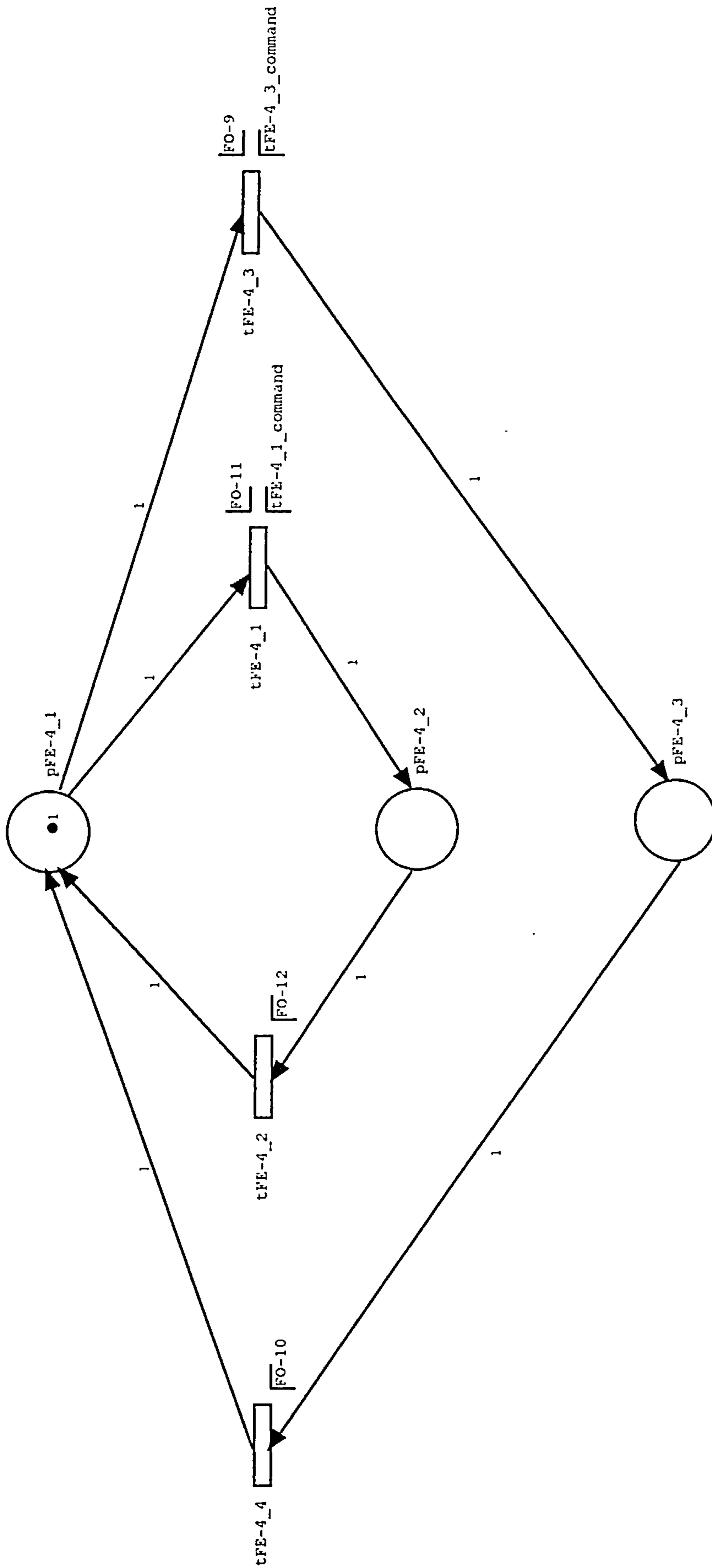
FE-2: Behaviour Diagram: stock_prep_entity



