A Reference Model for Information Specification for Metalworking SMEs

by

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A Doctoral Thesis

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Dedication

To my parents, Mr. and Mrs. Toh,
for their love, encouragement and support.

Abstract

The work reported in this thesis offers a novel basis for the realisation of specifications for information requirements to meet the distinct operational requirements of metalworking SMEs. This has been achieved through the development of a reference SME enterprise model based on fundamental ideas of the holon and fractal factory concepts. The novel concept of a node holon is introduced, which allows the representation of the human dominated interactions in a company based on the fundamental concepts of the holon. This offers a competitive alternative to the methods for enterprise modelling and information specification which are based solely around business processes and procedural rules.

A new representation for the organisation of the SME has been based on identifying the major zones of activity within the enterprise, which is seen to provide a more appropriate representation for companies whose basis for operation is informally structured. Two classes of zones have been identified, these are the business support zone and manufacturing zone. The relationship between a top down description of the enterprise as zones and the complementary bottoms up modelling of the enterprise based on concepts of the node holon are described in detail.

A critical study of two candidate modelling architectures, namely CIMOSA and ARIS will show the applicability of the individual architectures for the task information specification. The constituents of the SME enterprise reference model is placed within the context of contemporary enterprise modelling practice by mapping against one of the architectures. This will demonstrate how the architectures can readily accommodate new modelling approaches whilst retaining their major advantages, thereby increasing their applicability and potential uptake.

The reference SME enterprise model has been readily applied in the study of an SME, where a representation of the company has been achieved solely on the current organisation of its business support and manufacturing activities. The holonic aspects of the enterprise have also been successfully modelled. This process is supported by a CASE tool which has it constructs underpinned by the reference SME enterprise model.

Acknowledgements

I wish to thank Dr. S.T. Newman for providing invaluable support throughout the course of my research. The friendship of Dr. Newman and his family is greatly appreciated. My experiences working with Dr. Newman as an undergraduate student and researcher, in particular the competition for the IEE Lord Austin Prize (1995), will be warmly remembered.

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I am grateful to my friends and colleagues in the "Penthouse Suite", particularly Dr. J. Harding and Dr. B. Yu, for their encouragement and discussions which have been very beneficial. Also to the staff in the Department, T. Downham, D. Hurrell, J. Jones, T. Smith, J. Singh, R. Temple, who have made my stay in the Department very memorable, and especially C. Turner and D. Walters, who have provided expert computer support.

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Contents

Glossary of Terms

Holon: A term coined by Koestler (1967) which describes a Janus-like entity which is an assertive or self-contained whole, and at the same time, behaves as an integrative or dependant part within a more expansive hierarchy (The prefix *holo-* meaning complete, total: from the Greek word holos, i.e. whole) + (The suffix *on-* meaning elementary particle; from the Greek word *on*, i.e. being).

Holarchy (Holarchic system): A system comprising co-operating holons, organised in such a way that superordinate holons contain subordinate holons and establish their operating environment and external interfaces (Koestler, 1967).

Holonic information system (HIS): The holonic information system (HIS) is the business information system which has its information specifications derived from an instance of the SME enterprise reference model. The requirements for the HIS are captured in accordance to the RM-ODP standard which describes the specification for the IT configuration to realise the network.

Holonic information system (HIN): The realisation of the holonic information system (HIS) is the holonic information network.

Information technology (IT): Information technology is a tool designed to collect, store, process, disseminate and use information.

Information specification CASE tool: The information specification computer aided software engineering (CASE) tool is a prototype application, which has been developed to support the process of developing the SME enterprise model. The structure of the software is based on the constructs of the reference SME enterprise model.

Node holon: The node holon is an abstract representation which has been introduced to denote the composite of human holon, equipment and information interface. The node holon will allow human interactions to be modelled in terms of the fundamental holonic concepts of control, cooperation and autonomy.

Node holon (Hard): This distinguishes those node holons which perform manufacturing tasks; these are classified as hard node holons.

Node holon (Soft): This those node holons which perform information processing tasks; these are categorised as soft node holons.

Reference SME enterprise model: The reference SME enterprise model is used as the basis for realising the specifications for the HIS information requirements. It is a conceptual or data model, whose constructs are partially instantiated or populated. The reference SME enterprise model has been conceived to adequately represent the dominance of human interactions.

SME enterprise model: The SME enterprise model is an instance of the reference SME enterprise model, which captures the specific data relating to a particular SME.

Chapter 1

Introduction

The metalworking industry consists of a wide spectrum of companies ranging from large manufacturing enterprises, to small, owner-managed sub-contractors. In the face of increasing competition, both categories of industry are under significant pressure to improve business performance and both require the availability of high quality information. Within the modern manufacturing enterprise, it is widely recognised that computer based systems and information technology (IT) can significantly improve the level of response to customer demands.

Driven by the progress in computer and communication technologies, the application of higher levels of automation to the manufacturing system to improve productivity has become increasingly feasible, with computer integrated manufacturing (CIM) emerging as the paradigm for the larger manufacturing enterprise. These companies, out of necessity, work with hierarchical and deterministic planning and control structures. The complexity involved in building these CIM systems requires structured approaches where individual phases of the design to implementation process is precisely defined. These are often supported by generalised models and modelling methodologies to reduce system complexity to a manageable level. Models are often used to describe a manufacturing enterprise progressing towards CIM in terms of the principal components, processes, constraints and information sources. These models are frequently supported by CASE tools in the deduction of systems specifications.

The metalworking small to medium enterprise (SME) occupies the other end of the spectrum. Whilst some of these companies may possess a niche market, others frequently play the role of being the company at the end of the supply chain. As a consequence, many SMEs work in a volatile environment, employ small numbers of workers and are heavily dependant on their dedication and flexibility to cooperate. This places a heavy emphasis on the capability to communicate the status of the company so that employees are able to observe the latest customer order priority on an individual basis and respond appropriately with a wider view of the business. It should be noted that the information flows and the information storage requirements are very different to those found in larger companies and the SME businesses cannot be supported by the same concepts in information systems and IT specification. The contemporary specification models and methodologies which have their pedigree in providing support for the specification to implementation of hierarchical and deterministic CIM systems become unsuitable.

The work reported in this thesis offers a novel basis for developing a specification of the information requirements for SME metalworking companies. This task is supported by a reference SME enterprise model, where the information specifications constitute an instance of this model. The fundamental concepts of the holon and ideas of the fractal factory have had a significant influence on the structure of this model. As a consequence, it is seen to be more appropriate for the SME than alternative modelling approaches, by providing support for the preferred business practice rather than inflict constraints.

This work is being continued under the research programme GR/L27077 "IT Tools to Improve the Manufacturing Performance of Metalworking SMEs", funded by the Control Design and Production (CDP) Group of the EPSRC.

The thesis is organised into sixteen chapters, the overall structure and contents are depicted in Figure 1.1. Chapter 2 establishes the context of the work and explicitly defines the problem area which the research will address. The aims and objectives of the research are also identified, and the scope of the work is described.

Chapter 3 sets the research context with a survey of related issues such as hierarchical planning and control architectures, this is contrasted with planning and control issues in volatile environments. A brief review of human centred manufacturing is given, with a detailed account of the holonic manufacturing ideas and concepts of the fractal factory. Finally, a number of salient points will be drawn from the review and discussed.

The main theme of Chapter 4 is on the contemporary practice of enterprise modelling and modelling architectures. The methodologies, and reasons for enterprise modelling, together with the type of enterprise models which result is explained. This chapter includes a detailed study of the CIMOSA and ARIS modelling architectures as these have the most significant impact on the research.

Chapter 5 provides a review of contemporary information systems through a number of selected products to show their range of functionality. Standardisation efforts which have been devoted to providing enhanced networking capabilities are described; particular attention is paid to the reference model for open distributed processing (RM-ODP) and the ANSI/X3/SPARC DBMS architecture.

Chapter 6 discusses structured approaches to systems design and implementation; particular attention is paid to the supporting role of modelling architectures in information specification. A critical comparison between the CIMOSA and ARIS architectures is given, this is carried out within the overall framework of the SSADM structured methodology. The ARIS architecture is selected for the basis of the research and reasons for this choice are highlighted and explained. This chapter also identifies the main problems to be addressed by the research.

Chapter 7 introduces the concepts and overview of the research approach. Reporting of the major piece of research work which has been carried out commences from this chapter.

Chapter 8 identifies the information requirements of the SME and how these are to be met using two sources of information sources, namely the order and manufacturing models. The information requirements are related to de facto standards for IT and database architectures.

The concepts behind the reference SME enterprise model is explained over two chapters; Chapter 9 explains the philosophy of data capture which underpins the development of the enterprise model; particular attention is paid to the information requirements of the company. Use of the Booch modelling formalism is also explained. Chapter 10 describes the new modelling approach which is based on holonic systems concepts.

The reference SME enterprise model is subsequently mapped onto the ARIS architecture in Chapter 11. The major constructs of the enterprise model are described within the context of the architecture.

Chapter 12 shows evidence of the applicability of the reference SME enterprise model by demonstrating how a company can be modelled using the constructs and methods behind the model. A brief account of the business aspects of a selected metalworking SME, A.O. Henton, is given and is accompanied by a description of how the major aspects of the reference model are realised.

The CASE tool for information specification is described in detail in Chapter 13. A brief introduction to the computational environment of Visual C++ is given. This is followed by a description of the fundamental components of the CASE tool, where major aspects of its functionality will be highlighted.

Chapter 14 brings together a number of the major issues of the research in order to formulate the conclusions and areas for further work. Major aspects of the SME enterprise model are discussed, with the aim of highlighting the key issues which have been addressed and also to contribute the impressions and opinions which have been gained from the work.

The conclusions from the research are presented in Chapter 15; the major contribution and novelty of the work are also highlighted. Finally, the recommendations for further work are outlines in Chapter 16.

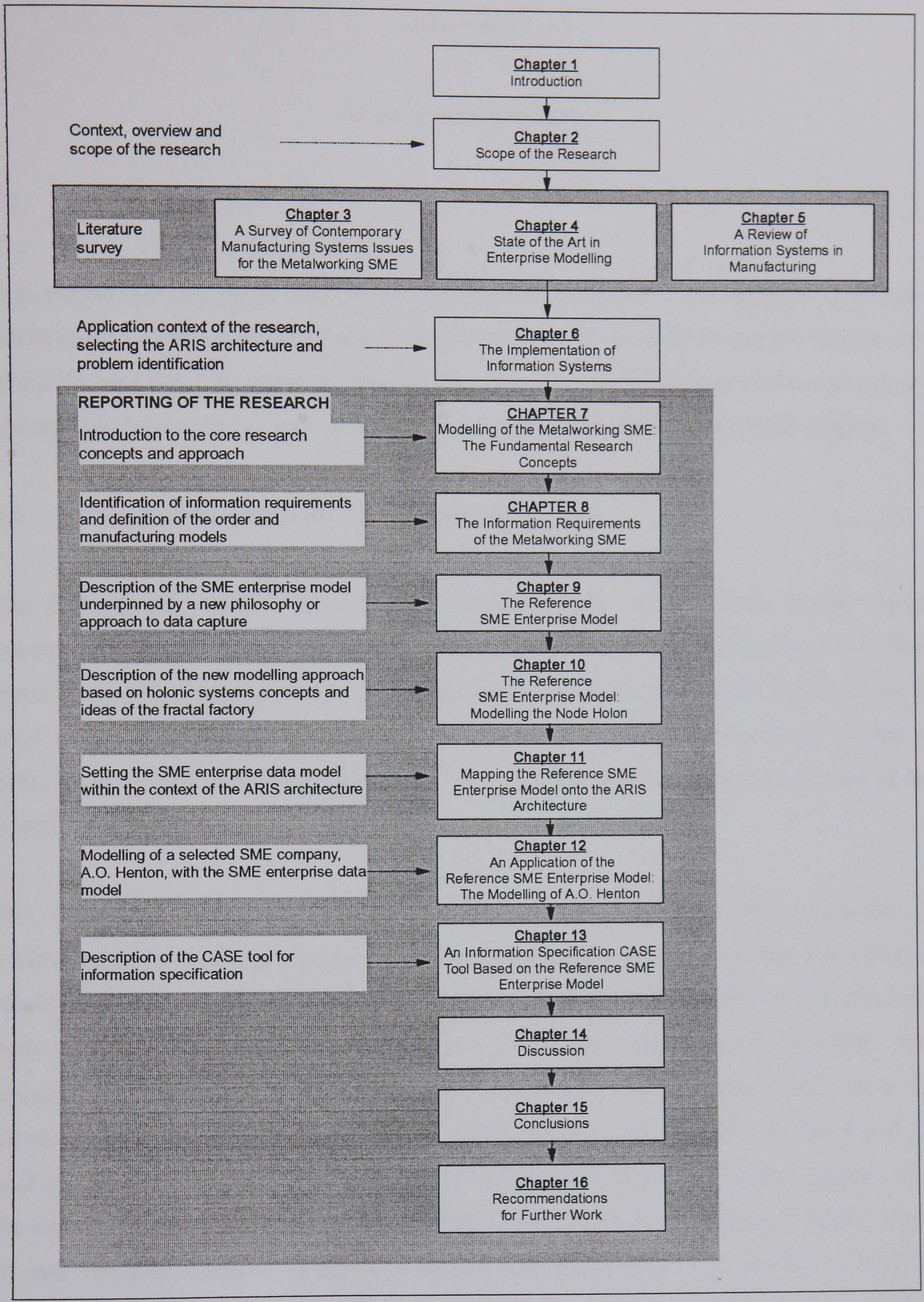

Figure 1.1: The structure of the thesis.

Chapter 2

Scope of the Research

2.1 Introduction

This chapter will provide an overview of the application context of this research. The issues which relate to the realisation of an information system will be outlined and the specific area which the research will address is highlighted. The aims and objectives of the research are presented in detail and the scope of the research is outlined in the final part of this chapter.

2.2 Context of the Research: The Metalworking SME

The focus of this research is on the metalworking SME; in comparison to their larger counterparts, smaller enterprises tend to have flatter organisational structures as they have fewer employees. The managers tend to perform a broader range of activities and may even be involved in the manufacturing tasks. The complexity and volatility in daily operation that an SME sub-contractor encounters, is largely due to the position they occupy at the end of the manufacturing supply chain.

The larger organisations reduce the complexity of their manufacturing operations by minimising product variety, keeping production stages independent and by being less willing to tolerate frequent changes in customer specifications. The SME on the other hand, is obliged to survive by absorbing the uncertainty which the larger companies exclude from their manufacturing systems. This is particularly true for the sub-contractor which faces the constant short term pressure to fill capacity. Detailed plans are invariably disrupted and the skill of operations management becomes that of coping with these frequent disturbances. It is the nature of these small owner managed firms to be inventive, idiosyncratic and highly flexible in their operation (Fuller, 1996). The natural business strategy is to tolerate changes to customer requirements and rushed demands, and accept as many orders as possible to fill the capacity and share the available resources.

The relatively small size of the SME makes it an unsuitable candidate for highly developed hierarchical computer based planning and control architectures and many are predisposed to the implementation of DNC technology as a cheaper alternative (Toh and Newman, 1996). The use of shop floor IT systems, which are specified through conventional or ad hoc methods provides, limited enhancement to the performance of the company as no method currently takes into consideration the interactions which are human dominated. The performance of the SME can be enhanced if appropriate IT support is given, this requires an accompanying new approach for specifying the IT system requirements.

2.3 Overview of the Implementation Process of An Information System

The realisation of an IT network from specification to implementation is supported by structured approaches. These are discussed in chapter 6. A simplified representation of the structured approach is illustrated in figure 2.1. It can be seen from the figure that the specification to implementation process is broadly divided into two phases. The first phase, which is user dominated, involves analysis of a current system and identification of the requirements. The result of this phase of activities is the requirements definition in terms of a set of specifications for the IT system. The second phase of the process, which is vendor dominated, involves the activities which realise the IT network based on the specifications produced.

The work reported in this thesis is restricted to the first phase, and in particular, is directed to the major task of specifying the information support requirements. This is illustrated in figure 2.2, which shows a more detailed view of the requirements definition stage. The specification of information requirements forms a major component of the requirements definition activity. The specification of information requirements is a key phase of the structured approach and is supported by modelling architectures, e.g. CIMOSA (AMICEE, 1991) and ARIS (Scheer, 1992). It can be seen from figure 2.2 that both architectures have a major viewpoint within which the information specifications can be modelled.

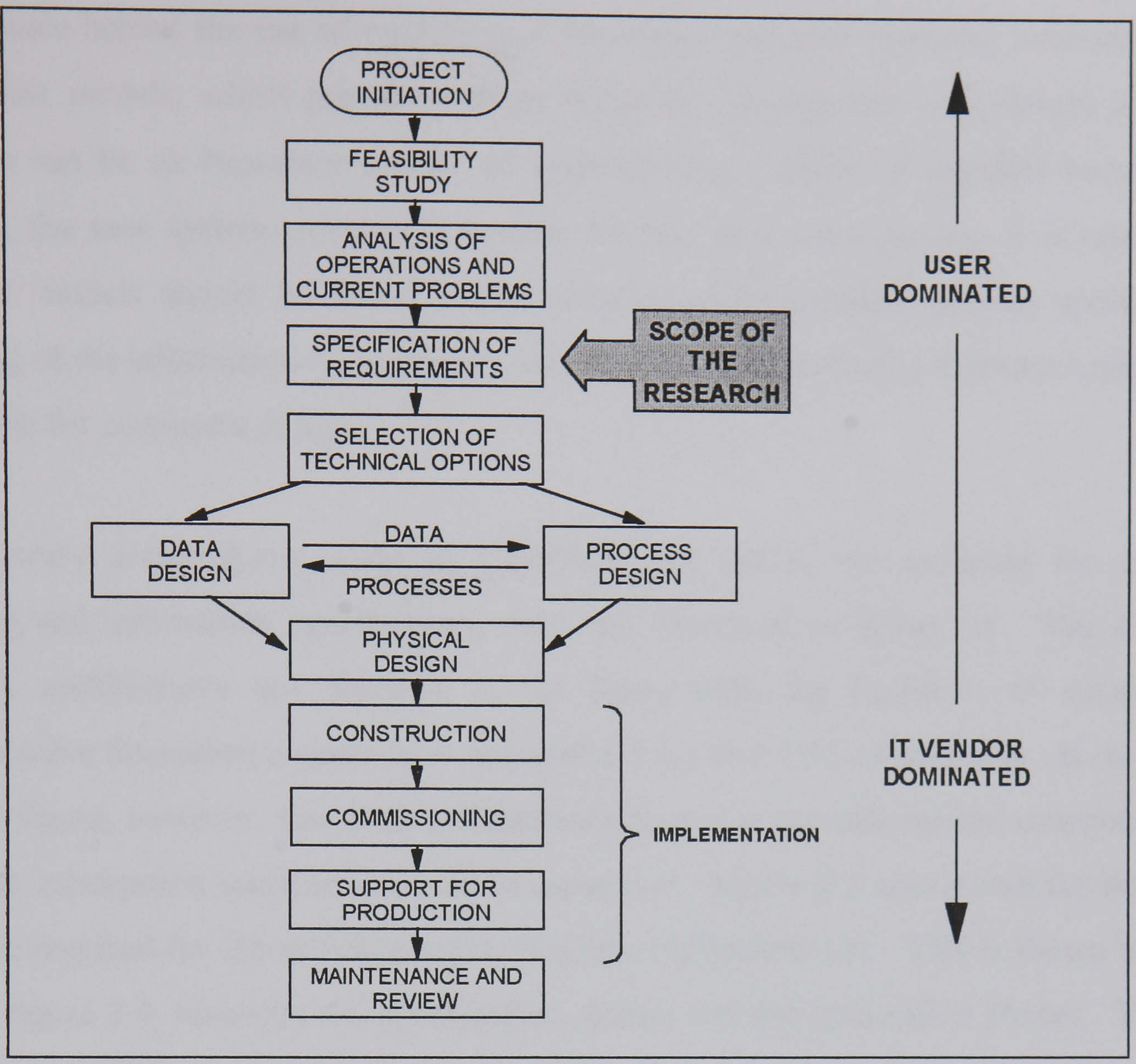

Figure 2.1: Scope of the research set in context of a structured approach to information systems implementation (Based on the SSADM methodology).

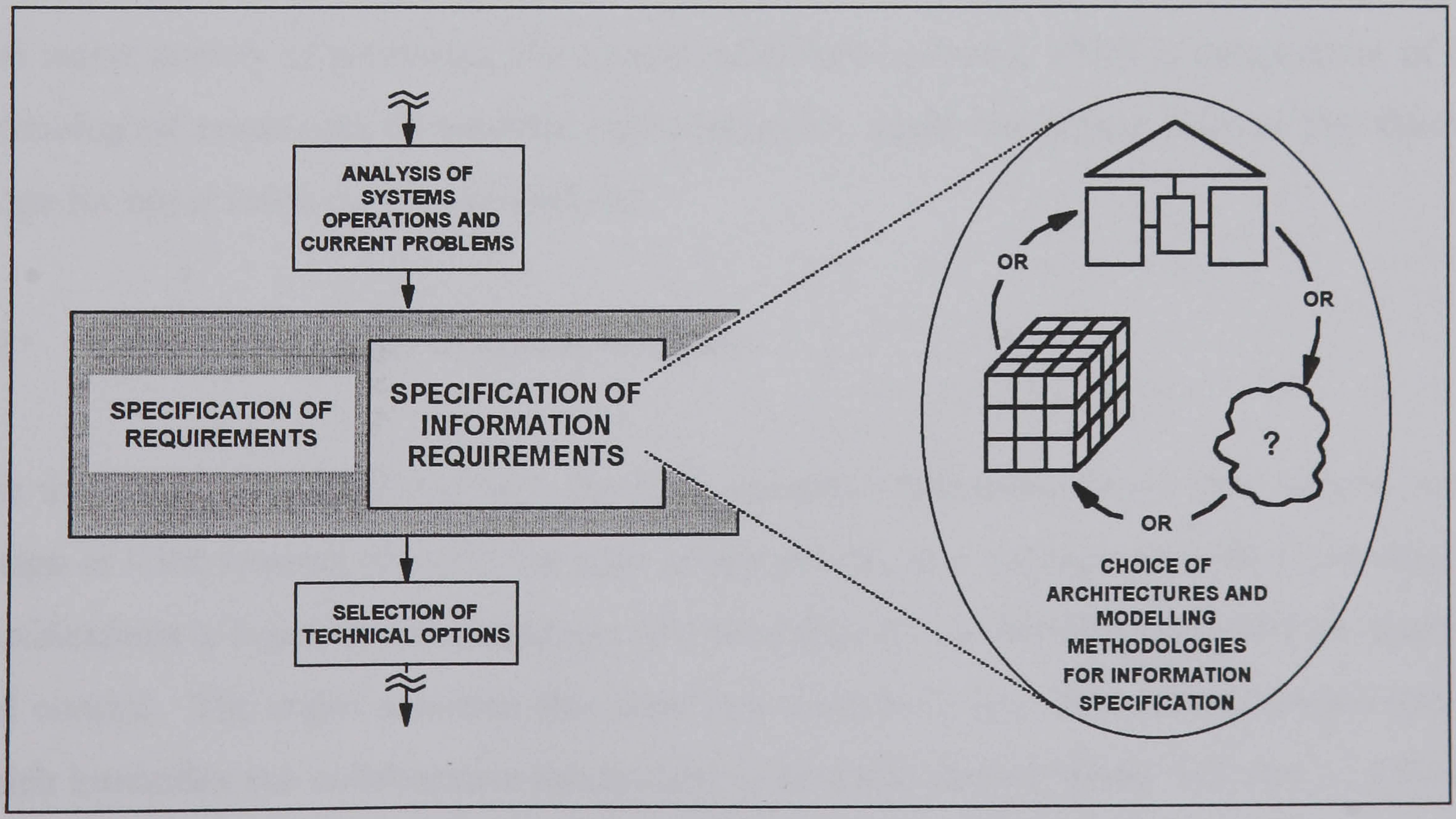

Figure 2.2: The requirements definition stage of the SSADM: A detailed view of information requirements specification supported by a choice of modelling architectures.

The rationale behind the use of modelling architectures and accompanying methodologies is that explicit models, which provide a direct focus on the activities and objects within the enterprise can be an important enabler of understanding. Much of the data necessary for designing the new system exists in enterprise models, as a consequence, it is rational that enterprise models should be linked to the creation of information systems specifications. Modelling of the information requirements, in turn, can be supported by software tools that are responsible for consistent design.

Contemporary architectures, such as CIMOSA and ARIS, are available for enterprise modelling and information specification, these are illustrated in figure 2.3. The ARIS and CIMOSA architectures are depicted in the figure with the minimum of detail, but a comprehensive discussion is given later in sections 4.5.5 and 4.5.6 respectively. It can be seen from the figure, however, that both architectures have a major information viewpoint within which the information specifications can be generated. Figure 2.3 also shows the three steps which are required for the realisation of a database implementation. This is shown in greater detail in figure 2.4, these are the specification, design and implementation phases. The latter two activities which involve the design and realisation of the database implementation are, in general, invariant for the majority of architectures and are well within the capability of contemporary methodologies available. The work reported in this thesis is restricted to the first major activity of generating the neutral information schema, which is independent of the technological constraints of database implementation. Here, the author believes that there is scope for novel research to be carried out.

2.4 A Statement of the Research Problem

The methodologies associated with the contemporary architectures have their origins in the design of CIM systems intended for large organisations, as a consequence, the production of specifications is based on an assumption of a deterministic and hierarchical model for planning and control. The major assertion that there is a need for a new class of information system which intensifies the collaborative interactions in an SME metalworking company to improve its response to customer requirements. This correspondingly requires a methodology to underpin the specification of the appropriate information requirements.

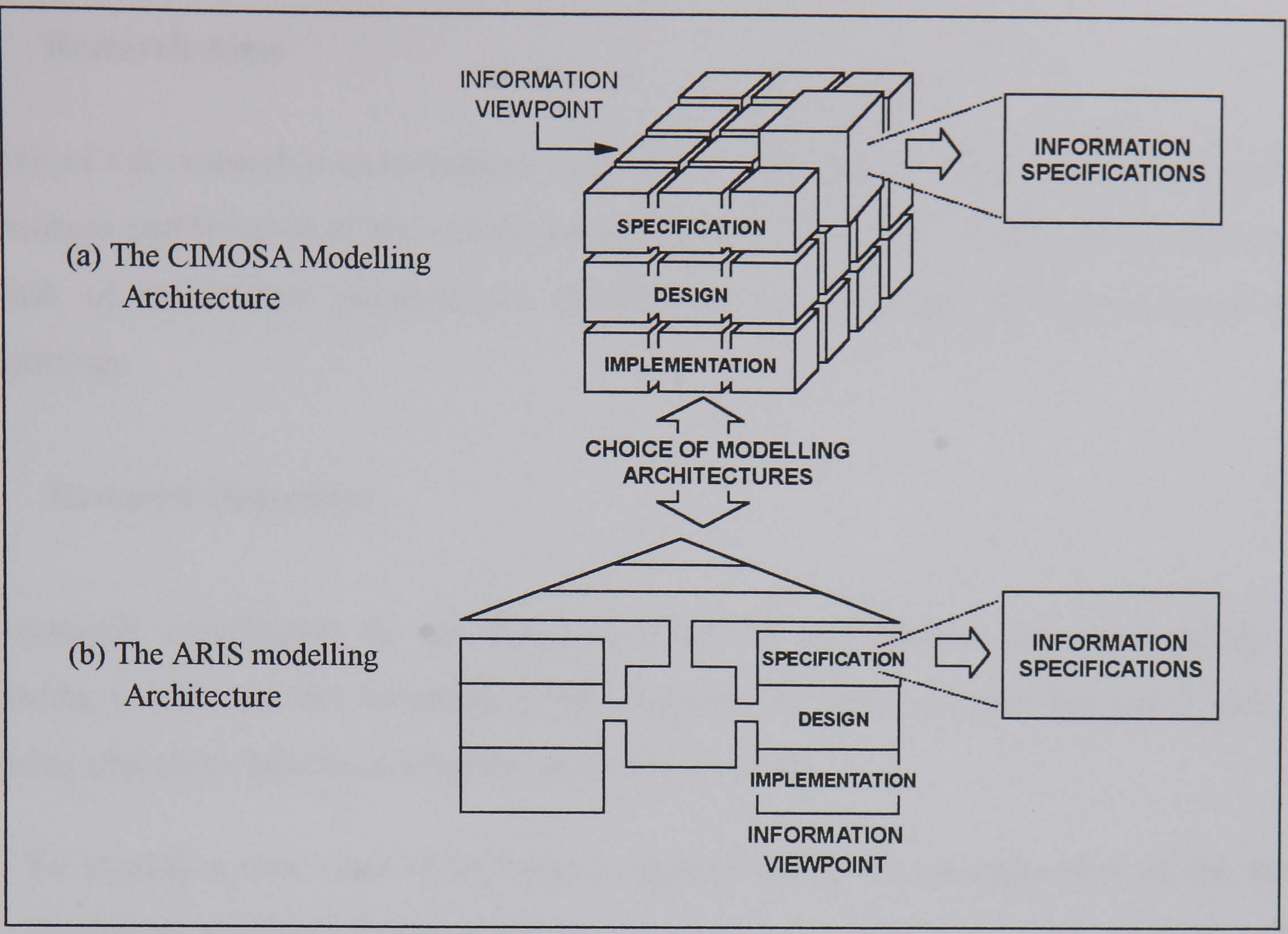

Figure 2.3: The generation of information requirements specifications using:
(a) The CIMOSA Architecture (AMICEE, 1991).
(b) The ARIS Architecture (Scheer, 1992).

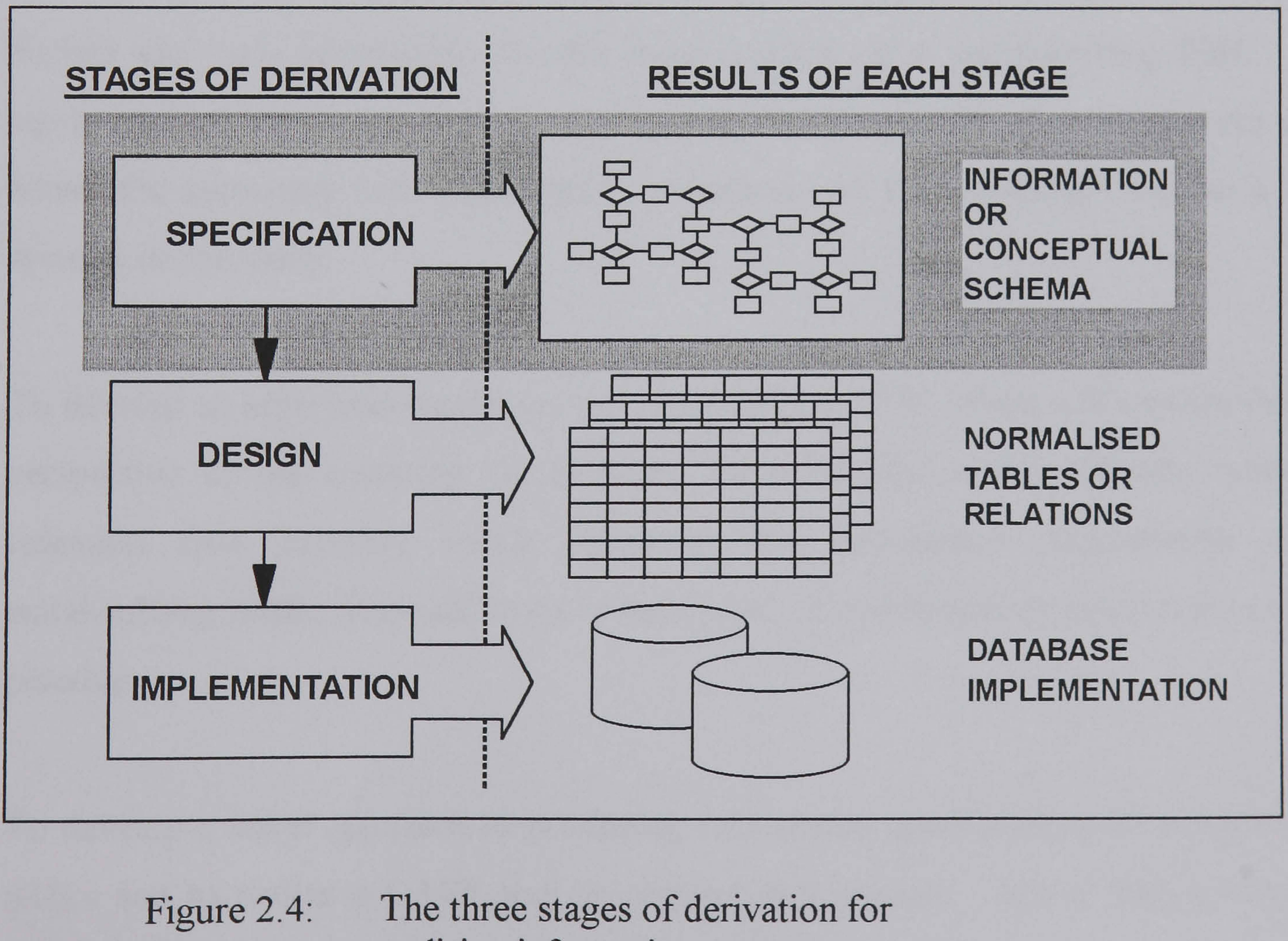

Figure 2.4: The three stages of derivation for realising information support.

2.5 Research Aims

The aim of this research is to investigate a new class of information system which will enhance the business performance of the metalworking SME and to make a significant contribution to the task of information requirements specification by exploring an accompanying novel methodology.

2.6 Research Objectives

The research contribution in this thesis is aimed at providing a new methodology and supporting CASE tool for information specification. In order to meet the stated aims, the following objectives have been established for the research:

(i) To identify a new class of information system which will be supportive of the human dominated activities and interactions throughout the business. The research will be directed at the means for the provision of appropriate information support.

(ii) To critically study contemporary manufacturing paradigms with a view to identifying a distinct and new perspective for the representation of a metalworking SME. This representation has to provide the most appropriate support for the management ethos, where the autonomy and collaborative interactions of the individuals will be a major systems design issue.

(iii) To develop an enterprise model for the metalworking SME which will capture this new perspective of the company. In addition, the enterprise model will also contain a reference data structure which represents the information requirements of the metalworking SME. This will be set in the context of contemporary enterprise modelling practice.

(iv) To develop a novel approach to producing information specifications for metalworking SMEs and to realise a CASE tool to support this process. This CASE tool will be underpinned by the reference SME enterprise model.

(v) To set the results of the research work against established enterprise modelling architectures and methodologies as a basis of comparison. To further enhance the process of comparison and potential applicability of the method, the research will be based, where possible, on de facto standards for information systems and information specification.

2.7 Scope of the Research

The scope of the research work which has to be carried out to realise the objectives listed above are presented in the following sections.

2.7.1 Literature Survey

A comprehensive literature survey is to be carried out, covering areas directly related to the research. A study of planning control architectures will be presented, this will be followed by an investigation into planning and control within highly volatile environments. A study of modern manufacturing paradigms such as the holonic and fractal factory will be carried out, this will highlight the fundamental principles which influence the research. The literature survey will include a comprehensive study of current enterprise modelling practice, contemporary modelling architectures and includes a selection of modelling formalisms. Attention has to be paid to the state of the art in manufacturing information systems and the provision of information support, this part of the review will encompass the relevant IT specification standards and architectures for database management systems. Finally, a number of salient points will be drawn out from the literature survey and discussed.

2.7.2 The Role of Architectures in the Information Specification Process

The aim of this is to identify the major task of information specification in the wider context of structured systems approaches for the realisation of an IT system. In addition, the relevant IT standards have to be identified to underpin the work in order to increase the potential applicability of the research output. An established methodology is to be used as an exemplar, in this case, the structured systems analysis and design and methodology (Ashworth and

Goodland, 1990) has been chosen. This work subsequently focuses on the information specification task and the modelling frameworks which are available to support the process. The main thrust is to carry out a critical appraisal of modelling architectures to identify the most appropriate as a basis for developing the CASE tool. The comparison between the architectures will also identify areas where there is scope for novel research to be carried out to develop a modelling method for information specification.

2.7.3 Identification of Information Requirements for the Metalworking SME

The nature of the information support requirements are dependant on the type of industry and diversity of its business. In order to progress the research, the scope of application is restricted to SMEs with no product design activity. The information specifications form the basis for the database implementation in the realisation of the information network; the specification therefore plays a fundamental part in realising the most appropriate information support. The subject of this area of research is the identification of major issues which influence the contents and structuring of the information specifications. The use of de facto standards for information specification adds further structure to the work.

2.7.4 The Development of a Novel Representation for the Metalworking SME

The aim of this work is to identify a new class of information system, and an accompanying modelling approach for the specification of information requirements. This is to be supported by a study of a number of modern manufacturing paradigms. The methodology and resulting information system has to be supportive of human dominated interactions and enhance the business performance of the company. The modelling methodology for information specification has to be capable of capturing the nature of the business and requires an approach which is more suited to representing the more informal organisational structure which is highly flexible in operation.

2.7.5 Development of a Reference SME Enterprise Model

The main focus of this research is to develop a conceptual basis for the development of the reference SME enterprise model. The reference model has to capture the information requirements as a standard information structure which is generally applicable to the class of metalworking SMEs. It also has to include other relevant aspects of the enterprise which allow an instance of the information specifications to be created. A significant aspect of this work is to integrate into one holistic model, both the reference information structures and the new representation for the SME developed as part of the research which has been identified previously under sections 2.7.3 and 2.7.4. A modelling formalism has to be selected to represent all aspects of the enterprise model consistently, establishing a formal basis for implementing the CASE tool.

2.7.6 Mapping the Reference SME Enterprise Model Against a Contemporary Modelling Architecture

An approach is required to enable an appropriate assessment of the research. The basis for assessment is the comparison of the reference SME enterprise model against other established modelling methodologies. This is carried out by mapping the contents of the enterprise model against a contemporary modelling architecture. The choice of architecture to be used is based on the results of the critical evaluation of different candidate architectures, which falls under the research outlined in section 2.7.2. The projection of the reference SME enterprise model against the selected architecture also identifies the structure and principal components of the CASE tool which has to be developed to capture an instance of the model.

2.7.7 Application of the Reference SME Enterprise Model

Work will be conducted to study and model a metalworking SME to show evidence of the applicability of the reference SME enterprise model. The main aim is to demonstrate how a company can be modelled to enable the suitability of the design of the enterprise model, and the capability of its modelling constructs, to be demonstrated and tested within the context of the company chosen. This will include a brief account of the business aspects of the company and is accompanied by a description of how the major aspects of the reference model are realised.

2.7.8 The Realisation of a CASE Tool for Information Specification

The aim of this work is to show the results of the research in the form of a CASE tool for information specification and provide a computational environment for the information specification process. The reference SME enterprise model is used to underpin the modelling constructs of the CASE tool. This modelling tool should provide the scope and flexibility to rapidly configure and edit models of different enterprises and subsequently create specifications for the information. This will show that it is possible to derive a new modelling approach and supporting CASE tool for information specification, based on the new representation which is seen to be more appropriate for the metalworking SME.

Chapter 3

A Survey of the Contemporary Manufacturing Systems Issues for the SME

3.1 Introduction

The purpose of this chapter is to present a survey of the issues which immediately impinge on the metalworking SME. The role of an appropriate planning and control architecture is stressed in conjunction with the implementation of an IT system; alternative architectures for planning and control are briefly described. Emerging manufacturing paradigms which place a larger emphasis on human factors are identified, a number of relevant paradigms are highlighted and examined in greater detail.

3.2 Architectures for Production Planning and Control

It is widely recognised that information technology (IT) can improve the level of responsiveness in manufacturing companies. However, any IT implementation has to be underpinned by an appropriate company wide standard for planning and control. The structure for production planning and control underpins the interaction of manufacturing system components and directly influences the flow of control and monitoring information (Veerami, 1994). The planning and control strategy is the cornerstone of any manufacturing enterprise, the choice of which is determined by the class of industry and must be placed in the context of the business. Manufacturing control refers to the planning and coordination of all shop-floor activities in a manner which achieves desired objectives, such as the completion of a task by a specified due date (Browne et al., 1996).

Four types of manufacturing control structures have evolved, these are the centralised, hierarchical, heterarchical and the hybrid control architectures (Dilts et al., 1991). In larger human dominated environments, the complexity of the production problem becomes too large for a single person to understand or effectively manage using centralised control, and some division of mental labour is needed (McKay et al., 1995). Heterarchical and hybrid strategies have been the subject of research which is centred around negotiation-based control structures for highly automated manufacturing.

Hierarchical and heterarchical control represent two extreme approaches to control architectures. Manufacturing planning is typically viewed as a hierarchical process (Browne et al., 1996), and this is illustrated in figure 3.1. The distinguishing feature is that the planning horizon is divided into smaller periods as the level of planning reaches operational levels. In large and complex manufacturing systems, hierarchical control is used to provide the system with an adequate time frame for reaction to disturbances and to coordinate and delegate decisions to simplify decision making at each level.

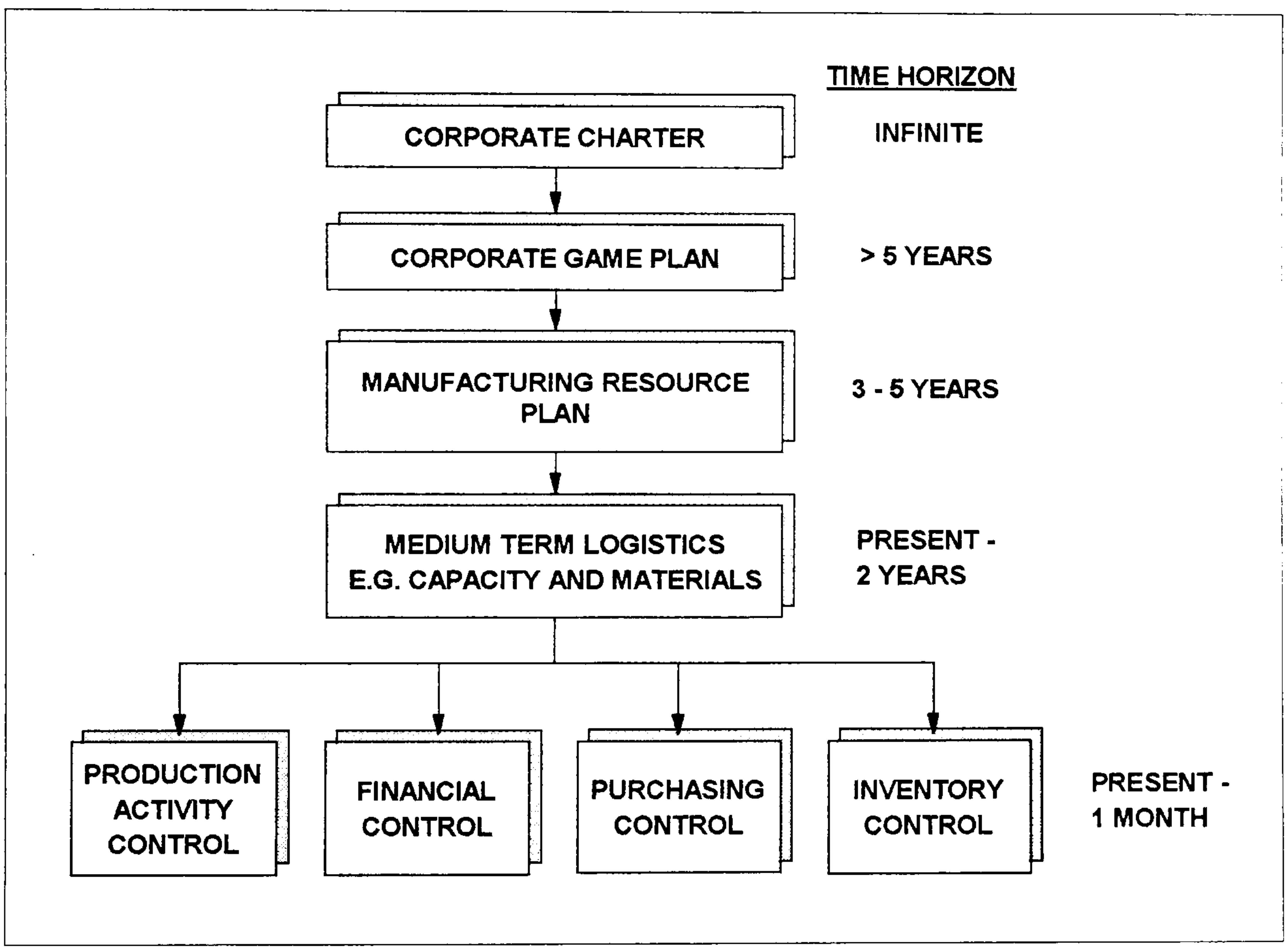

Figure 3.1: An hierarchical view of production planning (Browne et al., 1996).

The GRAI CIM Reference Model, illustrated, in figure 3.2(a), is based around the principle of hierarchical planning and control (Doumeingts et al., 1993). A further discussion of the GRAI reference model will be given in section 4.5.2. However, it can be seen from the GRAI planning grid shown in figure 3.2 (b), that decision making for a hierarchically structured planning system is categorised into strategic, tactical and operational levels. This structure is intended primarily to enable a periodic review of the decisions and the opportunity to launch an appropriate corrective process when inconsistencies, such as unanticipated deviations, are detected between the actual system status and normal operation (Doumeingts et al., 1992).

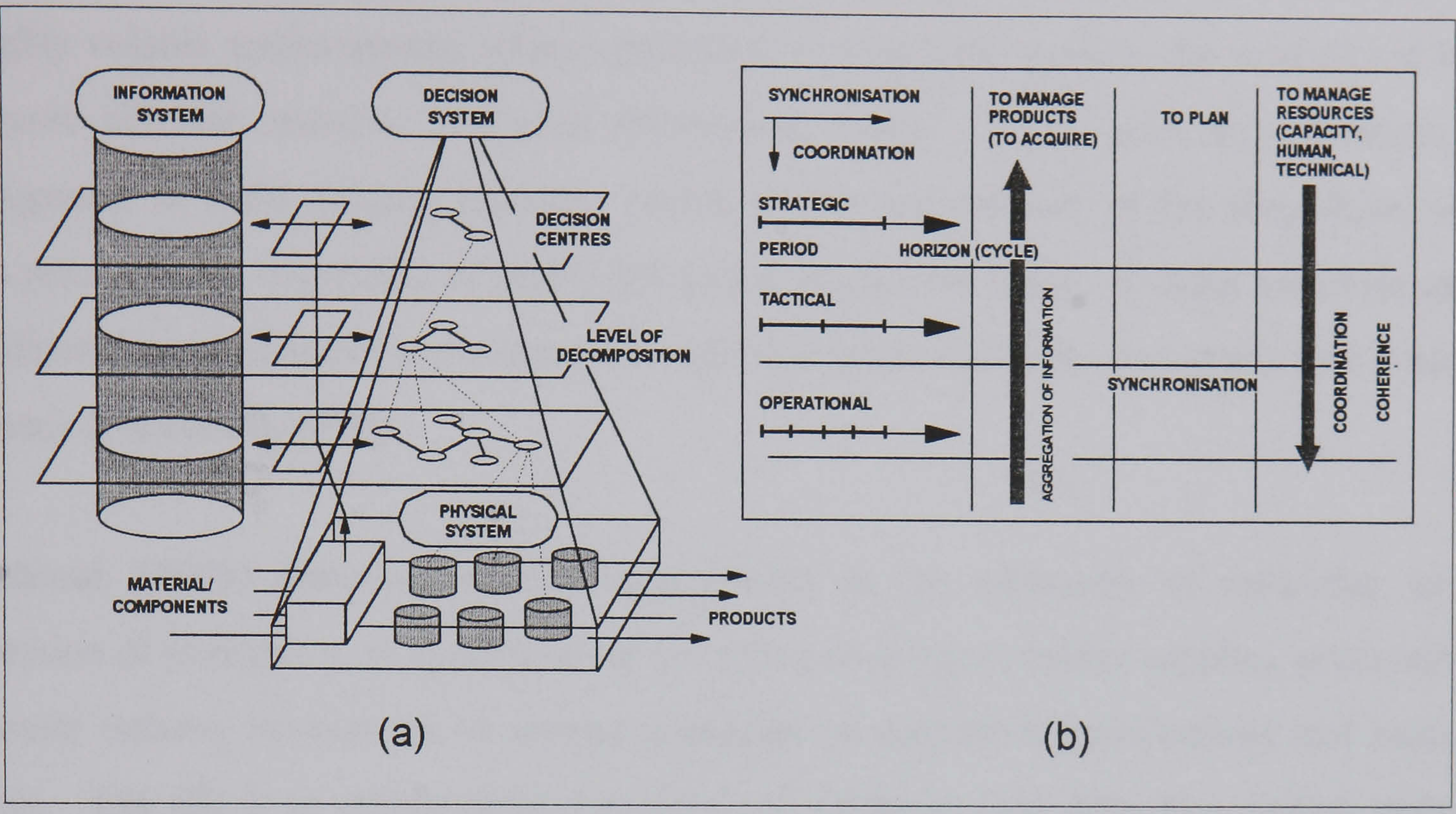

Figure 3.2: The GRAI methodology based on a hierarchical planning and control architecture (Doumeingts et al., 1987)
(a) The GRAI conceptual CIM model.
(b) The GRAI GRID showing the planning horizon.

Hatvany (1985) states that highly centralised and hierarchically ordered systems tend to be rigid, constrained by their very formalism to follow predetermined courses of action. As an alternative, he suggests a cooperative heterarchy, where the individual participants are highly intelligent to cope with unforeseen situations. Based on these concepts, Duffie (1986), proposes a system of heterarchical control which is aimed at highly automated environments. The core of this research centres on a series of design principles which produce a system of cooperating and autonomous entities.

The principle of autonomy enforces localisation of information and control (Duffie, 1986). A manufacturing cell has been designed on these principals of heterarchical control, where intelligent autonomous entities cooperate based on negotiative part oriented scheduling (Duffie and Piper 1987). Fault tolerance in highly automated heterarchical systems is enforced by the isolation of entities in the system, elimination of master-slave relationships and minimisation of global information (Duffie et al., 1988).

3.3 Planning and Control in Highly Volatile Environments

The coordination of manufacturing activities on a day-to-day basis becomes the dominant task in highly volatile environments, where opportunities frequently arise at the operational levels for more efficient resource allocation (Nicholson, 1985). Under such circumstances, the management of order priority becomes central to the coordination of the shop-floor, which often results in the overruling of highly developed production plans. If order priorities can be coordinated more effectively, the more dramatic and substantial is the response to the customer demands (Nicholson, 1985).

Westbrook (1993) describes priority management as the allocation of resources, or the expression of preference, to specific order or order groupings (whether supplies, production or customer orders), in response to current pressures on operational productivity and customer service. The aim is to relieve these pressures and minimise their disruptive impact upon the wider economic and strategic goals of the company.