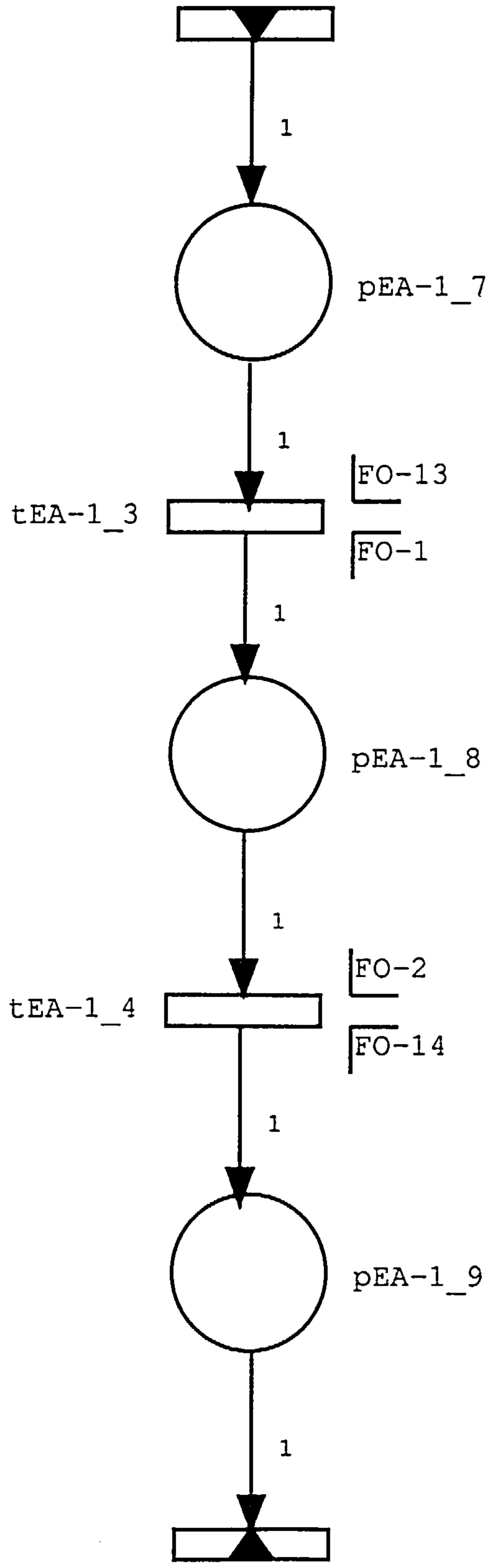
FE-3: Behaviour Diagram: cylindrical_process_entity



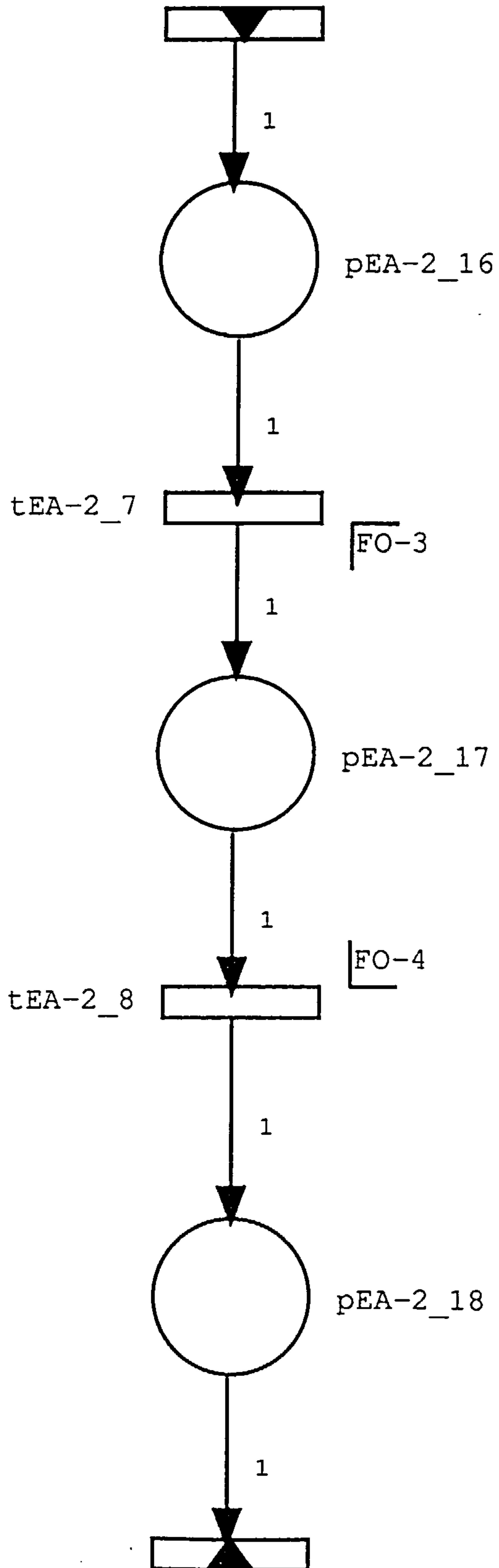
FE-4: Behaviour Diagram: mill_process_entity