The order status of the company is communicated so that employees are able to observe the latest order priority on an individual basis and respond with a wider view of the business (Westbrook, 1995). The technique of order-book modelling is where an integrated data file of the current operational status is developed in terms of order flows and interactions. Priorities can be discussed between several departments and the processing or expediting of individual orders can be considered in terms of company-wide targets (Westbrook, 1995).

The resulting data structure is called the order-book model, which is designed to give vision and insight to the state of the company's customer commitments from acceptance to dispatch. The object is to improve on the pure "ad hoc" impulse response to individual priorities as they impinge on individual departments (Westbrook, 1995). The information should represent a company wide view and should be provided in sufficient detail to permit a consensus of priorities to be established. There is an opportunity for IT to provide a supporting role in the harnessing and provision of the necessary information in assessing the interactions between priorities. This requires the specification of information requirements and the presentation of the information in terms of workable, clearly structured lists of data items for individual departments and employees (Westbrook, 1995).

3.4 Human Factors In Manufacturing Systems Design

The work on human centred advanced manufacturing technology (AMT) was pioneered by Rosenbrock (1983) at the University of Manchester Institute of Science and Technology (UMIST). This work was subsequently incorporated into ESPRIT 1217 (1199), titled "Human Centred CIM Systems". The objective of human centred technology or socio-technical design is to produce human centred CIM building blocks, in which people are given responsibility for those tasks best performed using human skills (Cooley, 1987, Schmid et al., 1994). In a human centred system, the range of activities for which each operator is responsible is maximised to include, for example, production work as well as quality and planning related activities. The concept of human-centred manufacturing relies on skill enhancement rather than skill replacement, moreover and the development of human-computer based tools provides people with assistance in the management of complex situations (Schmid et al., 1994).

The tasks within the factory must be organised such that, in all areas, people are able to apply a substantial range of their skills rather than just a small "useful" part. The work of Slatter (1990) concentrated on the development of a framework of human-centred design criteria to guide the design and implementation of both hardware and software to assist operators in the management of a flexible human-centred turning cell.

The design of human centred systems encompasses the important component of human factors engineering, which focuses primarily on abilities, limitations and other human characteristics. Chapanis (1996) states that human factors engineering is the application of human factors information to the design of tools, machines, systems, tasks, jobs and environments for safe, comfortable and effective human use. An exemplar of this approach can be found in the development of a man-machine interface by the controller manufacturer Keller Ltd., where matching the needs of operators and users is the main theme (Fuchs-Frohnofen et al., 1995). A human centred approach, on the other hand, takes full advantage of the potential increases for productivity, better quality and greater flexibility provided by the better utilisation of human skill, experience and the power of modern computer technologies (Schmid et al., 1994).

3.5 Manufacturing Paradigms

The rapidly changing pressures which are bearing down on the manufacturing industry have created an environment where the study of paradigms has become an area of major interest (Bell, 1995). In general, a paradigm describes a conceptual framework within which scientific theories are constructed, it represents a world belief composing the total constellation of values and techniques shared by a group or society (Rolstadas, 1993). Manufacturing paradigms influence the way realities are observed and understood, the critical study of these is important and contributes to the better understanding and description of real production problems. The holonic and fractal paradigms have emerged recently, these are of significance to the author's research and are described in the following sections.

3.5.1 The Holonic Manufacturing Paradigm

In general, the holonic manufacturing paradigm, with its branch of bionic manufacturing, has its origins in concepts introduced in a book written by Koestler in 1967 (Koestler, 1967). His work, titled the "Ghost in the Machine", was directed at the fields of evolution and experimental psychology[1]. The arguments which Koestler presented led him to cite examples from a range of social and biological organisations (Koestler, 1967). He asserted that any organisation with some degree of coherence and stability was hierarchically ordered, where in

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[1]The field of experimental psychology, was at that time, governed by the dominant behaviourist school of thought, which held the opinion that psychology could be studied with the methods and concepts of classical physics, and that quantitative measurement was the only acceptable scientific method. As a consequence, the complex phenomena of human behaviour had to be reduced to atomistic elements of behaviour which were assessable to quantitative measurement. Results from the studies of these atomistic elements of behaviour then provided, through crude analogies and extrapolation, all the necessary elements to predict and control human behaviour. A further a self-imposed limitation (which Koestler referred to as the de-humanisation of man), excluded all mental events and introspection from the study of psychology, and reduced the experimentation to the study of animals in preference to humans. Koestler rejected the prevalent opinion, arguing that the attempt to reduce the complex activities of man to the hypothetical "atoms of behaviour" found in lower animals produced next to nothing that was relevant. Koestler stated "Throughout the dark ages of psychology most of the work done in the laboratories consisted of analysing bricks and mortar in the hope that by patient effort somehow one day it would tell you what a cathedral looked like". Koestler asserted that a complex hierarchy could not be reduced to a sum of its parts, nor have its properties predicted from those parts.

general, certain principles or laws applied at all levels of the hierarchy. Koestler perceived in 1967, the characteristics of well ordered systems which he termed open system hierarchies (Koestler, 1967). Using the parable of the watchmaker[2], Koestler (1967) argued that the materialisation of any highly complex system had to be established on the basis of an hierarchy composed of stable, intermediary structures on a series of levels. This has provided the basis of a top-down approach for describing the complex organisational structure of an enterprise.

A fundamental property of the intermediate structures, was termed by Koestler (1967) as the "Janus-effect". These intermediary structures were described as assertive or self-contained wholes, and at the same time, integrative or dependant parts within a more expansive hierarchy. Koestler introduced the term "holon" to describe nodes on the hierarchical tree which can be characterised by the "Janus-effect". Holons operate purposefully in what is known as a "holarchy", which is an assembly of holons; this distinguishes a stable, complex system within which self-contained intermediate forms can be identified (Koestler, 1967).

The literature contains a diverse range of interpretations of Koestler's concepts for manufacturing. The application of these ideas was first studied by Suda (1989, 1990), who discussed the dynamic organisational structure of a highly automated holonic manufacturing system. The Japanese initiative on Holonic Manufacturing involves a multi-national collaborative research activity under the Intelligent Manufacturing Systems (IMS) programme. This collaborative effort also involves several Japanese companies, namely Hitachi Ltd., Toshiba Corp., Yaskawa Electric, Fanuc and Hitachi Seiko. In addition, the consortium includes the academic members of Keio University and Kobe University (Anon., 1990, Anon., 1995). The ultimate aim is to develop a solution for high variety and variable lot manufacturing through the development of an architecture for highly decentralised manufacturing systems, built from a modular mix of autonomous, cooperative and intelligent elements (Valckenaers, 1994, Van Brussel, 1994, Van Brussel et al., 1995, Leeuwen and Norrie, 1997).

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[2]Koestler cited the parable of one highly successful watchmaker who developed a method of constructing watches from sub-assemblies, as opposed to the method employed by another watchmaker who assembled his watches from individual constituent parts. In the event of a disturbance to the work, which resulted in the watches falling apart, the watchmaker who used sub-assemblies had to begin the construction process from the intermediate sub-assemblies. The business of the second watchmaker, on the other hand, was floundering since the invested labour was wasted and the assembly process had to restart from the constituent bits.

The branch of bionic manufacture has its origins in Koestler's description of organelles, ribsomes, cells and DNA in a biological holarchy (Koestler, 1967). Systems are modelled on the structures and interactions of organisms, which simultaneously exhibit autonomous and spontaneous behaviour within hierarchically ordered relationships (Okino 1989a, 1989b). Two complementary concepts to bionic manufacturing have been advanced, they are the Bio-modelon approach (Okino 1989a and 1989b) and the DNA and BN information approach (Ueda, 1992).

Deen (1993) investigated the cooperative issues in holonic manufacturing; in this, the basic structure of a holon and the coordination rules between each are proposed, detailing how joint goals are achieved in a cooperative manner. Work has been published which takes an holonic top-down view of an enterprise (Nakane and Hall, 1991, Mathews, 1995). This has not been accompanied by structured approaches or modelling methods.

3.5.1.1 Holonic Manufacturing Systems

Suda's concepts of the holonic manufacturing system is of greater relevance to this thesis and is presented in more detail in this section. The formation of holonic manufacturing systems may be taken from two approaches, the first is a top-down structuring approach and the second is based on a bottoms-up development[3]. The work of Suda (1990) has evidence of both viewpoints. In a top-down description of the formation of holonic manufacturing systems, he states that the characteristics of the Holonic system is its dynamic organisational structure (Suda, 1990). Suda identifies four essential components of an holonic system, these are the information processing, physical distribution, machine and the decision making systems. These four core components are to be found within the organisation of any focused group or holon, illustrated in figure 3.3, where each has recursive elements of, for example, the decision making and the information processing components (Suda, 1990).

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[3]In a top-down approach, a system is envisaged as a single global function which is decomposed into sub-functions equivalent to the original function (Gane and Sarson, 1979). Each sub-function then becomes the starting point for a further decomposition until the lowest level of description is of sufficient detail. The top-down approach is more amenable to systems analysis and management tasks (Williams, D.J., 1994).

In a bottoms-up approach, the system is synthesised from its elements, where the exact description of the inputs and outputs and the characteristics of the flows and conversions are known. The bottoms-up functional integration approach is better suited to systems synthesis (Williams, D.J, 1994).

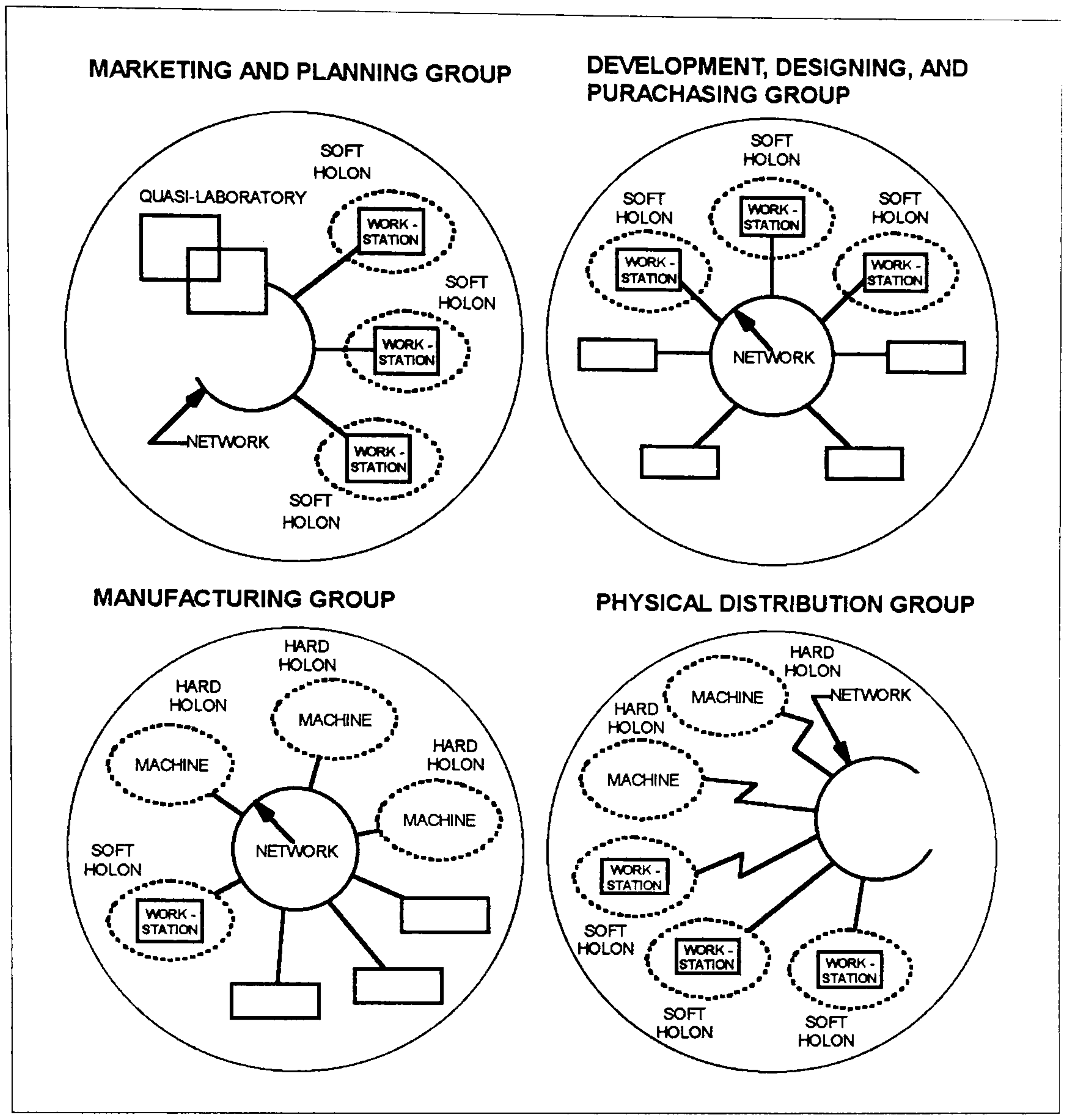

Figure 3.3: Components of an holonic manufacturing system with detail of each group (Suda, 1990).

This dynamic organisation has to be facilitated by a comprehensive information system. The organisation of the company into these focused groups improves the services to customers, where the groupings are flexible depending on the nature of the business and the pursuit of given targets. As shown in figure 3.3, there are information processing (soft holons) and the actual manufacturing equipment (hard holons) within each focused group; this provides the basis for the bottoms-up development of the holonic manufacturing system. Suda (1990) listed important network functions required for holonic manufacturing, which are summarised in the following points:

(i) Every holon itself is designed with self-monitoring, diagnosis and restoration functions for unmanned operations. Peer holons are mutually supportive, acting accordingly to set criteria in the event of faults.

(ii) Each holon has a bi-directional communication capability for communication with the total system and with other holons in the "holarchy". This gives the holon the capacity to report its condition to both the neighbouring holon and the system.

(iii) Every holon has a more ambitious specification when compared with the alternative conventional manufacturing unit to enable it to perform additional jobs in emergency conditions; the acceptable balance of cost and performance has to be decided on an individual basis.

(iv) The holonic production system monitors the condition of the system so that it can detect abnormal conditions, provide diagnostics and separate the defective holon from the system without adversely affecting any other holon.

Human operators in an holonic manufacturing system play an important role and human intervention is made possible via a man machine interface (MMI). Suda considered that whilst an operator can operate several holons, no holon exists for which man plays no part (Suda 1990).

3.5.2 The Fractal Manufacturing Paradigm

The fractal paradigm for manufacturing enterprises was introduced by Warnecke (1993). Warnecke defines the central structuring element of a manufacturing enterprise as a fractal, illustrated in figure 3.4. The fractal represents an independently acting corporate entity, whose goal and performance are described in terms of self-similarity, self-organisation, self-optimisation and high individual dynamics.

The characteristic of self-similarity underpins the fractal concept; it refers to the alignment of the global goals of the company and the localised goals of the fractal, which ensures that individual activities do not compromise the overall unity (Warnecke, 1993). The dynamic restructuring of a manufacturing area, shown in figure 3.5, is such that the internal relationships (flow of material, staff and information) within a fractal are closer and more intensive than those to the outside (Warnecke, 1993, Klopp et al., 1997). The mechanism of structuring is largely on an analysis of the interrelationships within and between fractals, where in the interest of serving the whole company, these independent elements form themselves into groups even in the absence of external pressure.

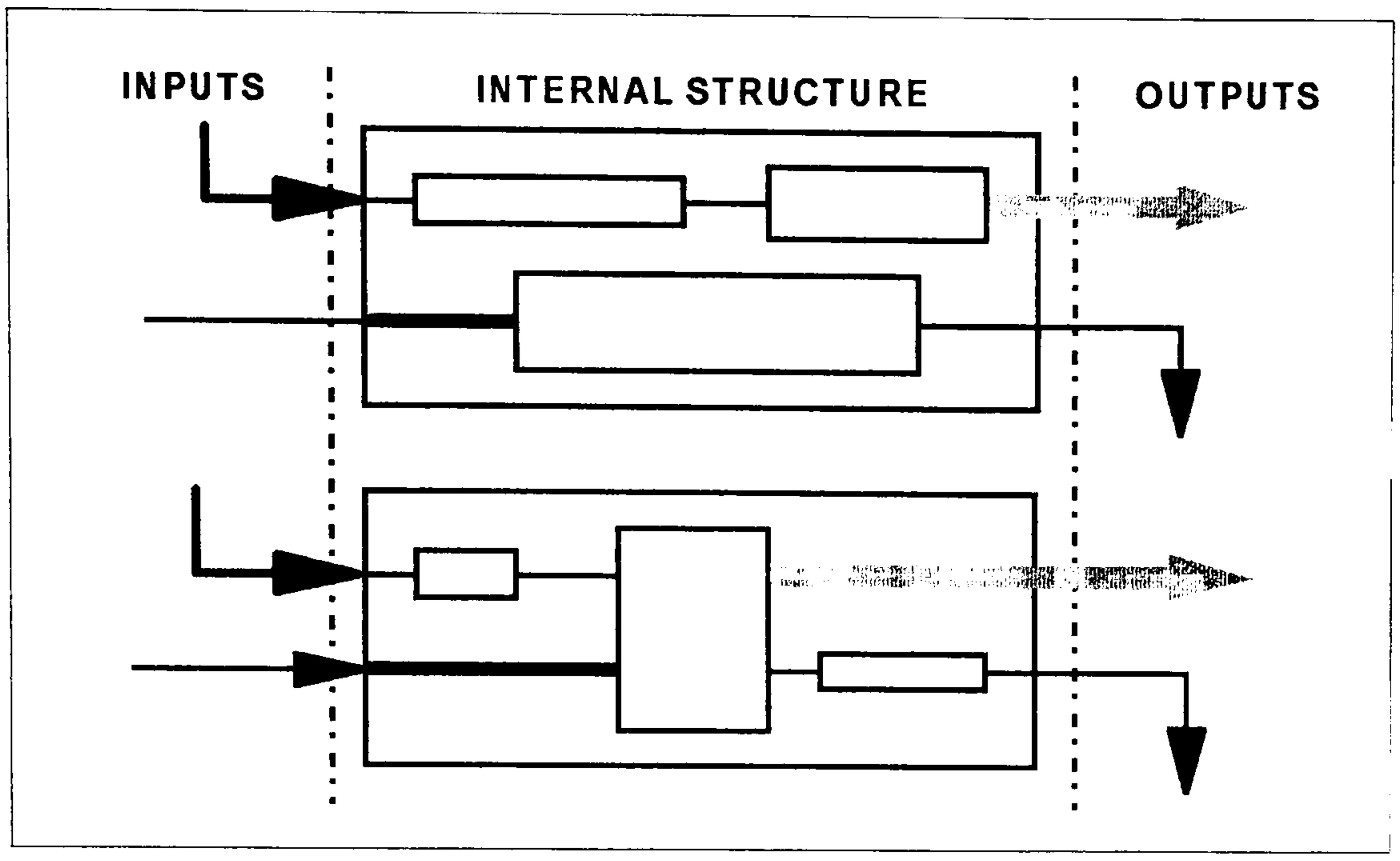

Figure 3.4: Self similar fractals: The central structuring element of a manufacturing enterprise (Warnecke, 1993).

The fractal factory is an integrating concept and is multi-dimensional, ensuring both horizontal and vertical goal alignment; direct communication takes place along the horizontal level of operational levels instead of instructions and information being transmitted through vertical levels of an hierarchy (Warnecke, 1993). Individual fractals have, therefore, to be networked via an efficient information and communication system and determine their own access to the data. In a dynamic environment, individual fractals formulate their own goals and methods, and employ appropriate resources to complete their task (Sihn, 1995).

The basis of autonomous working for the fractal is such that whilst the job order comes as a top-down specification, actual planning and implementation planning is based on a bottoms-up process (Warnecke, 1993). Each fractal must itself be a fractal factory, with the capacity of entrepreneurial thinking and acting in all areas down to the individual employee. The internal and external structures of the fractal company are thus founded on the skills of the work force and in addition, the holistic approach embodies an increasing regard for human needs (Warnecke, 1993).

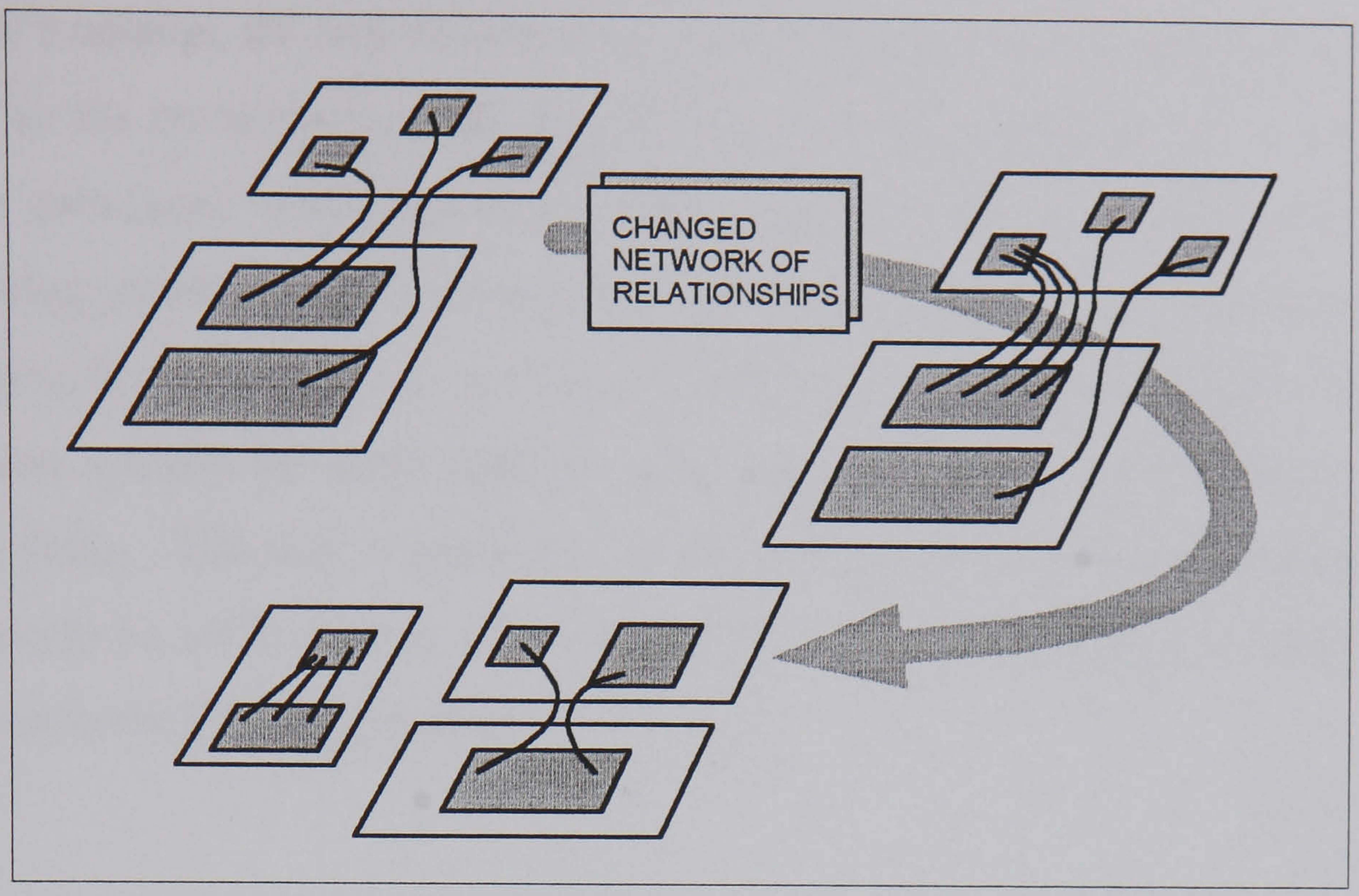

Figure 3.5: The dynamic restructuring of a manufacturing area (Warnecke, 1993).

3.6 Epilogue: A Critique of the Issues Impinging on the SME

Warnecke (1993) states that distinct expression in terms of new paradigms, which are not merely an extension of existing models, is necessary to stimulate awareness which is a precondition to bring about a change in self-image and mindset. A manufacturing paradigm can be seen, therefore, as a vehicle for expressing an overall motivation or commitment towards achieving the goal of better business performance. Achieving success in an intensely competitive environment may ultimately depend on the application of advanced manufacturing technologies, in conjunction with a unifying standpoint which communicates an overall sense of direction and carries the internal values or corporate culture of the company. It is fitting to reflect on the profundity of the chosen title of Koestler's epoch making book.

The socio-technical design approach (section 3.4), which provides guidelines for the allocation of responsibilities to humans in a manufacturing system, will be undoubtedly be relevant. The work, which is reported in this thesis, applies Koestler's fundamental concepts as a way by which the human dominated interactions can be characterised and modelled, with the aim of capturing current and improving business practices. However, the question of whether the fundamental holonics based modelling concept may be considered as a means to support socio-technical design must be left as an issue for further research.

In the author's opinion, the lack of reference models and appropriate modelling formalism have contributed to the problems faced in the application of the paradigms. Moreover, there is a tendency for paradigms to be consultancy driven, which results in overselling and hype. Some of the emerging paradigms will contain more tractable concepts for developing new modelling methodologies; the work reported in this thesis offers a basis for the realisation of a new class of information systems for small metalworking companies based on Koestler's fundamental ideas of the holon. This task is supported by an reference SME enterprise model. This work has therefore, to be set in context of contemporary enterprise modelling practice, a review of which is given in the following chapter.

Chapter 4

State of the Art in Enterprise Modelling

4.1 Introduction

The main theme in this chapter is to introduce the principles of enterprise modelling and the state of the art in modelling methods and architectures. The most prominent enterprise modelling architectures are presented. The reviews on the CIMOSA and ARIS architectures represent a more detailed discussion as these have the most impact on the research.

4.2 Enterprise Modelling

Enterprise modelling is a rapidly developing technical field and is becoming part of a systematic engineering approach called enterprise engineering, which encompasses modelling, analysing, designing and implementing integrated enterprise systems (Vernadat, 1996). In enterprise engineering, the process of design involves balancing a set of competing requirements; the products of design are models which enable designers to reason about structures, make trade-offs when requirements conflict, and in general, provide a blueprint for implementation (Burkhart, 1992, Booch, 1991).

An enterprise model is a symbolic representation of individual facts, objects and relationships that occur within the enterprise, these definitions and descriptions may apply at any scale (Marshall et al., 1992, Burkhart, 1992). As an abstract, simplified representation of some specific aspect of the system under consideration, an enterprise model amplifies the important characteristics and conceals the details which are considered to be of low or no importance at a given abstraction level (Jorgenson, 1992, Doumeingts and Chen, 1992).

In general, the reason for conceptualising various aspects of an enterprise in terms of formal models is to supply an explicit method for the understanding, controlling and monitoring the enterprise (Burkhart, 1992, Bernus et al., 1994). The modelling exercise itself should contribute to enterprise goals. The major effort involved in collecting the data about an ongoing activity for subsequent review and analysis, itself contributes to a better understanding of enterprise activities and their interactions.

The application fields for enterprise models are not only aimed at the improvement of organisational structures; the construction of enterprise models may embrace overall system architecture, product design, project management, software specification or to establish the information requirements for database design (Wilson and Weston, 1995). Therefore, models would already be in existence in various forms which can address virtually any aspect of an enterprise, these components of the company are not purchased; they are built over time by the enterprise. Two broad categories of enterprise models can be distinguished, these are factual and conceptual enterprise models.

4.2.1 Factual Enterprise Models

The first category consists of factual enterprise models. In this application, the activity of model building results in symbolic models that correspond directly in some way to the things of interest to the organisation (Scheer, 1992). The information represented may be coded in many distinct formats, this is depicted in figure 4.1, these range from representations in textual form as policies or procedures, mathematical formalisms, languages or graphical tools (Doumeingts and Chen, 1992). A typical enterprise may have several models spanning from simple structures like organisational charts, process flow data and spreadsheets, to more complex structures such as product or manufacturing models (Goranson, 1992).

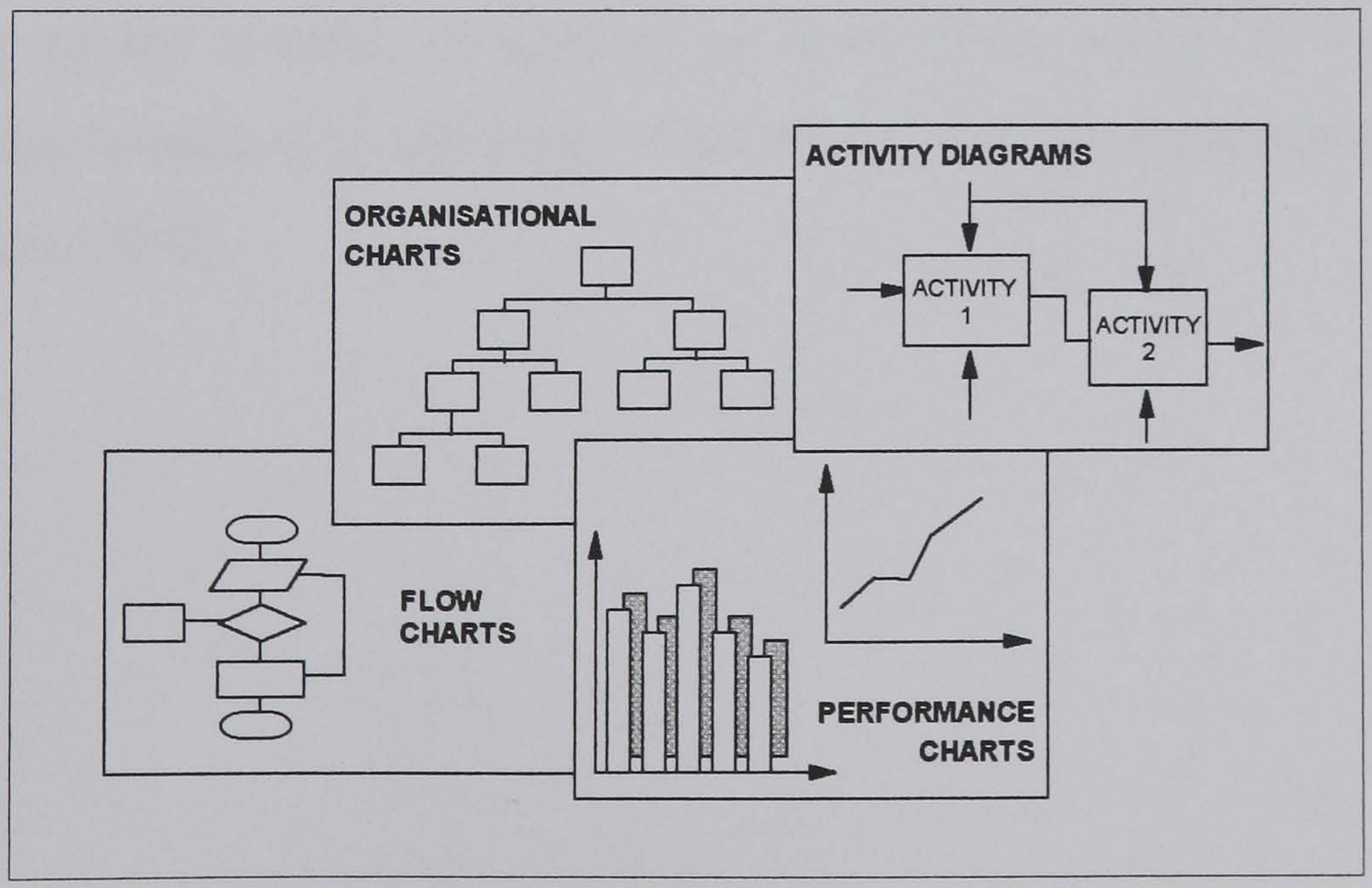

Figure 4.1: Factual enterprise models.

These models may be used to define the roles of the employees expressing their mutual obligations, common goals and responsibilities which distinguish roles in a community. To control their own operation, users of these enterprise models will not only have to understand their model, but to help modify and maintain it (Burkhart, 1992). Making concepts and procedures clear through a medium of physical images, which present information structured in a highly visible format, provides a focus on errors and problems. This helps employees understand and recognise situation types and provide documented procedures for the execution of plans or activities (Miller, 1996).

4.2.2 Conceptual Enterprise Models

The second category is that of conceptual enterprise models (Fox, 1993, Hars et al., 1992). Conceptual enterprise models, shown in figure 4.2, are specific instances of data or semantic models, these are described in greater detail in section 4.3.1. This area of application originates from database and repository technology environments (Abrial, 1974, Chen, 1976).

The distinction of conceptual enterprise models has become significant as data models have evolved, through formal modelling methods and modelling technology environments (based on CASE tools), into a means for enterprise modelling and to improve information integration (Hars and Scheer, 1992, Fox et al., 1993, Ray and Wallace, 1995, Zhang et al., 1996, Singh and Weston, 1996). Presently, data or semantic models are also known by a variety of other names, depending on the context, or application; other terms which are frequently used are data models or meta-models (Lin and Fang, 1993, Hsu, 1994, Rozenfeld et al., 1994, Koonce et al., 1996, Scheer, 1992).

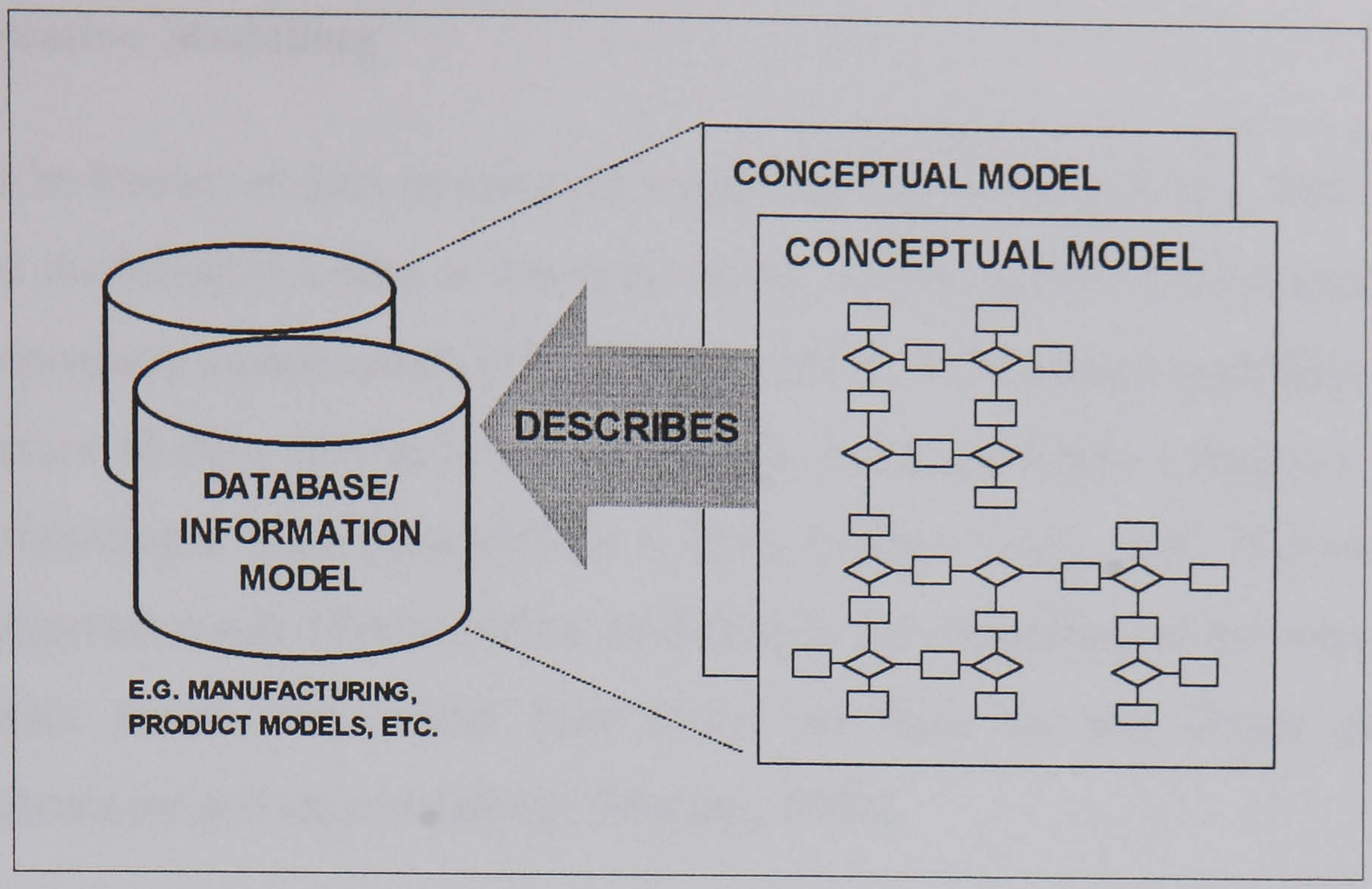

Figure 4.2: The description of data structures using conceptual models.

4.3 Formalisms for Enterprise Modelling

The typical aspects from which an enterprise can be described are the function, organisation, resource, information, this however, is not a conclusive list and other aspects can be included. To represent a selected aspect of an enterprise, modelling formalisms can be used. A modelling formalism is a means to represent pieces of knowledge that have to be transmitted unambiguously (Bravoco and Yadav, 1985). The term is used to express the idea that languages (graphical or textual) are employed allowing models to be built according to associated concepts, permitting a level of formality of representation (Doumeingts and Chen, 1992).

A formal notation to describe and understand an organisation minimises the problems of communication, inconsistency and ambiguity (Bravoco and Yadav, 1985). The various approaches to modelling may be broadly divided into four categories, these are information modelling, functional decomposition, data flow and object oriented. These may or may not be directly associated with a particular methodology or reference architecture (Williams et al., 1993).

4.3.1 Information Modelling

This may also be known as data or semantic modelling (Chen, 1976, Codd, 1981). The result of information modelling is a data or semantic model, which represents the meaning of data in database or repository environments (Chada et al., 1991). Information modelling is concerned with the structure of data, so that it can be properly managed within a database, this focuses solely on representing a "data network" for a given system (Codd, 1981, Nijssen and Halpin, 1989). An important result of information modelling is the structuring of the enterprise data as a semantic data model, this model then forms the basis for the design of application independent databases and data interfaces (Mertins, 1992).

An important concept of information modelling is that data is considered independently of the processing that is required to transform the data. Graphical modelling tools include Entity-Relationship (Teorey et al., 1986), Entity-Relationship-Attribute (Chen, 1976), IDEF1x (Bruce, 1992, Adelsberger, 1995), NIAM (Nijssen and Halpin, 1989), EXPRESS-G (Schenck and Wilson, 1994) and the M* Methodology (Vernadat et al., 1989). Object oriented techniques have also been applied for information modelling (Joergensen, 1992). Whilst these graphical methods listed above are excellent for dealing with group communication problems, they are not computer executable. Here, the EXPRESS information modelling language provides a textual based solution that conforms to a special syntax which can be parsed by a suitable compiler (Schenck and Wilson, 1994, Step-Tools, 1992).

4.3.2 Functional Decomposition

In functional decomposition, a system or part of a system is envisaged as a single global function. The system is then decomposed into sub-functions equivalent to the original function and the interfaces between the sub-functions are identified (Gane and Sarson, 1979). Each sub-function then becomes the starting point for further decomposition into sub-functions and the identification of lower-level interfaces. This process may continue until the lowest level of description is of sufficient detail. Structured Analysis and Design Technique (SADT) is one such method which facilitates the building of a functional model, providing an informal description of a system in terms of a hierarchy of functions (Gane and Sarson, 1979). The

IDEF0 graphical modelling method is based on the SADT technique (CAM-I, 1980, Colquhoun et al., 1993, Jorgensen, 1995). Applications of the IDEF0 modelling formalism can be found in Bravoco et el. (1985), Colquhoun et al. (1988) and Colquhoun and Baines (1991).

4.3.3 Data Flow Modelling

Data flow modelling views a system solely as a network of information schema transformations, data flow and data stores, the modelling is usually carried out with Data Flow Diagrams (DFD). Similar to functional decomposition, data flow modelling usually follows a "top-down" developmental approach. A methodology which applies the data flow approach is the Structured Systems Analysis and Design Methodology (Ashworth and Goodland, 1990). As a consequence of the weak emphasis on the data stores represented in data flow models, the methodology is usually applied in conjunction with information modelling concepts (for example, ERA or IDEF1x, etc.).

4.3.4 Object Oriented Modelling

Object orientation offers an approach to modelling which is more consistent to the way humans think about problems. This approach models a system through modules or classes, where each class manages an object of the system. The use of classes and inheritance provides a simple and expressive model for the relationship of various parts of the system's definition and assists in making components reusable or extensible in systems construction (Manola, 1990). An object oriented approach results in the definition of a system which closely parallels the application domain, thus assisting in systems design and understanding.

There is a great deal of literature dealing with the development of object oriented systems. Champeaux et al. (1992) compare twelve object-oriented analysis methodologies and describe their differences. Monarchi et al. (1992) evaluate twenty three object-oriented analysis and design methodologies. The popular approaches to the development of object oriented systems are Booch (1991), Coad-Yordon (1991), Rambaugh et al. (1991), and Shlaer and Mellor (1992).

4.4 Multiple Viewpoints of An Enterprise Model

An enterprise is a complex system which performs a large number of functions (processes and activities) by means of its resources, using materials and information to achieve business objectives or goals. A combination of the various aspects which need to be captured results in a multiplicity of viewpoints represented within an enterprise model; the number of views captured should depend on its intended application (AMICEE, 1991, Scheer, 1992, Vernadat, 1996). A viewpoint within an enterprise model represents a set of selected elements concerning the domain studied, different views allow the analysis of a particular aspect of an enterprise without having to take into account all the other points of view at the same time (AMICEE, 1991).

No single modelling technique is adequate for all situations; to express all the constituents of a complex system, more than one modelling method has to be used (Booch, 1991). Within an individual viewpoint of an enterprise model, modelling formalisms should provide sufficient scope and modelling capability, in terms of constructs and notations (i.e. rich or extensive in semantics), to capture the concepts and factual information (Vernadat, 1996). The direct application of different modelling formalisms, i.e. in their individual graphical or textual forms, results in an enterprise model which is not integrated, as there may not be any correspondence between the different notations used (Kaaramees et al., 1994). PERA and GRAI are examples of enterprise modelling architectures which produce non-integrated models. In contrast, CIMOSA and ARIS modelling architectures result in an integrated enterprise model. These architectures are now described in the following sections.

4.5 Frameworks and Architectures for Enterprise Modelling

Modelling architectures provide the situation and syntax to allow easy identification and interpretation of the structure and contents of a model, e.g. views, levels (Bernus et al., 1994). An architecture is used to organise the relevant viewpoints and the multiplicity of models (e.g. specification, design and implementation models) which may result from enterprise modelling.

Many of the modelling architectures were originated for the design and the implementation of CIM systems (Chen et al., 1990). These are based upon describing the invariant elements and relationships which the individual CIM system was conceptually composed of, in addition to their functionality (Vallespir et al., 1991, Doumeingts and Chen, 1992, Rood, 1994). Moreover, these models also described specifications which could be transformed into the working system (Chen et al., 1990). The impetus for developing enterprise reference architectures is that a large part of an integration project is common to every type of enterprise, thus the similarity can be captured, standardised and utilised. Generally accepted architectures can be supported by reference models and a range of modelling products which make the entire modelling endeavour efficient in time and cost (Williams et al., 1993).

Williams et al. (1993) point out two interpretations of reference architectures. They state that an enterprise reference architecture (in the narrow sense) contains a system of models which describe, from various points of view, the integrated enterprise as it is going to function. There is also another category of enterprise reference architectures (in the broad sense) which describe the enterprise in various stages of its development. Mayer and Painter (1991) distinguishes the latter interpretation (of architectures in the broad sense) as modelling frameworks. Thus, frameworks include within their constructs, the capability to describe enterprises in various stages of development (or situation types). Hence, CIMOSA (AMICEE, 1991), ARIS (Scheer, 1992), the structured approach of SSADM (Ashworth and Goodland, 1990) and PERA (Williams, 1994a) may be classified as modelling frameworks. However, it should be noted that throughout much of the literature, the terms frameworks and architectures have been used synonymously and this distinction is not usually made.

4.5.1 The Purdue Enterprise Reference Architecture (PERA)

The Purdue Enterprise Reference Architecture (PERA), and its associated methodology, provides a guide through all the phases of a systems integration program (Haren and Williams, 1990, Williams, 1994a, Williams, 1994b, Purdue, 1994). The reference architecture, illustrated in figure 4.3, is characterised by its layering structure, which provides a framework under which the various aspects of an enterprise may be described. As it is intended to be easily understood by non-computer scientists, the descriptions used in the methodology and graphical presentation of its overall structure of the systems development process are informally based (Williams, 1994a). PERA does not prescribe an associated set of modelling formalisms which would be necessary if the modelling process were to be computer based. Rather, each stage of the architecture may be viewed as a sub-architecture to which any number of appropriate modelling tools may be assigned to perform the design tasks (Williams et al., 1994).

As illustrated in the figure, the development of the enterprise architecture is centred around two main systems, the first is the physical manufacturing system and the second is the information processing system (Williams, 1994a). These two systems are described at the definition phases of the project using the manufacturing and information sub-architectures respectively. A distinct feature of the PERA architecture, shown in figure 4.3, is the definition of the human role in the information and manufacturing system. PERA defines this scope during the design phase of the project by identifying or demarcating the human and organisational boundaries within the manufacturing and information architectures (Williams, 1994a).

It should be noted that PERA does not provide the capability to model the human component, rather, it gives the scope to discuss and define the tasks which will be fulfilled by people in the organisation (Williams et al., 1994). The actual degree of involvement of human and technology in the final implementation of the information or manufacturing system is indicated by the Extent of Automation, which is subject to economic, social laws and directives. The humanisability line indicates the extent to which human involvement may possibly be implemented, subject to human skills, abilities in terms of speed of response and physical strength, etc. The automatability line indicates the extent of technology in terms of its capability in actually automating the task (Williams, 1994a).

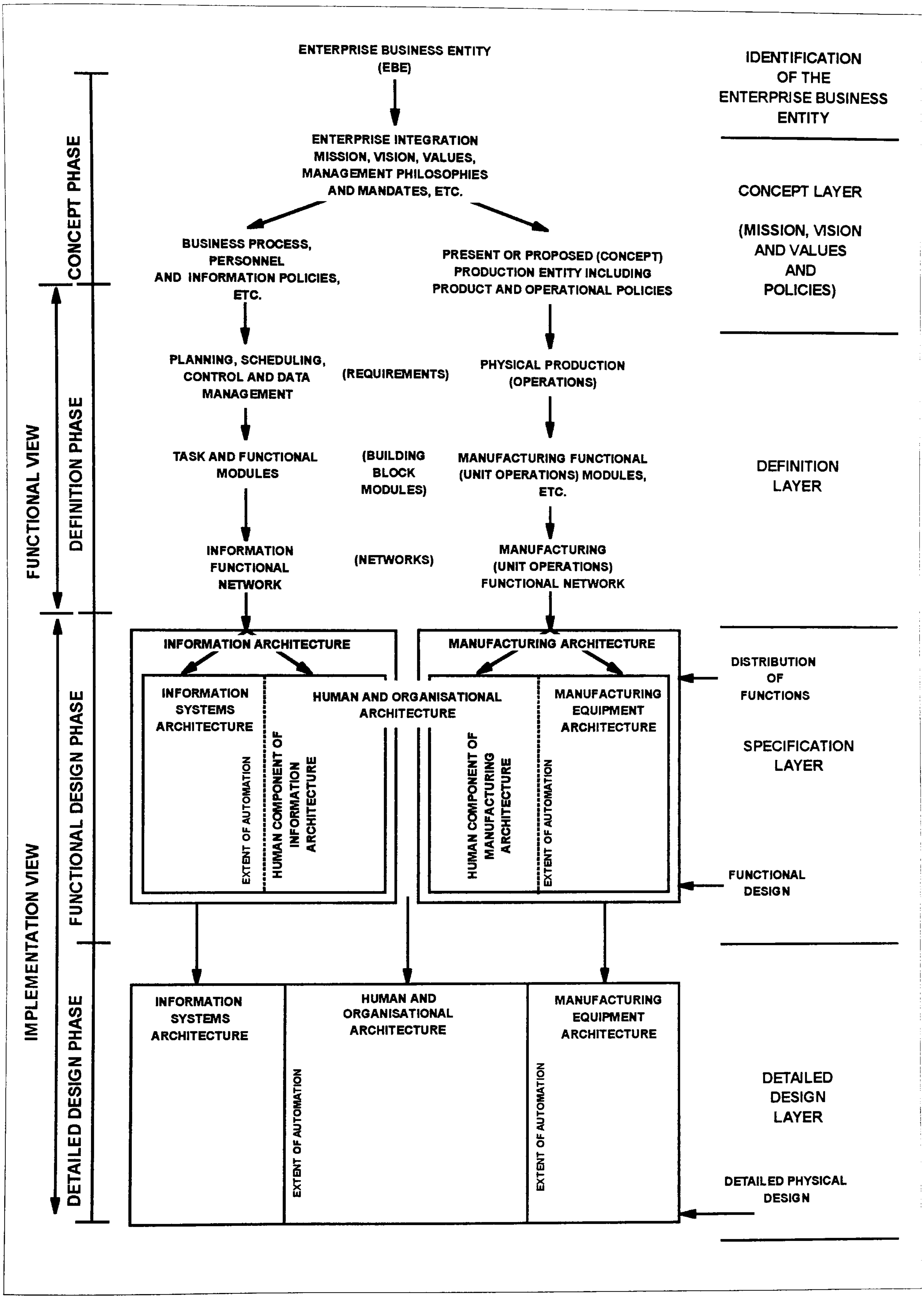

Figure 4.3: The structure of the Purdue Enterprise Reference Architecture (Williams, 1994a).

4.5.2 The GRAI Methodology

The GRAI-Integrated Methodology (GIM) was developed to provide an integrated methodology for the analysis and design of advanced manufacturing or CIM systems (Doumeingts et al., 1987, Doumeingts, G., 1989, Doumeingts et al., 1992). The GRAI methodology is developed for user oriented design rather than for technical oriented design (Doumeingts et al., 1993). The methodology comprises a set of components, these are (Roboam et al., 1989):

(i) The GRAI global (or CIM) reference model which gives the generic structure of the system to be studied, this has been illustrated previously in figure 3.2.

(ii) The GIM structured approach for the design and implementation of the system, illustrated in figure 4.4.

(iii) The GIM modelling framework with associated modelling formalisms to describe the various aspects of the system, illustrated in figure 4.5. The modelling formalisms used are IDEF0 for functional modelling, ERA for information modelling.

(iv) Performance evaluation criteria with which the system can be evaluated.

The aim of the GRAI reference model is to give a generic description of the manufacturing enterprise focusing on the control aspects of the system. At a conceptual level, the global reference model is composed of three systems, these are the information, decision and the physical system. In order to define exactly the boundaries of the domain being studied and to model the main functions of the manufacturing system, a functional view is added (Doumeingts, 1993). This results in the GIM modelling framework which is shown in figure 4.5, which is organised into abstraction levels and is further divided into a user oriented and technical oriented part. Developments have so far concentrated on the user oriented part, the technical oriented part of the GRAI modelling framework is still to be developed.

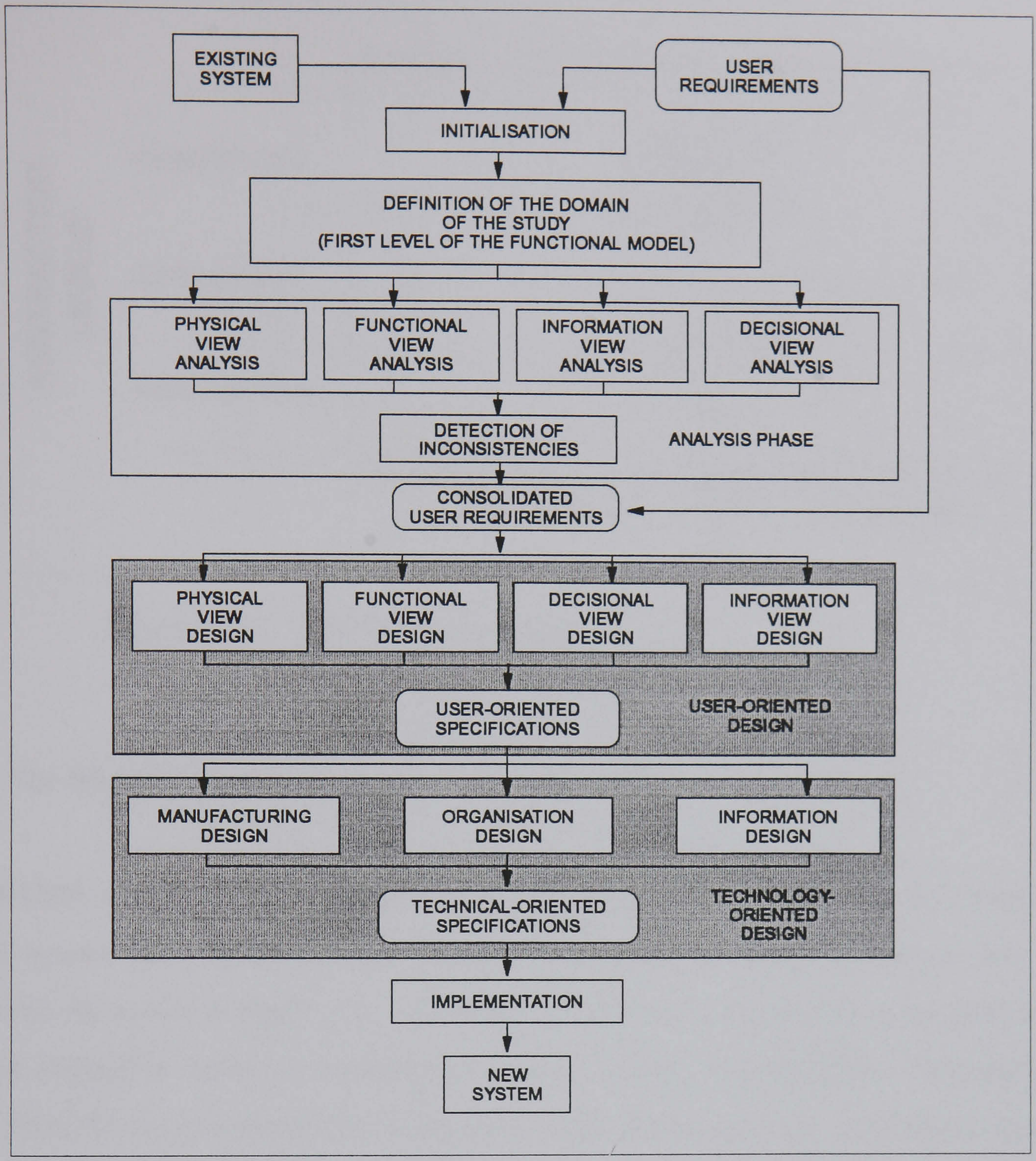

Figure 4.4: The structured approach of the GRAI methodology (Doumeingts et al., 1987).

The user oriented part of the GRAI methodology is supported by modelling formalisms to describe the information, decision, physical and functional views (Doumeingts et al., 1995). Of these four views, the GRAI methodology provides a more extended analysis of the decision aspects of the manufacturing system. For this purpose, two modelling tools are introduced in the GRAI methodology, these are the GRAI-GRID and the GRAI-NET (Doumeingts, 1989). Initial analysis of the production management system is carried out using the GRAI-GRID to identify the key planning and control centres. This is followed by detailed decomposition and analysis of the individual planning and control activity using the GRAI reference model of the decision centre in conjunction with the GRAI-NET (Doumeingts, 1989).

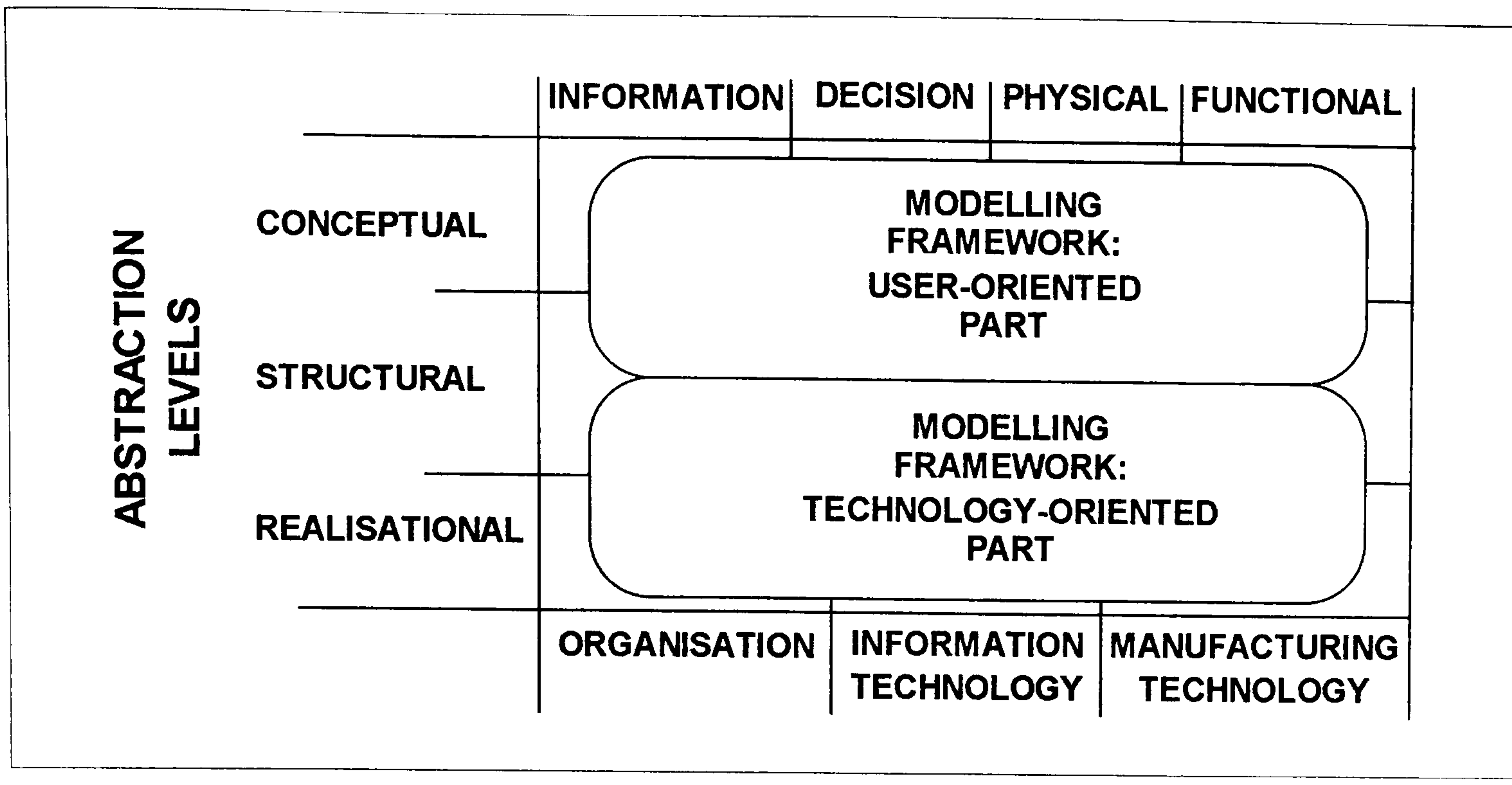

Figure 4.5: The GRAI modelling framework (Doumeingts et al., 1987).

4.5.3 The SSADM Methodology

The SSADM methodology (Ashworth and Goodland, 1990), leads step by step from an existing system to a future system taking into account evolution objectives and specific constraints, illustrated in figure 4.6. Each stage consists of a set of tasks to be performed; the tasks are defined in terms of required inputs and outputs or deliverables (Longworth et al., 1988). SSADM is accompanied by techniques which define how the individual stages of the structured approach are performed, these are supported by modelling formalisms such as data flow diagrams, logical data structures, entity life histories and logical dialogue design (Longworth and Nicholls, 1986).

4.5.3.1 The Structured Approach of SSADM

Six stages of the SSADM realisation process are fully supported by techniques and modelling formalisms (Ashworth and Goodland, 1990), these stages are highlighted in figure 4.6. Analysis of the organisation in terms of its existing system is carried out to understand the operations and data requirements. This is an important aspect of the technique to provide a firm basis for the design of the future system.

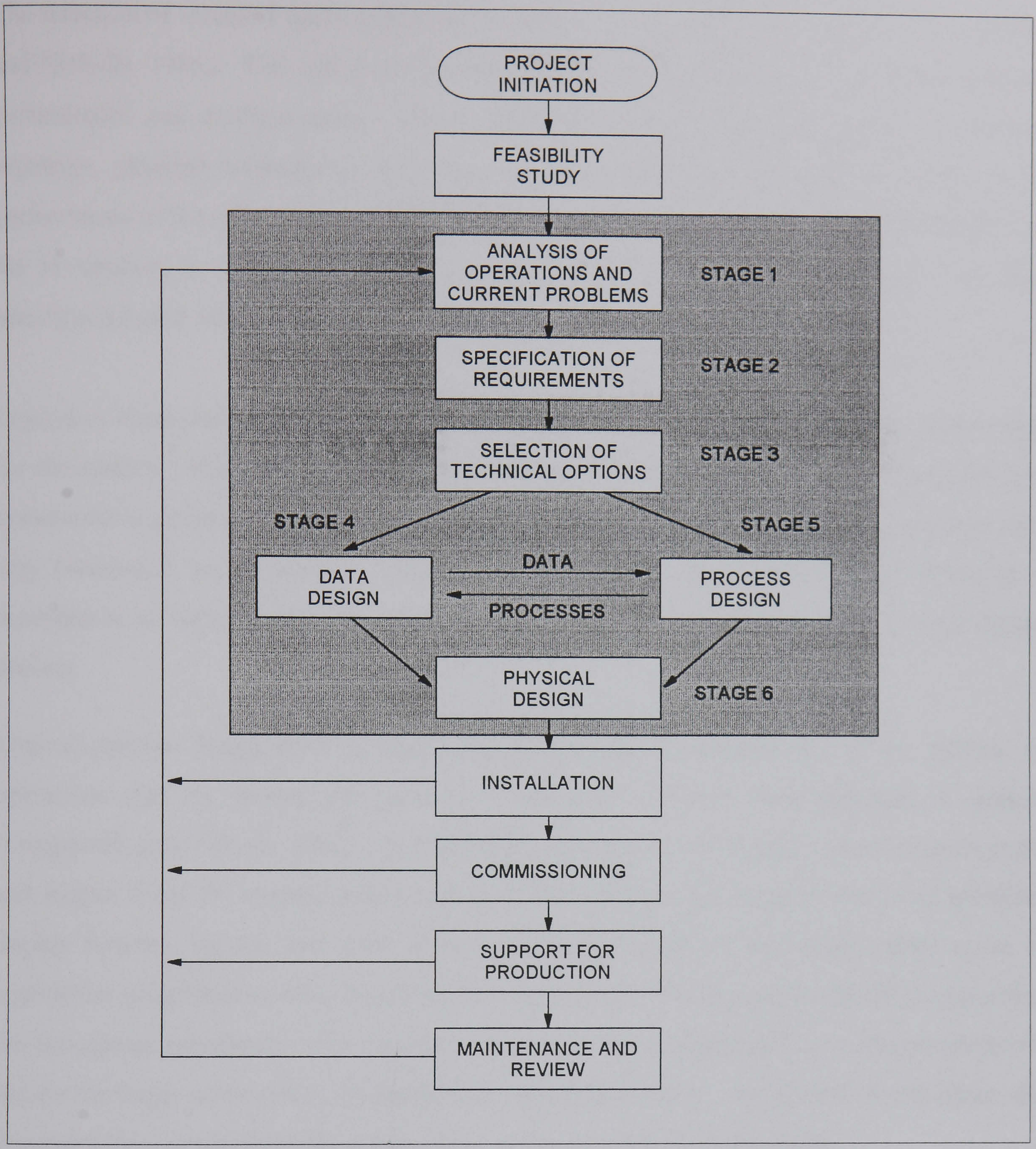

Figure 4.6: The structured approach of the SSADM methodology (Ashworth, 1990).

Specification of the requirements involves extracting the logical view of the system, from the understanding obtained from the previous stage, in terms of what the new system is supposed to achieve (Ashworth and Goodland, 1990). This will involve aspects of both current operations and decisions about what must be included in the new system.

The selection of technical options involves the choice of the final system hardware (Longworth and Nicholls, 1986). This will invariably require the careful consideration of various enabling technologies and configurations. These range, for example, from the choice of network topology, physical transmission medium, communication protocol, network access or the performance of the information network. The purchase of new equipment requires input from the IT vendors to compile the different implementation options for the system. The final selection is based on the most appropriate solution which is economically viable.

Logical or conceptual data design involves formally documenting the information requirements for the system. SSADM is a data driven method, which means there is an assumption that systems have an underlying unchanging data structure, although processing requirements may vary (Ashworth and Goodland, 1990). Within SSADM, this underlying data structure is modelled at an early stage of the methodology and forms a major part of the systems design process.

Logical process design involves specifying the processing requirements of the system, or operations that the system will perform in response to events, data enquiries or updates (Longworth and Nicholls, 1986). This includes a description of the data content of every input and output from the system, which will form the basis for the detailed design of graphical display formats, reports and form layouts; these specifications are subsequently given to application programmers who create the user interfaces. Physical design involves converting the conceptual specifications for data and the processing requirements into a design which will run on the target environment (Ashworth and Goodland, 1990). At the end of this phase, the documentation required for the subsequent construction phases is produced.

4.5.4 Integrated Enterprise Model (IEM)

The concept of the Integrated Enterprise Model (IEM) is to provide the basis of representing the different aspects of manufacturing enterprises as one unique model (Spur et al., 1990). The approach is aimed at the production of a comprehensive enterprise model of business processes and data structures (Mertins et al., 1992, Mertins et al., 1995), this is shown in figure 4.7.

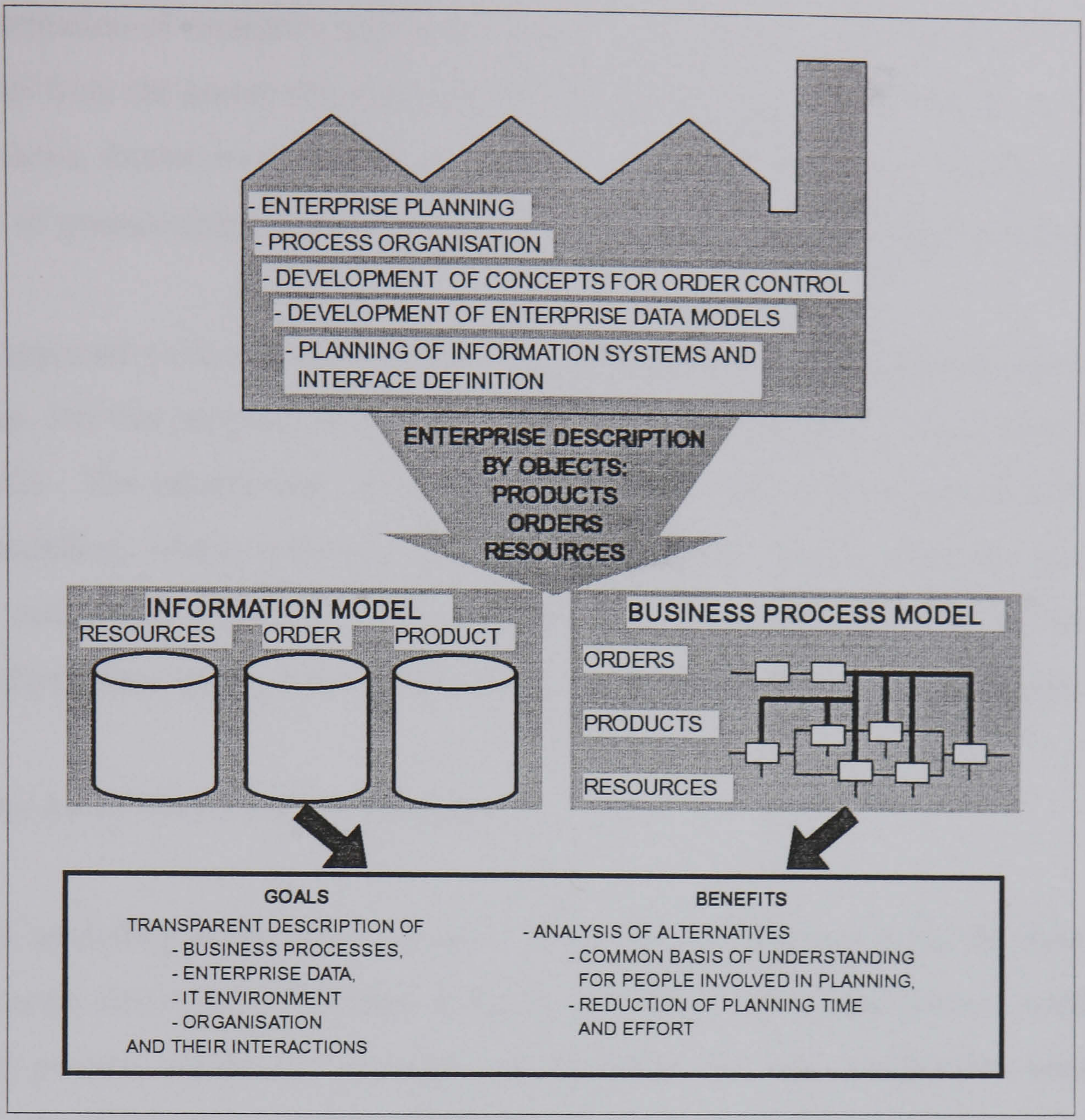

Figure 4.7: The IEM enterprise model (Spur, 1995).

The IEM comprises two main views, namely the business process and the information view. The development of an integrated enterprise model is underpinned by the object oriented modelling approach, based on a standardised kernel of the generic information object classes and a generic activity object class (Spur et al., 1995). The kernel information model comprises the generic "Product", "Orders" and "Resource" object classes, illustrated in figure 4.7. These three generic information object classes are used in conjunction with the generic activity object class to provide the basic constructs for the generation of a particular enterprise model (Mertins et al., 1992).

The object oriented modelling approach allows the representation of enterprise objects and their properties in accordance with one of the abstract objects classes and its related attributes. During the modelling process, the addition of sub-classes to reflect different enterprise objects, has to be carried out by deriving the sub-classes from one of the three kernel object classes.

The representation of enterprise objects by the derivation of sub-classes allows the inheritance of attributes from the kernel object classes (Mertins et al., 1992). In addition to the function and data views, further modelling views can be incorporated, by the development of specific subclasses of generic object classes by identifying class specific attributes and attribute values.

The IEM approach to functional modelling is to describe the manufacturing process as a series of activities. For this purpose, the generic activity model (IEM-GAM) was proposed (Mertins et al., 1992). The relationship between the function and information view is established by activity modelling, where activities change and process the objects which are classified into products, orders and resources. The capability to execute the activity is provided by the resource object class and an order object class is used to trigger the execution of the activity.

4.5.5 The ARIS Modelling Architecture

The ARIS modelling architecture (Scheer, 1992, 1993) is derived from the structure of a general process description, illustrated in figure 4.8. The process description is used to model a selected process within the business and identifies the key components related to its execution. As depicted in the figure, the elements of a process description includes the events which trigger the process, the resources used to execute the process, the personnel responsible for the tasks and the information which supports the process (Scheer, 1992).

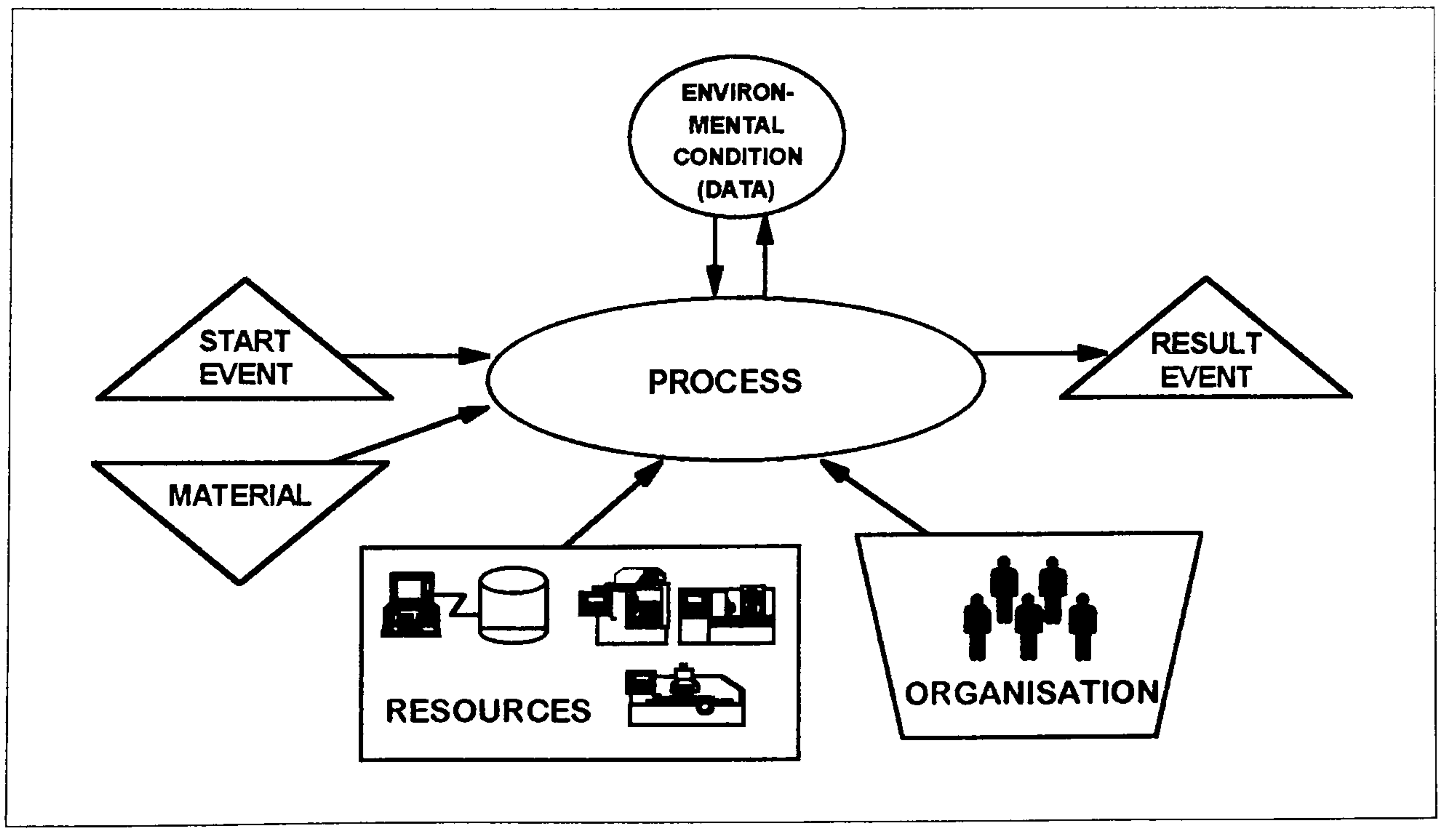

Figure 4.8: The ARIS process model (Scheer, 1992).

The ARIS architecture which results from the process chain description comprises four views, namely the function, organisation, information and control view. The architecture is shown in figure 4.9. The first three modelling views of the architecture are directly associated to the description of the process chain; the function view models business processes in terms of functional and goal structures (Scheer, 1992). The functions are decomposed into their functional structure, processing sequences and their support using decision models. The organisation view models the organisational units responsible for the tasks defined in the process model. Apart from their responsibility for functions and data, organisational units are modelled as users of the interfaces of the information system (Scheer, 1992).

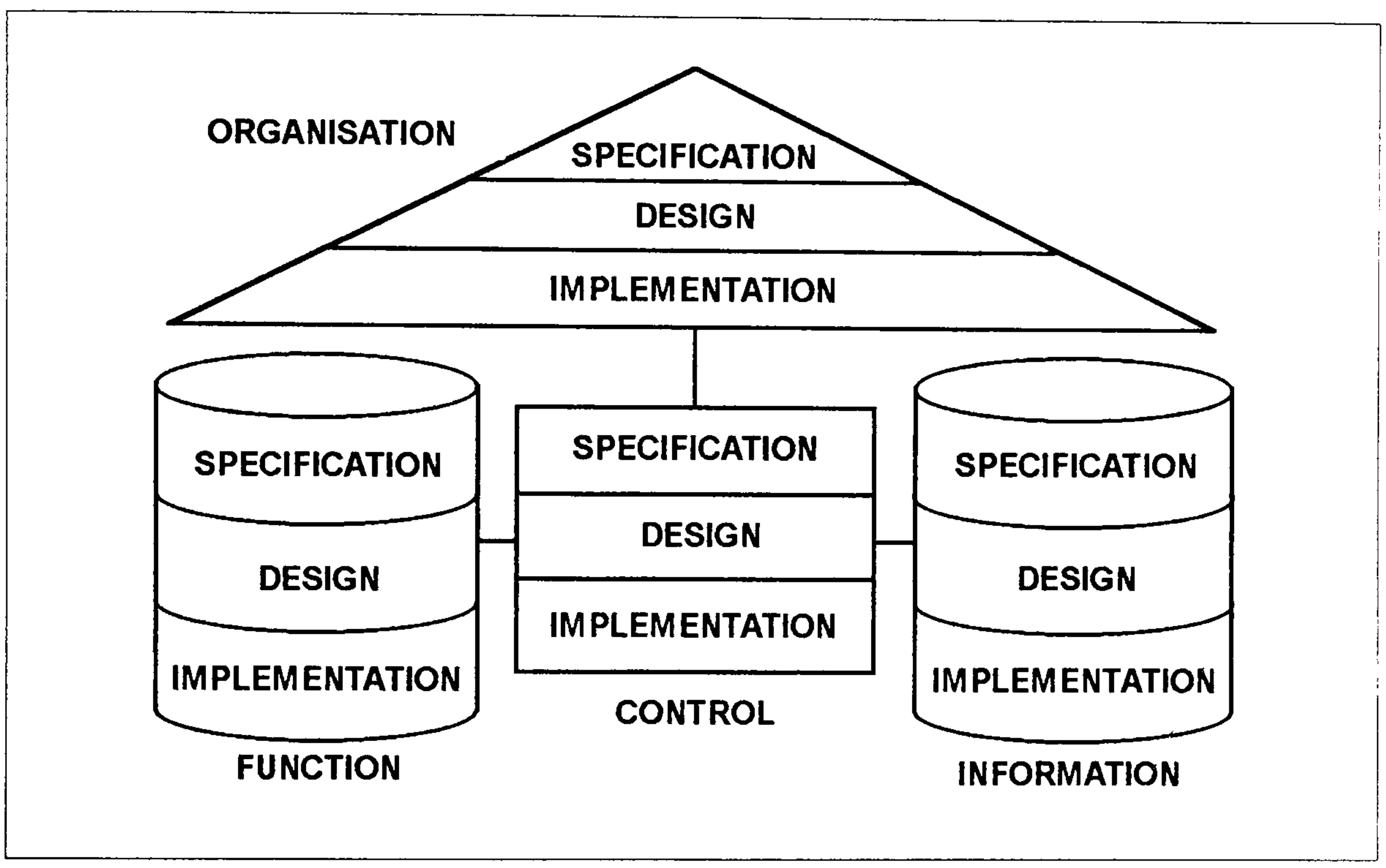

Figure 4.9: The ARIS modelling architecture (Scheer, 1992).

The information view models the "conditions in the task environment", which provide the supporting information parameters for the processing functions. The Entity relationship attribute (ERA) formalism is used to describe the conceptual data model in the information view. Scheer (1992) introduces the broad concept of the task environment to absorb all those components of an information system which are not to be handled from their own descriptive viewpoint. The parameters in the task environment might be, for example, related to the products to be created, inventory levels, or parameters related to the resources employed. The relationship between the function view and information view, is that the performance of any activity or task results in an alteration to the conditions in the information environment (Scheer, 1992).

As a result of separating the process chain description into individual modelling viewpoints, the relationships between the individual components are lost. The task of the control viewpoint is to reunite the separately considered views; this allows the various components within individual viewpoints to be introduced independently with associations between the elements (Scheer, 1992).

In addition to the modelling views, the modelling process is supported from design specification to the production of implementation models. The design specification transforms the requirements definition at the organisation view into the topology of the data processing system; essential requirements for the structure of the computer network are derived from the application requirements of the organisational units (Scheer, 1992, 1993). In relation to the function view, the design and implementation stages translate the functional specifications into application or software structures. In the information view, the conceptual schema is translated into the physical data structures required by a specific database management and application systems. In the control view, implementation issues which are isolated from the user at the specification level are re-introduced. For example, the relationship between the user (organisation) and application program or module (function view) may be specified as the user authorisation in the form of a password (Scheer, 1992, 1993).

The modelling formalism chosen to represent the concepts within individual viewpoints captures solely the elements to be described and their associations with each other. In order to ensure that the interdependence between the individual building blocks can be consistently analysed and modelled, the ARIS architecture employs a uniform modelling formalism across all four views (Scheer, 1992, 1993). This results in the creation of a meta-model of the constructs chosen to capture the functional, information, organisational and control aspects of the enterprise model. Entity relationship attribute (ERA) diagrams are used to represent the objects and relationships which need to be captured by the meta-model. This is an important concept which results in a model that is integrated across all four views, and thus, enables the ARIS architecture to be directly implemented as a CASE tool. The ARIS architecture is supported by a computer based modelling tool called the ARIS-Toolset which provides a modelling environment for business process modelling and re-engineering of managerial information systems (Scheer and Kruse, 1994).

The scope of the ARIS architecture does not focus primarily on the domain of computer integrated manufacturing systems, rather it deals also with business oriented issues such as the design of managerial information systems within enterprises (Scheer and Kruse, 1994). For example, this includes the modelling of sales order processing, production planning and inventory control processes. The focus of ARIS, therefore, is on the integrated modelling of enterprise wide information and software engineering, based around functional and organisational aspects of the enterprise (Scheer, 1992, 1993).

4.5.6 The CIMOSA Modelling Architecture

The ESPRIT Consortium AMICE has developed the CIMOSA modelling framework aimed at enterprise modelling and model based operational control and monitoring (AMICE, 1991). The overview of the CIMOSA modelling framework is illustrated in figure 4.10, which shows the different steps of the methodology for building a particular implementation model. As shown in the figure, the CIMOSA modelling framework is commonly depicted as decomposed into constituent sub-models (Jorysz and Vernadat, 1990a). The decomposition occurs along three dimensions or orthogonal principles, namely the model derivation, generation and instantiation.

The first dimension decomposes the framework into three levels of modelling, where each level denotes a different degree of model derivation. The three levels of modelling produces the specification, design and implementation models to describe various states of the system respectively, during its specification to implementation life-cycle (AMICE, 1991). At the specification level, modelling is aimed at the business user rather than IT professionals. Therefore, emphasis is placed on providing a means for expressing the contents of a particular enterprise model in a user related language. More detailed and closer relations to IT descriptions are provided in the “downstream” systems design and implementation models. The CIMOSA modelling process thus begins with the creation of the requirements specification model, from which the design specification model is created and finally an implementation description model is derived which captures the implementation specifications (Vernadat, 1994a).

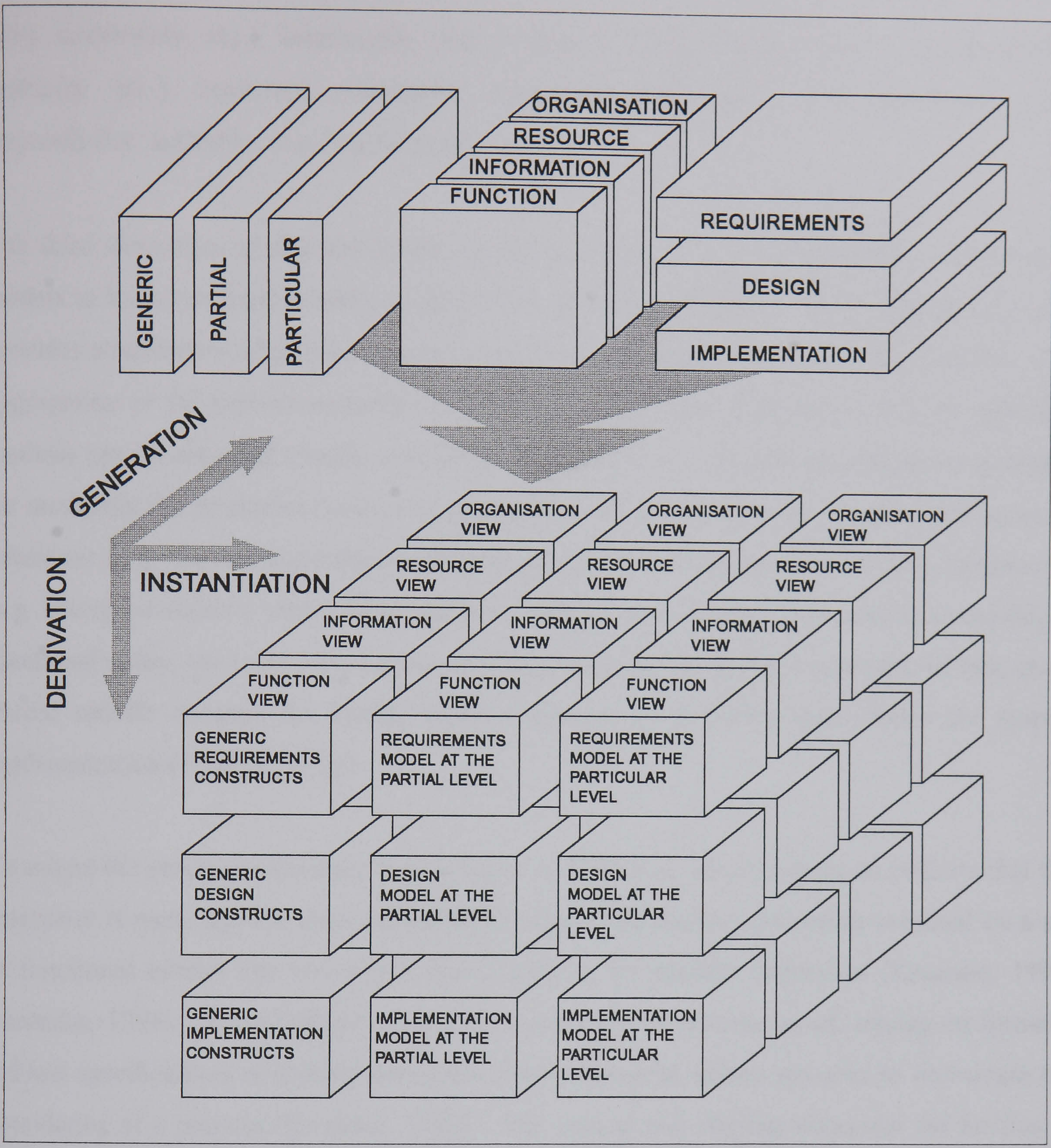

Figure 4.10: The CIMOSA modelling framework (Jorysz and Vernadat, 1990a).

The second dimension of the framework describes the generation of modelling views which allow the analysis of a particular aspect of an enterprise. The CIMOSA framework contains four modelling viewpoints, namely the function, information, resource and organisation view (AMICE, 1991). Within each view, related constructs or building blocks are prescribed which enable the creation of consistent models according to defined modelling concepts. Generic constructs are provided for modelling the enterprise function (e.g. enterprise activity, functional input and output etc.), behaviour (e.g. domain and business process, procedural rules, constraints, etc.), information (e.g. enterprise objects, object views and information elements, etc.), resources (capability, functional entity, etc.) and organisation (e.g. responsibility, authority, organisational unit, etc.).

The third dimension of the framework is the provision of a set of constructs which allow models to be instantiated in terms of degrees of generality (AMICE, 1991). The generic level provides a repository of generic constructs which are applicable to all types of industries. The aggregation of the generic constructs into a more specific set of partial models (or reference models) can be aimed at specific enterprises and industries. Generic constructs are provided for modelling the enterprise function (e.g. enterprise activity, functional input and output etc.), behaviour (e.g. domain and business process, procedural rules, constraints, etc.), information (e.g. enterprise objects, object views and information elements, etc.), resources (e.g. capability, functional entity, etc.) and organisation (e.g. responsibility, authority, organisational unit, etc.). Partial models enhance the model building process by providing components for system implementation (AMICE, 1991).

To model the enterprise functions and behaviour, CIMOSA adopts a resolute position that the enterprise is made up of a large collection of concurrent business processes executed by a set of functional entities (or resources) that contribute to business objectives (Kosanke, 1992, Vernadat, 1996). The CIMOSA modelling architecture is process based, relying on formally defined specifications of domain processes where enterprise events are used to demarcate the boundaries of a process (Kosanke, 1995). The central and starting viewpoint for building a particular model in CIMOSA is the function view, its constructs capture in a top-down fashion the enterprise domain processes, business processes and enterprise activities. CIMOSA defines the process as an occurrence of some duration, defined by its triggering condition and process behaviour (Kosanke et al., 1996).

The three other views capture the information, resource and organisation aspects associated to the business processes and enterprise activities. Hence, the resource view models the assets required for carrying out the enterprise processes and the organisation view models the decision making authority and responsibilities associated to the processes (Jorysz and Vernadat, 1990a).

The fourth view is the information view (Jorysz and Vernadat, 1990b), this involves the identification of business information used during enterprise operations for planning, control and decision making. Only the information which is required for the business operation concerned is modelled (Jorysz and Vernadat, 1990b). CIMOSA supports the identification of information principally through its use in the operational processes of the manufacturing enterprise. The information is captured in terms of enterprise objects, which are in turn, composed of information elements manifest as object views. The collection and structuring of attributes of all objects which are identified during the modelling process leads to a particular enterprise information model (Jorysz and Vernadat, 1990b).

4.5.7 The Generic Enterprise Reference Architecture and Methodology (GERAM)

The Generic Enterprise Reference Architecture and Methodology (GERAM) is based on a comparison of the various dominant architectures for enterprise integration, namely the CIMOSA, PERA and GRAI-GIM architectures (Williams et al., 1993, Bernus et al., 1995, Williams, 1995). The aim is to draw upon, and consolidate the best features of the individual candidate architectures into a complete and robust generic enterprise reference architecture for enterprise integration programs (Vernadat, 1994b, Williams, 1994c). The first major proposal for such a consolidated architecture was made by Bernus and Nemes (1994) called the GERAM. The resultant architecture is illustrated in figure 4.11. The GERAM is a framework which consists of six major components, these are listed below (Bernus et al., 1995).

(i) *Generic Enterprise Reference Architecture (GERA)*. This is the definition of enterprise related concepts, with the primary focus on the life-cycle of the enterprise.

(ii) *Generic Enterprise Engineering Methodology (GERM)*. This is the description, on a generic level, of the process of enterprise integration. The methodology is a detailed process model, with instructions for each step of the integration project.

(iii) *Generic Enterprise Modelling Tools and Languages (GEMT&L)*. The GERAM will have an associated set of modelling formalisms and tools to express the various forms of descriptions of the enterprise. These will be a set of recommended languages and tools which can be used for enterprise engineering.

(iv) ***Generic Enterprise Models (GEMs)***. Generic enterprise models capture concepts which are common to all enterprises. These can be used as tested components for building any specific enterprise model.

(v) ***Generic Enterprise Theories (GTs)***. Generic enterprise theories describe the most generic aspects of enterprise-related concepts. Generally, these are considered to be the "meta-models" which describe the rules and facts about the enterprise models.

(vi) ***Generic Enterprise Modules (GMs)***. Modules are products, which are standard implementations of components that are likely to be used in enterprise integration. Generic modules can be configured to form more complex modules.

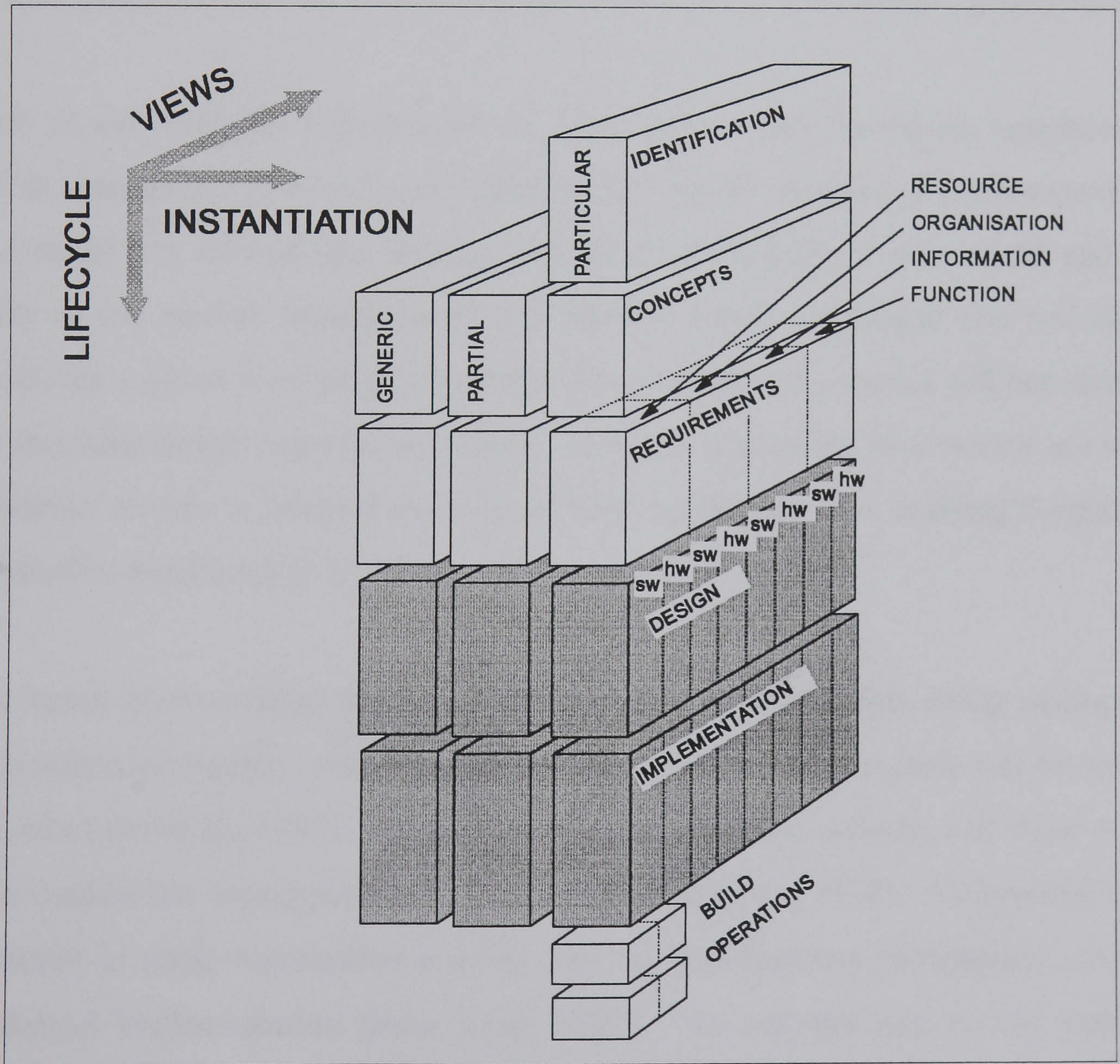

Figure 4.11: The modelling framework of the GERAM (Vernadat, 1996).

The purpose of the GERAM is to serve as a unifying perspective and a reference for the whole community concerned with the area of enterprise integration by providing consistent definitions of the terminology, a robust modelling environment and a detailed methodology. It is intended to promoting good engineering practice for building reusable, tested and standard models (Bernus et al., 1995).

4.6 Enterprise Reference Models

In spite of all the diversity in manufacturing enterprises, there will invariably be a backbone structure of manufacturing in terms certain functions, certain decision points and certain information handling processes which will universally be present. These invariant aspects may be captured as reference models, often termed also as partial models, with defined data structures and rules which would be general enough to be applicable to various enterprises with specific characteristics, for example, based on size or class of industry (IMPPACT, 1992).

Reference models may be implemented as a set of standard modelling templates and be provided as a means by which end users adapt to the specific situation of the company. Thus a reference model can substantially decrease the effort of designing a new model and maintain the quality of the models created (Hars and Scheer, 1992). Although this will reduce the dependence for a priori knowledge, the availability of a reference model will not eliminate the need for specialist design expertise and skills. As much as possible, new models are built upon these reference models in which there is established confidence, thus enabling designers to fall under controlled conditions (Hars et al., 1992).

Software based environments for model engineering are increasingly being underpinned by enterprise reference models, where a number of instances of these models can be created and stored (Grabowski et al., 1995). A database which maintains a collection of these conceptual enterprise models are distinguished as repositories (Jorgenson, 1992). Conceptual enterprise models stored in these repositories may be used as specifications (conceptual schemas) for actual database implementation (Hars et al., 1992). An example may be the realisation of instances of "on-line" enterprise models such as product or manufacturing models for information management tasks.

4.6.1 Reference Models for the Provision of Information

The information requirements of an enterprise may be captured in as a data model which contains the system of data elements and rules presented as a formal, logical description of a particular system of information objects and their relationships (Jorgenson, 1992, Hars et al., 1992). As the majority of the enterprise activities are involved with the processing or use of information, the definition and conceptual structure of this information (e.g. product, manufacturing models etc.) becomes an important resource in its own right.

A reference data model for information is a generic or reusable conceptual model for specification of the information requirements which supports potentially a wider range of industries and enterprises (IMPPACT, 1992). The task of creating a reference data model is a particularly important task to aid the design process of any information system; it should establish, in an organised structure, much of the enterprise information requirements. The structuring and data content of the reference model is not determined by specific or permanent rules, rather it is determined by the intended application for the information model.

The use of a supporting repository of reusable data models is emphasised by CIMOSA (AMICEE, 1991) and GERAM (Bernus et al., 1995). In accordance to the definitions given by the GERAM, data models (semantic or conceptual models) correspond to generic enterprise theories. Their realisation results in instances of information models (or databases) which correspond to the GERAM concept of enterprise modules. The following sections will give a brief discussion of two classes of reference data models, namely product and manufacturing models.

4.6.1.1 Product Data Models

A product data model therefore, defines the form and content of product data to support various activities at different product development phases, using a single master representation (Krause et al., 1993). The computer representation of product data requires a product model, which defines the form and content of product data, and a product model, which contains data which is specific to the particular product concerned (Mckay et al., 1997). When fully populated, it should contain enough information relating to the product from conception to disposal. A significant approach towards the implementation of integrated product models is the development of the ISO Standard 10303 Standard for the Exchange of Product Model Data (STEP) which defines a neutral data format for the representation and exchange of product data (Gu and Chan, 1995).

The issue of product modelling can be a major part of the concurrent engineering (CE) paradigm for product development (McKay et al., 1996). Concurrent engineering is designed to meet the challenge of developing new products that have the shortest lead time, the highest quality and lowest cost. The use of product data should not be restricted to the support of product innovation and design, but also include manufacturing, testing, quality assurance, sales and marketing, etc. The use of a product model in the support of reverse engineering (RE) centres on capturing and modifying information and knowledge from an existing product to create a substitute (Borja, 1997). This indicates that product modelling, whilst being a unique subject in itself, is a very broad topic which is closely related to many other challenging issues in modern manufacturing engineering and complete product life-cycle concerns. Therefore, product modelling must not only support new product development strategies, but must also deal with other manufacturing-related models such as manufacturing models.

4.6.1.2 Manufacturing Data Models

Manufacturing data models capture and structure the data required to describe the manufacturing facility and capability of a particular enterprise for product realisation. A review of manufacturing models can be found in Molina (1995). In general, the information in the manufacturing model describes how the resources and processes in a company are organised and used. Manufacturing models include information relating to an enterprise in terms of the organisation of its manufacturing facility, i.e. shop, cell, workstations etc. The manufacturing resources are described in terms of its production machinery, tools, fixtures and operators etc. The manufacturing capability of the enterprise is captured in terms of the available processes.

The manufacturing model represents the necessary information required to provide reliable manufacturing capability information for the support of product life-cycle activities (Molina, 1995). It can also provide the necessary information to support process planning activities which generates information for manufacturing. The information representing the detailed manufacturing capability can be used, in conjunction with information reflecting the current status of a company, to provide the necessary information for manufacturing activities such as production planning and control (Rembold and Nnaji, 1991). In order to achieve this, the manufacturing model will have to include the dynamic status information relating to tooling and fixture location, machine loading and shop capacity, process costs etc.

Chapter 5

A Review of Information Systems in Manufacturing

5.1 Introduction

This chapter provides a review of information systems in manufacturing. An overview of the diverse functionality of information systems is presented through selected commercial products. Manufacturing integration and the provision of information through information models is discussed. Standardisation efforts which have been devoted to providing enhanced networking capabilities are briefly described. Particular attention is paid to the reference model for open distributed processing (RM-ODP) as it is rapidly becoming a de facto standard for the specification of open distributed systems and has an immediate significance on this research.

5.2 The Origins of Shop Floor Information Systems

The ambition to improve manufacturing performance places a heavy burden on the accuracy of information and an information network capable of delivering the information. The origins of information technology on the shop floor can be related back to the 1970's, to the introduction and development of direct numerical control (DNC) networks (Toh and Newman, 1996). In addition to the associated paper tape problems with early numerical controllers, there was a need to circumvent the problem of providing costly interpolation computers (Charney and Srinivasan, 1971, Spur and Wentz, 1971).