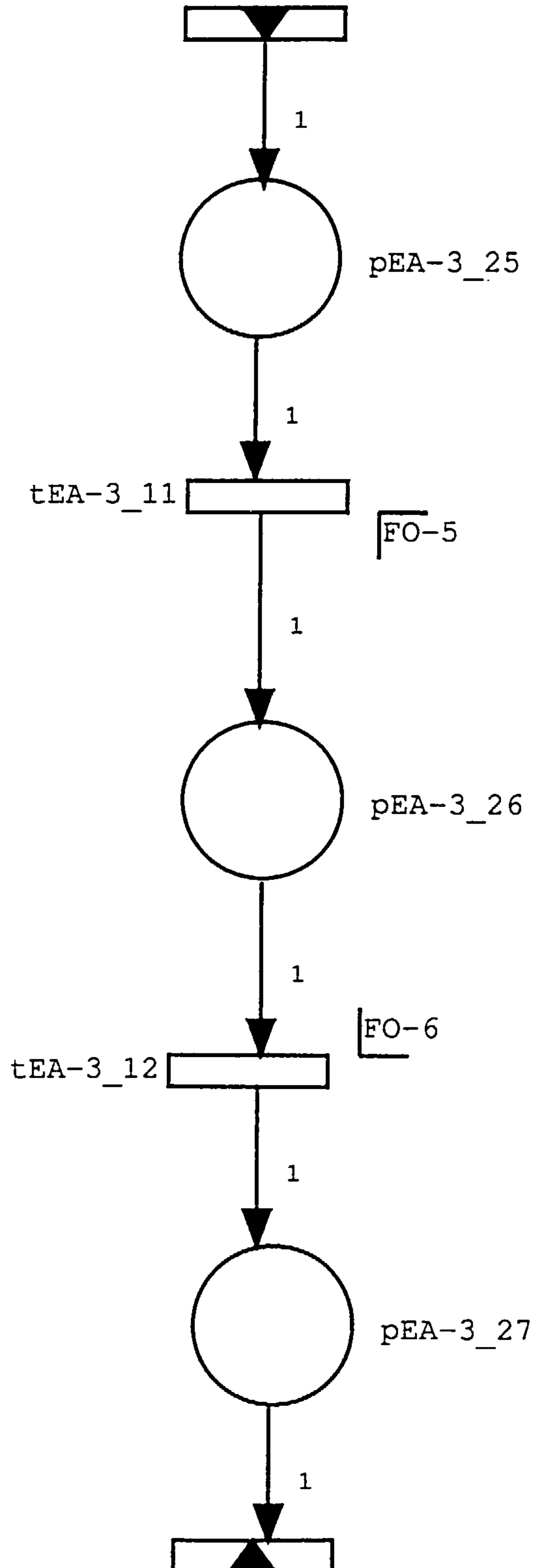
EA-1: Behaviour Diagram: prepare manif info