With the introduction of computer numerical controllers (CNC), direct numerical control progressed to distributed numerical control, whose acronym is also DNC (Vogel and Schultz, 1984). Today, DNC may be encountered as an all embracing term which describes a more comprehensive shop floor control system. These comprehensive DNC systems include additional functionality or "extension functions", which increasingly control the processes and monitor all the equipment in the manufacturing facility (Quinlan, 1988, Mitchell, 1993, Lovetri, 1983, Tonshoff and Schmiedeskamp, 1984, Firm, 1987, St. Charles, 1987). A more conventional approach would be to view DNC technology distinctively as a module of a wider contemporary shop floor information system, where DNC refers to the discharge of the "basic functions", thus distinguishing the basic functionality of part program management and movement. Through a selected number of examples, the functionality of these contemporary information systems are described below.

5.3 The Functionality of Contemporary Shop Floor Information Systems

The interrelationships between the work in progress, machines, people, tools and materials in any manufacturing enterprise is highly complex; the functionality of an information system is to provide the necessary insight on the order progress, work and material allocation, machine capacity and status, which will enable the employees to anticipate and resolve issues in a timely fashion. In general, a modular approach is used to provide the software configuration which meets the specific needs of the manufacturing operation of different companies. Design of contemporary information systems are invariably founded upon the concepts of open system architectures in order to create a system which will allow integration with other systems, and to allow for future expansion of functionality in terms of additional software modules.

The common functions and processes which have been developed are for example computer aided design (CAD) and computer aided engineering (CAE), computer aided manufacturing (CAM), computer aided process planning (CAPP) and manufacturing resource planning (MRPII) systems. Information is generated or altered when the information processing applications are used or when activities are performed by the employees. Business level applications include financial applications, sales order processing or sales ledgers. The information system must also enable the collection of the information and provide the storage in terms of databases for the information, where these databases may also be distributed.

The functionality of the individual contemporary information systems is as diverse as the product range currently available. Exemplars of information systems are the Micross Manufacturing System (Kewill, 1996), ERT-Seiki (Ert-Seiki, 1996) and FAMOS Manufacturing DNC System (Famos, 1995), the former represents a higher end solution for total manufacturing management. The latter represents a system in a more basic form to address the most immediate needs of the business in terms of a low level DNC system whilst allowing for future growth.

The information systems products from ERT Seiki and FAMOS consists principally of a host DNC software system on which an NC file manager maintains file directories for individual machine tools. Access is given to these directories in the host computer via the standard DNC terminals at individual machine tools. Both systems include the standard functionality typically associated to DNC systems such as editing functions for NC programs, machine performance monitoring and analysis, factory status reporting and graphics displays. The graphics displays enables the incorporation of drawings with manufacturing data; the graphics includes component, set-up and tooling drawings. The transfer of manufacturing data is no longer restricted to NC files, but includes the handling of manufacturing data such as the tool offsets assigned to NC programs and operational instructions for manual workstations and tool assemblies (Ert-Seiki, 1996, Famos, 1995).

The Micross Manufacturing System consists of a modular suite of software and includes Stock Control, Bill of Materials, Materials Requirements Planning, Purchase Order Processing, Works Order Processing and Sales Order Planning (Kewill, 1996). The suite of software supports the operation of the enterprise from job costing and sales order processing, which provides the commercial entry of customer orders, to the dispatch of the orders. The production management system includes production control, material and job scheduling, monitoring, data collection and the production of shop floor documentation.

5.4 The Application of Information Systems for Manufacturing Integration

Manufacturing integration has been the subject of considerable research and development in recent years. Different forms of integration can be identified, these provide different levels of integration, these are (i) physical integration, (ii) application integration and (iii) business integration. Physical integration concerns the interconnection of physical components of manufacturing systems by means of computer networks and communication protocols. Application integration concerns the interconnection of information based software packages such as computer aided design (CAD) systems using STEP (ISO 10303, 1994). Business integration concerns full enterprise integration and coordination of the business operation.

Application and business integration requires a good assessment of the enterprise operation, rules and structure in terms of functions, information systems, resources, applications and organisational units. These two levels of integration require enterprise models, e.g. product, manufacturing models etc., which capture a knowledge base of the enterprise, provides a common understanding (or semantic unification) of various concepts. This also requires an integrating infrastructure providing the physical and application integration (AMICEE, 1991).

At the business integration level, two extremes of enterprise operation or organisational structure may be described. At one extreme, there will be the possibility of very close monitoring of all individual operations and a central system of coordination to control the entire network of activities throughout the company. At the other extreme, the availability of information can allow the decentralisation of decision making (Lee et al., 1995).

5.5 The Provision of Information Via Information Models

The term "information integrated systems" identifies the information systems where the primary mechanism for achieving integration is information (Rozenfeld et al., 1994). The integration of all aspects of the information places a major emphasis on enterprise information models and the modelling of the information (Singh and Weston, 1996). The integration in these class of systems is only possible if the information required for the successful operation of the enterprise is identified and provided in a computer executable format, i.e. via the development of an information or enterprise model (Lin and Fang, 1993). These correspond to the Generic Enterprise Modules (GMs) of the GERAM methodology (Williams et al., 1993), introduced previously in chapter 4. The use of both the order and manufacturing models is a particular exemplar and is discussed later in section 8.2.

Molina (1995) considers that the information necessary to support the realisation of design and manufacturing functions in an enterprise can be captured and represented in two information models, namely the manufacturing and product model. The emphasis on information is therefore shifting from product models (those that represent product data) to include models which represent manufacturing facilities. The latter have become an important element of the range of enterprise models as they capture and represent the information regarding the manufacturing resources of an enterprise (IMPPACT, 1992).

An information model must therefore represent an enterprise from multiple perspectives in accordance to user requirements. The information contained within these models will need to be accurate to support different levels of decision making (e.g. strategic, tactical and operational) and must also be available in appropriate degrees of abstraction and aggregation (Molina, 1995). The information models must provide the insight into the current state of the enterprise in terms of the order progress, work and material allocation, machine capacity and status, and also include access to past decision rationales.

5.6 Enabling Technologies for Information Systems

The application of IT networks depends heavily on an extensive application of computers and communication technologies which are not yet invariant. With the contribution from technological factors to the economic viability of systems integration, the focus of systems integration has shifted from the problems of interfacing disjoint systems (islands of automation), to facility wide and recently to enterprise-level integration (Weston, 1995). The important developments to support the integration of plant wide networks concern standardisation efforts centred on open systems architectures and standard communication protocols. Recently, a model for open distributed processing has been developed for the construction of distributed or interconnected systems in a multi-vendor environment, these are discussed in the following sections.

5.6.1 Standards for Networking and Communication

The implementation of a communications network requires careful consideration of various enabling technologies and design configurations; these range, for example, from the choice of network topology, physical transmission medium, communication protocol, network access or the performance of the information network. Contemporary distributed networks in the form of Profibus (DIN, 1996) or LonWorks (Echelon, 1996), etc., are examples of the many proprietary solutions which are broadly termed as fieldbuses. These, in turn, map on to the International Standards Organisation's seven-layer Basic Reference Model for Open Systems Interconnection (ISO/OSI) (ISO/OSI, 1995). The ISO/OSI architecture or its derivatives provides the foundation for integrated, manufacturing or office-based data communication, which ensures the compatibility of any device connected to the network. Communication standards which have been based on the ISO/OSI reference model include the Manufacturing Automation Protocol (MAP) and Technical Office Protocol (TOP) (Pimental, 1989). The computers and other devices which are compliant to the standards, are highly structured in terms of their use of specific rules, formats, protocols and interfaces which then enable them to communicate.

5.6.2 Open Systems Concepts

Open systems concepts describe the support for the business by flexible configurable application software, databases, networks, hardware and related employees and organisation structures (Mertins, 1992). The network communication devices have hardware and software platforms which are being increasingly based on open systems architectures (Altintas and Munasinghe, 1994, Pritschow et al., 1993). An open systems platform for machine controllers proposed by Pritschow et al. (1993), consists of hardware and a number of generic control independent software functional units such as operating, communication and graphics system. An open system is defined as one which enables applications to operate from a variety of platforms from multiple vendors and are able to inter-operate with other system applications (Pritschow et al., 1993). This work stresses the importance of designing modular functional software and hardware independent general CNC systems adaptable to machine tools, robots, and manufacturing cells. The result of the research is a generic platform, upon which a combination of hardware and software modules can be configured for particular machine control problems (Spearling, 1995). The advent of open systems has provided the opportunity for new functionality to be easily included at the individual workstation, which can provide the operator with support that was previously available at a cell control level (Toh and Newman, 1995).

5.7 Standards Based Specifications for Information Systems

The construction of distributed or interconnected systems in a multi-vendor environment depends on the creation of suitable standards which allow the specification of the required behaviour of the components which make up the system. Such a standard must provide an organising framework for the substantial body of specifications which is typically associated to large and complex systems (Linington, 1992). The standard has also to enable the construction of distributed software applications without having to take account of the potential diversity of hardware, operating systems and communication mechanisms in the underlying computer network. This will establish a basis for system design and implementation, allowing the use of common components, design methods and representations. These requirements have resulted in the specification of the Reference Model for Open Distributed Processing (RM-ODP) (ISO/IEC, 1995). It is expected that the ODP initiative will also significantly influence and promote opportunities for producing inter-operative software which itself, can be physically distributed in nature.

5.7.1 The Reference Model for Open Distributed Processing (RM-ODP)

The RM-ODP was created with the aim to produce a reference model for describing open distributed systems; it provides a standard upon which a wide range of specifications for distributed systems could be integrated and solves the problem of inconsistency across such systems. The objective of the ODP standardisation, in an environment of heterogeneous IT resources and multiple organisational domains, is to allow benefits to be gained from the distribution of information processing services (ISO/IEC, 1995). The general approach is object oriented, where the system is modelled in terms of the interactions of a set of component objects at identified interfaces. The development of a framework for system specification in order to realise the corresponding infrastructure components for distributed processing goes beyond interconnection and data communications; complying with the ODP architecture principles and conforming to ODP standards will result in open distributed systems (Linington, 1992).

The complete specification of any distributed system involves a very large amount of information and attempting to capture all aspects of the design in a single description is generally unworkable. The RM-ODP framework is therefore divided into five viewpoints from which the distributed system may be described (Linington, 1992). The five viewpoints of the RM-ODP are depicted in figure 5.1.

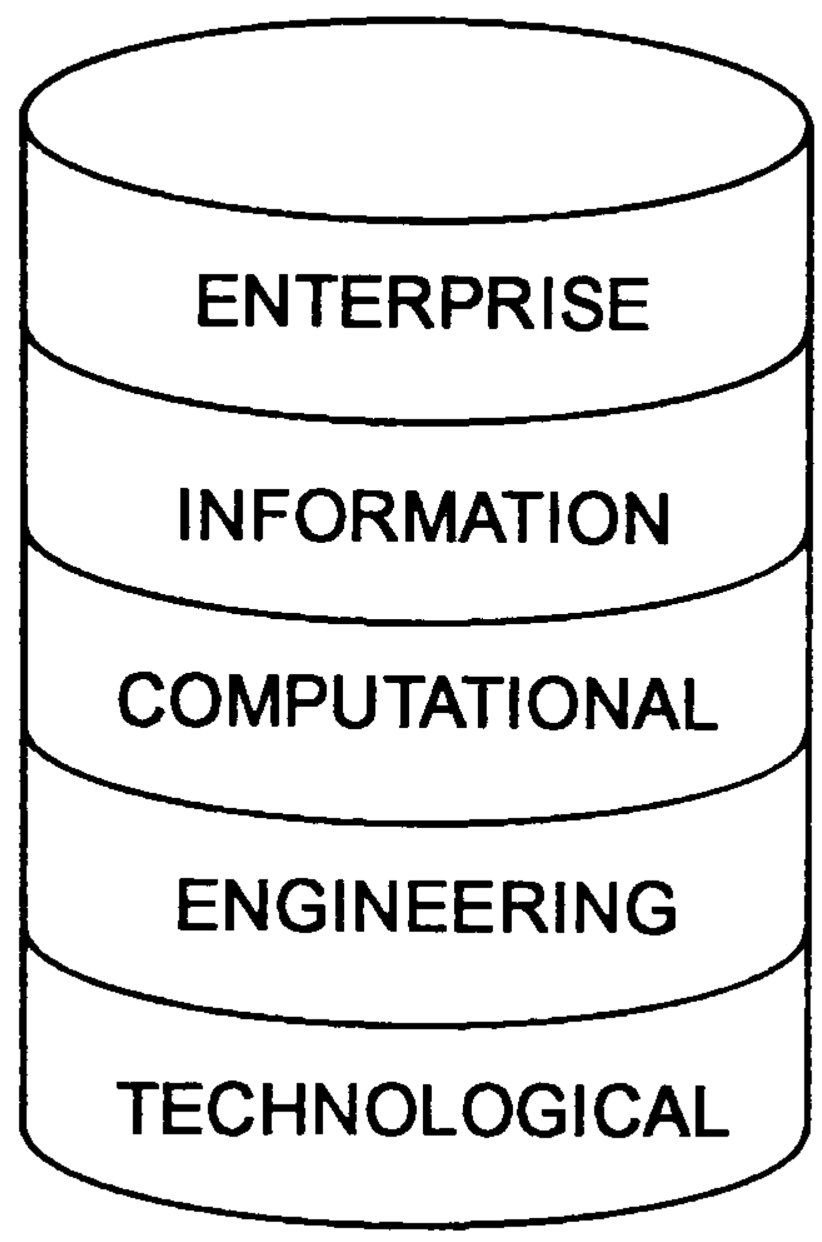

Figure 5.1: A depiction of the reference model for open distributed processing (RM-ODP) (ISO/IEC, 1995).

An individual viewpoint has an associated viewpoint language which expresses the concepts and rules which are relevant to a particular area of concern. This associated viewpoint language is designated to reflect the concerns of any particular group involved in the design process for that viewpoint (Linington, 1992). This is to allow the specifications for the system to be created in conformance to one particular aspect of the distributed system without having to deal with the full complexity of the system at any particular stage. The viewpoints are the (i) enterprise, (ii) information, (iii) computational, (iv) technological and (v) engineering viewpoints respectively (ISO/IEC, 1995), these are described briefly below.

(i) ***Enterprise viewpoint***. This viewpoint introduces the basic concepts for representing the ODP system in the context of the enterprise in which it operates, describing the users, owners and providers of the information processed by the system. The enterprise viewpoint describes the overall objectives of an ODP system, these include the roles and activities that exist within the enterprise, the interactions between the system and the environment in which it is placed, the organisational structure of the enterprise and the security and management policies with respect to the users. Creating a separate viewpoint to convey this information decouples the objectives set for the system from the way it is to be realised.

(ii) ***Information viewpoint***. This viewpoint describes the information which is held by the ODP about entities in the real world which enables a common understanding of the information handled by the individual components of the information system. The information specification is represented in terms of information objects, their relationships and behaviour. Basic information elements are represented by atomic information objects, more complex information is represented as composite information objects expressing relationships over a set of constituent information objects (ISO/IEC, 1995).

The information viewpoint is further described using a set of information schemata, which makes a distinction between conceptual, external and internal schema. This distinction into the three schemas is in conformance to the ANSI/X3/SPARC DBMS three schema architecture used in database modelling (Tsichritzis and Klug, 1972), to be described in section 5.7.2. The RM-ODP is neutral in that it only requires an appropriate specification be generated; few constraints are placed on the selected information specification notation (ISO/IEC, 1995).

(iii) ***Computational viewpoint***. This viewpoint contains the concepts, rules and structures for the specification of the ODP system from the computational viewpoint. This is concerned with the description of the algorithms and processing functions of the ODP system. The distributed system applications which change the information are described in terms of their decomposition into a configuration of interacting, abstract computational objects. The ODP system is made visible from the computational viewpoint by describing the operations of the computational objects and the behaviour they support at their interfaces. This description is independent of the computers and networks on which they run (ISO/IEC, 1995).

(iv) ***Engineering viewpoint***. This viewpoint contains the specification of the ODP systems in terms of the mechanisms and functions required to support the distributed interaction between the computational objects in the ODP. The system is described in terms of the specification of the protocols for the communication channels. For example, the language constructs within this viewpoint may encapsulate aspects of the seven layer reference architecture of the ISO/OSI for data communication, where particular instances of communication protocols used by the ODP may be described (ISO/IEC, 1995).

(v) ***Technological viewpoint***. The technological viewpoint is concerned with how the specifications of the ODP, involving details of the choice of technology in terms of the realised hardware artefacts with which the distributed system is constructed. This will include the hardware and software which comprise the local operating systems, the input-output devices, storage or points of access to communications (ISO/IEC, 1995). For example, the physical transmission medium which would be specified at the physical layer of the ISO/OSI architecture is described in this viewpoint.

The architecture of the RM-ODP is intended to be applicable to the majority of computational and IT systems. Other standards which are concerned with domain specific issues such as the ISO/OSI seven-layer architecture for data communication do not have this general applicability (ECMA, 1990). The scope of standardisation which the RM-ODP addresses extends embraces the entire distributed system; for instance, the ISO/OSI architecture which addresses specifically interconnection and communication protocol standards are just a subset of the issues considered. It is intended that in a mature phase of ODP standardisation, these domain specific standards may be described consistently within the RM-ODP, which will result in the integration of different systems architectures.

5.7.2 The ANSI/X3/SPARC Three Schema Architecture for Database Management Systems

The ANSI/X3/SPARC DBMS three schema architecture forms the basis for modern database architectures (Tsichritzis and Klug, 1972). The three schemas are the conceptual, internal and external schemas, which are is depicted in figure 5.2. This three level architecture was proposed primarily to address the issues relating to the concept of data independence. The dynamics of change inflicted on database systems invariably results in partial reorganisation of the data storage, modification of applications which use the data and revisions to the views of information in the enterprise. The concept of data independence insulates the user from the adverse effects of the evolution of the database environment; it should be emphasised that the three schema architecture does not provide the capability to avoid changes, rather it is the capability to reduce the trauma of changes. The three schemas are described in the following sections:

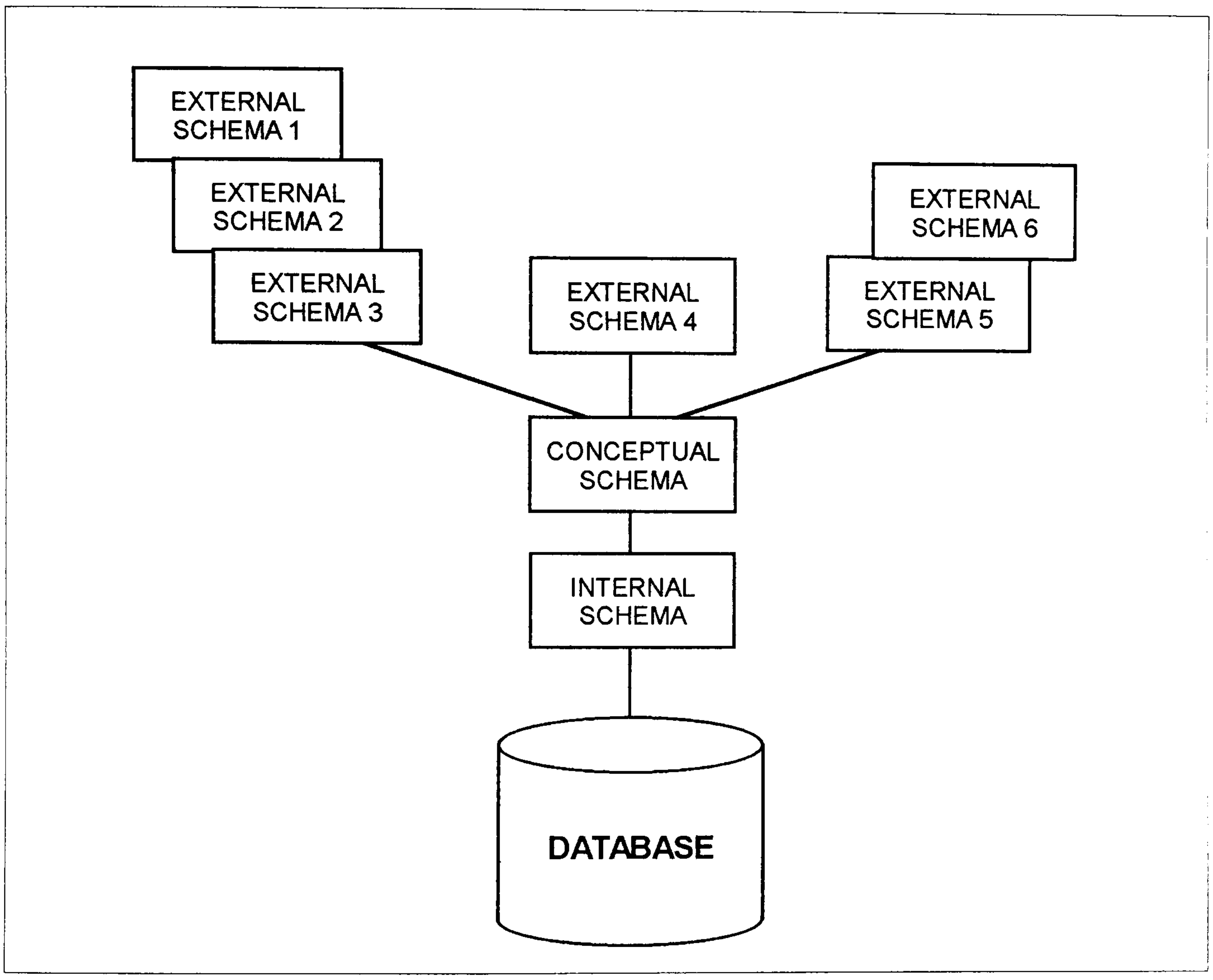

Figure 5.2: The ANSI/X3/SPARC DBMS three schema architecture (Adapted from Tsichritzis and Klug, 1978).

5.7.2.1 The Conceptual Schema

Conceptual data models, which may be termed as data models, are the basis for database implementation. A conceptual schema can be defined as a structured set of concepts which is independent of application(s) and independent of implementation(s). The conceptual schema represents the enterprise's description of the information as modelled in the database and is considered to be the most stable, relative to that of the internal and external schema. The conceptual schema may be informally invoked if there is a dispute occurring over the semantics of the information and must, therefore, be made explicit between users.

The conceptual information model, therefore, provides a consistent, common and unambiguous view which can be referenced by the users of the information system. The ANSI/X3/SPARC DBMS three schema architecture does not prescribe a specific information modelling formalism or language; it is however, stipulated that the conceptual schema should be described using some well defined language which has the potential to be standardised (Tsichritzis and Klug, 1972). This representation has to be independent of the way in which the information processing functions themselves are to be distributed.

5.7.2.2 The External Schema

There exists, within an enterprise, a number of applications or application systems; an application may be viewed as a part of the enterprise organised to accomplish a specific sub-goal in pursuit of the enterprise goal. For example, the enterprise may have amongst its applications payroll, sales order processing, or materials requirements planning. In addition to these applications, the individual users also require access to the information which can be used to provide an overall view of the status of the enterprise in terms of job location or machine utilisation, etc. This access to the data is achieved by introducing user views or external schemas which may not include all of the data in the database.

The external schema describes the data needed for a specific user or application in a form which is most convenient. The external schema consists of any number of views of the database, each of which is a collection of objects representing the entities, properties and relationships of interest to a specific application. Each external view of the database is associated with the external schema describing the objects in that external view of the database (Tsichritzis and Klug, 1972).

5.7.2.3 The Internal Schema

The internal schema describes how the information described by the conceptual schema is physically organised and stored in data storage media. At this level, the relevant computer storage structures, storage strategies and operational efficiencies are considered, where the main concern is the optimal run-time performance, which needs to be consistent to the processing requirements of the enterprise. The internal schema should reflect the current storage technologies; there may, therefore, be a number of different internal schemas, as each will reflect varying configurations depending the database hardware and software (Tsichritzis and Klug, 1972). The internal schema addresses issues such as space allocation, security, data integrity and techniques for data indexing and access paths.

The creation of an internal schema for the relational databases, for example, involves relational data analysis, or data design. The objective for relational data analysis is to organise all the system's data items into a set of well organised relations through several stages of normalisation. This essentially, involves the ordering of the identified data items into data groups in the most optimal way, specifying all the relationships between these data groups and possible access paths for data retrieval. The set of well normalised relations avoid certain undesirable properties such as unnecessary data duplications or redundant data (O'Brien, 1994).

Chapter 6

The Role of Modelling Architectures in the Specification of Information Systems

6.1 Introduction

The aim of this chapter is to identify the task of information specification within the context of established structured approaches for realising information systems. The role of modelling architectures is introduced, showing their applications at various stages of the design to implementation process. The main aim of this work is to investigate the particular role of enterprise modelling architectures in supporting the specification of information requirements. A critical comparison between two contemporary architectures, namely CIMOSA and ARIS, is made to identify the major features of both, so as to establish the most appropriate basis for developing an information specification CASE tool.

6.2 A Structured Approach to the Implementation of Information Systems

The design and implementation of an information system is a protracted task which involves diverse areas of expertise throughout all stages of the project. The requirements of the individual company have to be considered, along with the various enabling technologies and the highly competitive range of contemporary products available. To ensure the implementation of a system which is appropriate, a methodology should be used where individual phases of the design to implementation process are precisely defined. Methodologies are generally accompanied by a set of guidelines, techniques and procedures which the end-user can follow in order to carry out the project. This may involve the use of structured approaches, reference architectures and their associated modelling formalisms and graphical tools (Doumeingts and Chen, 1992).

Structured approaches cover all aspects of the project which is typically divided into phases, which can be analysis, design, development, implementation and operation phases. The reason for using structured approaches, as opposed to ad hoc methods, is that a complex project is organised into small, well-defined activities. By specifying the sequence and interaction of these activities, project planning and control becomes more effective. Exemplars include the structured approaches of the GRAI (Doumeingts et al., 1987), Purdue (Williams, 1994a) and SSADM (Ashworth and Goodland, 1990) methodologies. The following sections will highlight the SSADM methodology and focus on the task of information specification. It should be noted that the PERA and GRAI approaches could have been equally used, but the SSADM technique has been selected for the simplicity of its structure.

Of the whole framework, illustrated previously in figure 4.6, only six stages of the SSADM structured approach, illustrated in figure 6.1, are fully supported by techniques and modelling formalisms. Analysis of the existing system is carried out to understand the operations and data requirements, this is an important aspect of the technique which provides a firm basis for the design of the new system. A fully populated set of specifications for the information system is represented by the RM-ODP (ISO/IEC, 1995), illustrated in figure 6.1. As noted in the figure, realisation of the RM-ODP compliant specifications involves all the stages from requirements definition to the selection of technical options.

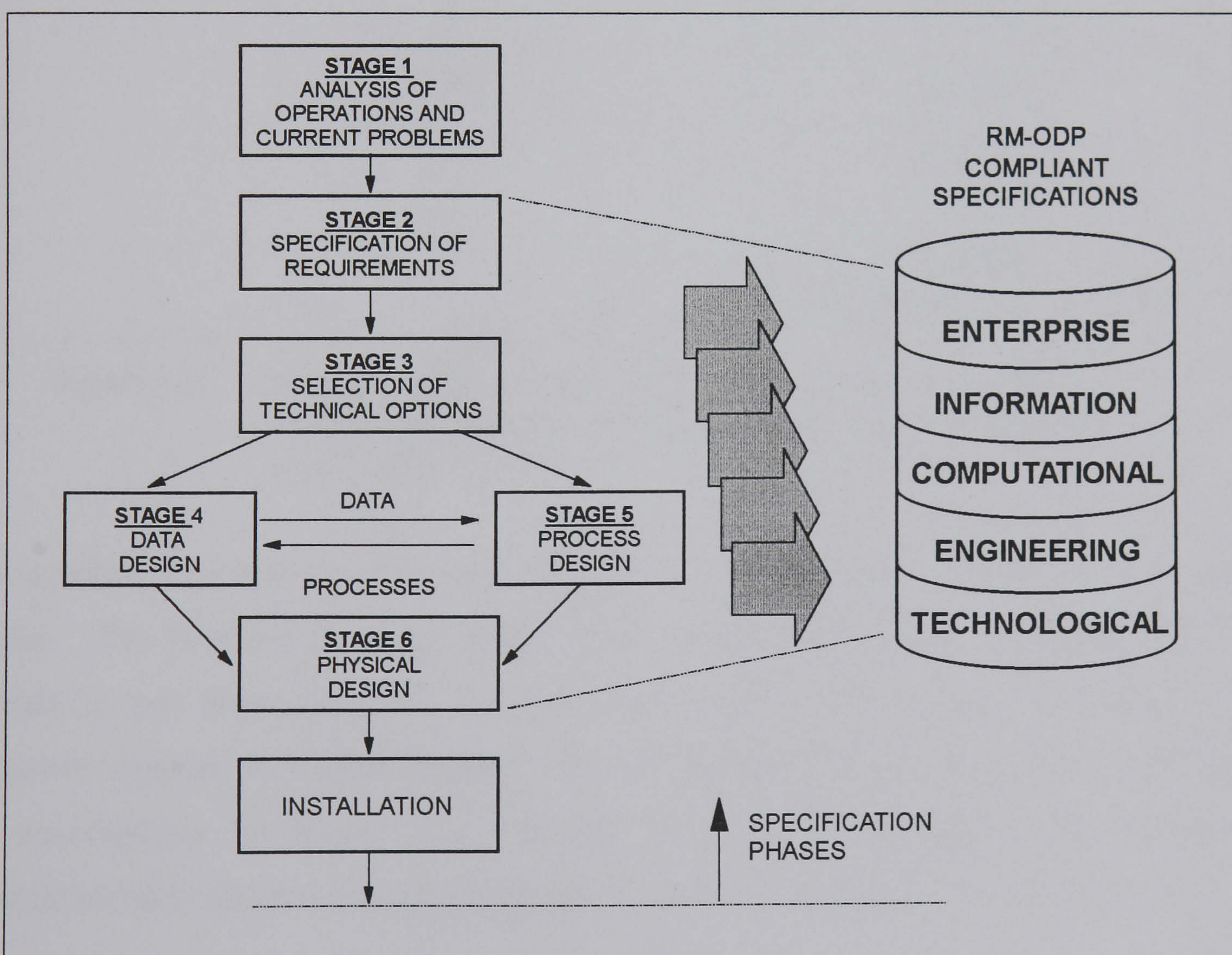

Figure 6.1: Stages of the SSADM structured approach to derive a complete RM-ODP compliant body of specifications (only the specification stages are shown).

Information which is stored, shared and processed by various applications and employees throughout the enterprise is a fundamental component of the information system and particular emphasis must be placed on its modelling and specification. The main aim is to enable the specification of central information structures consistent with the ANSI/X3 SPARC DBMS architecture (Tsichritzis and Klug, 1972). The use of the RM-ODP offers a readily accessible standard for capturing the schema specifications as an instance of its information view, this is illustrated in figure 6.2.

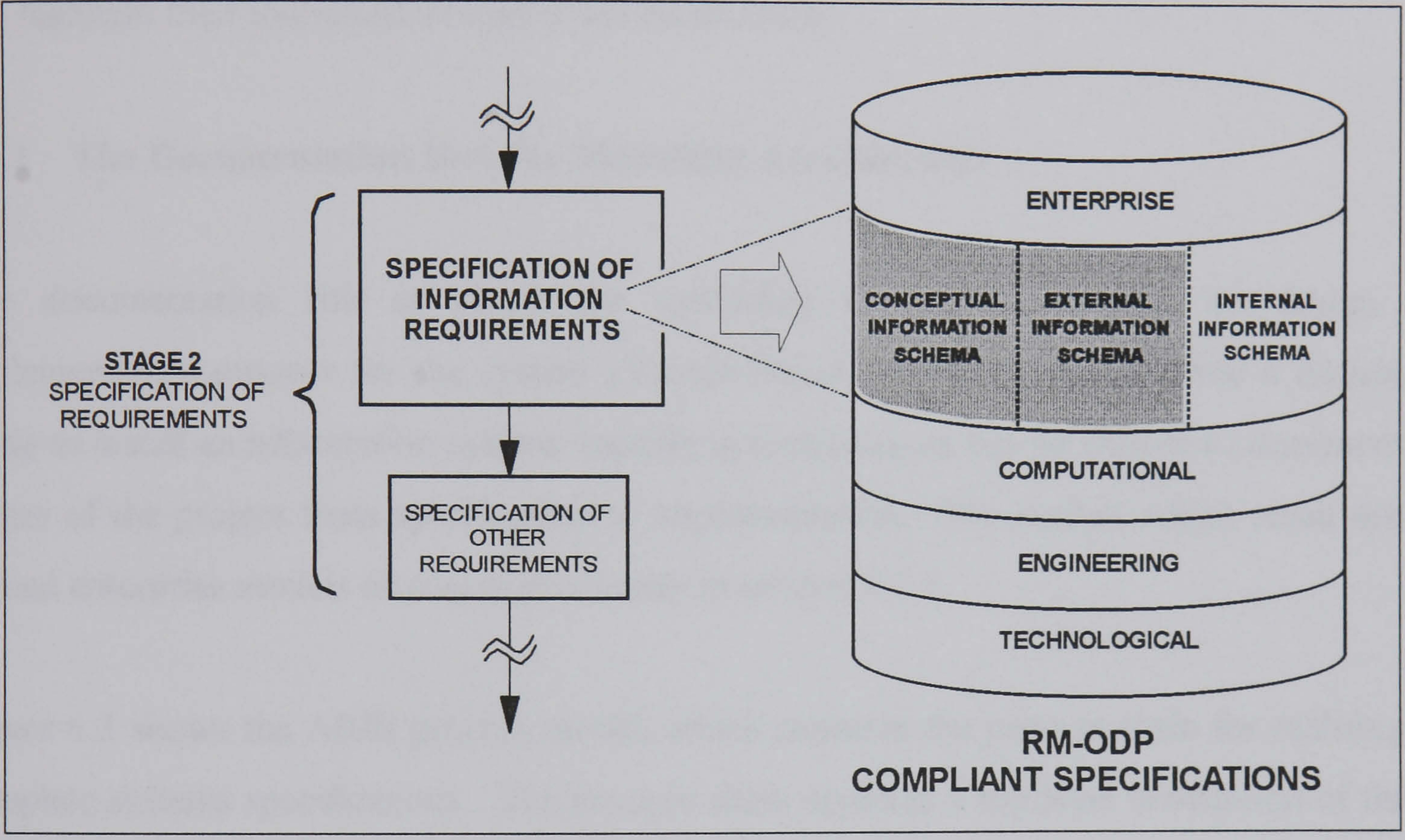

Figure 6.2: A detailed view of the requirements specifications stage: The task of realising the conceptual and external information specifications.

This is seen as the first of two major sequential activities for the realisation of information support. The first activity which results in the specification of the conceptual information schemas is user dominated; this an up-stream process which is kept independent of the constraints imposed by implementation. The second activity which involves the realisation of the specifications in terms of a network implementation, involves the down-stream construction and transition (or commissioning) stages of the SSADM methodology.

6.3 The Role of Modelling Architectures in the Realisation of Information Systems Specifications

Two main roles of modelling architectures, within the design of an information system, can be distinguished. The first role is where the modelling architecture captures the design to implementation process itself. The second role is where the architecture is used to derive the information specifications. The following sections will define and describe these two roles respectively. The positioning of the architectures at various stages of the specification cycle will highlight their individual strengths and applicability.

6.3.1 The Documentation Role for Modelling Architectures

The documentation role is where the modelling framework captures the design and implementation process for the system (Verrijn-Stuart, 1994). From the time a decision is made to install an information system, modelling architectures can be chosen to document the stages of the project from specification to implementation. The models which result are the factual enterprise models discussed previously in section 4.2.1.

Figure 6.3 shows the ARIS process model, which captures the process chain for realising the complete systems specifications. The process chain captures a top level description of the six stages of the SSADM structured approach. Analysis of the process chain results in unique viewpoints to describe the process. The resource view comprises the SSADM techniques which support the functions and activities involved in the specification process. The organisational units and personnel responsible for the tasks are described in the organisation view. The information view is constructed from the results of the specification process. The information view represents a model of the systems specifications, which in this example, is compliant to the RM-ODP. The start event which initiates the design project is the order for a new set of systems specifications and the terminating event is the delivery of a complete set of RM-ODP compliant specifications.

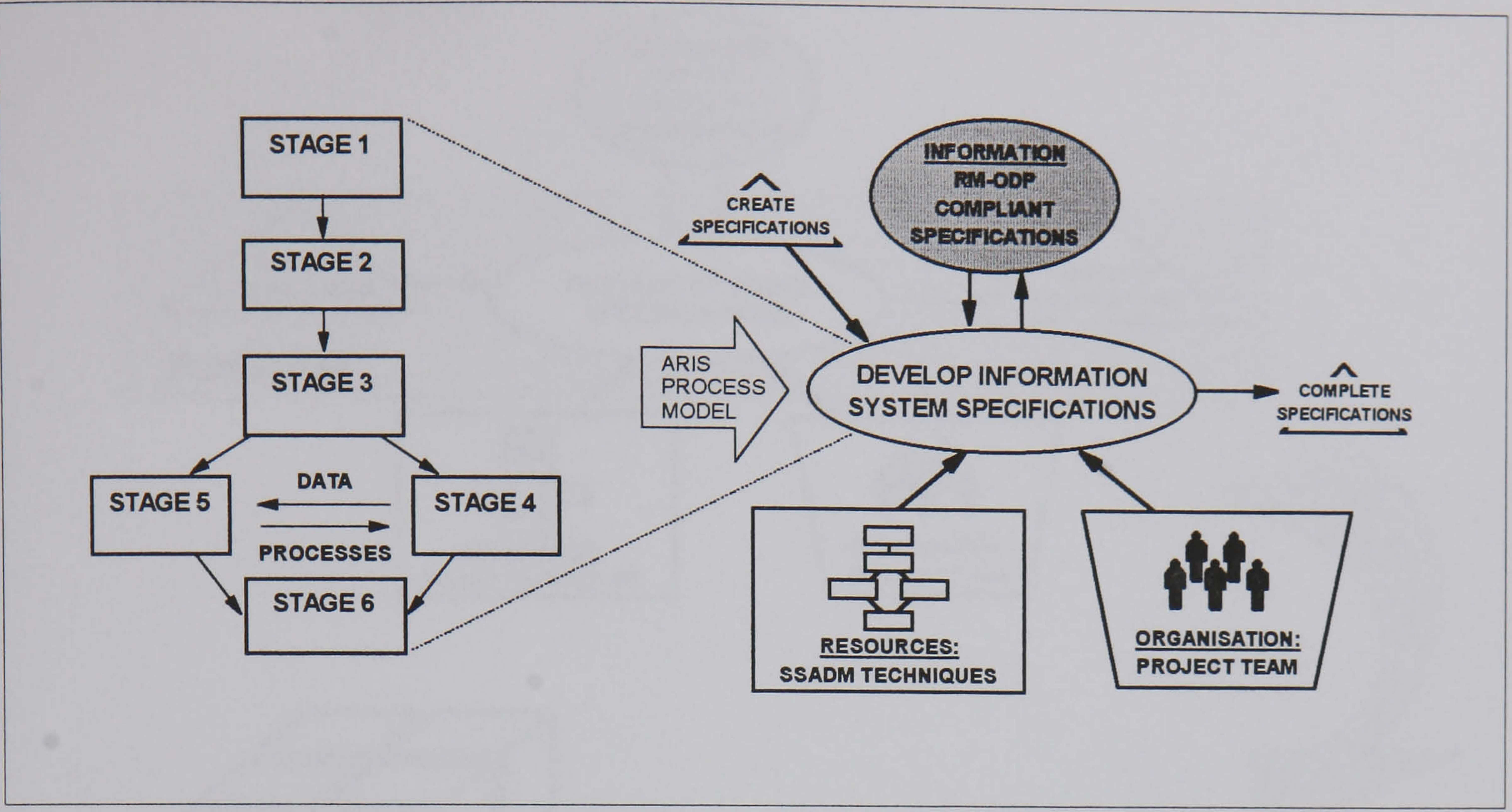

Figure 6.3: The use of the ARIS process model to capture the systems specification stages of the SSADM methodology

These views are captured as information about the project, from initiation to the delivery of the new system specifications. A formal description of the SSADM structured approach may therefore be created using the CIMOSA modelling methodology, which is founded principally on the function, information, resource and organisation views (AMICEE, 1991), illustrated in figure 6.4. This model can be decomposed into more detailed levels using the CIMOSA concepts of business processes and enterprise activities. The ARIS process model and its subsequent representation using the CIMOSA architecture, illustrated in figure 6.5, may also be used recursively to model the individual stages of the SSADM methodology.

The production of specifications for the information requirements, highlighted in figure 6.5, is one of the major tasks in the design of any information system. This is depicted by the ARIS process model, and is subsequently represented in terms of the CIMOSA constructs, illustrated in figure 6.6. The CIMOSA model of the information specification process includes a definition of the resources required to produce the specifications. One of the resources can, therefore, be an information specification CASE tool which produces the information requirements. It is noted in figure 6.6 that this CASE tool may itself be underpinned by either CIMOSA or ARIS, where deduction of specific requirements can be reached under the precisely defined and standardised circumstances prescribed by the architectures.

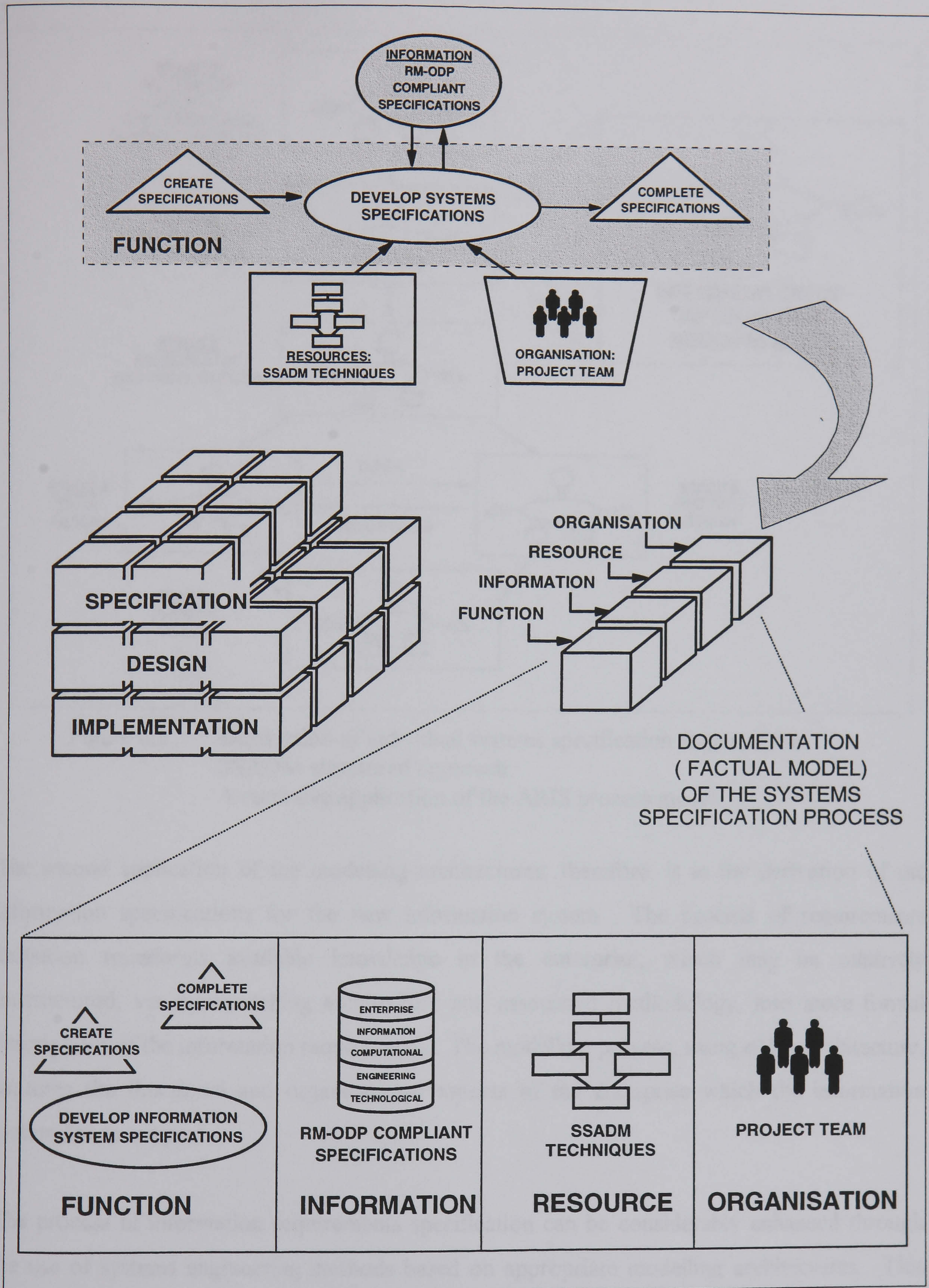

Figure 6.4: The role of modelling architectures:
The use of the CIMOSA architecture to model the systems specification stages of the SSADM methodology.

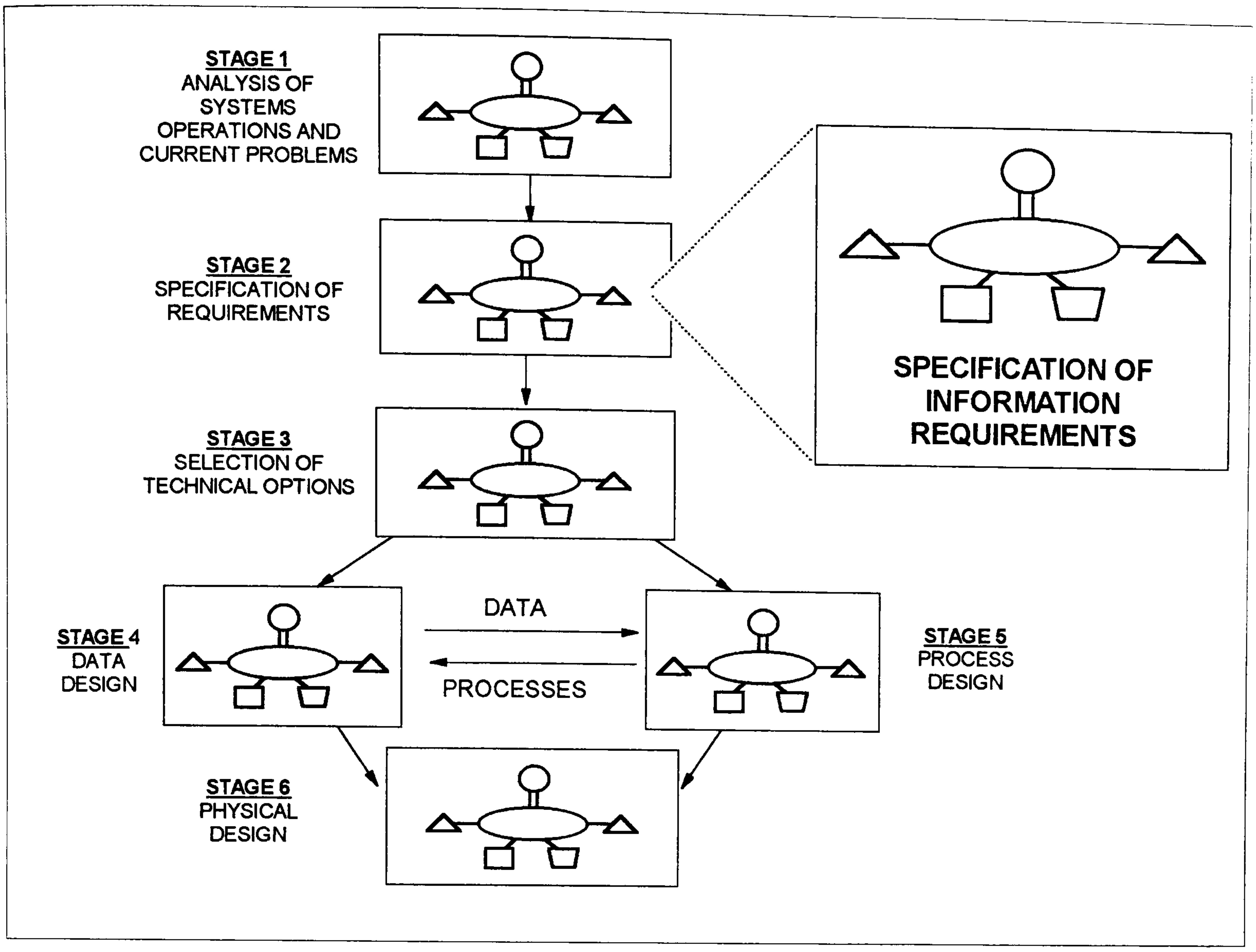

Figure 6.5: Description of individual systems specification stages of the SSADM structured approach:
A recursive application of the ARIS process model.

The second application of the modelling architectures, therefore, is in the derivation of the information specifications for the new information system. The process of requirements definition transforms available knowledge in the enterprise, which may be relatively unstructured, via the modelling architecture and associated methodology, into more formal descriptions of the information requirements. The modelling process, using either architecture, captures the functional and organisational aspects of the enterprise which the information system has to support.

The process of information requirements specification can be considerably enhanced through the use of systems engineering methods based on appropriate modelling architectures. This enables the specification to be built for study and evaluation. The output in terms of a model of the information specifications can subsequently be used by design processes to create implementation schema and software modules for the systems realisation (IMPPACT, 1992).

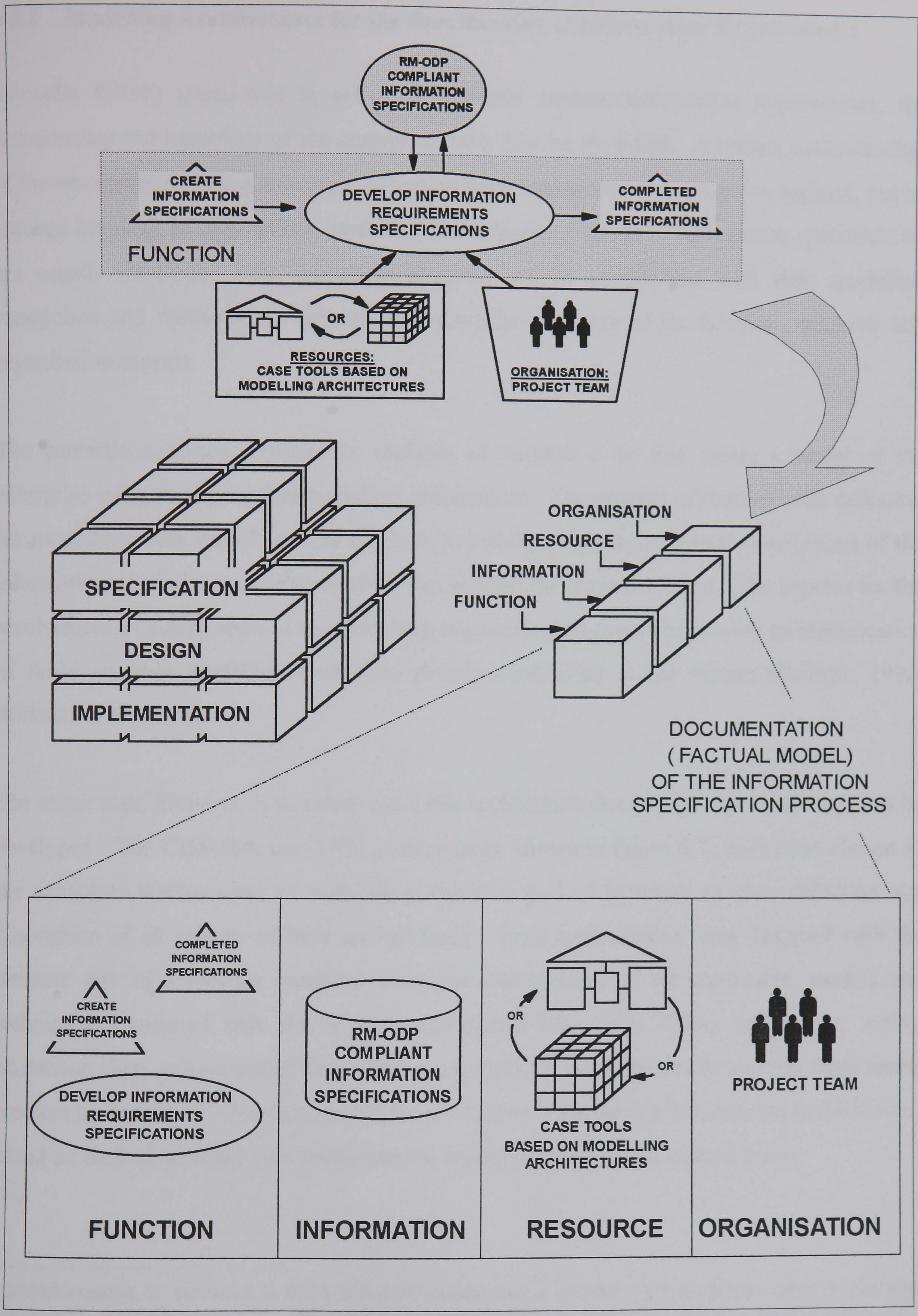

Figure 6.6: The role of modelling architectures:
The use of the CIMOSA or ARIS architecture for the specification of information requirements.

6.3.2 Modelling Architectures for the Specification of Information Requirements

Vernadat (1996) states that in order to correctly capture information requirements, the functionality and behaviour of the enterprise must first be modelled. A unique understanding of the enterprise, and the subsequent deduction of the requirements for systems support, can be reached by using an appropriate modelling framework. Therefore, information specifications are usually developed with modelling architectures, in conjunction with their modelling viewpoints and methods, to capture the enterprise in terms of its function, resource and organisation aspects.

The currently accepted solution for realising IT support is to first create a model of the enterprise using an appropriate modelling architecture. The process of requirements definition (or modelling) then transforms the available knowledge, into more formal descriptions of the information network specifications which can be used for implementation. The impetus for the involvement of CASE tools in the modelling engineering process is to provide an identification of those reusable modelling constructs already established in the system (Brough, 1992, Williams et al., 1994).

The major task, however, is to select a suitable architecture from which the CASE tool can be developed. The CIMOSA and ARIS architectures, shown in figure 6.7, have been chosen as the candidate architectures as each has a declared goal of formality in their definition and description of all aspects of their architectures. Both architectures were designed with the ultimate aim of achieving complete computer executability of all constructs, models and techniques associated with the architectures (AMICEE, 1991, Scheer and Kruse, 1994). Moreover, they contain within their framework methods which guide the process from model creation to execution[4]. The selection process involves a comparison between the architectures, based on their constituent viewpoints and the results of which are discussed below.

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[4] Model creation to execution is not a seamless process and a broader view should be taken of the term "execution". This process is better characterised by the term "model enactment", which is viewed as the ability to let the model evolve over time (Aguiar et al., 1995). In information design, model execution is the further development or engineering of a model which has been produced and adequately validated by an upstream model building process. The final execution of the conceptual information models is the implementation of the information databases.

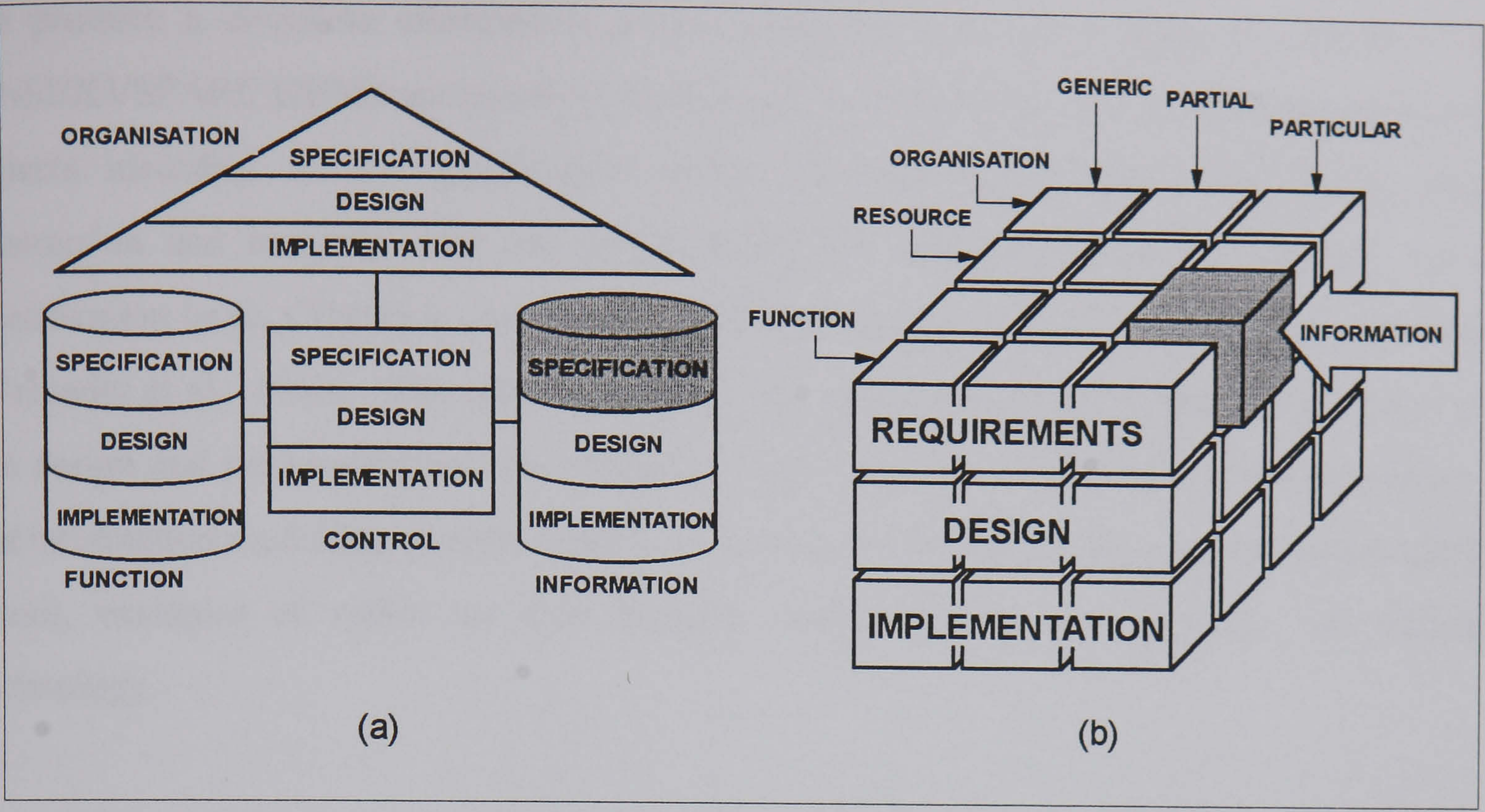

Figure 6.7: A choice of modelling architectures to support the task of information specification highlighting the information viewpoints:
(a) The CIMOSA architecture (AMICEE, 1991).
(b) The ARIS architecture (Scheer, 1992).

6.4 A Critical Comparison of the CIMOSA and ARIS Modelling Architectures

The CIMOSA modelling framework contains four views namely, the function, information, resource and organisation view, the major focus in this comparison is on the information view. This view involves the identification of information used or required for the business process of concern. CIMOSA supports the identification of information principally through its relationship with the processes of the manufacturing enterprise. The information is captured in terms of enterprise objects, which are in turn, composed of information elements manifest as object views (Jorysz and Vernadat, 1990b, AMICEE, 1991).

At the specification level of the framework, information analysis is achieved through an established relationship between the function view and information view. The formative stages of information modelling is carried out in the function view where functional analysis is performed. The task of object identification involves the specification of enterprise objects as the inputs and outputs of the enterprise activities (AMICEE, 1991).

To produce a complete information model consistent with the conceptual schema of the ANSI/X3/SPARC DBMS architecture, the semantics of the data has to be established from the objects identified at the specification stage. Concepts of object relationships, object abstraction and integrity rules are added during this information analysis phase. At the specification level, CIMOSA uses the M* methodology for modelling the information schema (Vernadat et al., 1989). The schema becomes the starting point for further development into the design and implementation specifications. The later design and implementation phases of the information modelling process takes into account the implementation and operation specific issues, examples of which are data security, assignment of user authority and database technology.

The ARIS architecture comprises four views, namely the function, organisation, information and control views. Similar to the CIMOSA framework, ARIS also supports the generation of requirements, design and implementation specifications (Scheer, 1992). Although both CIMOSA and ARIS architectures are process centred, one of the descriptive views employed in the architectures is different; the resource view is not identified in ARIS and CIMOSA does not emphasise the control view. The first three views of the ARIS architecture are directly associated to the model of the process chain; the function view models business processes in terms of functional and goal structures. The organisation view models the organisational units responsible for the tasks defined in the process model and the control viewpoint models the relationships between the three views (Scheer, 1992).

The information view of the ARIS architecture models the "conditions in the task environment", which provide the parameters for the process functions (Scheer, 1992). These parameters might be related to the products to be created, inventory levels, or parameters related to the resources employed. The information schema is modelled using the ERA diagrams. The interaction between the function view and information view, is established such that the performance of any activity or task results in an alteration to the conditions in the information environment (Scheer, 1992).

A fundamental difference between the ARIS and CIMOSA architectures is that the latter demarcates the resource description by a major (resource) viewpoint, whilst the former architecture subsumes the resource description into the information view. The ARIS approach takes into consideration that the resource entities may have information parameters that are used during the performance of a task. An example of this may be the status or location of the resource on the shop floor, cost of the resource, or the available quantity of that resource.

6.5 The Selection of the ARIS Architecture as a Basis for Information Specification

This positioning of the two architectures in perspective enables an appropriate architecture to be established as the basis of an information specification CASE tool. The study of both architectures has also enabled their major features to be identified and applied; the most important factor is to select an architecture which best suits the application. In this case, the ARIS architecture has been chosen as it provides the more suitable set of viewpoints.

Invariably, a large proportion of the information requirements relating to the operational issues of shop floor control involves the manufacturing resources. Moreover, the capacity of the manufacturing plant, which directly affects its ability to accept an order, does not remain unchanged, it varies according to the combination of machine and resource commitments at any particular time. The resource model, therefore, plays a pivotal role in providing information; managers make decisions to accept orders, or to invoke sub-contract resources by reviewing the level of factory capacity in terms of manpower and machine resources. The resource information structure has, therefore, to contain parameters relating to the level and location of material, expendable inventory, job sequences and the impact of job relocation on the capacity loading at machines. As such, it has been decided that the resources would be modelled within the information viewpoint, in accordance to the ARIS architecture, which allows the specification of the necessary information attributes to the factory resource entities.

It is important to note that this does not disprove the CIMOSA architecture; the resource information exists within the model, but mapping the information structure to the ARIS architecture does not demarcate the resource model nor emphasises its prominence as a major viewpoint. This reiterates the assertion made earlier in section 4.4, that the constitution and organisation of the enterprise model in terms of its architecture should be driven by its intended application.

6.6 An Architecture for Information Specification: Identification of Research Needs

The ARIS architecture has been selected to place the relevant viewpoints into context for information specification. However, this research has identified two aspects which need to be addressed:

(i) There is still a need for reference data models to describe or specify information structures, suited to particular enterprises, which would greatly enhance the use of these modelling architectures.

(ii) There should be flexibility within the individual viewpoints for alternative approaches to information capture (i.e. different modelling methods).

These two major issues are now discussed below.

6.6.1 The Need for Reference Data Models

The information viewpoint of CIMOSA and ARIS captures all the information or the conditions which are altered during the course of operations performed in the process chain model. The information view is therefore associated to the function view of both architectures through the process chain model. The end result of the modelling exercise with either architecture is a specification of the enterprise's information requirements. This is captured in the form of schema specifications within the information viewpoint, modelled in conjunction with the other viewpoints prescribed by the chosen modelling framework.

In CIMOSA, object views are translated into the external schema, which is in turn, aggregated to produce a global conceptual schema (Vernadat et al., 1989). However, there is an increasing demand imposed on information system design which requires the identification of information structures that facilitates re-use, sharing and extendibility (Hars and Scheer, 1992, Benjamin et al., 1995). An alternative approach would be to define the conceptual schema first and subsequently derive the enterprise object views.

A reference model for the conceptual information schema can be developed independently to provide more user support and guidance. The development of a generic structure of the information objects as a reference data model is a significant step to the realisation of the schemas and can enhance both architectures for the task of information specification. CIMOSA recognises this requirement for partial reference models, hence the emphasis on the dimension of genericity of its framework (AMICEE, 1991).

An appropriate reference model can substantially decrease the design effort by laying the partially populated reference schema specifications out in an organised semantic structure. In terms of the quality of the models created, conceptual schemas for particular enterprises which are derived from the same reference model are consistent. Their implementations are therefore easier to integrate and enable the sharing or exchange of information (Gielingh, 1992).

Therefore, there are advantages to be gained when reference data models are used to establish, within the information viewpoint, much of the information requirements of a manufacturing enterprise. Proposed reference models, however, should be applicable to a set of companies with specific characteristics and size. These reference information structures may then be instantiated in conjunction with the other inter-related viewpoints of the architectures and implemented after adaptation to the specific situation of the company (Scheer and Kruse, 1994, Hars, et al., 1992).

6.6.2 The Need for Alternative Approaches to Data Capture

The formal specification of a domain process in CIMOSA is based on a top down approach, where the context diagram, or starting point for the functional decomposition is the definition of a domain. Each identified domain consists of one, or a few domain processes. Functional analysis involves identifying a domain process, which is decomposed into business processes and enterprise activities. The behaviour of a domain process is defined by procedural rules, which link the individual enterprise activities in a flow of action, in accordance to the conditions set by the initiating event. The main purpose of the business process is to describe the rule based flow of control (or behaviour) within a selected domain of an enterprise. The CIMOSA and ARIS architectures have been intended for deterministic systems, and are based on the premise that all enterprises can be functionally decomposed into business process chains, where operational rules impose the unconditional execution of enterprise activities.

This is regarded to be unsuitable for the majority of SME companies which work under highly volatile conditions and may not be naturally characterised by business process chains and deterministic procedural rules. The specification of information requirements must capture the management style of the business and must be supportive of the patterns of work on the shop floor. It is, therefore, important to reiterate that the wide spectrum of businesses cannot be supported by the same approaches to information specification. The following chapters will introduce and report the results of a major piece of research work and a new approach to information specification.

Chapter 7

Modelling of the Metalworking SME:
The Fundamental Research Concepts

7.1 Introduction

This chapter provides an overview of the new concepts have been introduced and developed in this research. These include a new representation of the metalworking SME, a new class of information network and a methodology to derive the information specifications. The aim of this chapter is to introduce and provide a brief explanation of these new concepts, which will be described in detail in the following chapters.

7.2 An Holonic View of the Metalworking SME

The starting point of the research concepts in this thesis is the assertion that the human dominated interactions which occur within SME companies may be characterised in holonic terms. Koestler's fundamental study included social organisations consisting of hierarchies of semi-autonomous sub-wholes, branching into intermediaries of a lower order. The author considers that organisation of the SME can considered to be a particular exemplar. The representation of the casual SME holarchy may also be expressed in terms of organisational holons, shown in figure 7.1.

The entities existing within the SME, for example, would consist of the executive holon of the company and the operator holons working in the machine shop. This representation is the simplest configuration of an SME holarchy. The human holons operating in this holarchy are expected to display relative autonomy in their work. The executive holon represents the ultimate decision-making individual who may also be actively involved in the planning and adjustment of work sequences and in the execution of manufacturing activities.

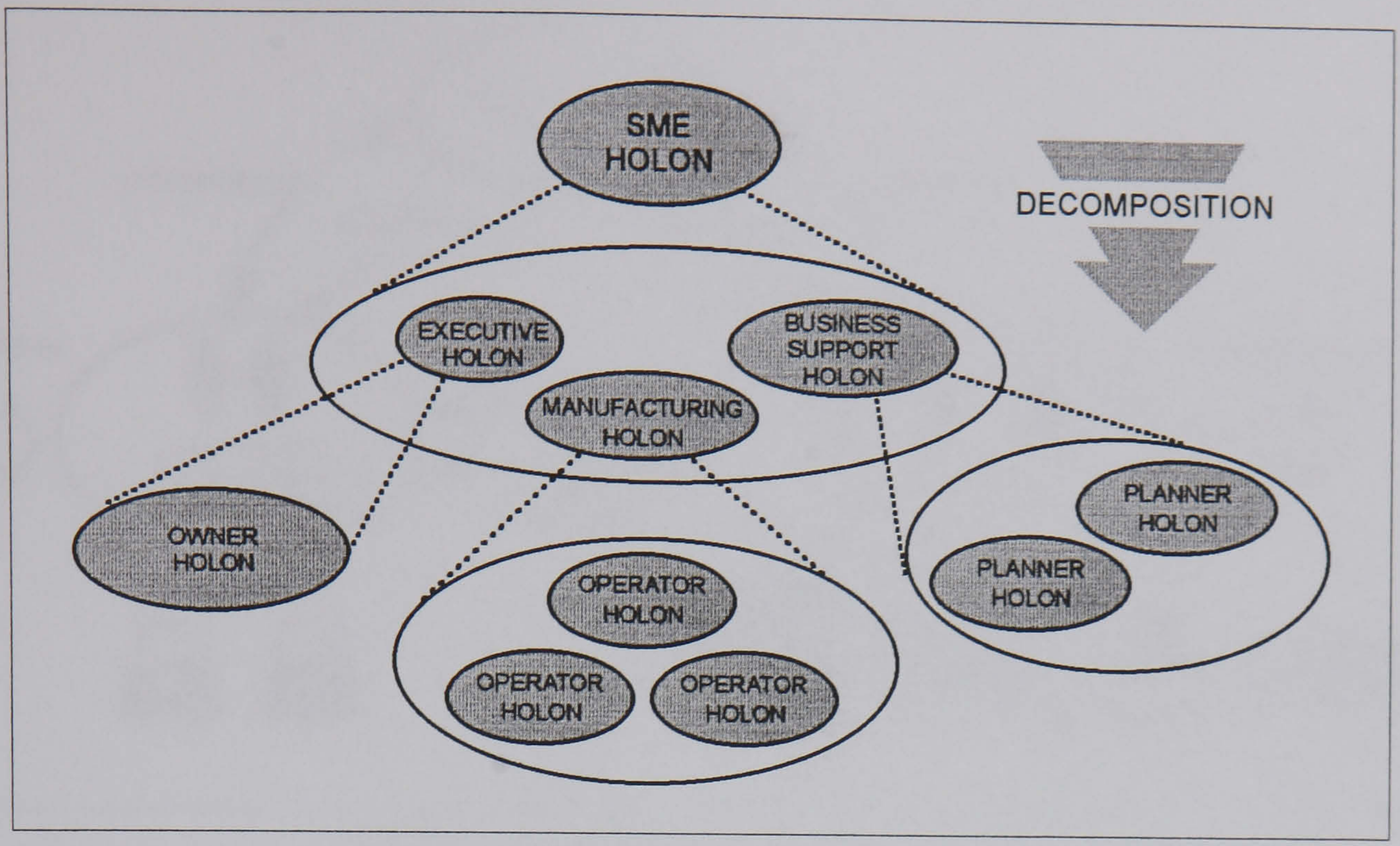

Figure 7.1: A representation of an SME as an organisational holon.

7.3 The SME Organisation as a Casual Holarchy

Within an SME, there is expected to be considerable interplay between the human holons in the holarchy relating to the planning and performance of daily production tasks, this is depicted in figure 7.2. The nature of the interactions which occur may vary from that of consultation and cooperation between holons, to that of control by a dominant holon. Control may be considered to be polarised cooperation, where an obligation is imposed on the subordinate holon to cooperate. The occurrence of these interaction types depends on the nature of the working relationship between the human holons; interactions between peer holons on the same level in the hierarchy will tend to be characterised by more instances of collaboration. An executive holon may exercise more control over the subordinate operator holon.

The inclusion of contemporary information support based on current information systems design methodologies contributes a limited enhancement to the performance of the SME and plays no active supporting role in the holarchy. The representation described above may be regarded as a casually structured holarchy, as the organisation of human holons who employ manufacturing and information processing equipment performs an unstructured role, in terms of information flow.

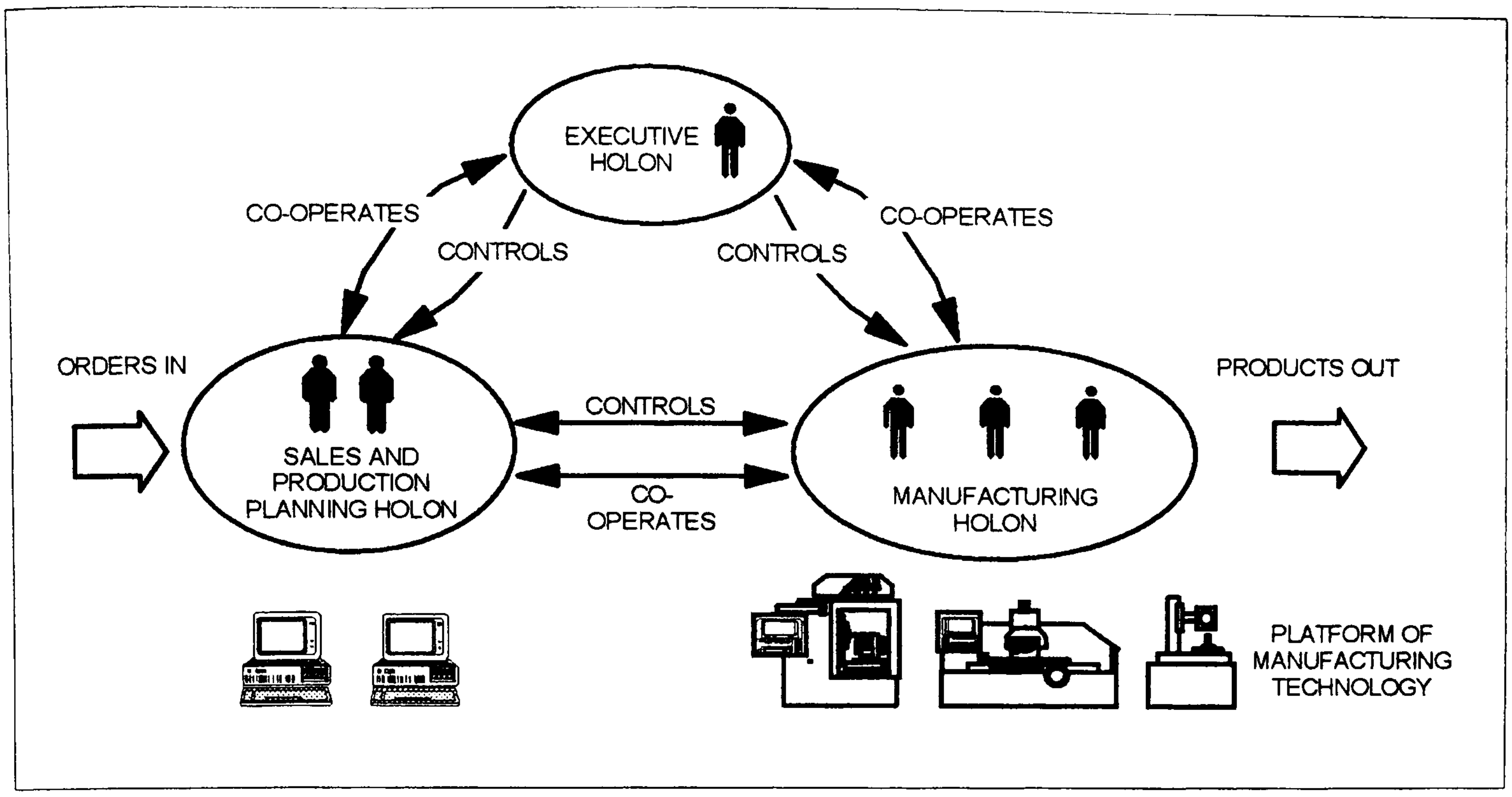

Figure 7.2: The SME as a casual holarchy.

7.4 The Holonically Enhanced SME

The performance of the SME can be considered to be holonically enhanced when it is supported by an information system, illustrated figure 7.3. A major step is taken when the holarchy is all embracing; this infers that both operators and equipment are integrated into an information network, whose specifications are underpinned by the fundamental holonic concepts introduced by Koestler (1967). Each node on the information network is populated by employee, supporting equipment and an information interface. The information and application support provided at each node is specified from a view of the system influenced by the holonic view of the system. The work reported in this thesis is the process which yields the specification for the information requirements which supports the operation of the business based on this new approach.

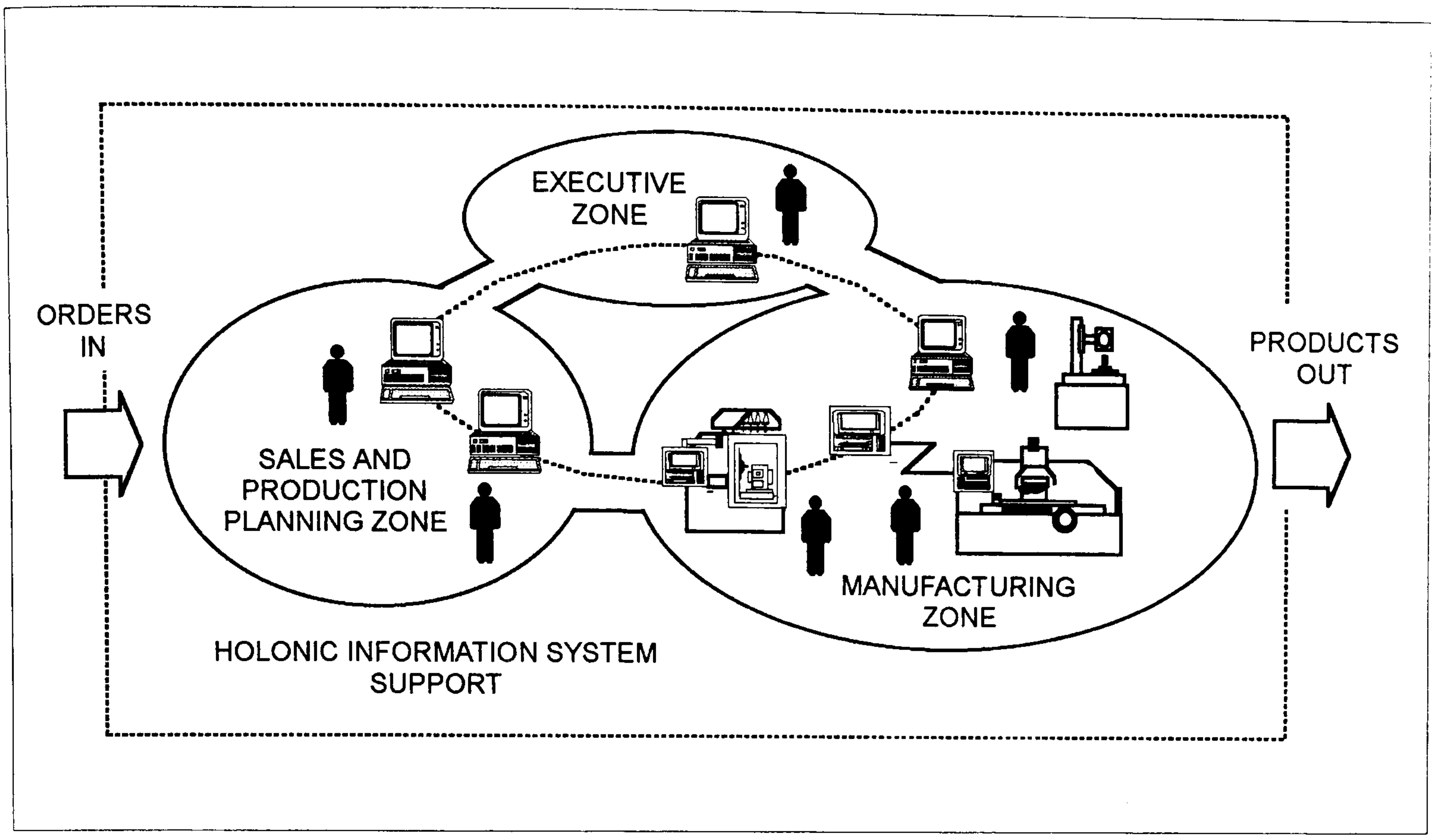

Figure 7.3: The holonically enhanced SME.

7.4.1 A Zone Representation for the SME

A zone representation, illustrated in figure 7.3, has been chosen to characterise the more informal and less hierarchically structured organisation of the SME. The zone representation has been influenced by Warnecke's top-down concept of the fractal factory (Warnecke, 1993) and Koestler's description of holarchies (Koestler, 1967), contrasting with the highly structured functional decomposition techniques. This provides the basis for a form of representation where the organisation within a company is less structured and more informal. The zone representation is explained in detail in section 10.2.

An example of this representation is a small business with no design function, which may be characterised by three zones of activity; the executive, production planning and manufacturing zones. This representation captures the interaction between the company and its customers and the manufacturing activity within the business. In a small company, where the division between the business and manufacturing zones is less discernible or useful, the zones coalesce into one. As the companies become larger and more complex, the number of zones increases subject to the diversity of operation and the representation may be extended to companies with greater complexity and scale.

7.5 The Reference SME Enterprise Model for Information Specification

A fundamental concept of this research is the creation of a new, reference SME enterprise model which enables the specification of information requirements. The structure of the enterprise model must be capable of representing the basic holonic concepts and information requirements. An information modelling tool can be subsequently developed to allow an instance of the enterprise model, and consequently, the information specifications to be realised. The author has identified three interacting fields of data which are needed to develop an adequate representation of the SME and instance of the information requirements, illustrated in figure 7.4.

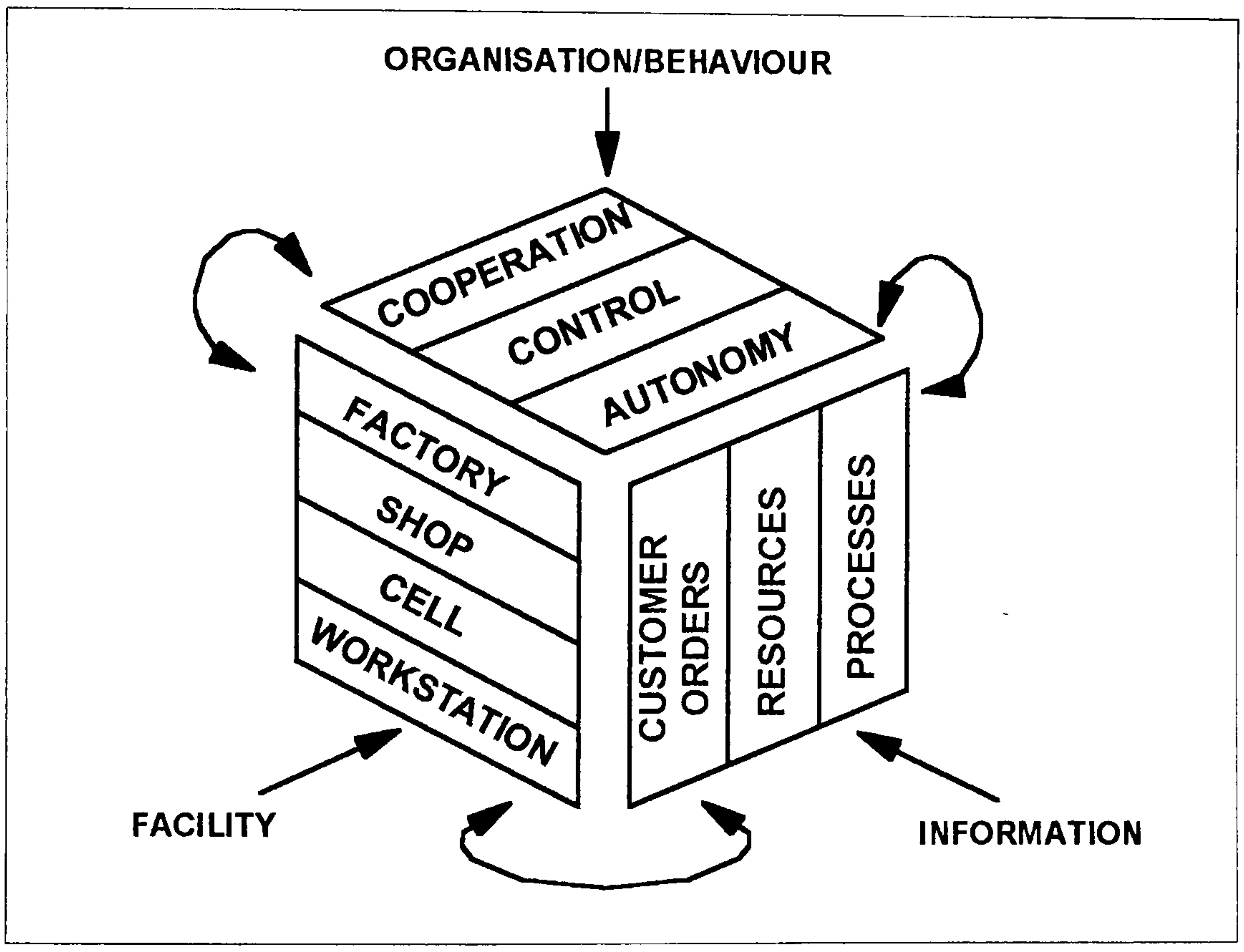

Figure 7.4: A three view approach to information capture for the SME enterprise model.

The first field of data relates to a description of the factory facility of the enterprise. The second field of data involves the information structure which needs to be held within the information system, these are represented by the order, resource and process data structures. The third field of data involves the organisation and behaviour of the enterprise which has been influenced by the fractal concept and ideas of the holon. The behaviour is characterised in terms of control, cooperation and autonomy in order to capture the human interactions. This three field approach to data capture which is to be discussed in detail in section 9.4, represents the philosophy or rationale behind the particular contents and structure of the enterprise model. The information structures to be identified are centred around the support of the human interactions which may be characterised in holonic terms. These interactions between the individual node holons occur primarily over the management of customer orders, manufacturing processes and resources. The process of information capture, depicted by the inter-related three field approach, is to identify the information, associated to a particular facility level, which would support the holonic aspects of the company.

7.6 The Node Holon

An enterprise model, which represents the enhanced organisation holarchy, must be all embracing. This prerequisite presents a problem when modelling an individual node on the information network, as there is no existing term to describe the unique combination of human holon, equipment and information interface (or IT product). The author has therefore introduced the node holon, which will be used to denote the composite of human holon, equipment and information interface, illustrated in figure 7.5. The characteristics of the node holon have been influenced by Koestler's fundamental definition of the holon and from Suda's classification into hard and soft holons (Suda, 1990).

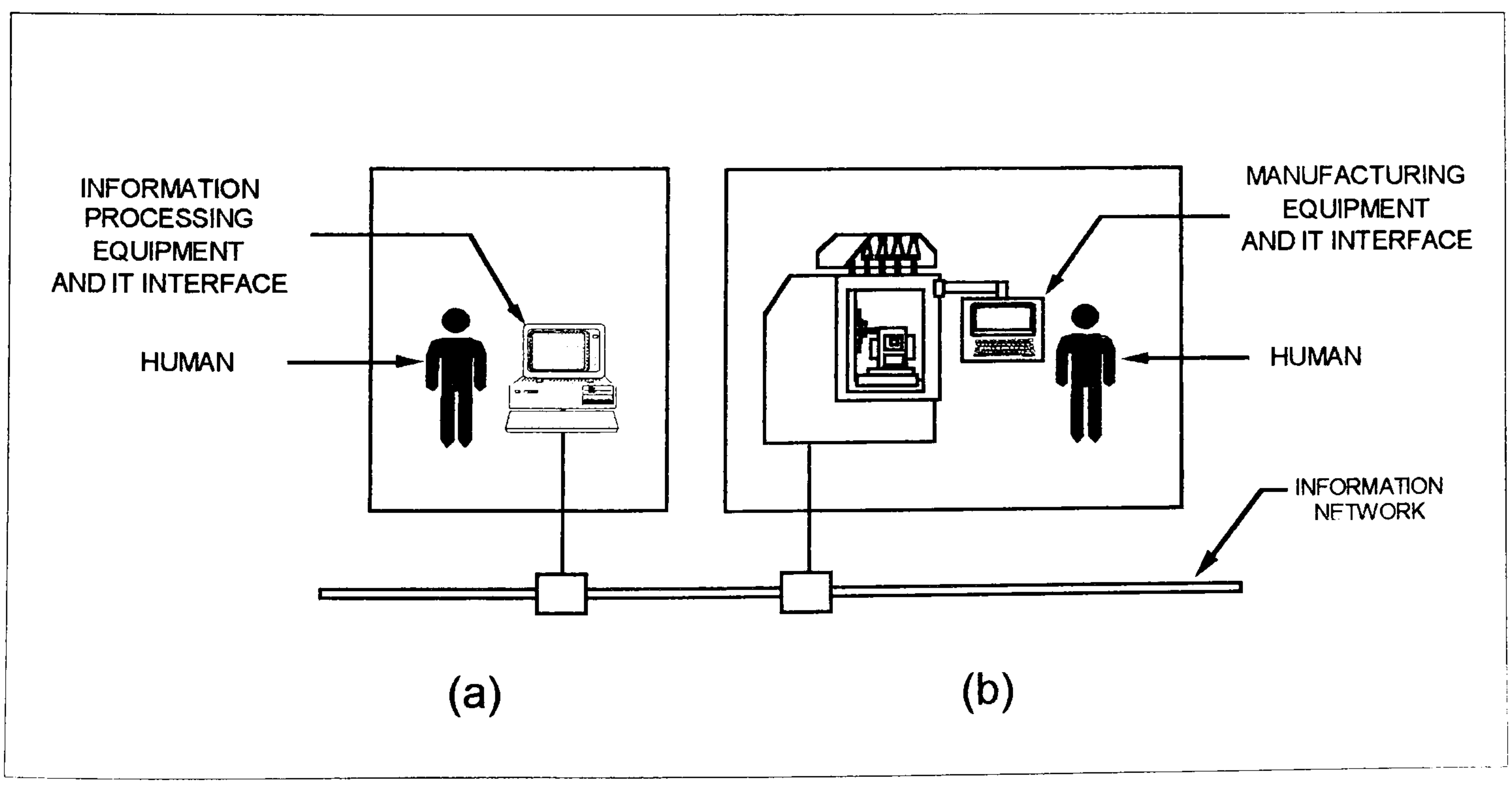

Figure 7.5: Node holons:
(a) Soft node holon
(b) Hard node holon

The node holon is an abstract representation which will allow interactions to be modelled in holonic terms. The new holonic approach introduced in this thesis has provided a new stance from which the cooperative and control interactions within the organisation may be described. This aspect of the company is captured in an enterprise model of the SME as a separate viewpoint, described in section 10.4. Two classes of nodes are depicted in figure 7.5, these are the hard and soft node holons. In accordance to Suda's definitions (1990), node holons which perform information processing tasks are categorised as soft node holons and those which perform manufacturing tasks are categorised as hard node holons.

This abstract representation enables the functionality and interactions of the node holon to be modelled in terms of Koestler's fundamental ideas of the holon, described in section 10.3. The self assertive tendency of the node holon is modelled in terms of its autonomy, the integrative tendency is modelled in terms of control and cooperation. Moreover, this abstract representation allows the specification of information support at each node.

7.7 The Holonic Information System

The holonic information system (HIS) has its specifications produced using the holonic concepts. In addition to the comprehensive functionality available through contemporary IT solutions, the HIS must fulfil one further requirement: it must enable the enterprise to make the transition from that of a casual holarchy to that of an enhanced holarchy. In a human dominated environment, it must be designed to facilitate and intensify the collaborative interactions between the employees. Moreover, the specification of the HIS must identify the additional information which may be necessary for decisions to made at the individual node holons, as part of their autonomous functionality.

7.7.1 The Holonic Information Network

The information system which results from the concepts described previously is termed the holonic information system (HIS) and the implementation, illustrated in figure 7.6, is the holonic information network (HIN). The HIN is populated with a number of classes of node holons, these range from the executive to the inventory node holons. The system is characterised by interactions between the individual node holons and a bi-directional exchange of information. In the implementation of the HIN, a node holon which involves, for example, a vertical CNC machining centre and it's operator will have the third component of IT products loaded into the machine controller, assuming an open systems architecture specification. Other examples will include the use of a proprietary interface unit, such as a ruggerdised computer. The manager who monitors the progress of customer orders via a terminal on the network will have the additional IT support at the computer terminal.

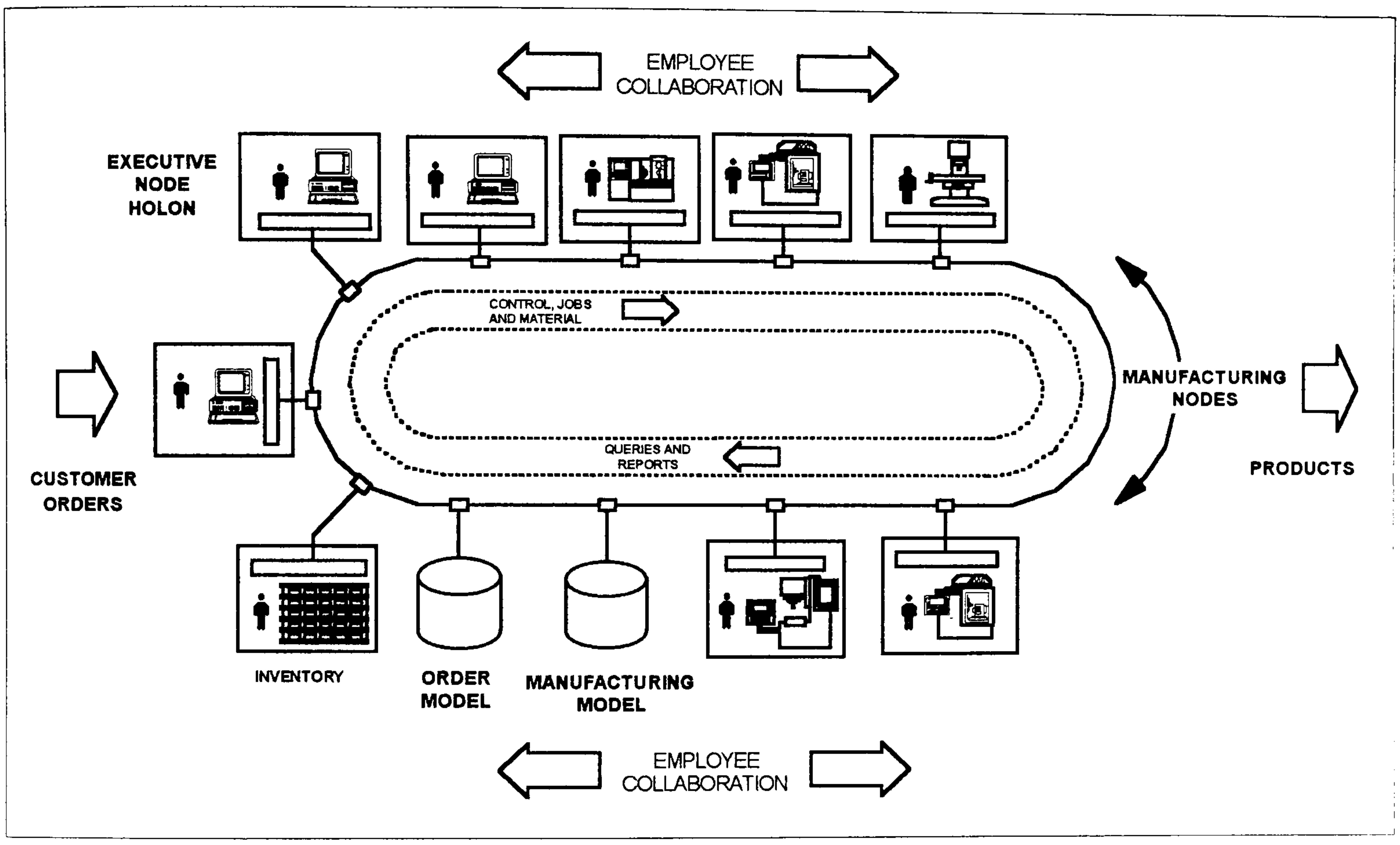

Figure 7.6: The holonic information network (HIN).

In addition to the comprehensive functionality available through contemporary IT solutions, the HIN must fulfil one further requirement imposed: it must provide the integrated backbone for communications between node holons on the network. It can be seen from figure 7.6 that the HIN is populated by two classes of node holons; those forming part of the business holon which employ information processing equipment are the soft node holons and those which form manufacturing holons are the hard node holons.

The design of the information network from an holonic stance results in enhancements in IT support available at the shop floor devices. A distinguishing feature, which sets them apart from their conventional counterparts, is that they are equipped with the proprietary IT support and interfaces for the employees to interact in an enhanced holonic manner. Access to the information stored within the databases is provided via application interfaces. It follows therefore, that there would be a need for proprietary IT support, which is not provided by the contemporary IT solutions, to facilitate the holonic behaviour.

7.8 The Specification of Information Requirements

Two major components of the information network, shown in figure 7.6, are the databases or information models which provide the necessary information support throughout the company. The information requirements of the SME, without a product development function, are seen to be adequately met by two models, namely, an order and manufacturing model. A first step in the realisation of the information specifications is to identify and classify the information objects that are of direct interest to the operation of the factory in relation to the two models. The expression of the conceptual information structures provides a starting point for the development of a complete specification for the databases. The fundamental holonic concepts then provides the link between the organisation and behaviour of the enterprise and the specification of information requirements, this is to be described in section 10.3. A distinctive feature of this approach is that it involves characterising the interactions between the node holons in terms of control and cooperation.

Chapter 8

The Information Requirements of the Metalworking SME

8.1 Introduction

This chapter discusses the information requirements for the metalworking SME. A fundamental concept in this thesis is that the information requirements may be captured adequately by two information models, which are the order and manufacturing models; the reasons and factors which have influenced this choice are explained. The use of the information viewpoint of the RM-ODP standard is discussed, with particular emphasis on how this has provided a focus on the information component of the system. In order to realise a complete information specification, the information viewpoint of the RM-ODP is further structured in accordance with the ANSI/X3/SPARC DBMS three level architecture. The specification of information requirements is explained in the context of this three schema architecture.

8.2 The Information Component of the Holonic Information Network (HIN)

Information manifests itself in many ways, it exists within the company as sales orders, bill-of-materials, route cards, job status reports, work lists and schedules. In as many ways information can appear, there are as many instances where it can be generated and used. Information is generated when the customer places an order, or when routing details are created for a job. Information is changed when operators manufacture the customer orders, when jobs are booked on or off, and when material is transferred from stock control. Managers make decisions to accept orders, or to invoke sub-contract resources by reviewing the level of factory capacity in terms of manpower and machine resources. Information also alerts production managers when expediting or rescheduling is required to meet priority jobs.

Information is a fundamental component of the HIN, where it is stored, shared and processed by various applications throughout the enterprise. The information is provided in terms of the order and manufacturing models, shown in figure 8.1. These models represent the memory of the enterprise in terms of valuable data and knowledge and it is important that careful attention must be paid to its modelling and management. The first step in the task of information modelling is to identify and classify the information objects that are of direct interest to the operation of the factory.

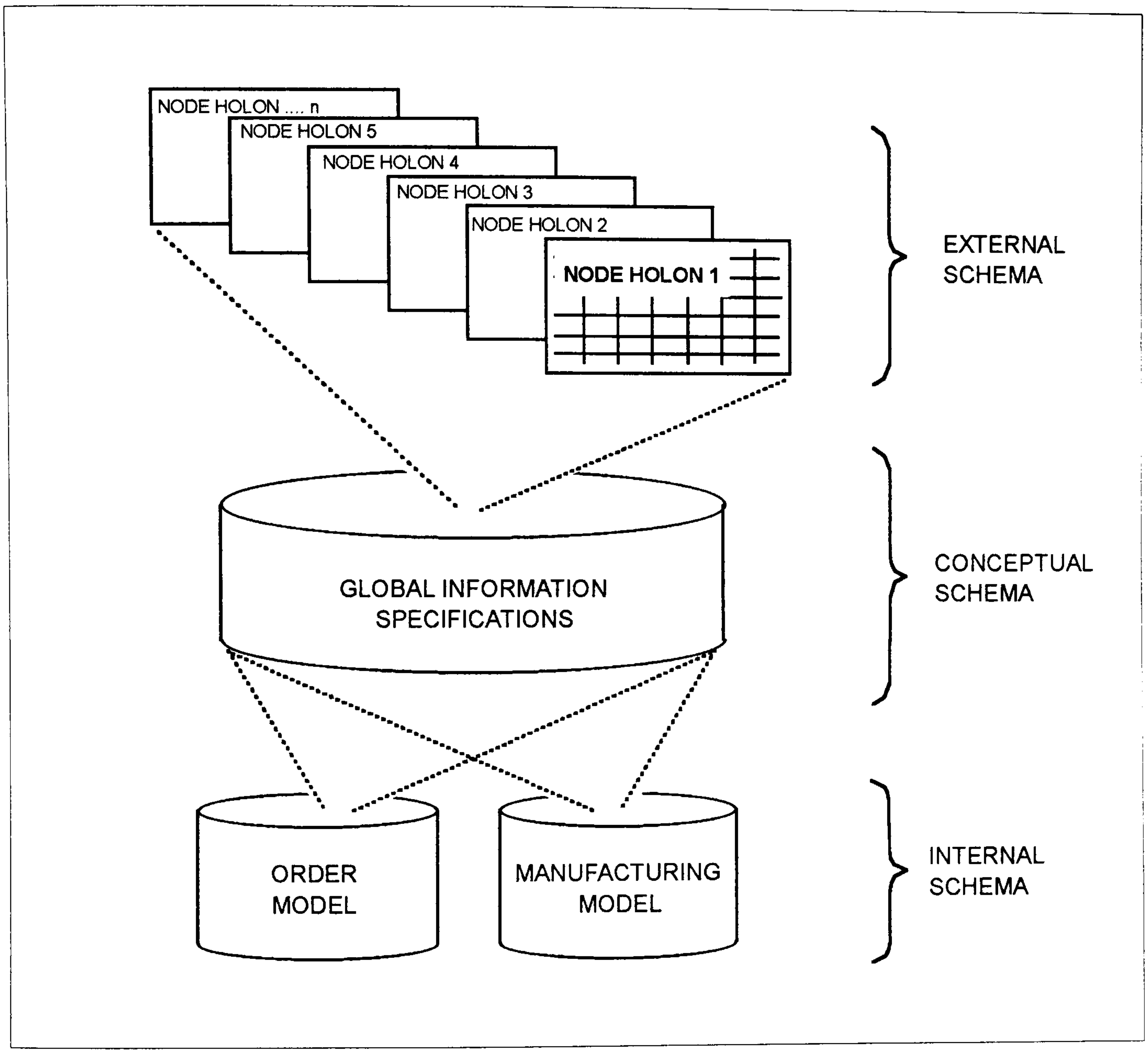

Figure 8.1: The information requirements of the metalworking SME in compliance to the ANSI/X3/SPARC (Tsichritzis and Klug, 1972) three schema architecture.