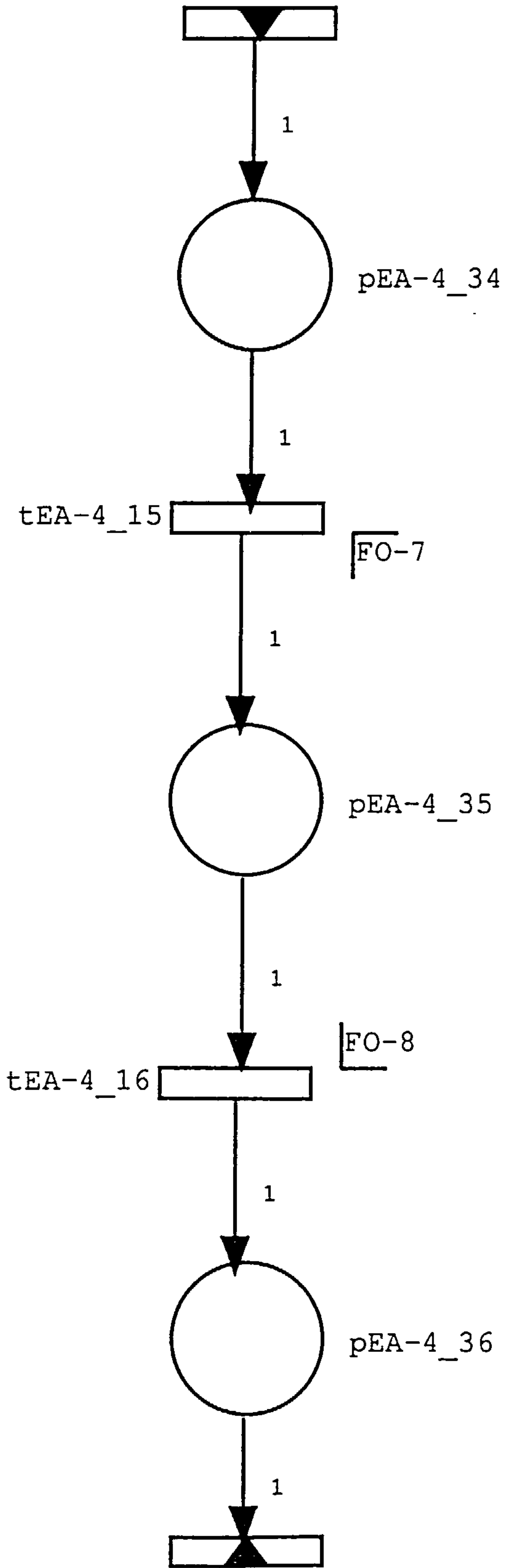
EA-2: Behaviour Diagram: cut stock



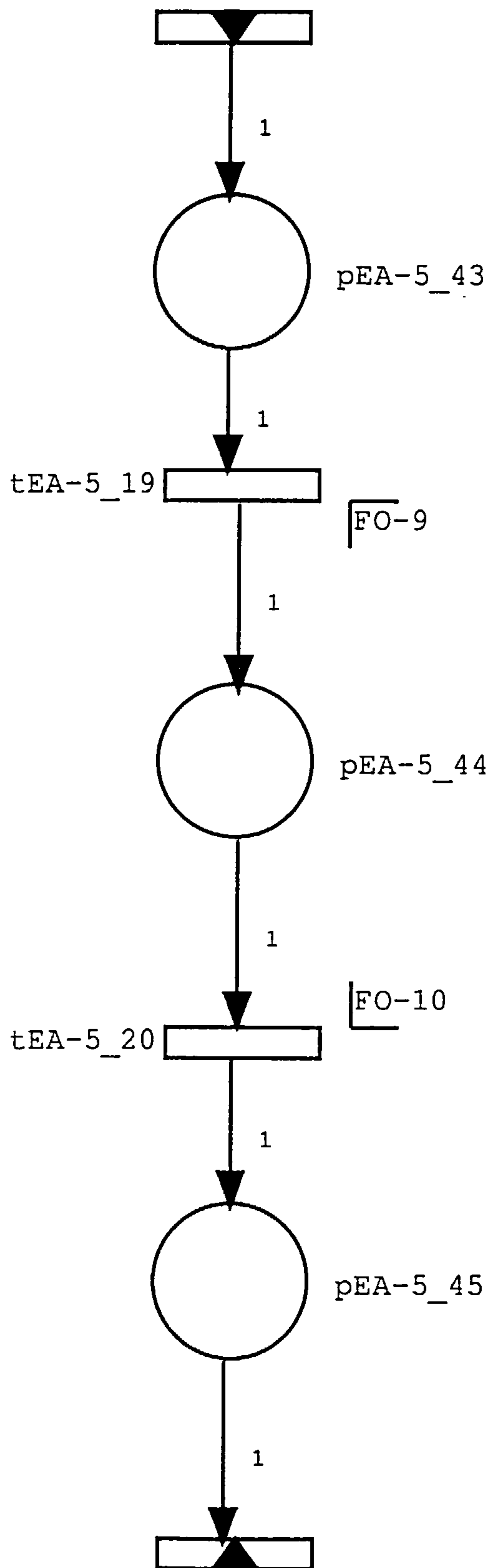
EA-3: Behaviour Diagram: turn base plate and boss