As a consequence of its volatile environment, the focus of the company management in a metalworking SME is centred around the manufacturing shop floor and the tasks of accommodating customer demands. The ideas of Nicholson (1985) and Westbrook (1993, 1995), which involved the use of an order data structure for the practice of priority management, have been a significant influence in determining the information requirements.

Although the information structures reported in this thesis are distinct, their work has affected the inclusion of an orders based model as part of the SME information structure.

The introduction of the order data structure is not enough; the capacity and available resources of the manufacturing facility directly affects its ability to fulfil orders. Hence, management of order priority must be considered in conjunction with the status of the factory facility and a model which captures this information is another essential component of the information schema specification. The work of Molina (1995) has provided the basis of the SME manufacturing model. Although the basic information structure of the Molina manufacturing model has been adopted, there are necessary extensions to the original model to accommodate the dynamic information requirements for shop floor control. The information system based on the combination of the order and manufacturing information structures is seen, by the author, to be adequate for the requirements of the SME. The order and manufacturing models are now described below.

8.2.1 The Order Model

The introduction of the order information structure for the SME is an important part of the information specifications. The emphasis on this component of the information system is not unexpected; the activities of the shop floor are centred on fulfilling the customer orders. There is, therefore, a need for an order model which defines a core information structure relating to the progress of work-in-progress which explicitly identifies, for example, the status and location of the orders.

The order model contains the information objects which relate to the orders that the factory processes. The information structure is designed such that each order can be for one or a number of jobs, these information objects have attributes which are specified during the specification process. Examples of these attributes are details of the customer, order due dates and process routes. The information caters to different users throughout the factory; the production planning node holon requires the status of the order in terms of the expected completion date or the location of the job on the shop floor. The machining node holon requires the due date which dictates, in part, the sequencing of work at the machine.

The order model also plays an important role in fluctuating customer demands, it provides the flexibility when planning for rushed orders, which often does not go beyond the necessary detail of a route specification. It has to enable jobs to be introduced with the minimal of planning detail and allows information to be built up as manufacturing progresses. A fluctuating level of machine and resource availability may require contingency plans which demand sub-contract resources. The order model also provides a source of standard processing routes for repeat or variant work, where standard routing is recalled from a library and amended for the current job. These alternative manufacturing options, together with the documented situation type, should be captured to reduce the planning time for repeat orders.

The order model captures a subset of information relating to the product collected during the manufacturing phase of its life-cycle, which for some applications, may be included into a product model. Whilst this would be unnecessary for the majority of industries, a particular example where this would be desired is the aerospace industry. Here, it is common for the procedures and manufacturing parameters such as the cutting tool type used to be recorded for particular components to sustain traceability.

8.2.2 The SME Manufacturing Model

The information component represented by the manufacturing model provides the representation of the SME's manufacturing facility, it's process capability and resources. This information has to be used in conjunction with the order model for the management of the order priorities. The SME manufacturing model is closely related to the model proposed by Molina in 1995 (1995). The structure of the Molina model is based on the National Institute of Standards and Technology's (NIST) four level characterisation of the factory facility (Albus et al., 1981). Therefore, the levels represented in the SME manufacturing model are also the factory, shop, cell and workstation, where at each, the resources, processes and strategies can be defined with varying degrees of abstraction to support the diverse information requirements of employees.

The information requirements of the employees are invariably related to the operational issues of shop floor control. Decisions to accept orders, or to invoke sub-contract resources are based on the level of factory capacity in terms of manpower and machine resources. The process of decision making thus requires information about the combination of machine and resource commitment at any particular time. The costing process also requires accurate information about machining or process costs and operation times. The manufacturing model also provides manufacturing process and resources information to enable the identification of alternative process routes for a job. In order to accomplish this, the process may have associated information parameters which may, for example, be the process cost, or the quality of surface finish which relates to the capability of the operation.

It is recognised that the availability of capacity in a factory does not remain unchanged, it varies according to the combination of machine and resource commitment at any particular time. The manufacturing model has a pivotal role, for example, in providing manufacturing processes and resources information to enable the identification of alternative process routes for a job. The basic information structure provided by the Molina model has been extended to contain parameters relating to the dynamic aspects of information such as the level and location of material, expendable inventory, the job sequences, and the impact of job relocation to the capacity loading at individual workstations.

8.3 The Information Specifications as an Instance of the Information Viewpoint of the RM-ODP

The work reported in this thesis is concerned with creating an instance of the specification for the order and manufacturing models, therefore the information viewpoint of the RM-ODP (ISO/IEC, 1995) is of the primary interest. The information specification of the RM-ODP is a model of the information that the HIS holds, this model ensures that individual components of an information system will share a common understanding of the items of information they communicate when they interact. In order to ensure that the interpretation of these items of information is consistent, the information viewpoint of the RM-ODP defines concepts which enable the specification of the information stored or used within the system.

Information held by the RM-ODP about entities captured by the order and manufacturing models is represented in terms of information classes and their relationships. Basic elements of data are represented by atomic information elements and complex information is represented by composite information elements, this is to be further explained in section 9.4.2. In the information specification, the semantics of data is represented using a global or conceptual information schema. This conceptual schema is used to represent information which is true for every user, in addition, a local schema for each node holon must also be specified.

8.3.1 A Three Schema Specification of the Information Requirements for the Holonic Information System (HIS)

Three aspects of the information requirements for the HIS have to be considered and specified in order to cover the user needs and also to reflect the current storage technologies of the databases employed. Firstly, the specification of the HIS must include all the necessary information found to be necessary for the operation of the enterprise, this is seen to be adequately represented by the order and manufacturing models. Secondly, the different information requirements of individual node holons have to be specified, these individual requirements would be a subset, or a different view, of the total information stored by the HIS. Thirdly, the information has to be stored in a form which would suit the operational requirements of the enterprise, which is determined by implementation specific issues such as the databases used, systems response or access security.

The information viewpoint of the RM-ODP is further structured in accordance with the ANSI/X3/SPARC DBMS (Tsichritzis and Klug, 1972) three schema architecture. This three level architecture, which requires the generation of conceptual, internal and external schema, has been chosen as it has a wide level of acceptance and forms the basis of modern database architectures. The architecture has reached a relatively stable state, in so far as the schema levels are concerned, and that future refinements to the architecture are not expected to result in the addition of new levels.

8.3.1.1 The Conceptual Schema Specification

The global information requirements for the enterprise is expressed in the conceptual schema specifications. Therefore, the conceptual schema for the HIS describes the collection of entities, properties and relationships to be structured within the order or manufacturing models. The entities of interest are the company resources, processes, orders and jobs. These have been identified as the key elements around which a reference information model will be developed. The argument for a reference schema or model for the information specifications has been presented previously in section 6.6.1. The expression of the generic conceptual information structures as the order and manufacturing information schemas provides a starting point for the development of a complete and specific information specification to meet a particular SME's requirements. This will result in a decrease in the amount of effort in designing a new data model. In addition, the consistent use of the data structures will enable the quality of the models to be evaluated over a number of implementations. The conceptual schemas for the order and manufacturing models are developed in section 9.4.2 .

8.3.1.2 The External Schema Specification

As the external schema describes the objects contained in a selected view of the database, each node holon which is interfaced to the HIS must, have an external view which provides the window to the information. The external view has, therefore, to be specified in accordance with the functionality of the node holon and its corresponding information requirements. As a result of the direct relationship between the process chain and the information environment, where the performance of an activity will result in changes to the information parameters in the task environment, modelling the function view is a prerequisite to modelling the external schema. This forms the fundamental basis for specifying the required information support, i.e. using the link between the functionality of the node holons and the information schema.

8.3.1.3 The Internal Schema Specification

The internal schema describes how the information described by the conceptual schema is physically organised and stored in data storage media. The internal schema maps the content of the conceptual schema on to the realities of computers with the aim of achieving optimal run-time performance and optimal storage space utilisation. The internal schema specifications which are technology dependant and address performance related issues are beyond the scope of this thesis.

Chapter 9

The Reference SME Enterprise Model

9.1 Introduction

This chapter describes the structure of the reference SME enterprise model, the concepts behind its constitution and the Booch modelling formalism which is used to model its constructs. The contents of the reference SME enterprise model are discussed in detail over two chapters, this chapter concentrates on the facility and information aspects of the model. The following chapter then describes the approach taken to model and translate the holonic representation of the enterprise into the specification of information requirements.

9.2 The Reference SME Enterprise Model

An enterprise model which is generic in nature, will contain an all embracing set of viewpoints and supporting modelling methods according to which all aspects of an enterprise can be described. The generic enterprise model which is depicted in figure 9.1, is seen as containing an extensive number of viewpoints and constructs, from which specific enterprise models may be derived.

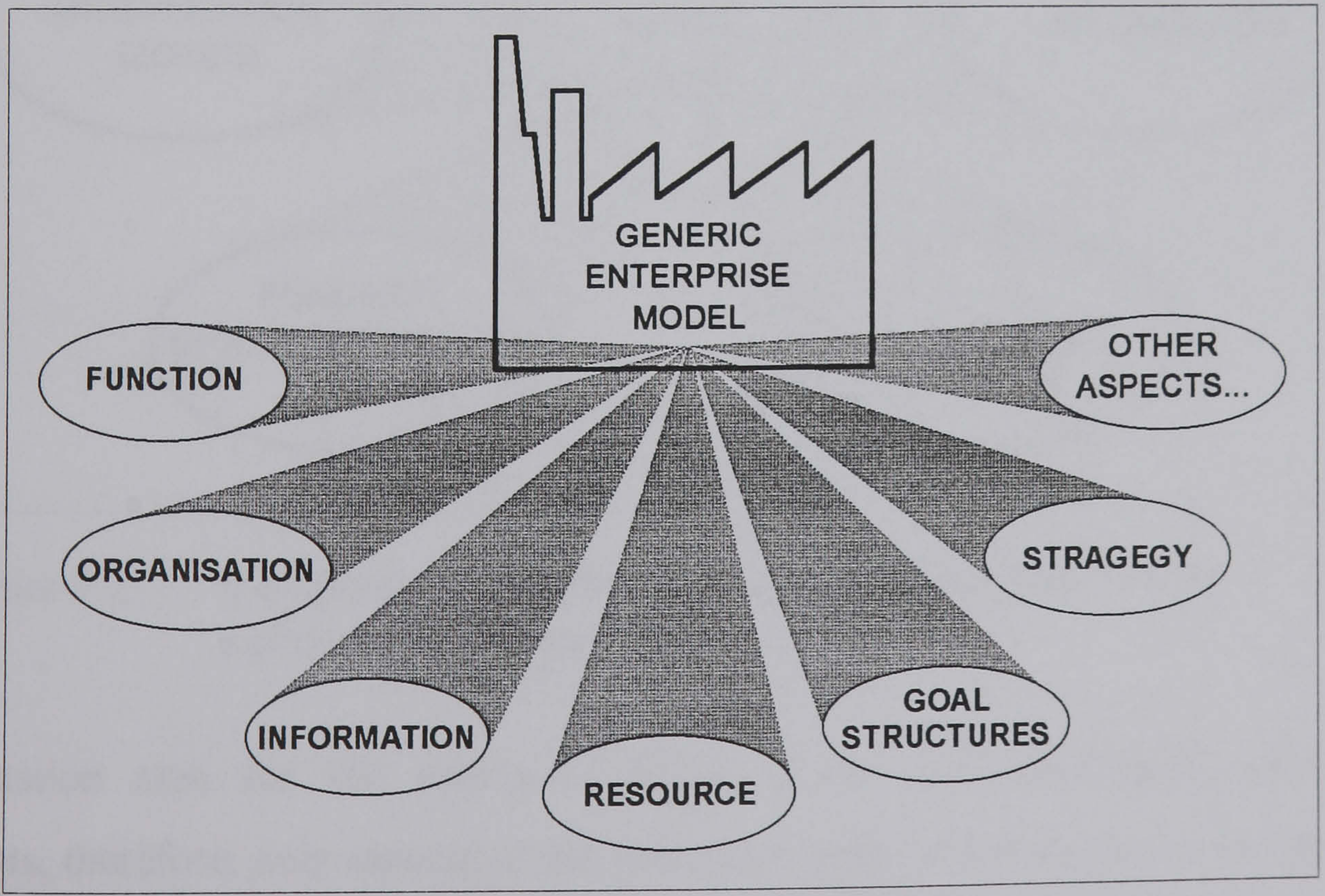

Figure 9.1: The generic enterprise model.

As figure 9.1 indicates, there may be a potentially unlimited number of aspects from which the enterprise can be described. Moreover, as new manufacturing paradigms emerge, some may provide a new perspective on the way an enterprise is observed and understood, creating the need for distinct descriptive viewpoints.

Typically, a particular enterprise model, such as the SME enterprise model, will only consist of a selection of the many possible views, this is illustrated in figure 9.2. The SME enterprise model, therefore, is a derivative of the generic enterprise model and contains a restricted number of viewpoints. Figure 9.2 shows that the constitution of the SME enterprise model, in terms of its descriptive viewpoints, has to be established through a philosophy of data capture.

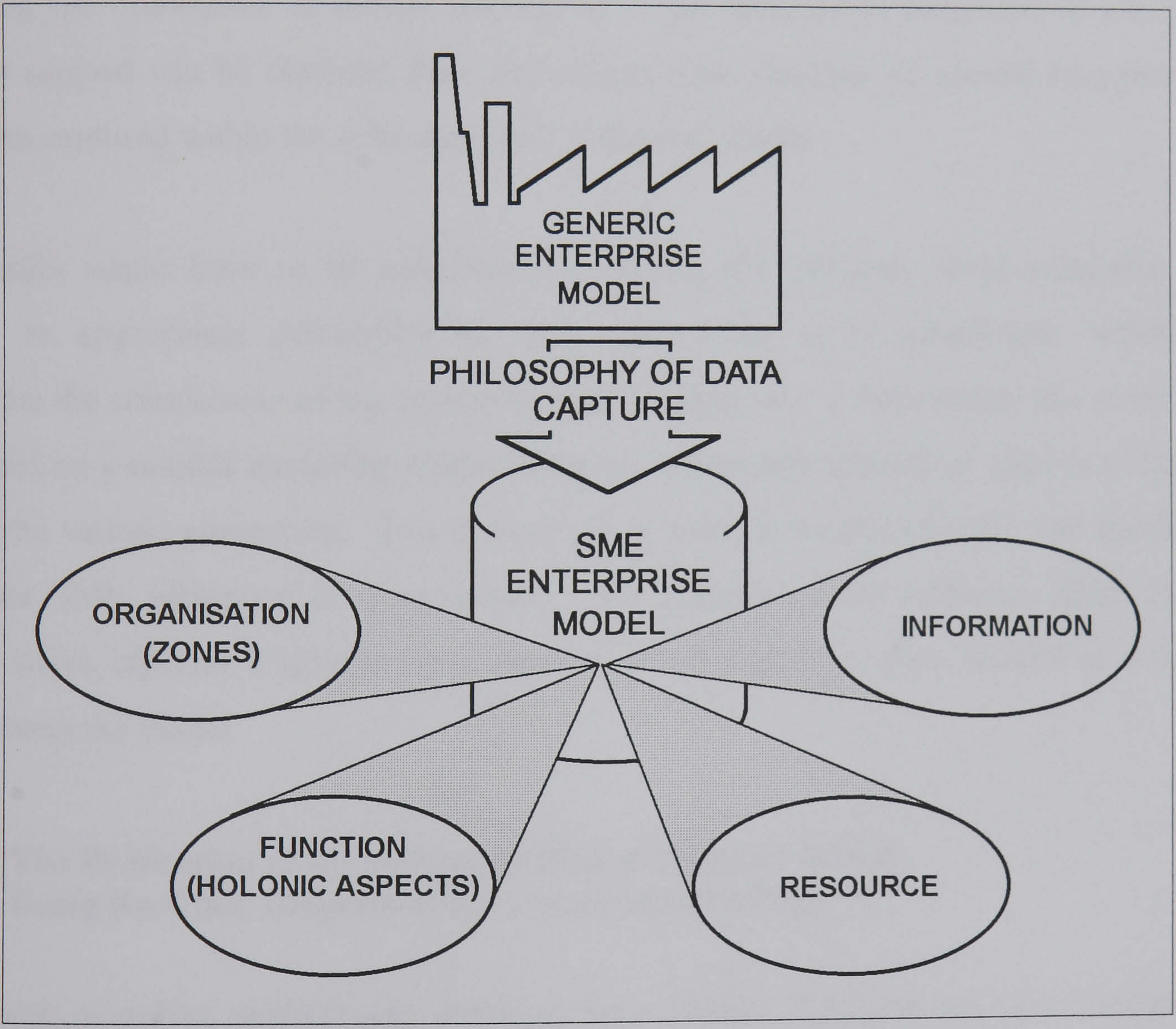

Figure 9.2: Viewpoints of the SME enterprise model determined by a philosophy of data capture.

The application area for the enterprise model is for the specification of information requirements, therefore, only aspects of the enterprise which are essential for the realisation of this task are modelled. The resulting reference SME enterprise model has to be a structured and logical representation of physical objects and concepts, which will clarify and unify the relevant knowledge of the enterprise for information specification. The result is a description of the enterprise model in terms of its architecture, which represents its invariant building blocks, shown in figure 9.2. These are models of the functional (derived from a holonic viewpoint), organisation (described in terms of zones) and the information aspects of the SME.

A fundamental role of the enterprise model is to establish, in an organised structure, much of the information requirements of the manufacturing enterprise in terms of the order and manufacturing models. Another major aspect of the enterprise model is the capability to model the metalworking SME, in accordance with fundamental holonic concepts, as a novel basis for reflecting the dominance of human interaction. The subsequent deduction of the required systems support can be obtained from this unique understanding of specific interactions and functions captured within the reference SME enterprise model.

Two major issues have to be addressed in deriving the reference SME enterprise model. Firstly, an appropriate philosophy for data capture has to be established, which would determine the constitution of the enterprise model. Secondly, a meta-model has to be created and based on a suitable modelling methodology to consistently capture all aspects of the model across the various viewpoints. This is essential in order to create a CASE tool based on the reference SME enterprise or meta-model[5]. An instance of the reference SME enterprise model, which captures a specific representation of a company is, then, termed as a particular SME enterprise model.

9.3 The Realisation of the Reference SME Enterprise Model Using the Class Diagram of the Booch Methodology

The Booch modelling methodology describes the existence of classes and their relationships in an object oriented applications system (Booch, 1991). The methodology has an established set of object oriented modelling semantics based on *inherits*, *has*, *uses*, *metaclass* and *instantiates*, to enable the conceptualising and modelling of relationships or associations between classes[6].

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[5]Although the meta-model and reference model represent the same concept, the term reference SME enterprise model will be used throughout the rest of this thesis to maintain a level of consistency in the usage of the term.
[6] The semantic relations will be shown in italics within the rest of this thesis.

For instance, the *inherits* relation is used to denote inheritance in object oriented programming. This is not strictly a semantic modelling principle, but is primarily used to model a software design mechanism which reduces redundant programming code.

It is therefore important to point out that the Booch class diagrams are used in two contexts in this research. Firstly, it has been used to establish the class structure for the reference SME enterprise model. The implementation of the modelling software, which is based on the object oriented programming paradigm, can be carried out directly based on the class structure of the model. Secondly, with extension to the semantics, the representation using the Booch class diagram becomes an effective communication tool. Relations such as *is_a*, *describes*, *performs*, *invokes*, *determines*, *subject_to*, or *accesses* are used to describe unambiguously, the concepts and relationships behind the enterprise model.

The use of an enterprise model to describe various selected aspects of an enterprise has been discussed in section 4.4. Within an individual viewpoint of an enterprise model, any modelling formalism can be chosen to represent the desired concepts. However, in order to create a CASE tool, an integrated enterprise model has to be created, with relationships between the individual viewpoints clearly identified. To achieve this, a semantic or meta-model of the individual modelling formalisms has to be created to abstract from the specific factual modelling constructs. This approach of expressing the individual modelling constructs through a uniform modelling formalism is employed by the ARIS architecture (Scheer, 1992).

A simple example is presented here to illustrate how the meta models are created when, for example, elements of the IDEF0 (CAM-I, 1980) activity modelling constructs are used within the functional viewpoint for activity analysis. Figure 9.3 demonstrates how the Booch class diagram enables the creation of a meta-model based on the constructs used in the IDEF0 activity modelling formalism. The semantic relations *subject_to*, *uses* and *has* are used to define the IDEF0 constructs, where an activity is *subject_to* control parameters, *uses* resources and *has* functional inputs and outputs. When a meta-model of the IDEF0 constructs has been created, the implementation of a CASE tool can be carried out to model instances of an activity described in accordance with the meta-model.

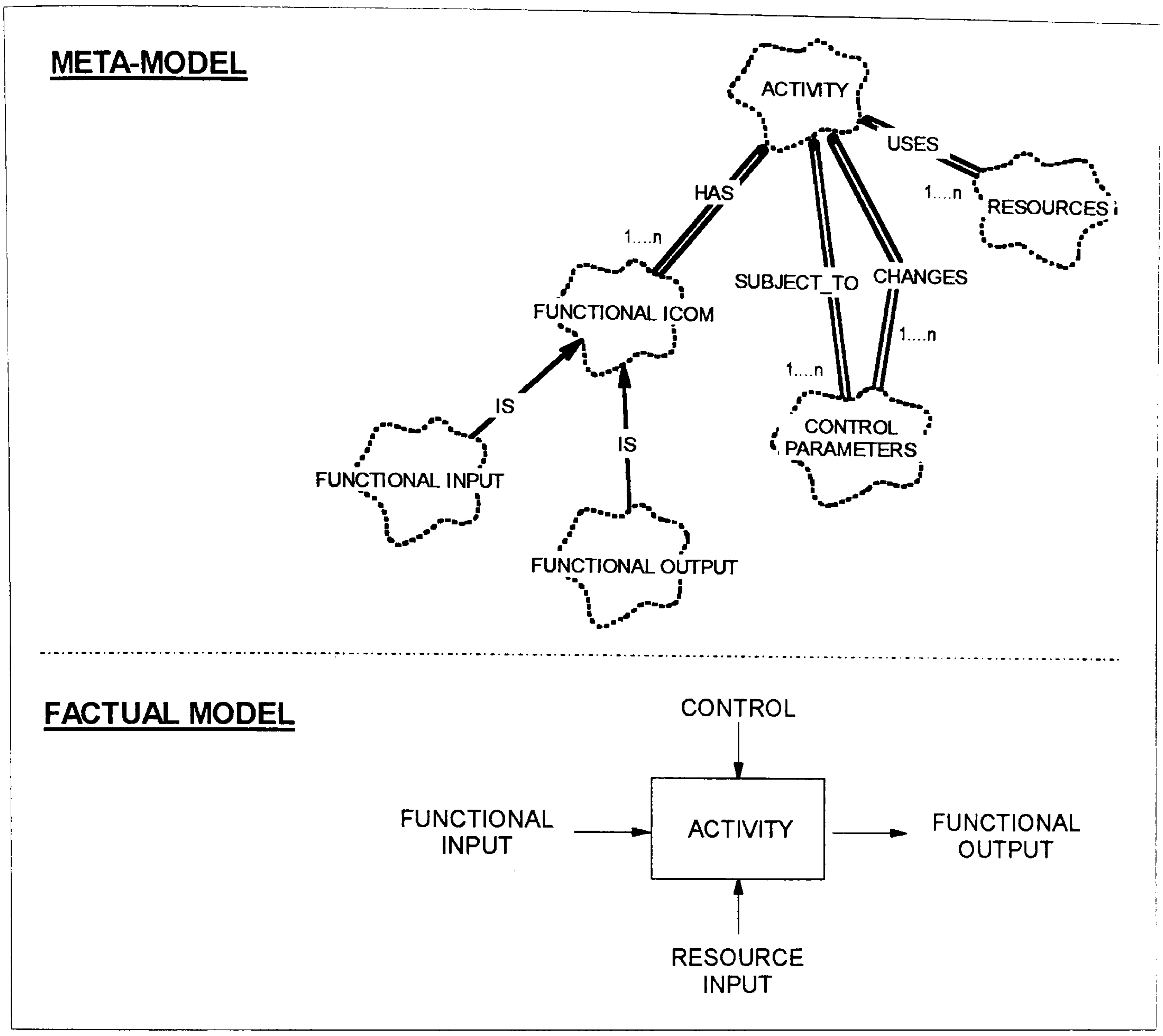


Figure 9.3: The creation of a meta-model of the IDEF0 activity modelling formalism using the class diagram of the Booch methodology.

Therefore, the constructs of any selected modelling formalism have to be decomposed into their constituent elements and represented in terms of objects and relationships in a meta-model. The different formalisms may then be represented in a uniform manner across the individual viewpoints of the reference SME enterprise model. If a uniform descriptive language is chosen throughout the individual viewpoints, a common semantic framework is maintained and the interdependencies between the individual constructs of the reference SME enterprise model can be explicitly established. The constituents of the enterprise model, to be described in the following sections, are captured using the descriptive formalism of the Booch class diagram. The Booch modelling formalism was chosen as it can be used to develop a structure of the reference SME enterprise model which can be directly implemented as a CASE tool to support the information specification process.

9.4 A Three Field Approach to Data Capture

In order to capture the necessary aspects of the enterprise, the author has identified three complementary fields of data capture. This forms the philosophy of data capture and has been introduced previously in section 7.6 and depicted in figure 7.4. The first field of data relates to a description of the factory facility of the enterprise. The second field of data involves the information structure which needs to be held within the information system. The third field of data involves the organisation and behavioural aspects of the enterprise, which captures the human dominated interactions according to holonic concepts.

The reference SME enterprise model is based around three major components, which result from the complementary fields of data capture. The three components are a facility model, a model of the information structure and a model which captures the organisation and holonic aspects of the company. This would consequently enable the capture of information relating to the orders, manufacturing processes and resources. The following sections will explain the three individual fields of data capture for the reference SME enterprise model.

9.4.1 Realising the Facility Field of Data Capture with the Booch Class Diagram

The first field of data relates to a description of the organisation of the enterprise facility in terms of a generic four level factory, shop, cell and workstation structure. This generic structure enables the manufacturing facility to be mapped against the four levels to produce an instance of the facility description. This first view is essential in order to model the organisation of the enterprise facility within which the information system is to operate.

The manufacturing facility is represented by the Booch class diagram as factory, shop, cell and workstation classes, illustrated in figure 9.4. Each level is modelled as a facility using the *is_a* semantic relation, hence, the individual factory, shop, cell and workstation *is_a* manufacturing facility. An instance of the manufacturing facility is modelled using the semantic relation ***has***, such that the factory facility ***has*** one or a number of shops. The shop facility in turn, ***has*** one or a number of manufacturing cells and which are subsequently modelled in terms of the number of workstations organised within its sector.

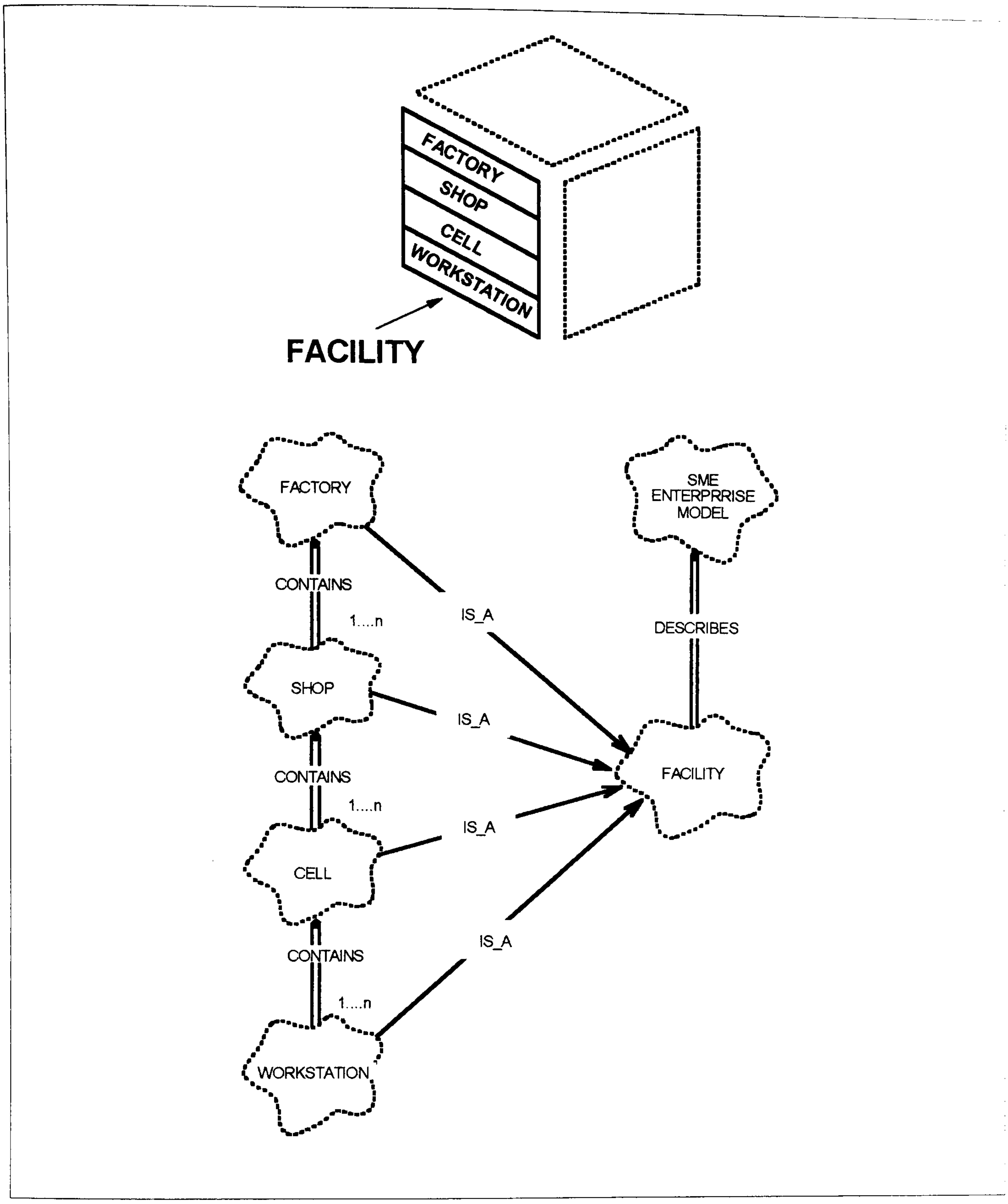


Figure 9.4: Modelling the manufacturing facility field of data capture.

An instance of the first field of data capture only results in a model of the factory as an empty facility. This implies that the facility field captures the organisation of the manufacturing facility in terms of the number of cells, workstations, etc., which does not capture any aspect of the manufacturing resources or processes associated to the particular facility. The manufacturing resources and processes, which a facility has, need to be described. It is important to point out that this is carried out within the second (or information) field of data capture, which is in accordance to the approach used by the ARIS architecture, described in sections 4.5.5 and 6.4.

9.4.2 The Information Field of Data Capture

The second field of data relates to the information structures which need to be captured by the reference SME enterprise model, this is illustrated in figure 9.5. The manufacturing processes, resources, order and jobs form the major information classes which constitute the manufacturing and order models. With reference to the second field of data capture shown in figure 9.5, the combination of the order and job classes are associated to the information relating to the customer orders.

The second field of data capture is associated to the SME enterprise model class using the semantic relation *describes*, where the enterprise model *describes* the information structures. The information structure of the SME enterprise model, in turn, *describes* the processes, resources, order and job classes. These form the generic information classes and information attributes can subsequently be associated to these individual information classes.

It can be seen from figure 9.5 that, at this stage, there is no relationship between the generic information and facility fields of data. This relationship is established only when a specific instance of the SME enterprise model is created for a particular company. This is an important concept, as the information structures can be developed independently of any specific company or manufacturing facility.

When these generic information structures are populated with information attributes, they can be applied directly as implementation specifications for the development of the manufacturing and order models. Alternatively, these information structures can be used as reference data models (or partial models), for new models to be built with the minimal of modification or adaptation. This application relates to the reference data models discussed in section 4.6.1 and correlates with the generic enterprise theories (GTs) used by the GERAM, discussed in section 4.5.7.

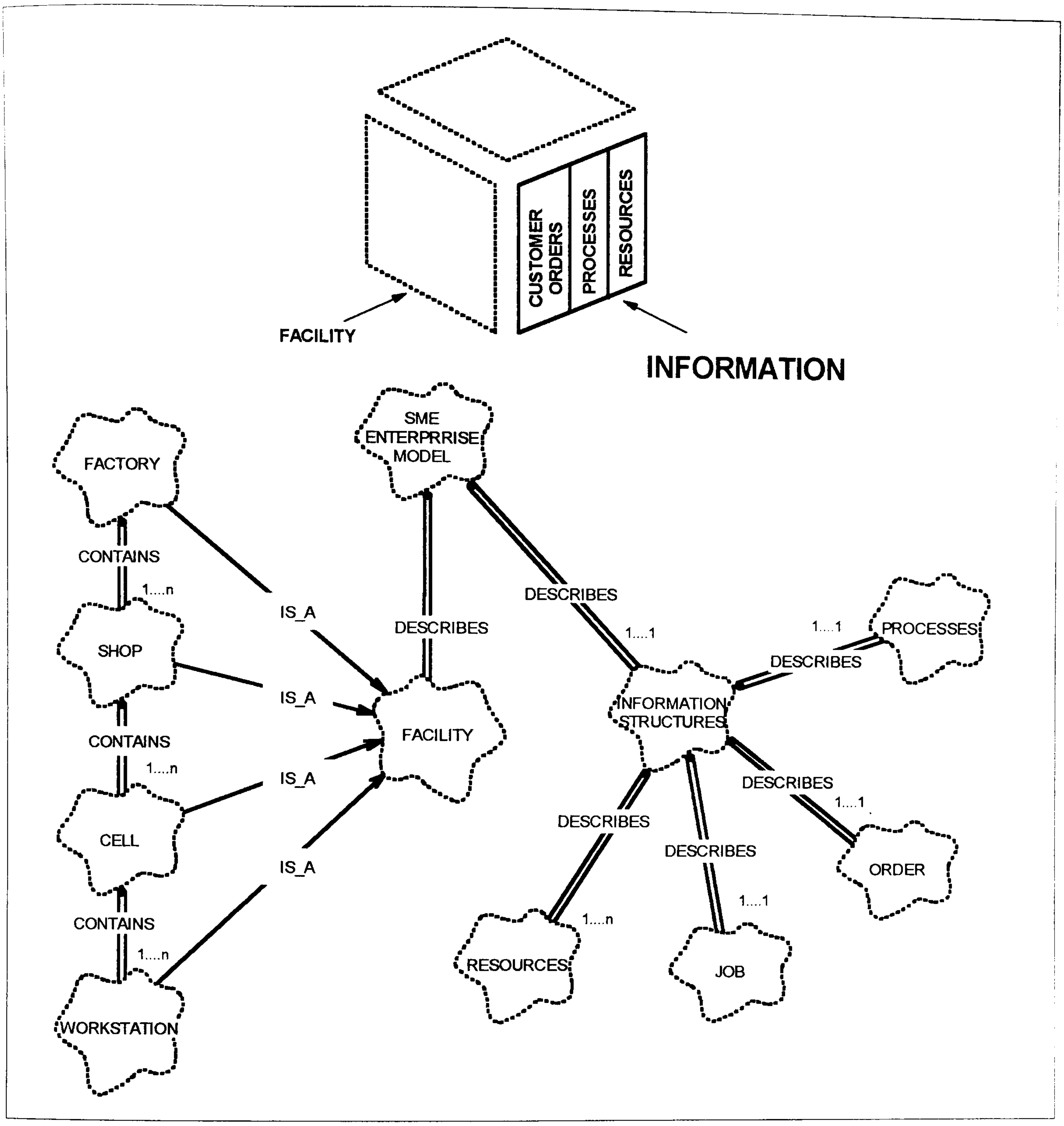


Figure 9.5: Modelling the information field of data capture.

The Booch class diagram has been applied to model the information structure as a set of information classes, where each class may be associated with information attributes, demonstrated in figure 9.6. The parent information class allows the definition of information attributes, as it is modelled as an "attribute carrier" such that an information class *has* information attributes. The fundamental resource, process, order and job classes are derived from this parent information class, with the individual child classes inheriting the capability of the parent class, thus allowing information attributes to be specified.

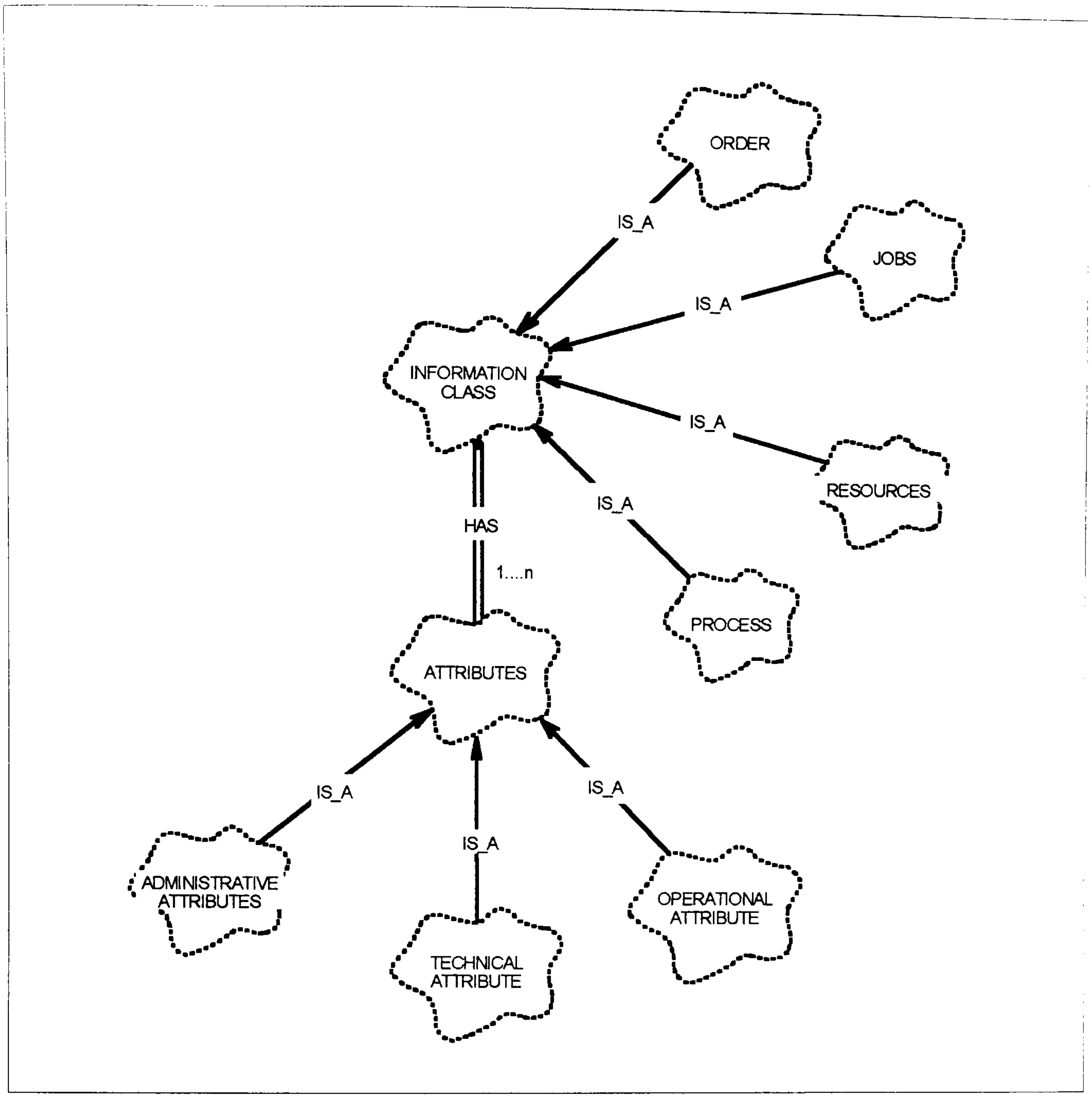


Figure 9.6: Modelling of the fundamental information classes.

As shown in figure 9.6, the customer orders, jobs, resource and process classes are modelled as information classes using the semantic relation *is_a*, facilitating the specification of the information attributes. This fundamental set of information classes may be extended by deriving other classes from the parent information class. The information attributes can be identified during the modelling process and associated to the appropriate class.

The attributes classes are further classified as (i) administrative, (ii) operational or (iii) technical attributes. This classification of attributes into the three groups is in accordance with the definitions given by Molina (1995):

(i) Administrative data is related to the suppliers of the resources and it is the information required to acquire the resource.

(ii) Technical data is the data concerned with the type, geometry, composition and properties of the production resources.

(iii) Operational data is associated with individual production resources regarding temporal conditions of the production resources such as planning data, usage and real time management.

In addition to this classification, an individual attribute may be of the simple or compound type, illustrated in figure 9.7. A simple attribute is the basic information element which the user may wish to specify. For example, the customer record class is likely to have a customer address as one of its compound attributes. Hence, the customer record *has* an address. The address attribute *is_a* compound type, which *has* and aggregation of simple attribute types which may be a house number, a street name or a city name.

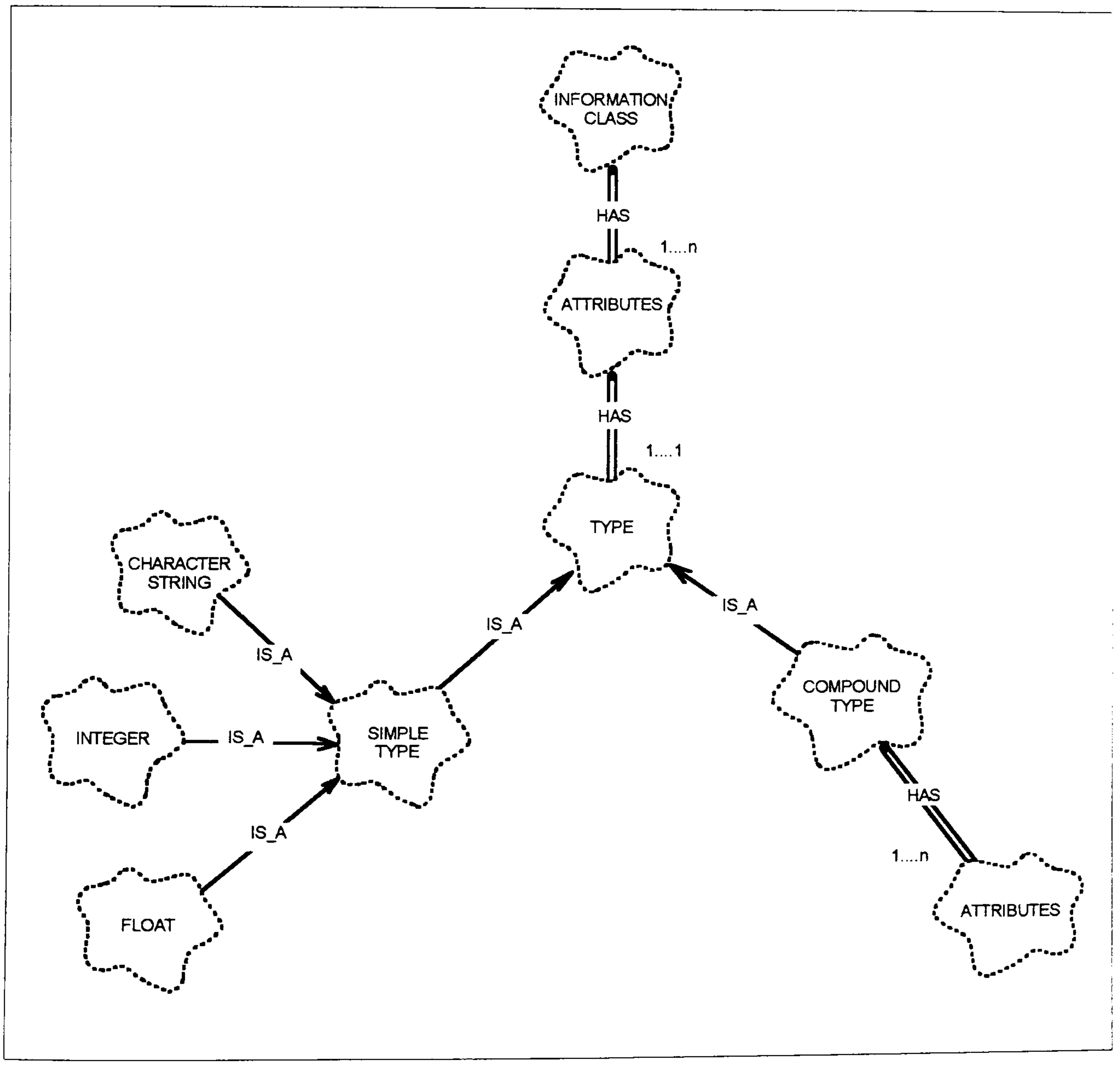


Figure 9.7: The classification of attributes of an information class.

9.4.2.1 Modelling the Resource and Process Taxonomies

It has already been discussed how the second field of data may be modelled independently of any specific enterprise. The data capture process can also be considerably enhanced with the use of generic process and resource taxonomies. In general, a taxonomy structure is often used as a common classification mechanism to organise knowledge within a particular domain of study. Taxonomies have been used as a means to establish common glossaries for the successful communication of concepts and ideas amongst multi-disciplinary groups involved in the design of CIM systems (Camarinha-Matos et al., 1995, Perakath et al., 1995). This gives a major advantage as it allows the generic structure of process and resource classes to be developed independently, as illustrated in figures 9.8 and 9.9.

The example illustrated in figure 9.8 shows a taxonomy or classification of processes which is derived from a generic process type at the top of the hierarchical tree to a specific type at the bottom of the decomposition. A classification diagram or taxonomy is created using the relation *is_a* which links a general kind of object with a specialisation of the kind. This has been applied for the creation of a process taxonomy, where processes are defined in a top down fashion, from a general level description to a detailed process description using the semantic relation *is_a*. Hence, a CNC machining process *is_a* material removal process which in turn, *is_a* manufacturing process.

The resource taxonomy can be also defined using the same generalisation-specialisation mechanism, this is illustrated in figure 9.9. Again, the semantic relation *is_a* can be used to model cutting tools or cutting coolant as expendable resources, which *is_a* operational resource, which in turn, *is_a* manufacturing resource.

The creation of taxonomies allows the different types of manufacturing resources and processes to be organised consistently in hierarchies. The taxonomy can be continually enhanced by the addition of new classes of resources or processes, or the creation of greater levels of abstraction. Maintaining the independence between the taxonomies and facility description promotes the reusability of the generic process and resource structures.

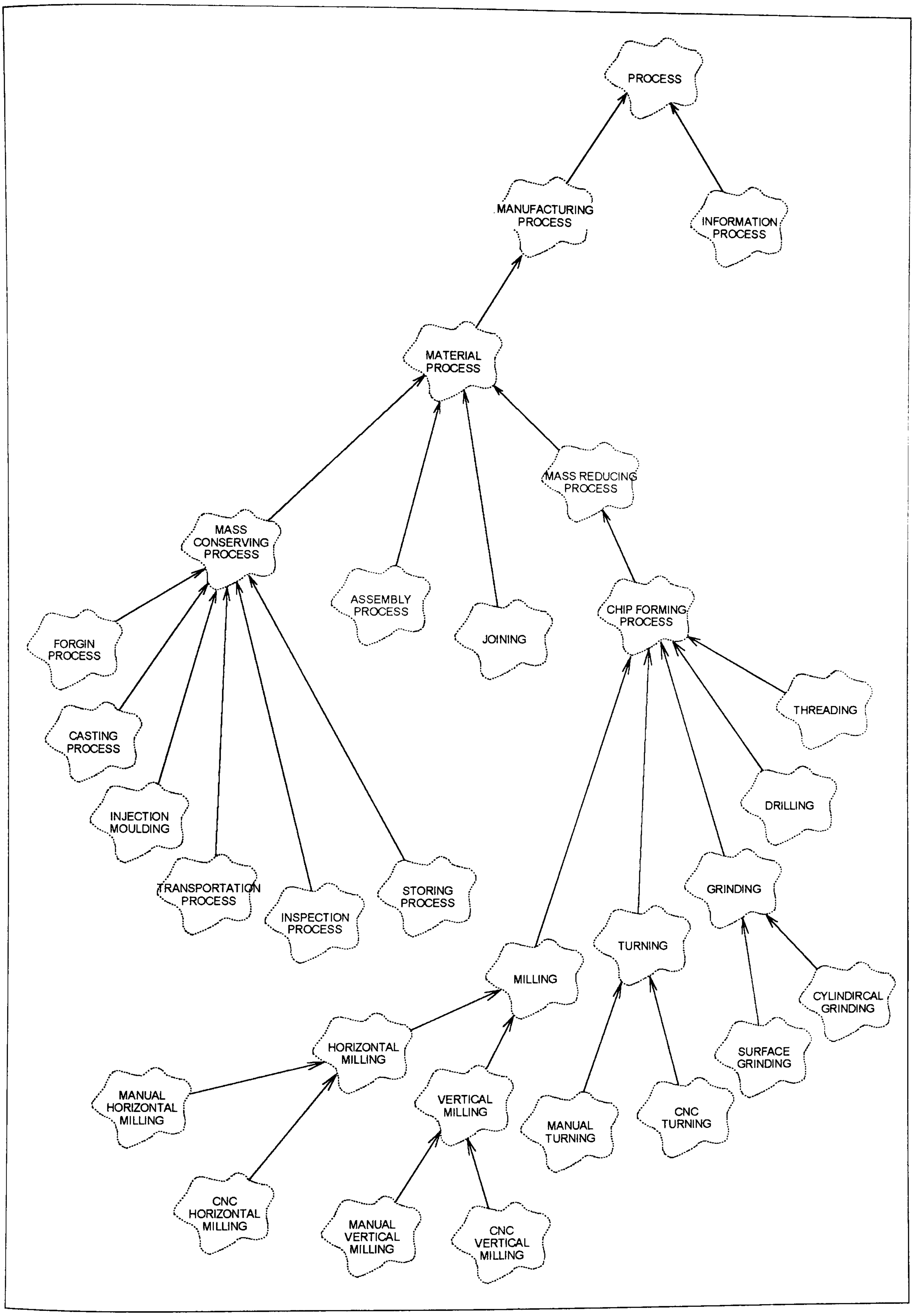


Figure 9.8: Modelling the process taxonomy (Adapted from Molina, 1995).

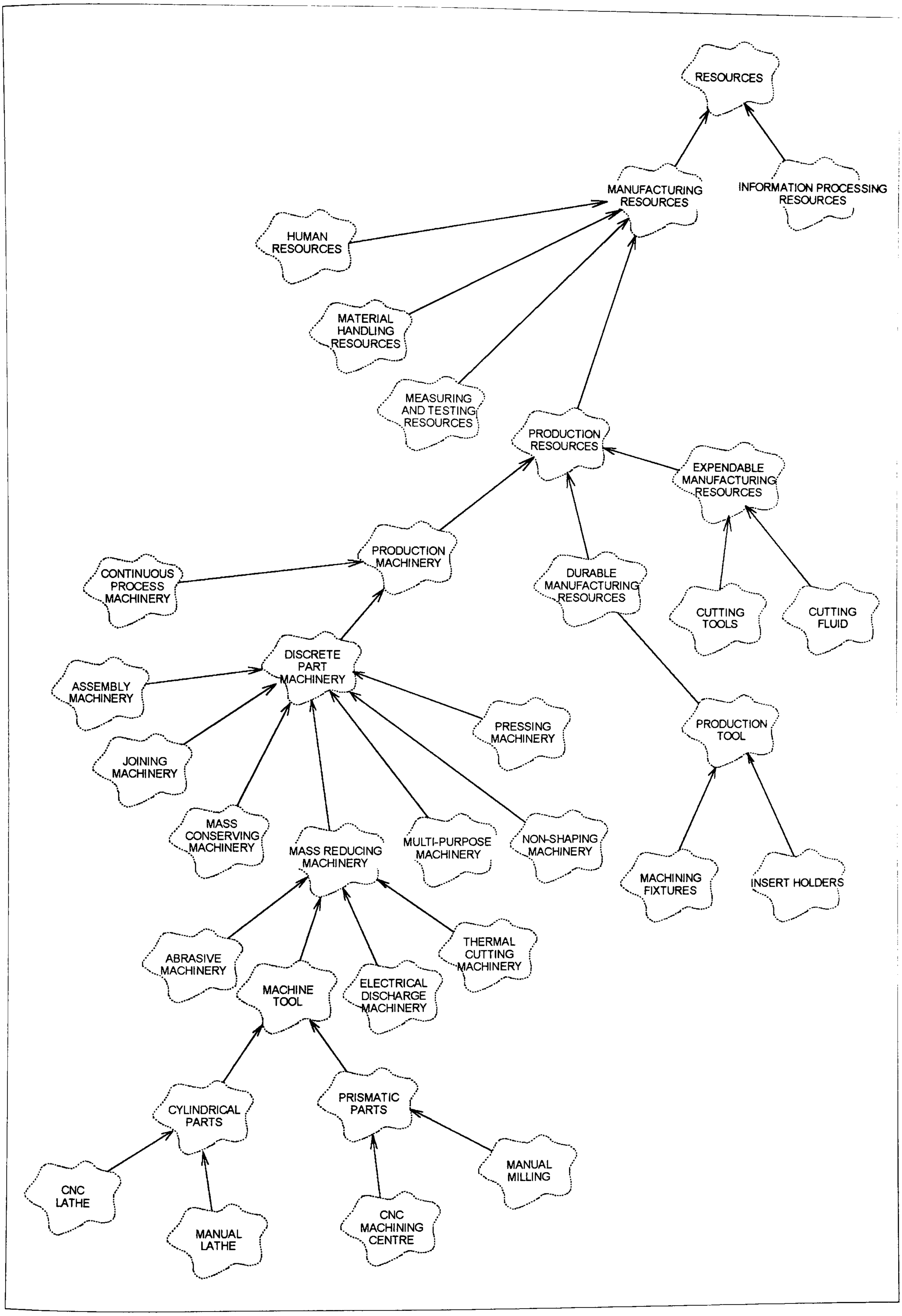


Figure 9.9: Modelling the resource taxonomy (Adapted from Molina, 1995).

9.4.3 The SME Manufacturing Model

The manufacturing model provides a representation of the SME's manufacturing facility, it's process capability and resources. The SME manufacturing model is shown in figure 9.10. The structure of the manufacturing model proposed for the SME is related to the model proposed by Molina (1995), which is based on a generic four level characterisation of the factory facility.

The information requirements of the employees throughout the enterprise are largely related to the operational issues of shop floor control, which involves the management of the facility resources and processes. The basic information structure provided by the Molina model has been extended to allow the modelling of information attributes such as those relating to the level and location of material or the cost of expendable inventory. The information structures for non-expendable operational inventory, such as fixtures and inspection gauges can also be specified in the instance of the SME manufacturing model.

It should be pointed out that the Molina manufacturing model allows the definition of resources, processes and strategies. The capability of modelling manufacturing strategies in the Molina manufacturing model was intended to provide supporting information which related to highly automated manufacturing facilities. However, it should be noted that the capability to model manufacturing strategies has not been incorporated, as it is the author's belief that its inclusion will not provide appropriate support in the manufacturing environment of an SME.

An instance of the SME manufacturing model is created by relating the first and second field of data capture during the enterprise modelling process, illustrated in figure 9.10. The purpose of this is to produce an instance of the facility description using the resource and process taxonomy sets. This allows the elements defined in the resource and process taxonomies to be selected and associated to an individual facility level, in accordance to the enterprise being modelled. The relationship is established such that the general facility class *has* resources and processes, illustrated in figure 9.10.

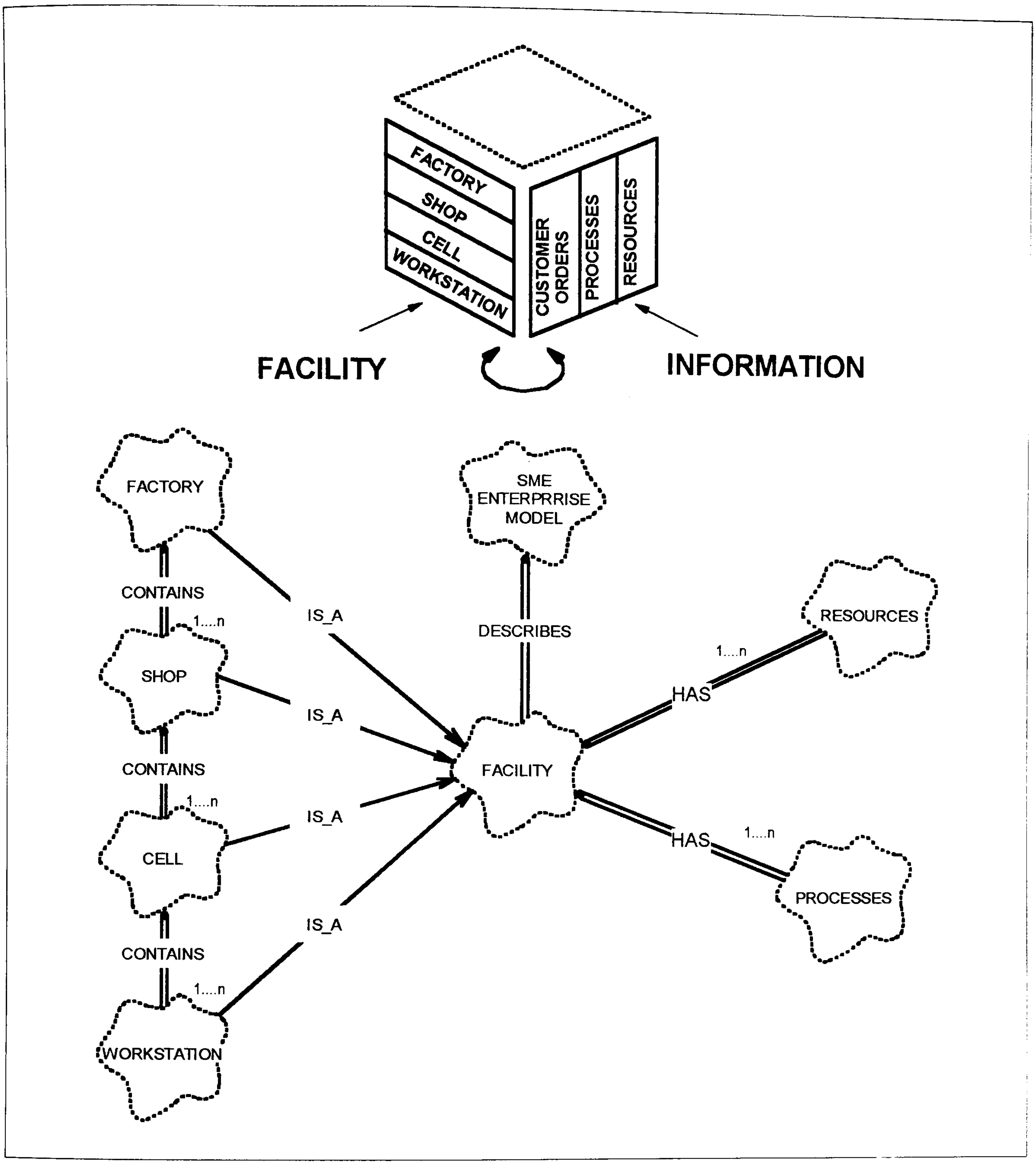


Figure 9.10: Establishing the relationship between the facility and information fields of data capture to create the manufacturing model.

The ability to model the resources and processes in terms of the facility level is important; it allows the capability of the facility to be described to varying degrees of abstraction, illustrated in figure 9.11. In the particular example shown, it may be that at the factory level, an abstract description of the process capability is desired. Therefore, an association can be made between the facility and the information field of data capture such that the factory facility *has* metal removal processes. If a more detailed description of the facility is desired at cell level, an association may be created so that a cell facility *has* CNC milling processes. This step is necessary in order to achieve a comprehensive understanding of the facility prior to specifying the information requirements. Modelling the process and resource classes in turn, enables the information classes to be identified, these will ultimately provide the sources of information about the manufacturing facility when the HIN is realised. The ability to create these associations is made possible by the CASE tool, which is described in chapter 13.

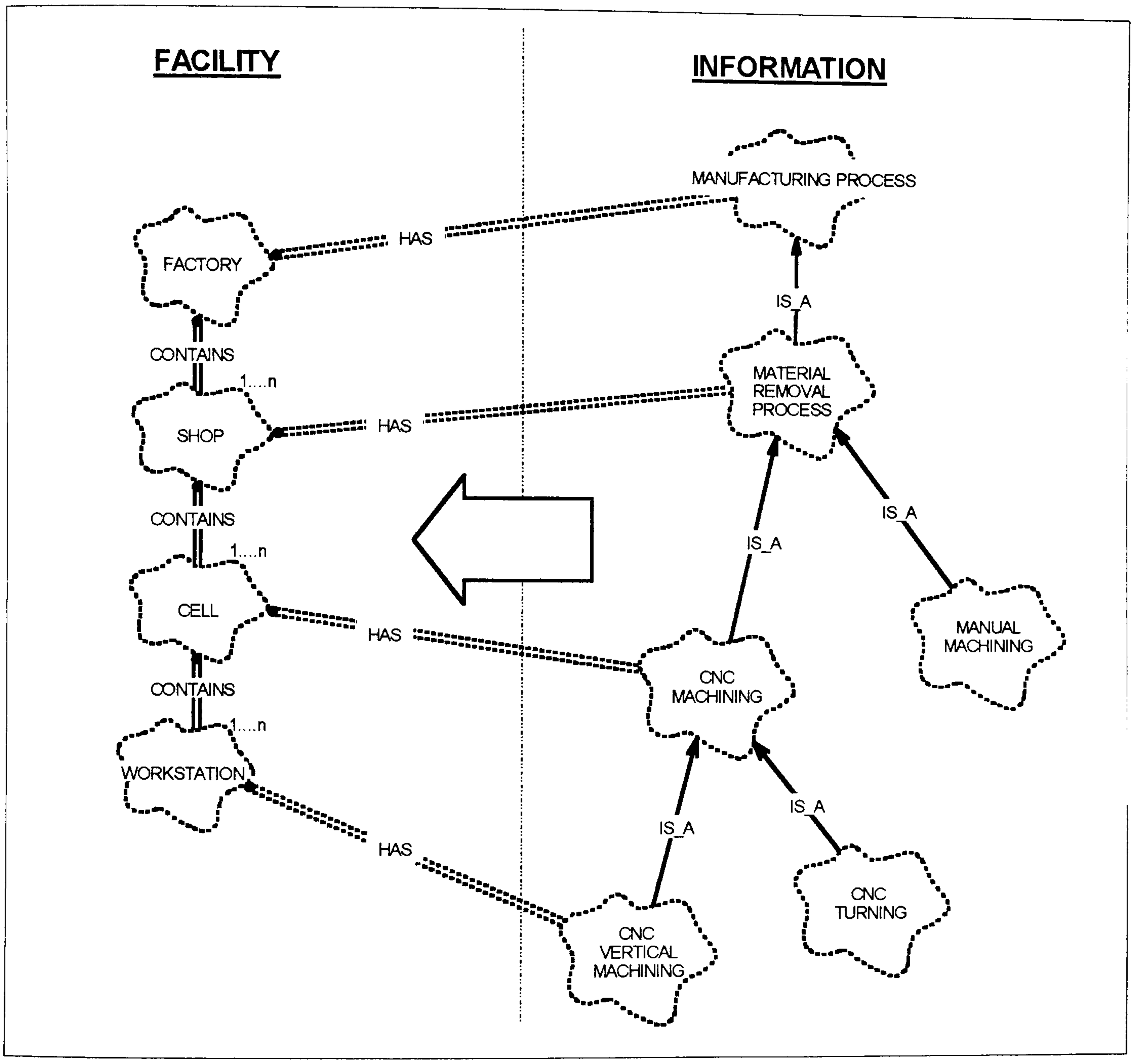


Figure 9.11: Associating the taxonomy structures defined in the information field of data capture to describe the facility with varying degrees of abstraction.

9.4.4 The Order Model

The order model contains the generic information classes which relate to the orders and jobs that the factory processes. Figure 9.12 illustrates the Booch class structure of the order model.

The order class is further classified into the historical and current order information classes using the semantic relation *is_a*, which as a consequence, allows appropriate attributes to be associated to each. The jobs class is associated to the order class using the semantic relation *has*, such that a particular customer order may contain one or many jobs. Hence, as shown in the figure, the order class *has* jobs. The jobs class is also classified, using the semantic relation *is_a*, into historical and current jobs.

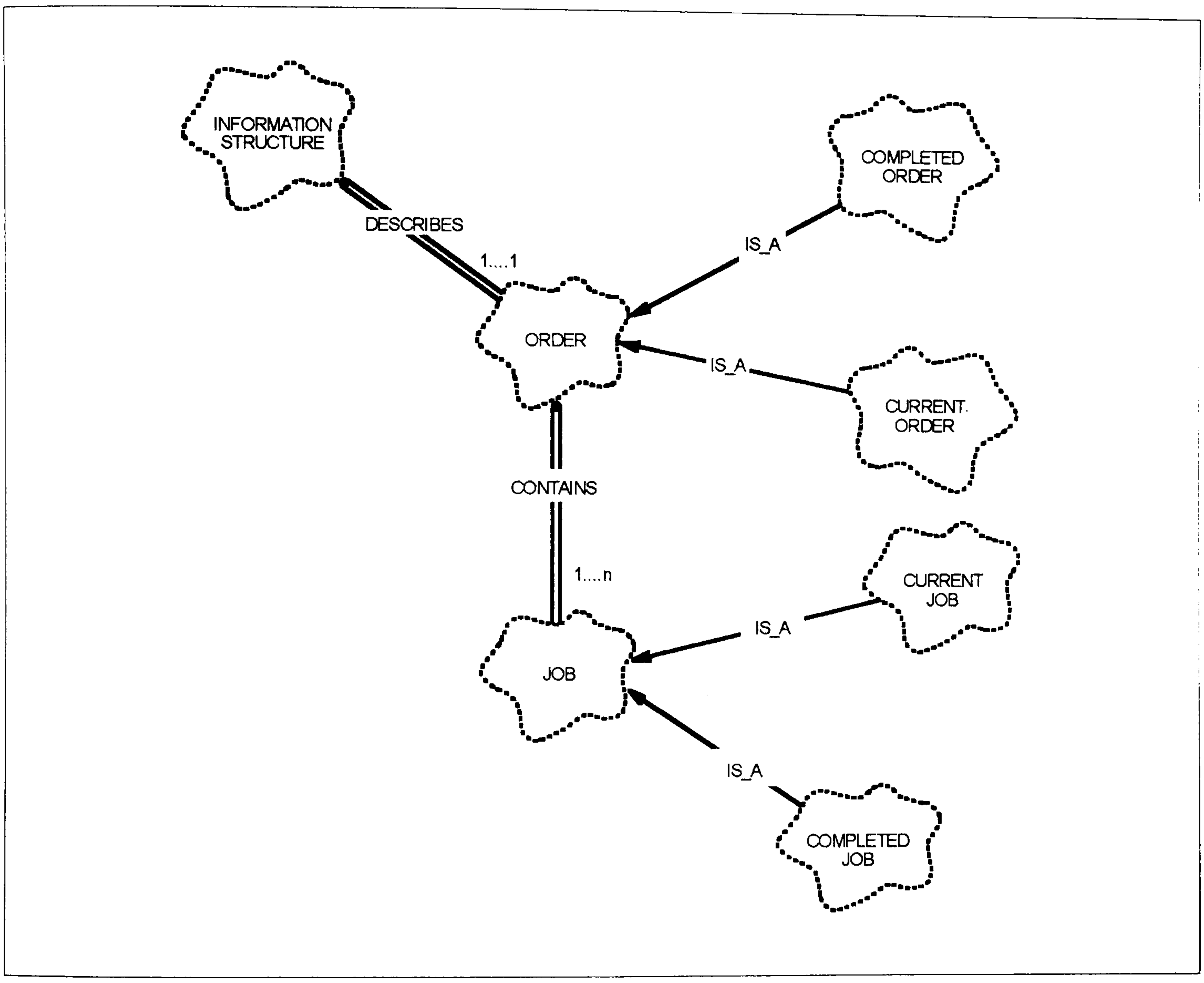


Figure 9.12: Describing the order model.

The pressures, imposed by rushed orders, on production planning require jobs to be introduced with the minimal of planning detail and must allow for information to be built up as manufacturing progresses. Very often, contingency plans brought about to circumvent machine problems or resource shortages need to be added to the information record for a particular job. Attributes which capture these alternative manufacturing options, together with attributes which record the situation type should be captured to reduce the planning time for repeat orders. Therefore, the order and job classes have attributes which are specified during the modelling process. Examples of the attributes are details of the customer, order due dates and process routes. This information caters to different users throughout the factory; the production planning node holon will require the status of the order in terms of, for example, the expected completion date or the location of the job on the shop floor. The machining node holon requires the due date established for the order which dictates in part, the sequencing of work at the machine.

The classification into historical and current order and jobs reflects the other role for the order model in supporting the production planning for rushed, repeat or variant work; instances of alternative manufacturing routes may be recalled and modified to save the development of a new route. Hence, it is necessary to identify the attributes specific to the historical or current type. An example of such an attribute may be the operation type, which is necessary to specify the procedures for producing a particular job.

9.4.5 Realising the Organisation and Behaviour Field of Data Capture

The third field of data, which is the pivotal issue in this research, involves the holonic dimensions of the enterprise, this is illustrated in figure 9.13. The third field of data capture proposed in this thesis is based on the fundamental holonic concepts; it offers an alternative approach to information specification, based on capturing the human interactions as opposed to contemporary methods. The holonic aspects are classed accordingly into autonomy, cooperation and control. In order to model the holonic aspects of the enterprise, the concept of the node holon is used to model the functional entities which perform the processes and activities in the enterprise. The details of the information specification model are discussed in the next chapter.

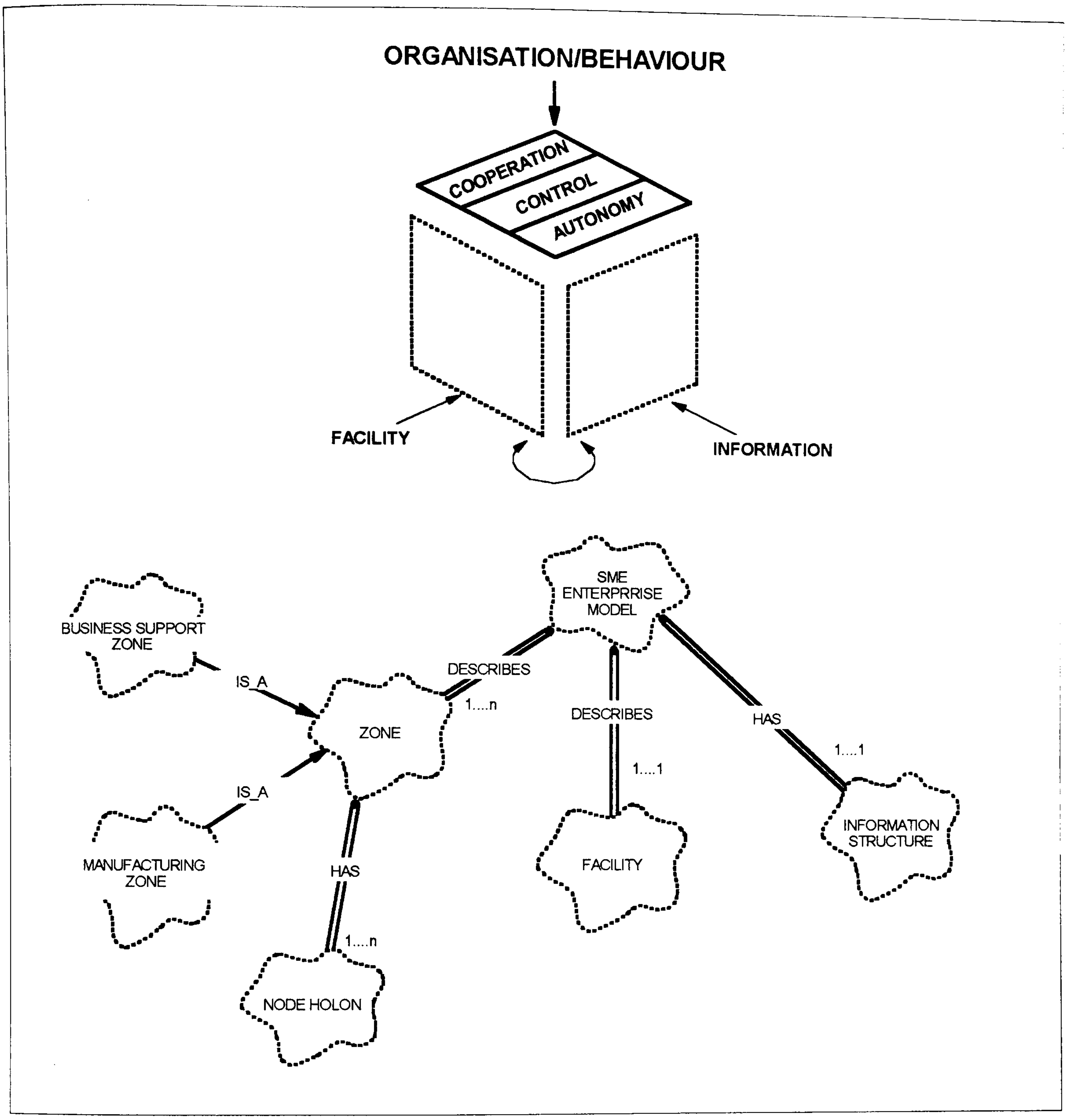


Figure 9.13: The organisation and behaviour field of data capture based on holonic ideas and fractal factory concepts.

Chapter 10

The Reference SME Enterprise Model: Modelling the Node Holon

10.1 Introduction

This chapter introduces the novel concepts which constitute the third field of data capture for the reference SME enterprise model. The use of the zone representation for the company is first explained, indicating where the fractal and holonic systems concepts have been of considerable influence to the work. The relationship between the zone and the node holon is subsequently explained. This is followed by a detailed description of the node holon and the approach to modelling its characteristics.

10.2 The Zone Concept

An assertion was made in section 7.4.1 that SME organisations are better characterised by interacting zones of activity. This representation has been illustrated in figure 7.3, which depicts the operation of a small company, where three zones are indicated viz. an executive zone, a business support zone and a manufacturing zone. As a particular example, the executive zone can include activities such as the planning and supervision of daily operations and liaison with customers and suppliers. The business support zone may include the processing of orders in two parallel avenues. The first avenue relates to the financial aspects in terms of costing, invoicing, etc. The second avenue involves production planning, routing or scheduling and the purchasing of material, etc. The manufacturing zone involves the implementation of production plans, monitoring the progress and ensuring that the production orders are completed on time. The representation of the business as interacting zones is not imposed on the company as a pre-ordained configuration, rather a particular representation is derived from a study of the business and its preferred view of the operation. This provides the starting point for the subsequent derivation of more appropriate information support requirements.

In seeking to enhance the operating characteristics of an enterprise, there remains a challenge of unifying the goals and activities of individual processes, whilst retaining sufficient flexibility in the holistic system formed. A formal link between Warnecke's top down fractal approach (Warnecke, 1993) and the complementary bottoms-up holonics (Suda, 1990) concept would be desirable, as this would establish a method to specify local goals for individual node holons, which are derived from the overall goals of the company. There is however, no such relationship at present. In this thesis, a simple association is assumed between top-down modelling using zones and the complementary bottoms-up modelling using holonics, where an individual zone acts as the starting point for the modelling of the node holons.

The choice of using the zone representation has been influenced strongly by Warnecke's top-down concept of the fractal factory, which contrasts with the highly structured functional decomposition techniques. The fractal paradigm attempts to derive an holistic approach from all the tendencies, considerations and variety of solutions which have been identified throughout the industry (Warnecke, 1993). The resulting concept is the fractal as the central structuring element of a factory and its associated characteristic of self-similarity.

The fractal factory concept offers highly refined and abstract views for the design of the organisational structure for manufacturing companies, which avoids precluding any range of design solution at the outset. Warnecke's work was targeted at maximising the business performance through top-down fractal structures. This is based on a high emphasis for the incorporation of personal human goals within a framework of company objectives and the maximum exploitation of the human potential in a company (Warnecke, 1993). Presently, the fractal concept also offers no formal representation or methodology for top-down implementation of fractals in conjunction with its concept of self-similarity.

The absence of a formal representation in holonic concepts for top-down modelling is not a criticism of Koestler's ideas; the views which are expressed in his book (Koestler, 1967) have, until only recently, been considered for the field of manufacturing. Koestler's original work was targeted at the study of evolution and experimental psychology, his concepts were centred around the holon which he used to depict the complex phenomena of human behaviour. In his studies he saw the potential to map his ideas of the holarchy to a wider range of structures which included human organisations. In this research the specification of the information requirements has to be carried out with a view of the requirements of the individual operators and the nature of operation in a human dominated environment. Koestler's ideas of the holon has provided powerful concepts for developing a bottoms-up modelling methodology, which can be used to model interactions within and between zones. The author's further development and application of Warnecke and Koestler's ideas will now be evidenced in the work reported in the rest of this chapter.

10.3 The Characteristics of the Node Holon

In order to provide a bottoms-up modelling approach to capture the human interactions and facilitate information specification, the author has introduced and developed the concept of the node holon as an abstract representation of the unique combination of the human holon, manufacturing or information processing equipment and the enhanced IT interface. The characteristics of the node holon have been influenced by Koestler's fundamental definition of the holon and from Suda's application of the holon for highly automated manufacturing (Suda, 1990).

(i) A node holon is characterised by a process, illustrated in figure 10.1, which may be an information or manufacturing process. In correspondence to Suda's classification into hard and soft holons (Suda, 1990), those node holons which perform information processing tasks are categorised as soft node holons and those which perform manufacturing tasks are categorised as hard node holons. The process gives the node holon it's identity, e.g. a turning node holon, a milling node holon or production planning node holon, etc. In addition, the node holon is also characterised by the facility level to which it is associated, hence it may be described as a factory, shop, cell or workstation level node holon.

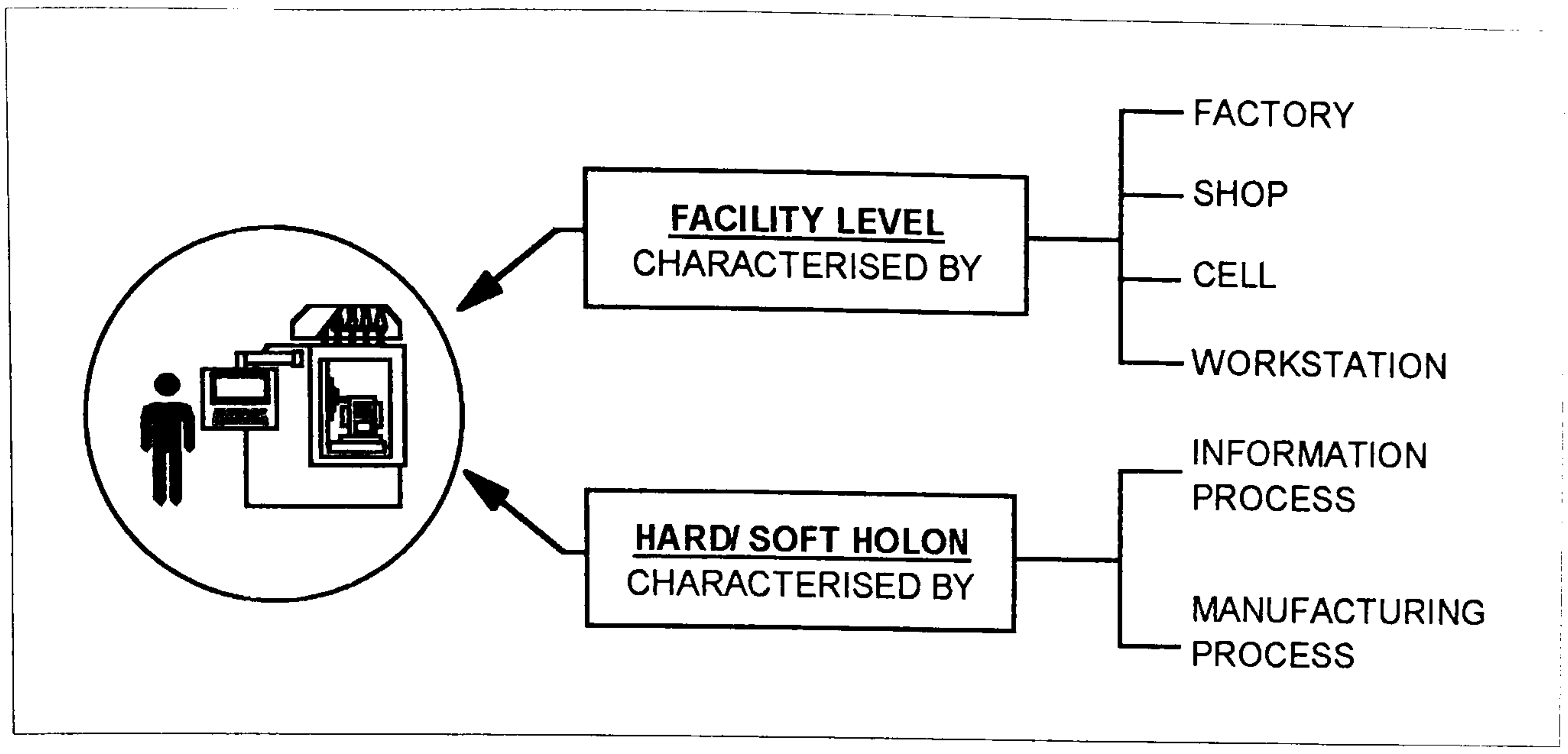


Figure 10.1: Describing the characteristics of a node holon in association to a facility terms of its process and level.

(ii) A node holon is a functional entity, it has the responsibility for the performance of a set of activities. Activities are modelled using an extended form of the IDEF0 formalism, shown in figure 10.2, characterising the inputs, outputs, controls and mechanisms (known as ICOMs). The formalism has been selected because it is easily understood and has been widely applied for activity modelling. The extended IDEF0 notation for activity modelling is introduced in this research, with the addition of the "control output" construct. This is necessary in order to model the information parameters which are altered during the performance of an activity. A similar approach is also used by CIMOSA (AMICEE, 1991) for analysis of enterprise activities (which has a further resource output ICOM).

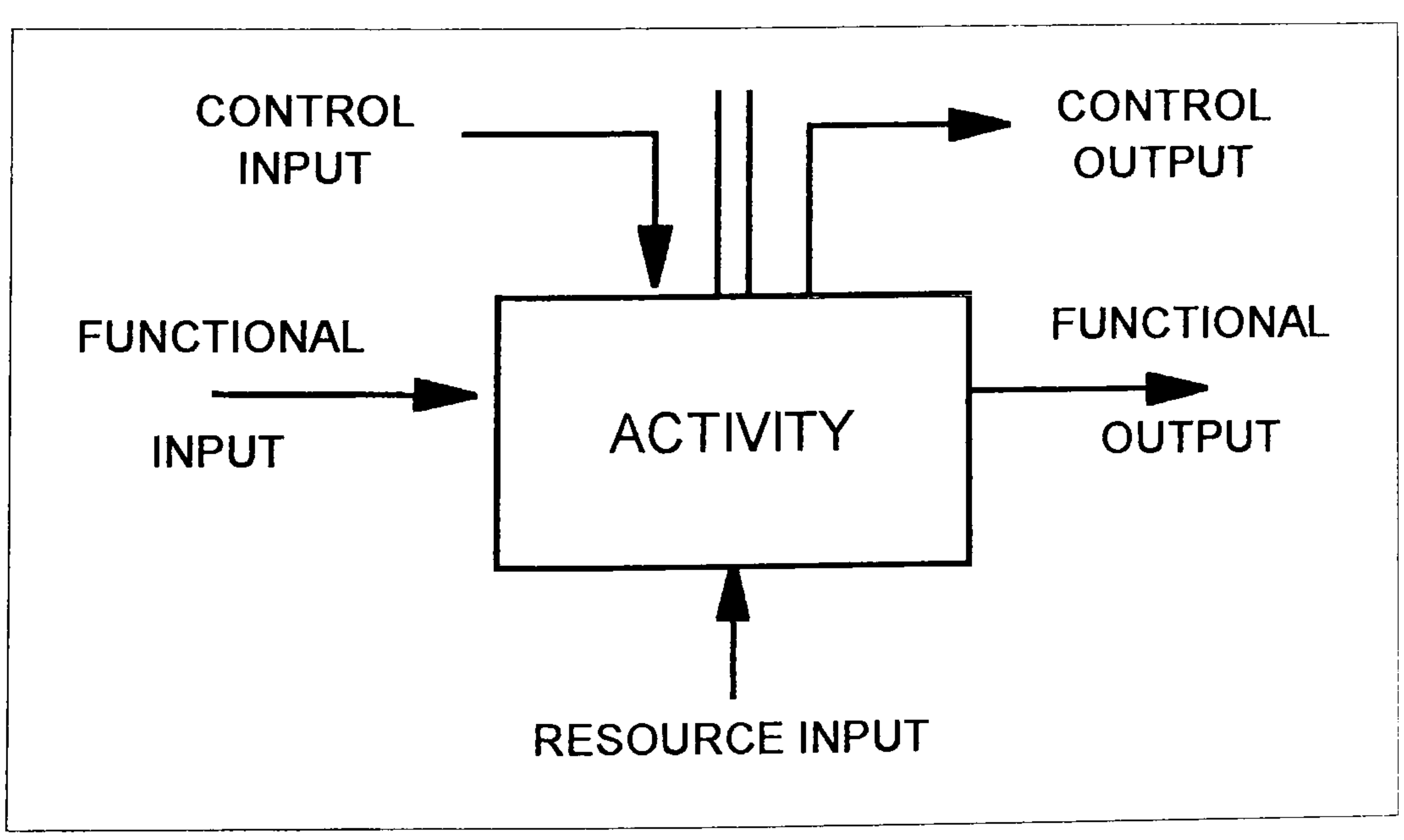


Figure 10.2: Elements of the extended IDEF0 notation for activity analysis

(iii) A node holon is modelled with autonomous, cooperative and control mechanisms, shown in figure 10.3. The autonomous mechanism captures the self assertive tendency of a node holon, hence, it has the autonomy to perform a defined set of activities. The cooperative dimension captures the integrative tendency; the primary tendency of the node holon is to cooperate, e.g. a turning node holon cooperates by accepting jobs from the production planning node holon and produces completed components.

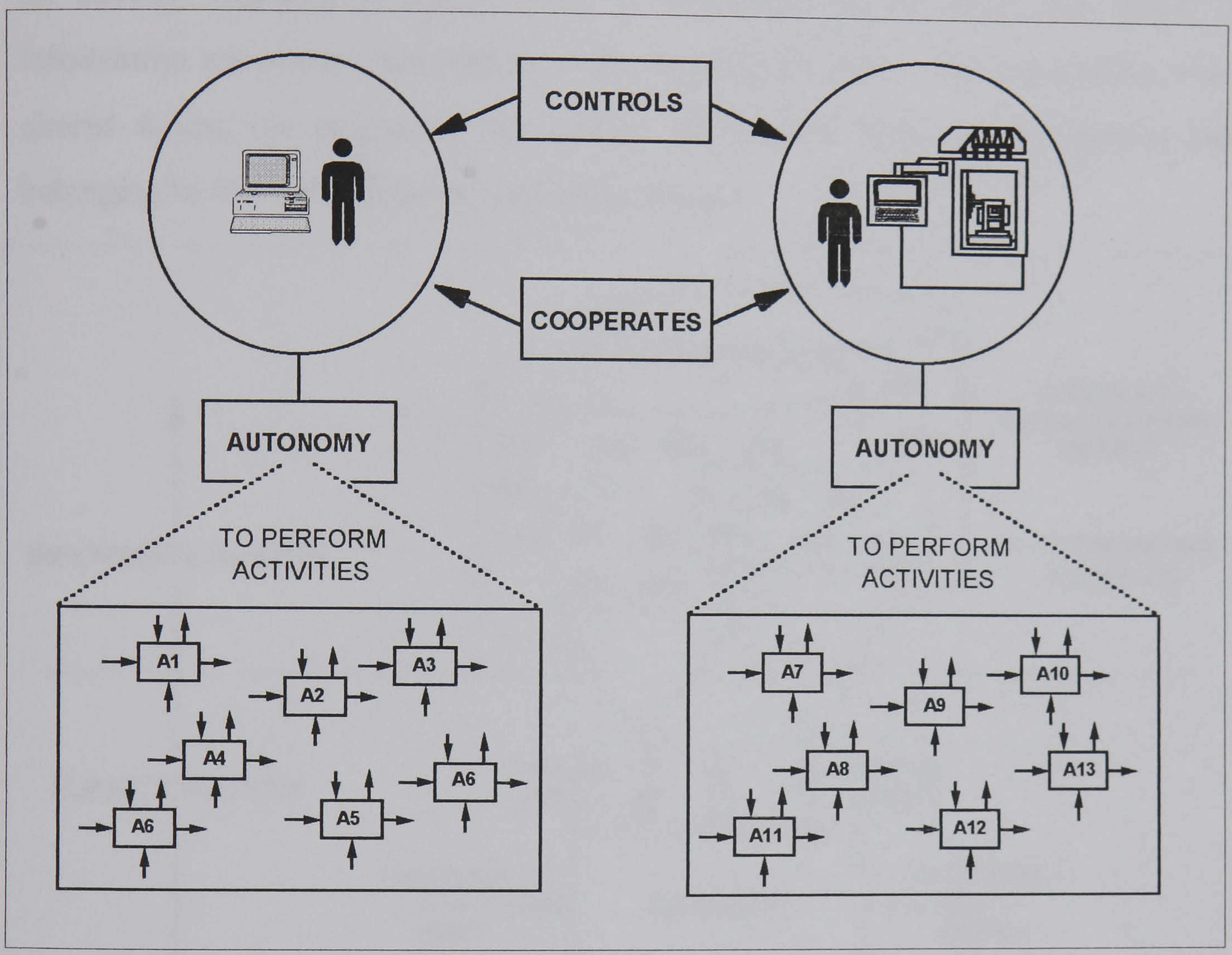


Figure 10.3: A depiction of the holonic aspects of node holons using autonomy, cooperation and control.

A third dimension of control is needed, where at a particular instance, a node holon may assert itself and control another holon. When one peer node holon controls another, the controlled node holon has a corresponding cooperative mechanism to meet the demand. When interactions occur between two node holons, activities are identified and analysed. The results of this activity analysis is the identification of data parameters which constitute the elements of the extended IDEF0 control input and output ICOMs. For example, a production planning node holon will invoke the cooperation of a machining node holon. Correspondingly, the machining node holon cooperates with the production planning node holon by producing the required components. The interaction between the two node holons thus identifies a due date for the order, which is a data parameter taken from the information models, as a control input ICOM for the machining activity.

(iv) The link between the information elements and the extended IDEF0 representation of the activity is established through the control input and output ICOMs. The performance of an activity, depicted in figure 10.4, is controlled by, or alters the values of the information parameters associated to the control ICOMs. The parameters which are altered during the course of the activity are derived from the information elements belonging to the manufacturing and order models.

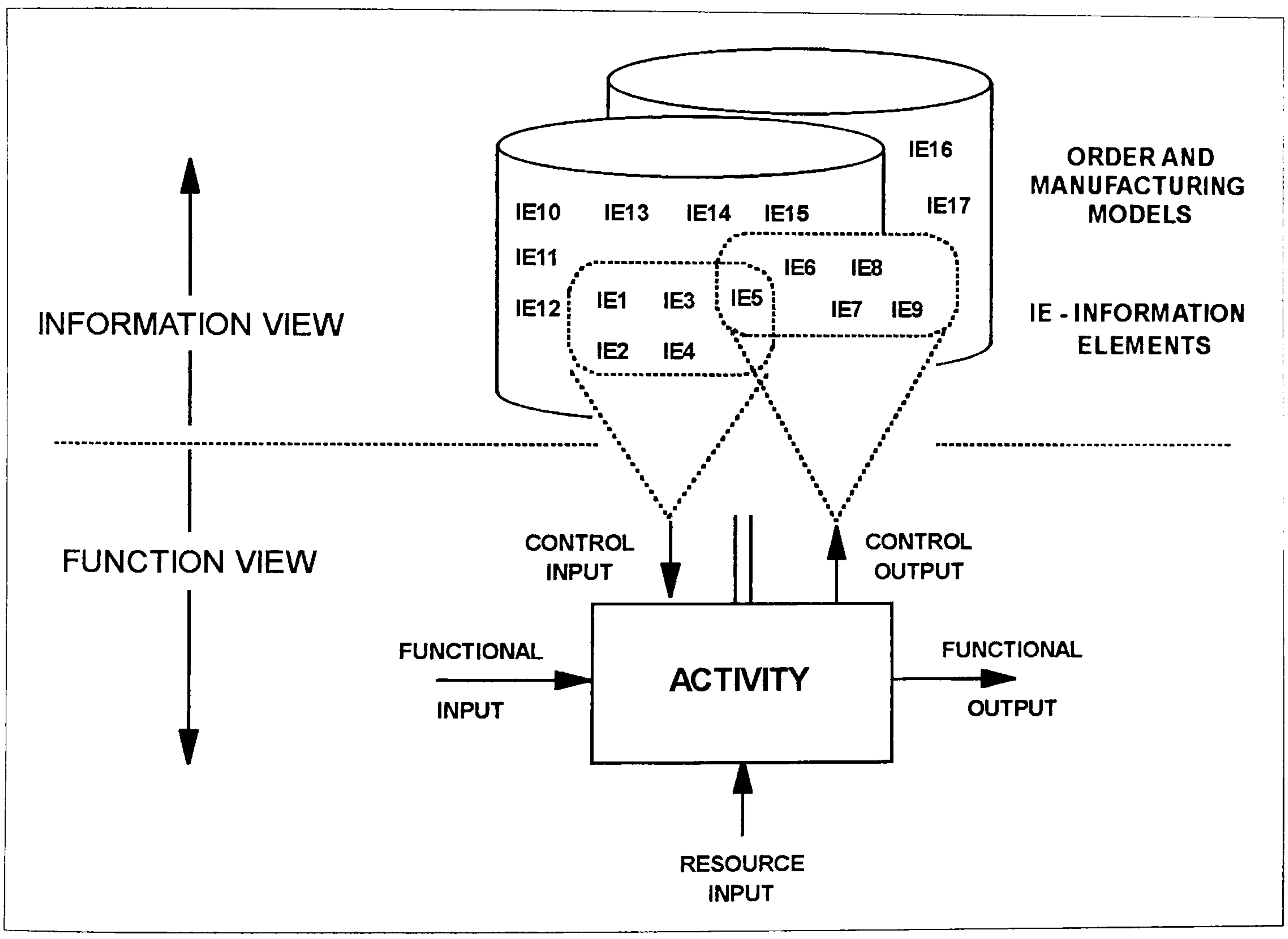


Figure 10.4: Establishing the control parameters during activity analysis using information elements from the information models.

(v) A negative contingency situation, illustrated in figure 10.5, occurs when a node holon is unable to fulfil the requirements exerted by the control parameter stipulated, i.e. "failure to meet due date". This contingency situation is associated with a causal object, i.e. no tools, etc. The node holon can resort to its autonomous mechanism, or its control mechanism to invoke other activities.

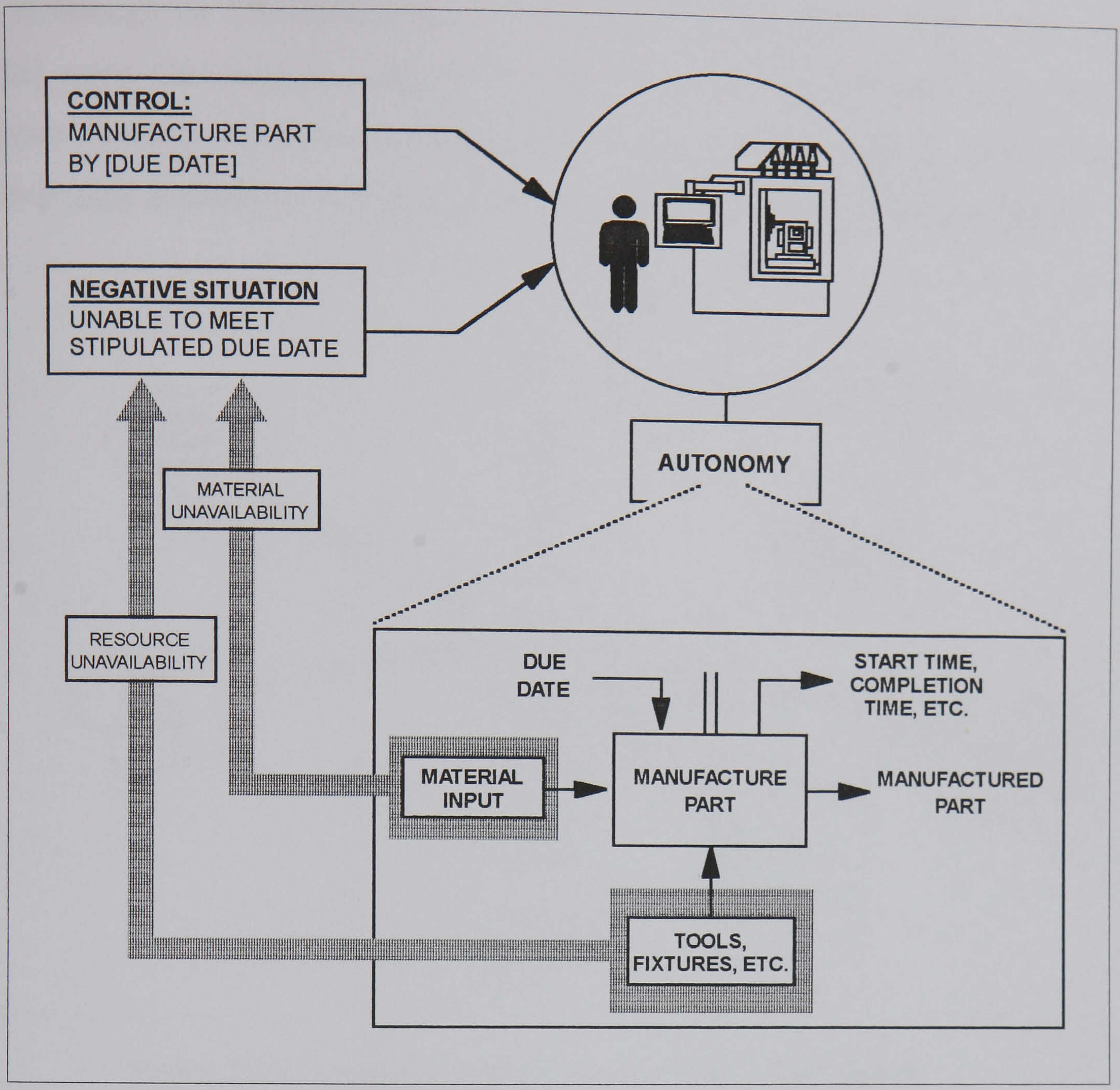


Figure 10.5: A depiction of negative situations or contingencies and their relation to the functional and resource inputs

(vi) By registering the cooperative and autonomous activities of holons during the modelling process, the "portrait" of the holon is built up. Modelling the activities enables the modelling of the information requirements to be specified that support the activities, i.e. specification of the parameters in the information environment.