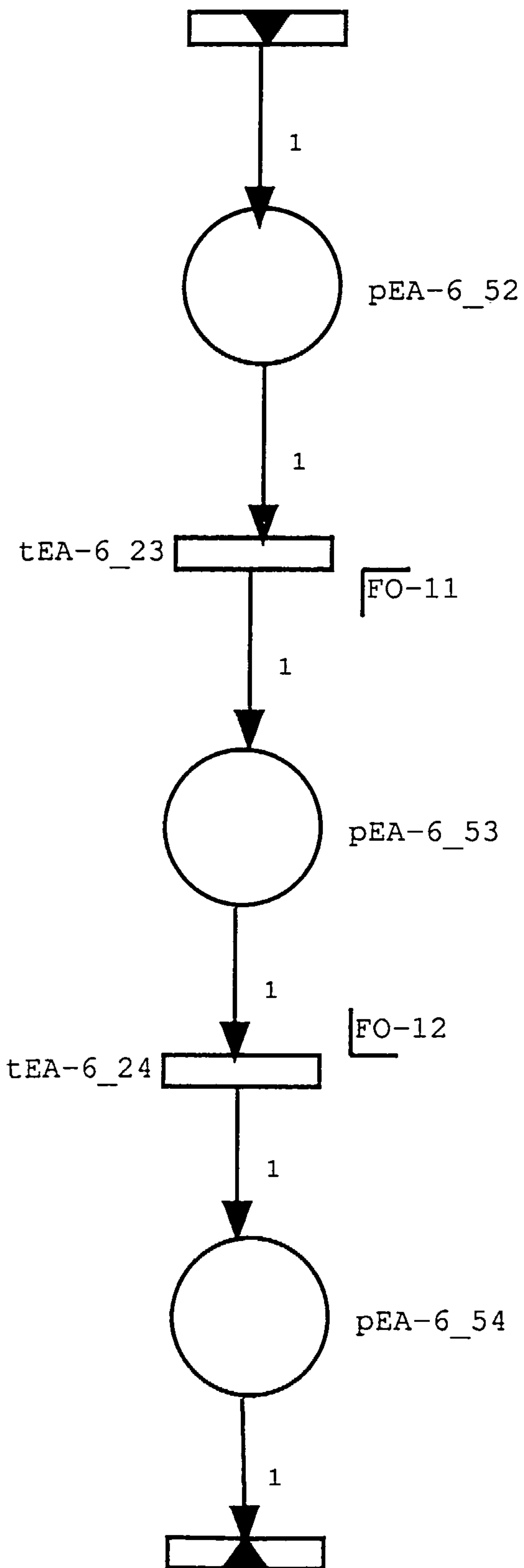
EA-4: Behaviour Diagram: drill centre



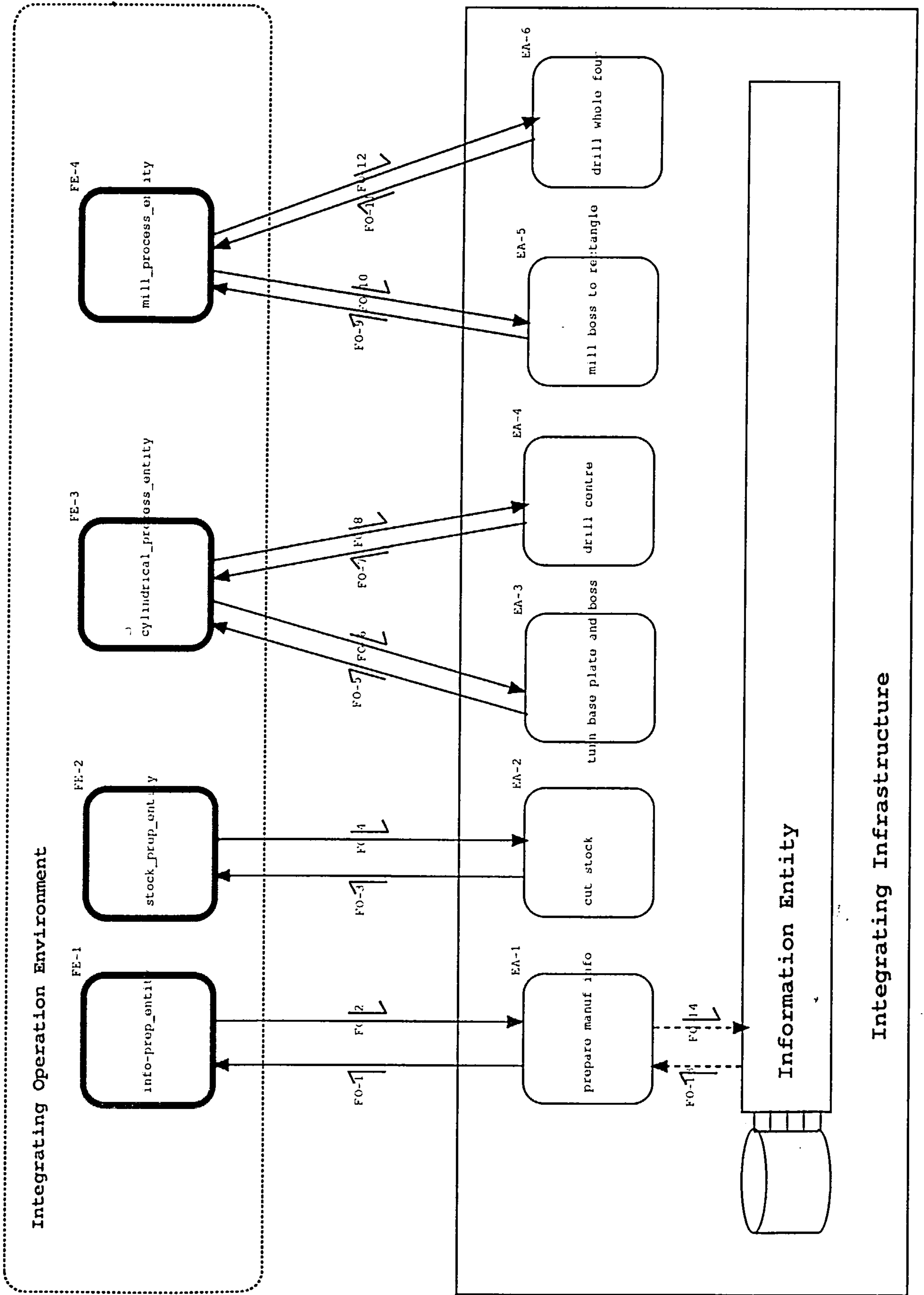
EA-5: Behaviour Diagram: mill boss to rectangle



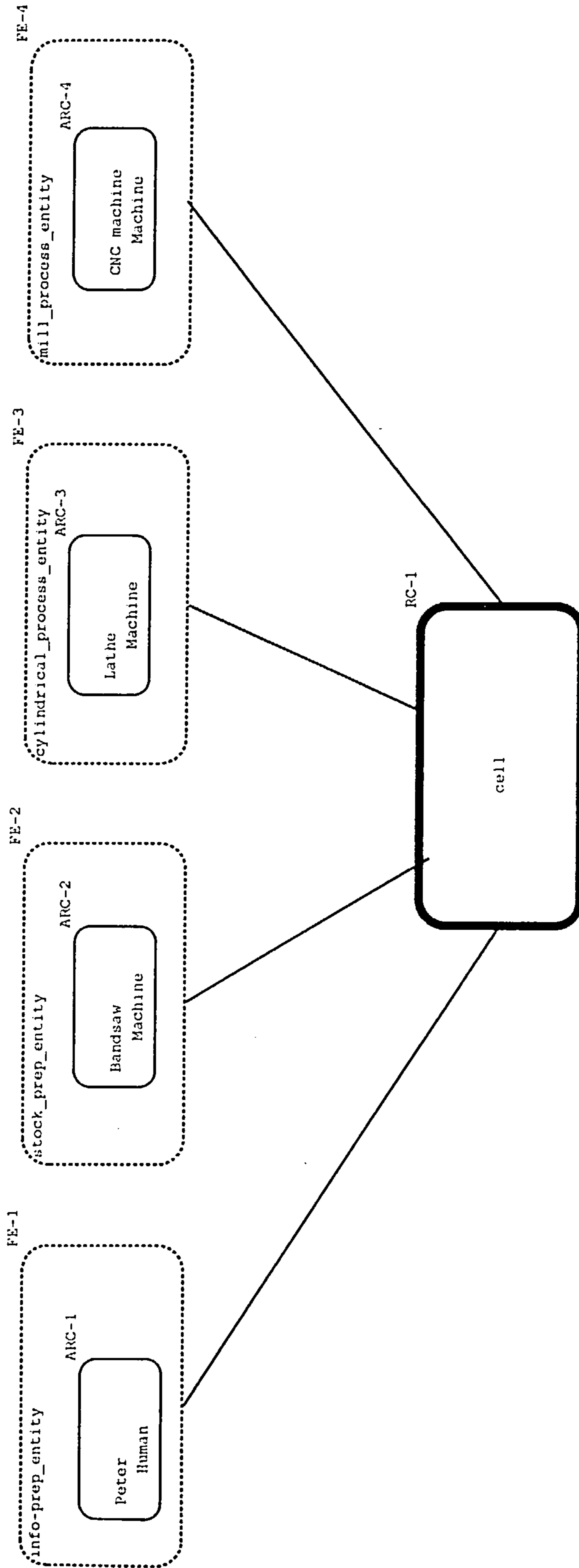
EA-6: Behaviour Diagram: drill whole four



Object Diagram: wheel coupling manufacture



Resource Diagram: wheel coupling manufacture



Configuration Diagram: wheel coupling manufacture