10.4 The Realisation of the Node Holon using the Class Diagram of the Booch Methodology

A model of the node holon is realised using the Booch modelling formalism. This ensures consistency with the information and facility fields of data capture discussed in the previous chapter. The following sections will explain how the characteristics described previously for a node holon are interpreted and modelled. The starting point for realising a model of the node holon is through an individual zone, as illustrated in figure 10.6. The zones have been classified using the semantic relation *is_a*, into business or manufacturing zones. The association between top-down modelling using zones and the complementary bottoms-up modelling using holonics is established such that an individual zone *has* node holons.

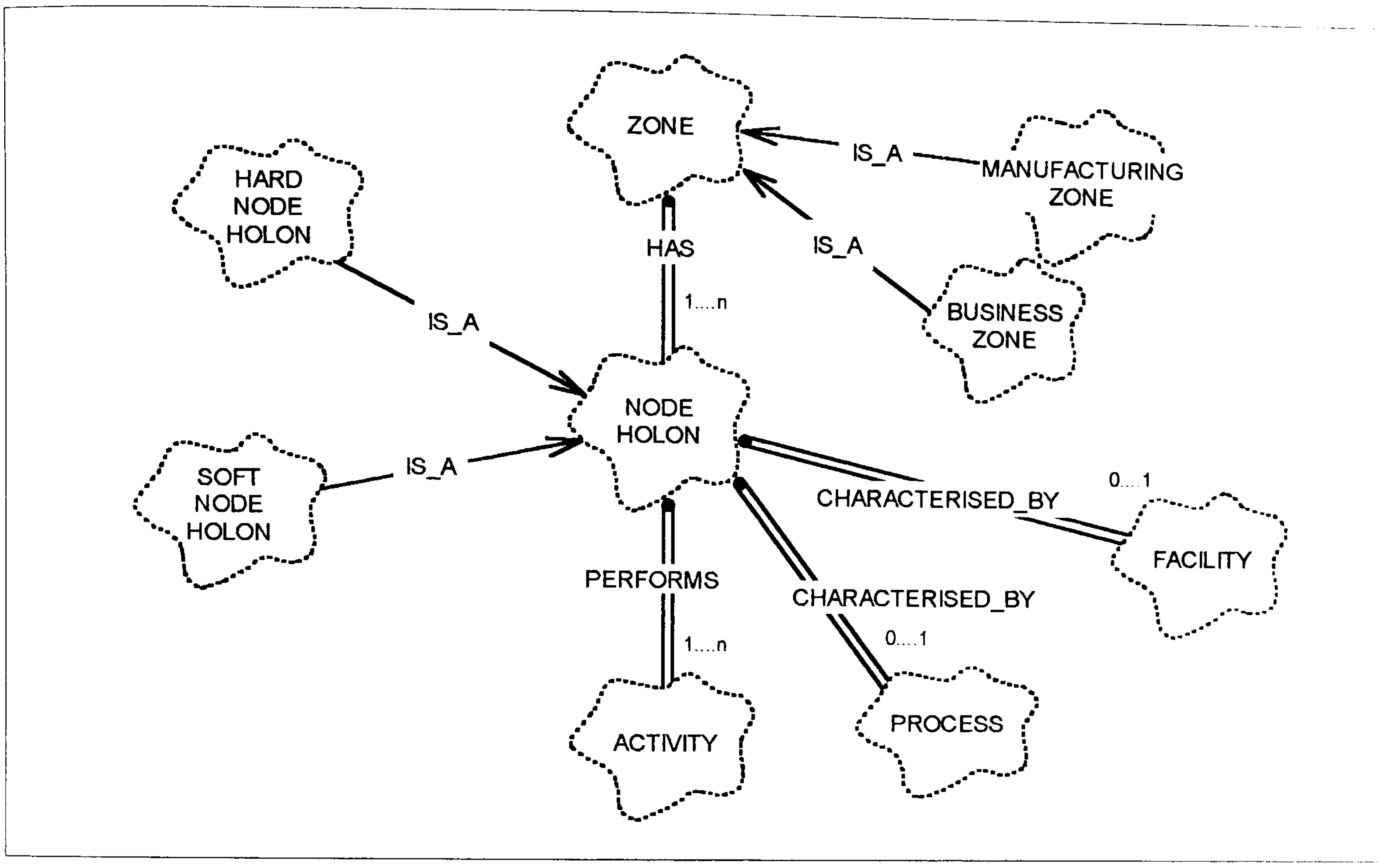


Figure 10.6: Modelling the characteristics of a node holon.

In order to identify the primary functionality of the node holon, the semantic relation *characterised_by* is used to associate the node holon with a process which is defined in the manufacturing model. Hence, a node holon with a vertical CNC machining centre would be *characterised_by* vertical CNC machining and *is_a* hard node holon which performs vertical CNC machining tasks. The principal functionality of the node holon is modelled using the relation *performs*, it therefore *performs* information processing or manufacturing activities. There are corresponding hard node holons and soft node holons, described such that a hard node holon and a soft node holon *is_a* node holon. In addition to performing its primary functionality, the node holon also *performs* a set of defined supporting activities. The activities are for instance, the setting up of a work piece or cutting tool, the purchase or acquisition of raw material or the preparation of an NC part program.

In addition to characterising the node holon in terms of its principal functionality, the author has decided that flexibility should also be given for the node holon to be *characterised_by* the facility level to which it is associated. An executive node holon may be characterised as a factory level node holon, or a machining node holon as a workstation level node holon. This provides an association between the organisation-behaviour and the information specification fields of data capture. Although the additional characterisation plays no active role in modelling its functionality, the ability to associate any node holon to a particular facility level will enhance its description.

The node holon is distinguished through the holonic mechanisms which define its capability for working in an autonomous manner, and its capability to interact with other node holons via control and cooperation. Therefore, the node holon *has* autonomy, control and cooperation mechanisms, as illustrated in figure 10.7. The node holon is also expected to have a degree of autonomy in performing the supporting activities, shown previously in figure 10.3. The assignment of these activities is carried out during the modelling of an individual node holon.

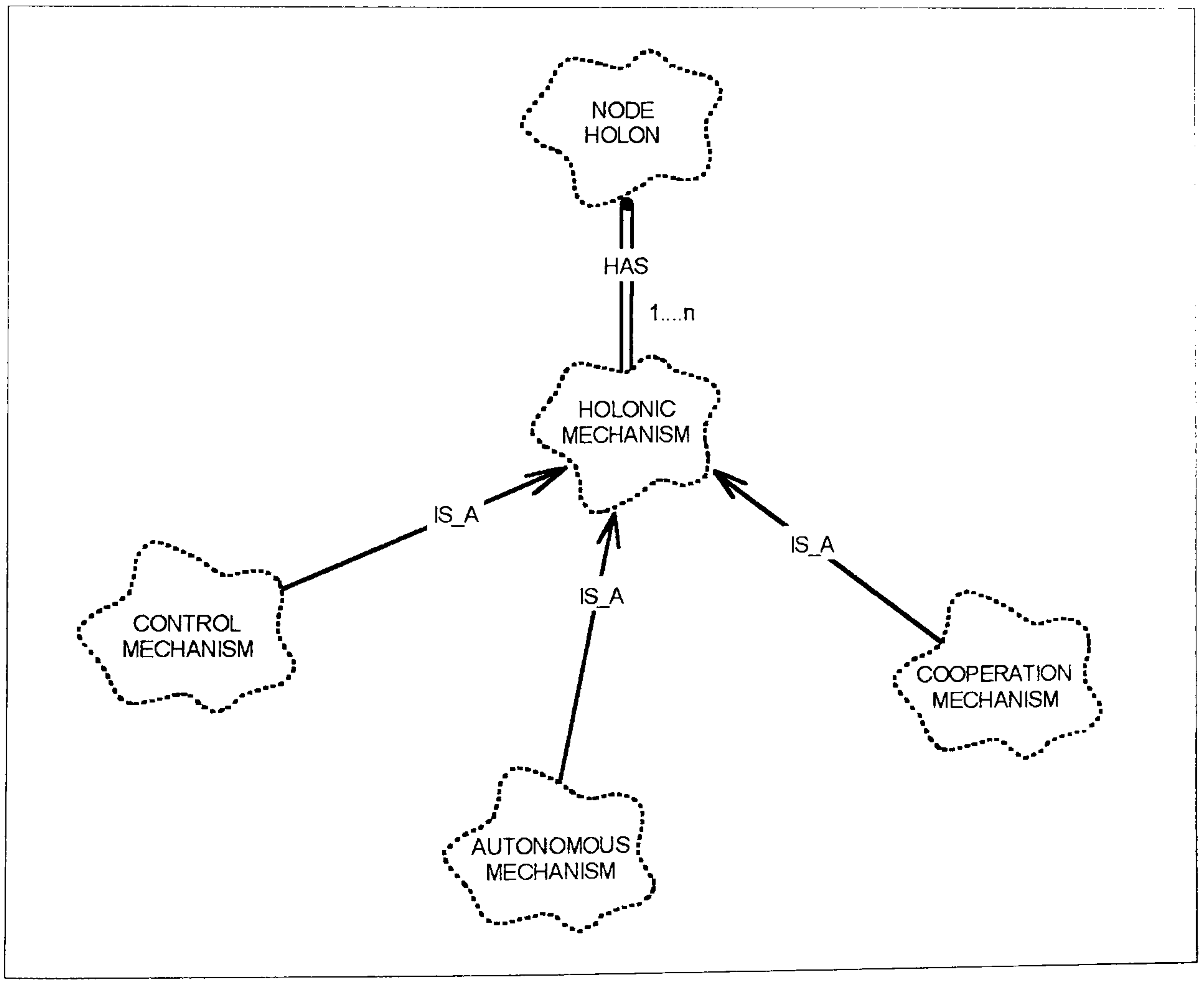


Figure 10.7: Modelling the holonic aspects using the fundamental autonomous, cooperation and control mechanisms.

10.5 Modelling the Functionality of the Node Holon

The functionality of a node holon is modelled in terms of the activities performed, using elements of the IDEF0 formalism, this is illustrated in figure 10.8. The IDEF0 formalism has been selected because it has been widely applied for activity modelling and is easily understood. The constructs of the IDEF0 formalism are the activity box, the functional input, control input, functional output and mechanism (ICOM). This formalism has been extended to include a control output component, which is similar to the formalism used by CIMOSA for modelling the enterprise activities. An activity therefore *has* functional ICOM constructs, where functional input and output *is_a* functional ICOM. The relationship between the resource which performs the activity is established using the relation *uses*, where an activity *uses* resources.

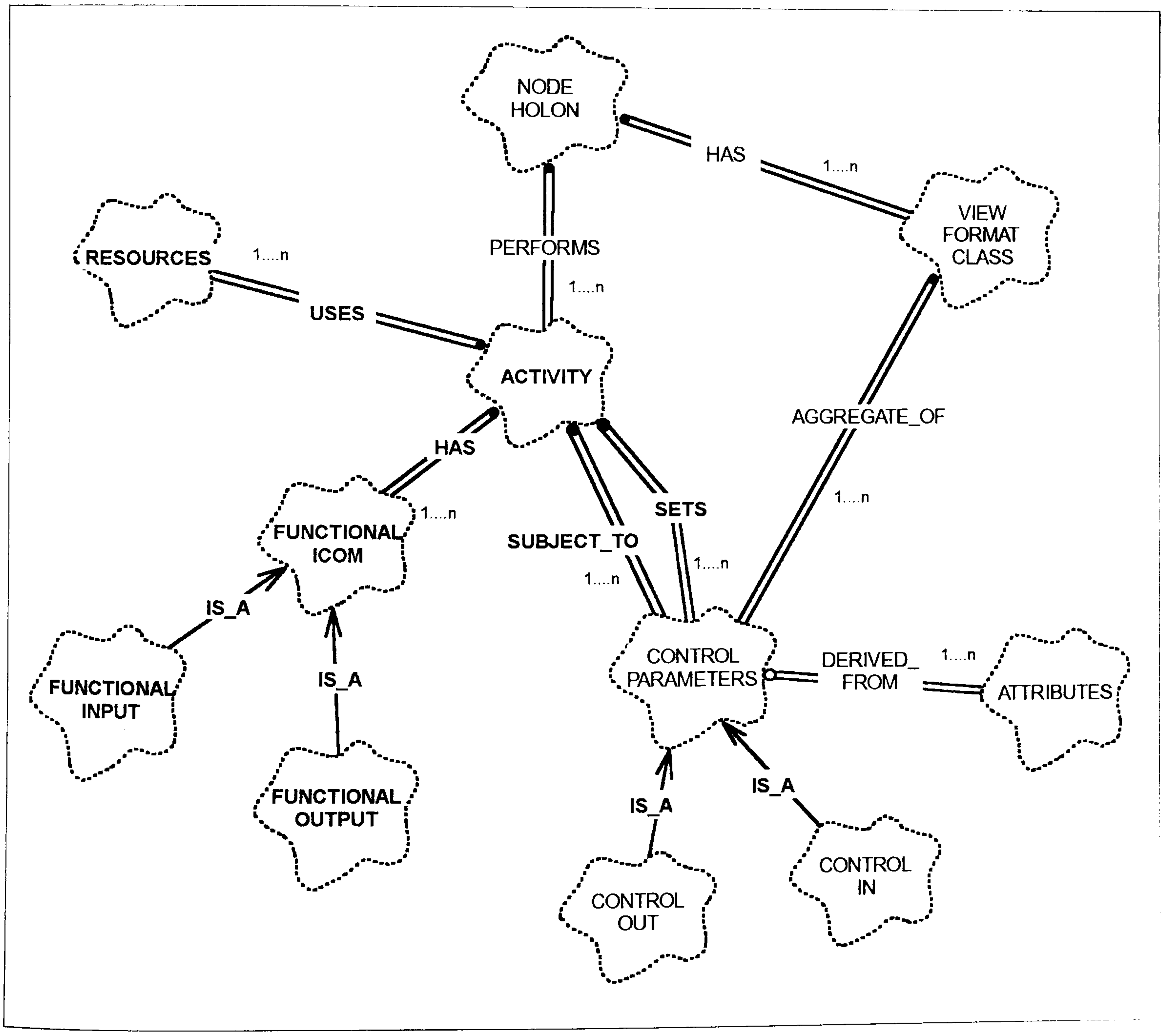


Figure 10.8: A meta-model of the extended IDEF0 formalism for activity analysis.

The relationship between the information specification model and the information structures, as depicted by the second and third field of data capture, is established by modelling the functionality of the node holon, depicted previously in figure 10.4. The decision to establish the relationship between the activity or process and information has been influenced by the ARIS approach, which establishes that the performance of an activity results in changes to the parameters in the "task environment" (Scheer, 1992).

The link between an activity and the information parameters is created through the control input and output ICOMs. Using the semantic relation *subject_to* and *sets*, the activities of the node holon are *subject* to control parameters and the performance of a process or activity *sets* the control parameters. The control input and control output parameters are *derived_from* the information attributes found in the information classes modelled in the second field of data capture. The remaining view format class, shown in figure 10.8, provides the means to describe the interface between the node holon and information structures, this is discussed in detail in section 10.8.

10.6 Modelling the Interactions Between Node Holons

The interactions in a casually occurring holarchy can be captured using the fundamental mechanisms of control and cooperation. A depiction of the interactions, shown previously in figure 10.3, has been modelled using Booch, this is illustrated in figure 10.9. The control mechanism may be regarded as polarised cooperation, which is used when node holons have to assert themselves over others. An example is where the planning node interacts with a machining node, exerting its control over the latter by setting a job due date. This establishes, by default, that the machining node has an obligation to cooperate with the mechanism of control by performing a machining activity. The ability to exercise control is not given exclusively to a hierarchically superior node holon; the machining node holon may well exert a degree of control over the planning node by enforcing a cooperative response such as a regeneration of the due date. The control mechanism may also be *invoked* over a peer node holon. If one node holon imposes control over another, it anticipates an obligatory reaction where the controlled node holon has a corresponding cooperative mechanism to meet the demand.

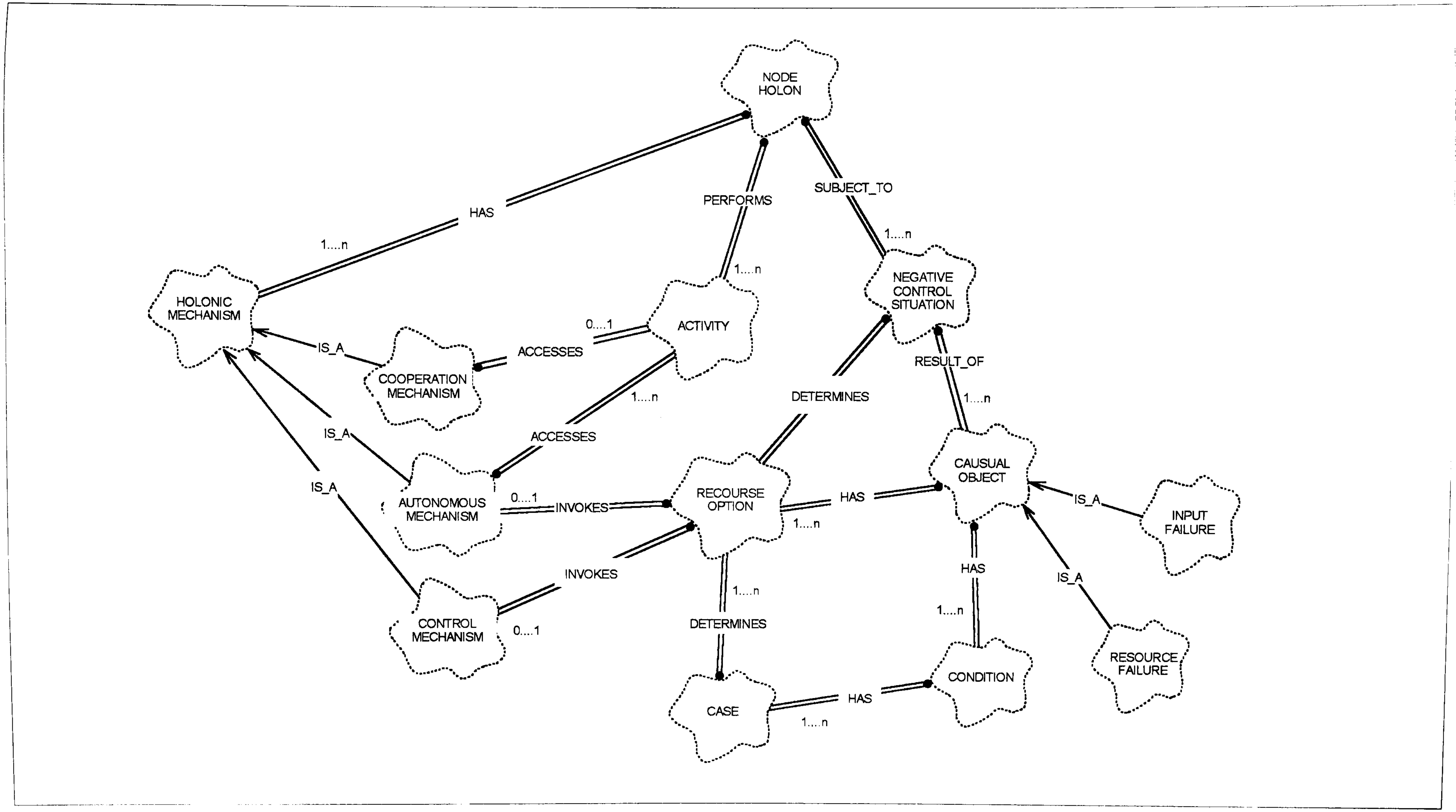


Figure 10.9: Modelling contingency situations and holonic aspects.

10.7 Modelling Contingency Situations

Many of the interactions between node holons occur out of necessity when shop floor contingencies are encountered. In order to further instantiate the holonic behaviour, a negative situation class is introduced, shown in figure 10.9. Any node holon is *subject_to* negative situations, which occur when the machining node is unable to fulfil the requirements stipulated by the control component of the activity, e.g. failure to fulfil the control imposed to meet due date. For each cooperation mechanism modelled, an associated negative situation is created.

A set of causal classes can be modelled with each negative situation, depicted in figure 10.5. Using the Booch class diagram (figure 10.9), these causal classes are the *result_of* the functional input and output modelled with the IDEF0 formalism. For example, a machining node holon requires cutting tools, raw material, or machining fixtures as functional inputs. Control is imposed on this machining holon which is then obliged to cooperate and meet the stipulated due date. A negative situation can occur where the machining node is unable to fulfil this obligation to cooperate. The causal class may be that the machining fixtures are absent, or there is a shortage of cutting tools or raw material.

Each causal class associated to a negative situation *has* one or a selection of recourse options. The node holon can resort to invoking its autonomous mechanism via the relation *invoke*, or its control mechanism to summon other activities into taking recourse actions. The modelling process may determine that the machining node holon *has* the autonomy to perform additional activities such as generate an alternative job sequence or to reallocate raw material from another job. In additional, the machining node holon may *invoke* its control mechanism over the production planning node holon to purchase new cutting tools. The production planning node will then have a corresponding cooperation mechanism and a new activity is generated which is to purchase new cutting tools. Therefore, the node holon's activities are *accessed* via its cooperation or autonomous mechanism.

A choice of more than one recourse options may be specified for each contingency situation. This, however, may be governed by some conditions which the enterprise may choose to impose. For instance, if the contingency was the *result_of* a shortage of cutting tools, a condition may be stipulated as the cost of the cutting tool. This in turn, may have a few case classes associated, which capture the established practice and guide the choice of recourse option. A case may be that if the cost of the cutting tool was less than a stipulated amount, the option would be to buy the cutting tool without the need for prior approval. Therefore, the case *determines* the recourse option. If the cost was greater than the stipulated amount, the corresponding recourse option could be to *invoke* the control mechanism so that the production planner will raise a purchase requisition for the tool. The control mechanism may also be *invoked* over a peer node holon to take over the machining task.

10.8 Modelling the Information Requirements of the Node Holon

The interface between a node holon and the attributes contained in the information classes is established through the control input and output ICOMS of the extended IDEF0 formalism (figures 10.4 and 10.8). A view format class has been introduced to enable the specification of the IT support to enable the data to be viewed. Hence, the view format is an aggregation of the information elements, such that a view format *has* information attributes. A selection of view formats may be described, these will include pie charts, tables or bar charts, etc. Examples of view formats will be job lists at a machining node, which will contain instances of attributes such as job number, quantity to be manufactured or due date, etc.

Therefore, by associating the second and third field of data capture, it becomes possible to create a specification of the information requirements by modelling the interactions between the node holons. The modelling process thus builds up a profile of the individual node holon in terms of its range of autonomous and cooperative activities, which in turn, enables the information requirements at each node holon to be specified. If information attributes are not found in the information structures, these can be established in the relevant information class thus creating the information specifications. Finally, the model of a node holon is shown in figure 10.10.

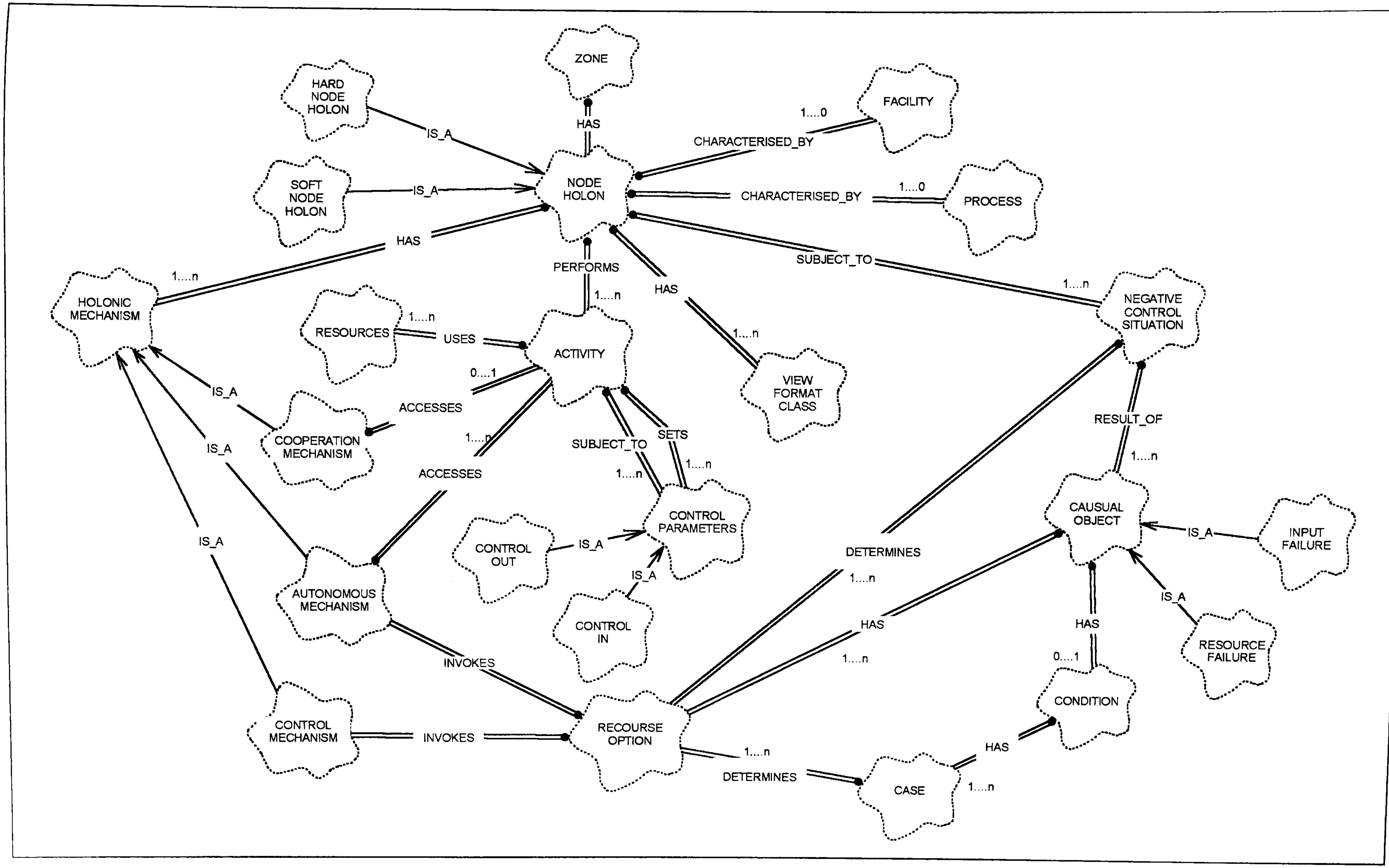


Figure 10.10: A model of the node holon.

Chapter 11

Mapping the Reference SME Enterprise Model onto the ARIS Architecture

11.1 Introduction

This chapter demonstrates how the contents of the reference SME enterprise model can be projected against the four viewpoints of the ARIS architecture. The model will be described in the context of these individual viewpoints, which will set this research in the context of contemporary enterprise modelling practice.

11.2 The ARIS Architecture as a Basis for Information Specification

The ARIS architecture (Scheer, 1992) for the task of information specification has been chosen as it appropriately maps out the structure of the reference SME enterprise model. The comparison which resulted in this choice has been presented in section 6.4. The results of the mapping, shown in figure 11.1, is achieved by establishing conceptual boundaries to demarcate the four viewpoints, within which the constructs of the model can be organised. The purpose of this is to enable the reference model to be described in the context of contemporary enterprise modelling practice and to offer an appropriate platform for comparison against other modelling approaches.

A major part of the reference SME enterprise model is the resource structure which has to contain the parameters which relate to the level and location of material, expendable inventory, job sequences and the impact of job relocation on the capacity loading at machines, etc. The process structure can also contain information parameters, an example of which is the process cost. It can be clearly seen from figure 11.1, that the resource and process structures are contained within the information viewpoint to allow the specification of the necessary information attributes. In accordance with the concepts associated with the ARIS architecture, the resource taxonomy of an enterprise has been modelled as information classes, enabling information attributes to be assigned.

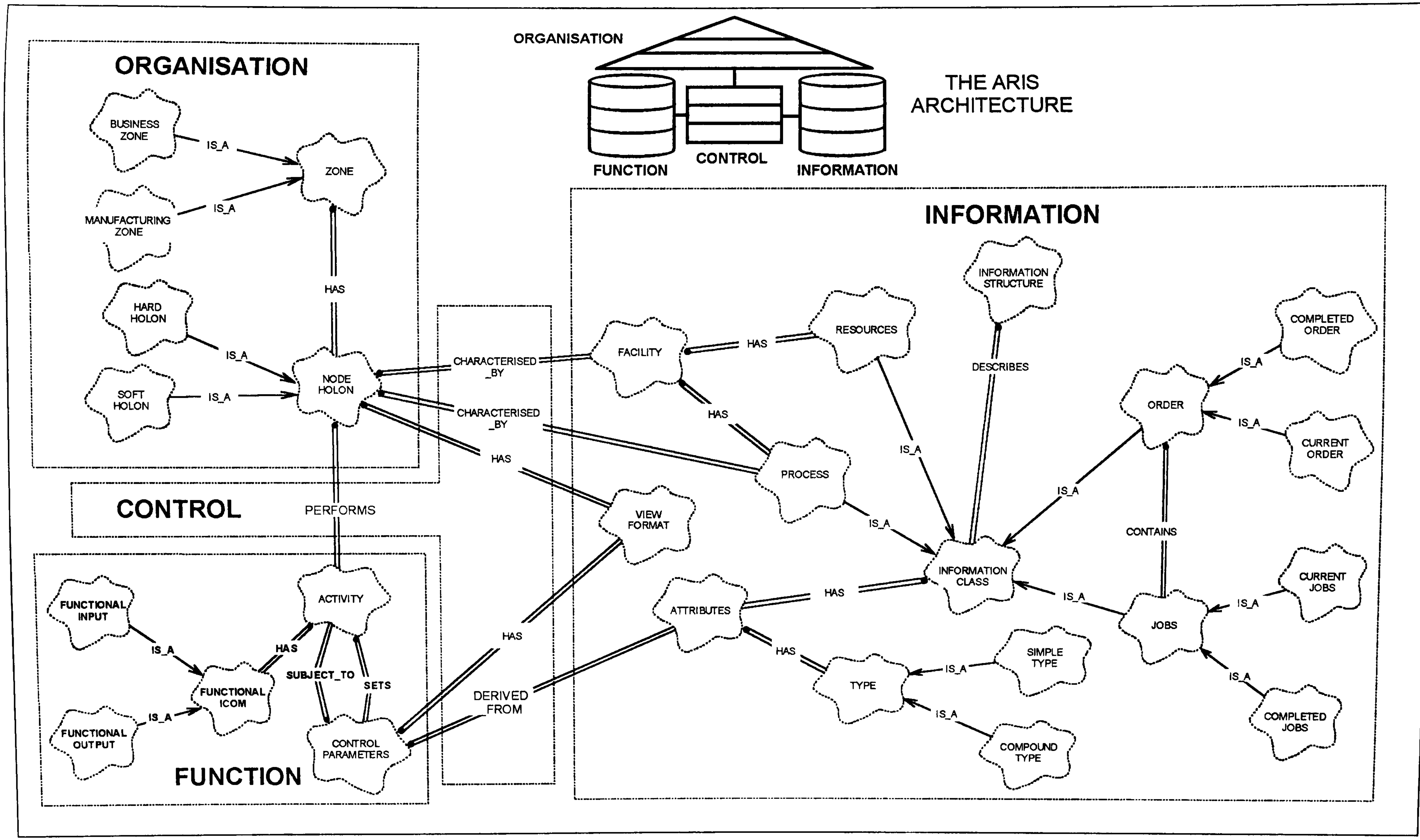


Figure 11.1: Mapping the SME enterprise reference model against the four viewpoints of the ARIS architecture.

It can also be seen that the contents of the reference SME enterprise model are captured using the descriptive formalism of the Booch class diagram to maintain a uniform semantic technique across all viewpoints. The advantage is that the formalism is also suited for conceptualising the structure of the CASE tool, which is based on the object oriented applications development language, Visual C++ (Microsoft, 1996). The application of a uniform methodology results in a direct correlation between the modelling constructs developed for the reference model and the structure of the modelling software. The representation using the Booch class diagram also plays an important role in effectively communicating the concepts which underpin the constructs used within the viewpoints. The contents of these four viewpoints are now described below.

11.3 The Organisation View of the Reference SME Enterprise Model

The organisation view of the reference SME enterprise model describes the enterprise in terms of zones. Hence, the reference model *describes* business and manufacturing zones. A sales office may be characterised as a sales zone which *is_a* business zone. A production planning office may be characterised as a production planning zone which in turn *is_a* manufacturing zone. An individual zone captures the node holons responsible for the tasks to be supported by the information system. Apart from their responsibility for the functions and data, these node holons are significant as users of the information system. The principal constructs used within the organisation viewpoint are, thus, the zones and the node holons.

11.4 The Function View of the Reference SME Enterprise Model

The function view, identified in figure 11.1, shows the enterprise functionality and behaviour modelled using the holonic concepts. This view describes the operations which are carried out in order to sustain the daily operation of the enterprise and captures the basic units of work which are executed by the organisational units or node holons. Hence, the enterprise activities which are performed by the individual node holons are contained within this viewpoint. The starting point for modelling the functional aspects of the enterprise is the node holon; the process is accomplished by modelling the profile of individual node holons, where each *performs* activities.

The modelling constructs, which enable the behavioural aspects of the enterprise to be captured in terms of the fundamental holonic concepts, are captured in the function view, illustrated in figure 11.2. Node holons in a holarchy have established relationships where each is obliged to cooperate with the control which is imposed by peer, subordinate or supervising nodes. Other behavioural aspects are described when shop floor contingencies occur, which are modelled in terms of a node holon being *subject_to* negative situations. The choice of recourse options may then be specified, which may involve the autonomous or invoking the control holonic mechanisms. Established business practices may be captured, or specified through conditions and case scenarios which govern the choice of recourse option. The principal constructs for modelling the function view are the activities, the associated holonic mechanisms, negative situation, causal objects, recourse options, condition and case classes.

11.5 The Information View of the Reference SME Enterprise Model

The information viewpoint, identified in figure 11.1, identifies the component of the reference SME enterprise model which captures the information used and altered during the performance of the enterprise activities. The information requirements are captured by the principal information classes, which are defined as carriers of the information attributes. The starting point for modelling the information classes is the facility, where the facility *has* an information structure which *contains* the principal information classes, namely the resources, processes, customer orders and jobs. Generic taxonomies, explained previously in section 9.4.2.1, can be created independently for the process and resource information classes, these structures can thus be reused. A particular instance of any company's information structure is defined in conjunction with the facility description to identify the appropriate set of information classes.

The approach to information modelling is to define the conceptual orders and manufacturing data models and subsequently derive the external schemas. Specification of the external schemas as used by individual node holons is accomplished through the use of view formats. These are containers for the information attributes selected from the global or conceptual information classes, which provide the information support. The principal constructs used in this viewpoint are the information, the simple and compound information attributes and the view format classes, shown in figure 11.1.

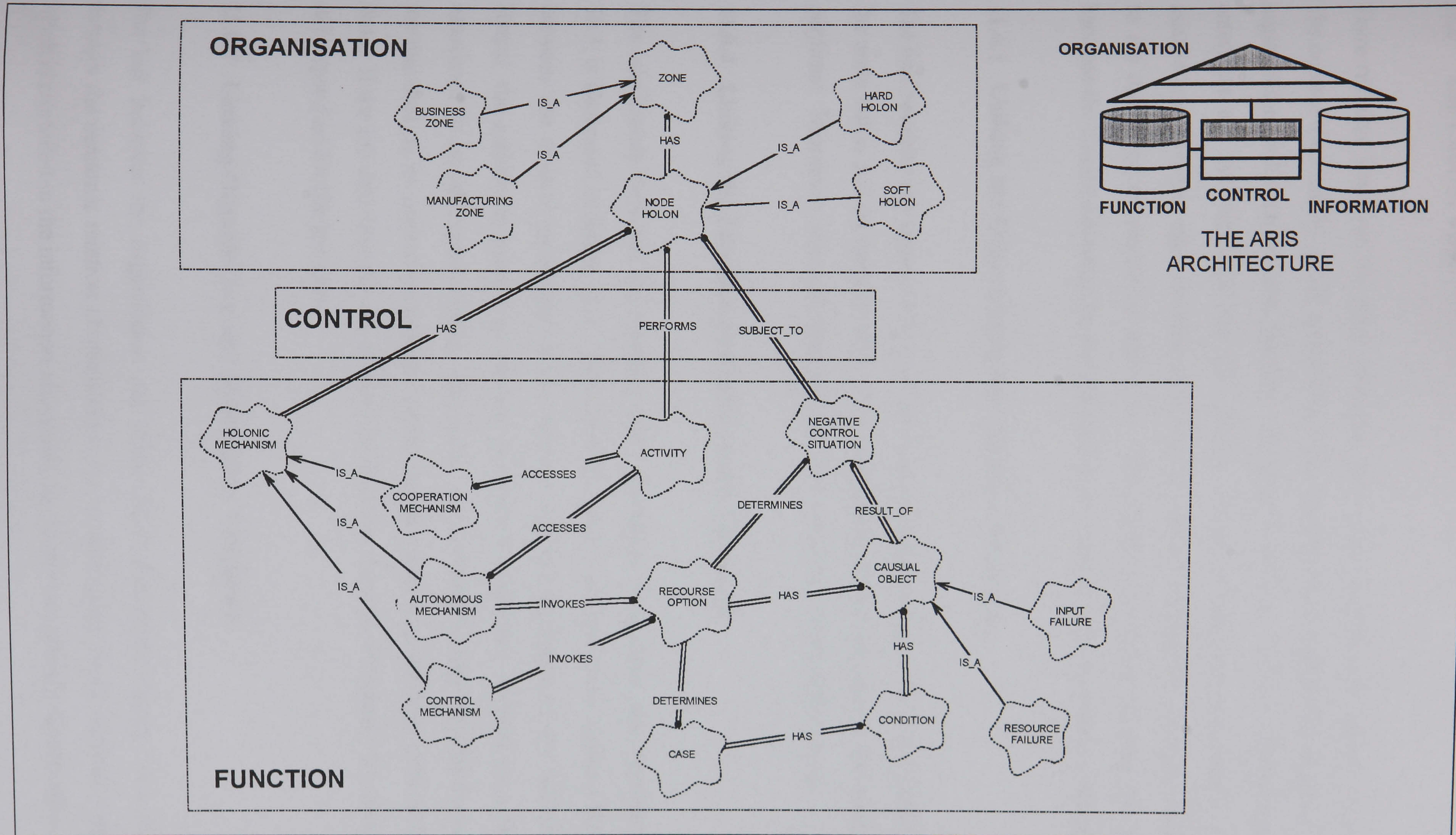


Figure 11.2: A detailed view of the constructs of the SME enterprise reference model mapped against the functional, organisational and control viewpoints of the ARIS architecture.

11.6 The Control View

There remains, however, the third principal view of the architecture, namely the control view. The control view of the ARIS architecture was introduced to reunite the separately considered organisation, information and function viewpoints (Scheer, 1992). These aspects of the enterprise are not unrelated and the control viewpoint has been introduced to model the associations between each, thereby allowing the task of information specification to be linked to the modelling of enterprise activities. The control viewpoint captures the relationships between the classes allowing the associations to be created in the modelling software.

11.6.1 Linking the Organisation and Function Viewpoints

The link between the organisation and function viewpoints, figure 11.1, is established between the node holon and its functionality. The association is characterised by the semantic relation *performs*. Moreover, the node holon is also *characterised_by* the facility level.

11.6.2 Linking the Function and Information Viewpoints

The relationship between the function and information viewpoints, also explained in section 10.3, is illustrated in figure 11.1. The semantic relation *derived_from* captures the association between the control parameter of the activity and the attributes of the information class. Hence, the activity is subject to control parameters which are *derived_from* the attributes associated to an information class. Modelling a machining activity will therefore identify the job due date as its control parameter, where the due date is an attribute derived from the job class. If the job due date did not exist as an attribute, the link will enable the missing attribute to be specified for the job class.

11.6.3 Linking Organisation and Information Viewpoints

The link between the organisation and information viewpoints, figure 11.1, is established through the semantic relation *characterised_by*, as each node holon requires a process class, which is modelled in the information viewpoint, to identify its primary functionality.

11.7 Epilogue: A Summary of the Research

The starting point of this research was that the assertion that the specification of information requirements should be founded on an established modelling architecture and supporting CASE tool. It was also decided that the ARIS architecture has the more appropriate set of modelling viewpoints. Two major research tasks, however, were identified at the end of section 6.6. To reiterate, it was argued that the contemporary architectures and associated modelling methods originally intended for realising specifications for deterministic systems cannot be appropriate for human dominated SME companies, without imposing unnecessary constraints. The second research task was to identify a reference data model of the information requirements.

At this juncture, these two tasks have been addressed and novel solutions have been presented. An enterprise reference model for deriving the information requirements for the metalworking SME has been developed and mapped onto the ARIS architecture. The enterprise model draws on the formality prescribed by the CIMOSA and ARIS modelling architectures for information specification.

The preceding chapters have demonstrated how the individual viewpoints of the ARIS architecture can be populated differently with specific methods, constructs and partial models. The origins of this reference model is the observation that small enterprises are inherently holonic in nature. Characterising the interactions within the enterprise in holonic terms is offered, therefore, as a more appropriate basis for instantiating the information requirements. The application of the reference SME enterprise model on a selected metalworking company will now be demonstrated in the next chapter. The CASE tool which has been based on the model to support the task of information specification will also be discussed in chapter 13.

Chapter 12

An Application of the Reference SME Enterprise Model: The Modelling of A.O. Henton

12.1 Introduction

The purpose of this chapter is to demonstrate how the reference SME enterprise model can be applied to model a metalworking SME, namely, A.O. Henton, Ltd. The first part of this chapter provides a brief overview of the business aspects of the company. This is accompanied by a description of how the major aspects of the reference model are realised and includes the facility, information and holonic aspects of Henton. It will be shown how the manufacturing facility of Henton can be projected against the four level structure of the facility model. The information structures of Henton are subsequently described in terms of the order and manufacturing model. It will be shown how the business and manufacturing organisation of the company can be characterised into business support and manufacturing zones. The final part of this chapter demonstrates, through a selection of three examples, how node holons are modelled and how the information support is specified.

12.2 Objectives of the Study

In general, the application of any reference model should be preceded by appropriate validation of its concepts and design. The objective of studying and modelling a metalworking SME, is therefore, to establish and show evidence of the applicability of the reference SME enterprise model.

For the purpose of this thesis, the validation of reference SME enterprise model through a rigorous study of a group of companies, with the aim of producing information specifications for each is impractical. However, it was found that Henton had already compiled a catalogue of its information usage in terms of its sales order forms, order book, planning cards, etc. (Henton, 1994). Moreover, the company has an established set of working procedures which have been comprehensively documented. The availability of a suitable company, with well developed information records and documentation of its working practices, provided an opportunity to validate the reference model by developing an instance based on the information which was already available.

The objective in instantiating the reference SME enterprise model based on Henton is to enable the applicability of the design of the enterprise model, and the capability of its modelling constructs, to be demonstrated and tested within the context of the company chosen. The study will therefore:

(i) Demonstrate how the zone concept discussed in sections 7.4.1 and 10.2 can be applied to model the zones of activity at Henton.

(ii) Show how the elements of data found in the shop floor documents can be characterised into order, job, resource and process information and associated correspondingly to the order and manufacturing data models.

(iii) Demonstrate how selected node holons within major zones can be identified and modelled using the fundamental holonic concepts introduced in this thesis.

The results of this work will now be reported in the following sections of this chapter.

12.3 An Overview of the Business of Henton

A.O. Henton Engineering Limited employs 62 people at its premises in Burbage, Nr. Hinckly, Leicestershire. The firm has no product design function, it operates as a specialist machining subcontractor for the aerospace and associated industries and undertakes large boring, CNC milling and turning, spark erosion as well as general machining for some 30 customers. The company was approved to BS 5750 (Part 2) in 1993. The business emphasis is to maintain a good reputation for quality and a good working relationship with customers. The operation of the company is based on specialist skills and flexibility in accommodating customer requirements.

Changes to the operating procedures by a principal customer has resulted in a significant variation in the order quantities being placed. Moreover, these orders can be rescheduled and quantities can be amended in individual transactions. The scheduled customer delivery requirements do not, in many cases, match the manufacturing batch requirements. To overcome this manufacturing mismatch situation, excess components from batch manufacturing are put into finished goods stock. Only items which are sold on a regular basis are treated in this way and sales are made from stock (when available). Currently, approximately 70% of the orders are repeated on a regular basis. If the items are not in stock, works orders are raised to cover the required manufacturing quantities. Typically, 18% of all invoices per month in the company require adjustment or requoting due to changes to delivery quantities.

With respect to the utilisation of IT tools, significant investment in computer systems has been undertaken over the past 10 years with regard to payroll, job costing, sales order book, shop floor documentation and stock control. This has been carried out through the introduction of the Micross system (Kewill, 1996) and other bespoke database programs. The firm wishes to retain its existing information system, update it where possible and improve the efficiency by integrating it with other current manual based systems.

12.4 Modelling the Manufacturing Facility of Henton

A schematic of the shop floor layout of the company is presented in Appendix I, this also includes a list of the machining resources. The manufacturing facility of Henton can be projected against the four level structure of the generic four level facility model, which has been discussed in section 9.4.1. This provides the basis which enables the description of the Henton facility, in terms of processes and resources, to be realised with a varying degree of abstraction at the individual levels. To represent instances of the facility description, the Booch object diagram is used, this is illustrated in figure 12.1, where instances of these objects represented in the figure are created and modelled using the CASE tool to be described in the next chapter.

The definition of the manufacturing facility begins with the definition of a factory, this represents a description of the facility at the highest level, which is followed by more detailed definitions at the shop, cell and workstation levels. The organisation of the manufacturing shop floor at Henton is based on a functional classification, at the shop level, eight manufacturing cells can be clearly distinguished, these in turn, consist of individual machining workstations. The cells are classified as: (i) CNC turning, (ii) Manual turning, (iii) CNC milling, (iv) Manual milling, (v) Manual drilling, (vi) Manual grinding, (vii) Honing and (viii) De-burring, finishing and packaging cells.

To illustrate the modelling of the manufacturing facility at workstation level, the CNC machining cell has been chosen. The CNC machining cell, which is included in the list of machining resources shown in Appendix I, consists of 6 CNC machining workstations. The resulting model is shown in figure 12.2. In the same manner, models of the other 8 manufacturing cells can be developed, where the Booch object diagrams can also be used to represent the particular instances of workstations contained in the individual cell.

12.5 Modelling the Information Structure of Henton

The information structure of the reference SME enterprise model describes three major aspects of the enterprise information requirements, contained by the resource and process data structure and the order data structure. In addition to establishing the contents of the order model, one of the main objectives is to identify the fundamental information classes from the generic resource and process taxonomies. The resulting selection of processes and resources from the respective taxonomies has to provide an appropriate set of classes to represent the company's information requirements. The modelling process is focused around these selected information classes, during which particular attribute definitions are created.

When the order and manufacturing models are implemented, these selected classes and their associated attributes are used to define the data fields for information storage. The information models will subsequently function by storing the factual data which supports the company activities. The following sections will highlight aspects of the resource, process and order structures respectively at Henton.

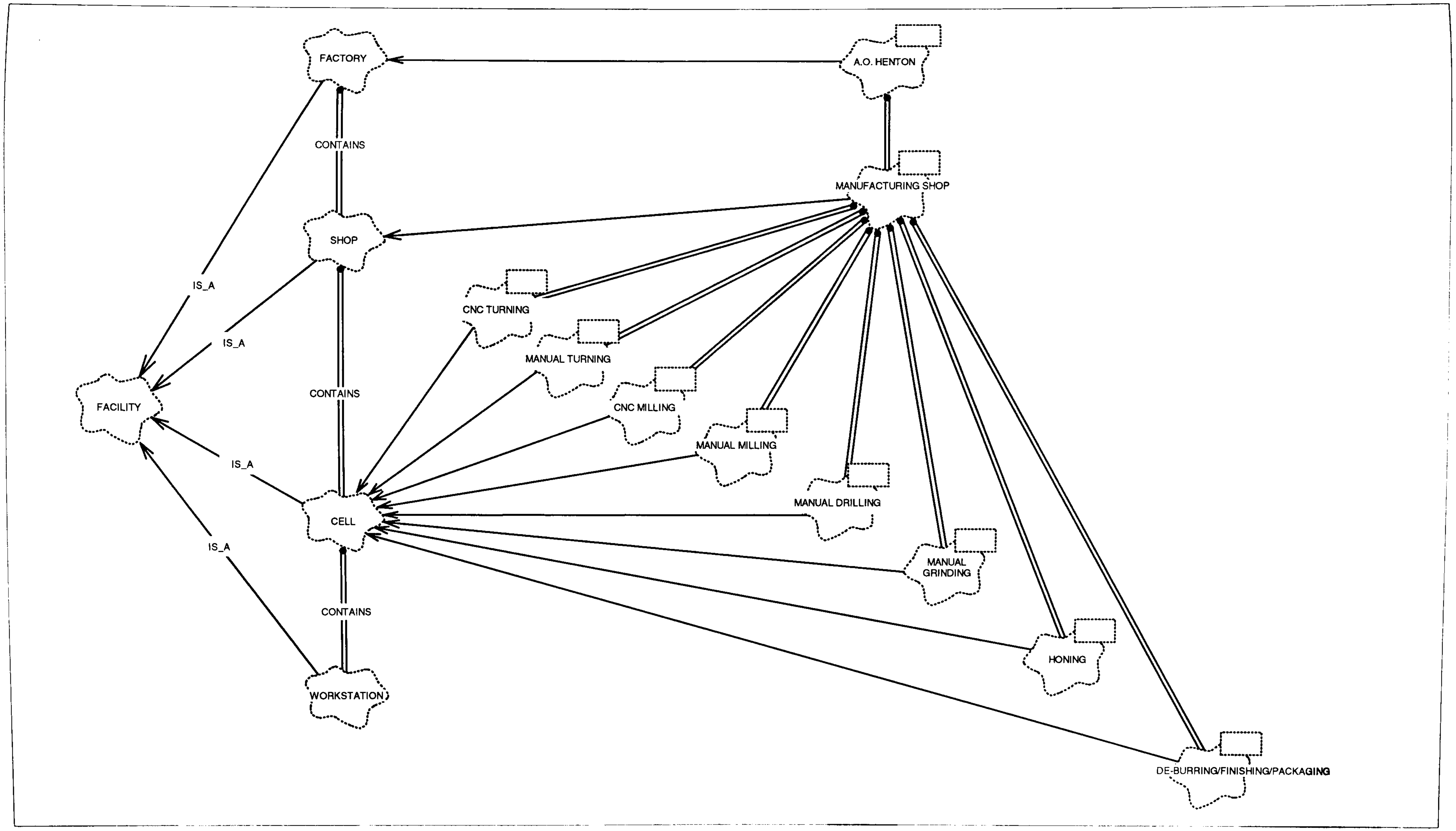


Figure 12.1: The manufacturing facility of Henton: Modelling the manufacturing shop.

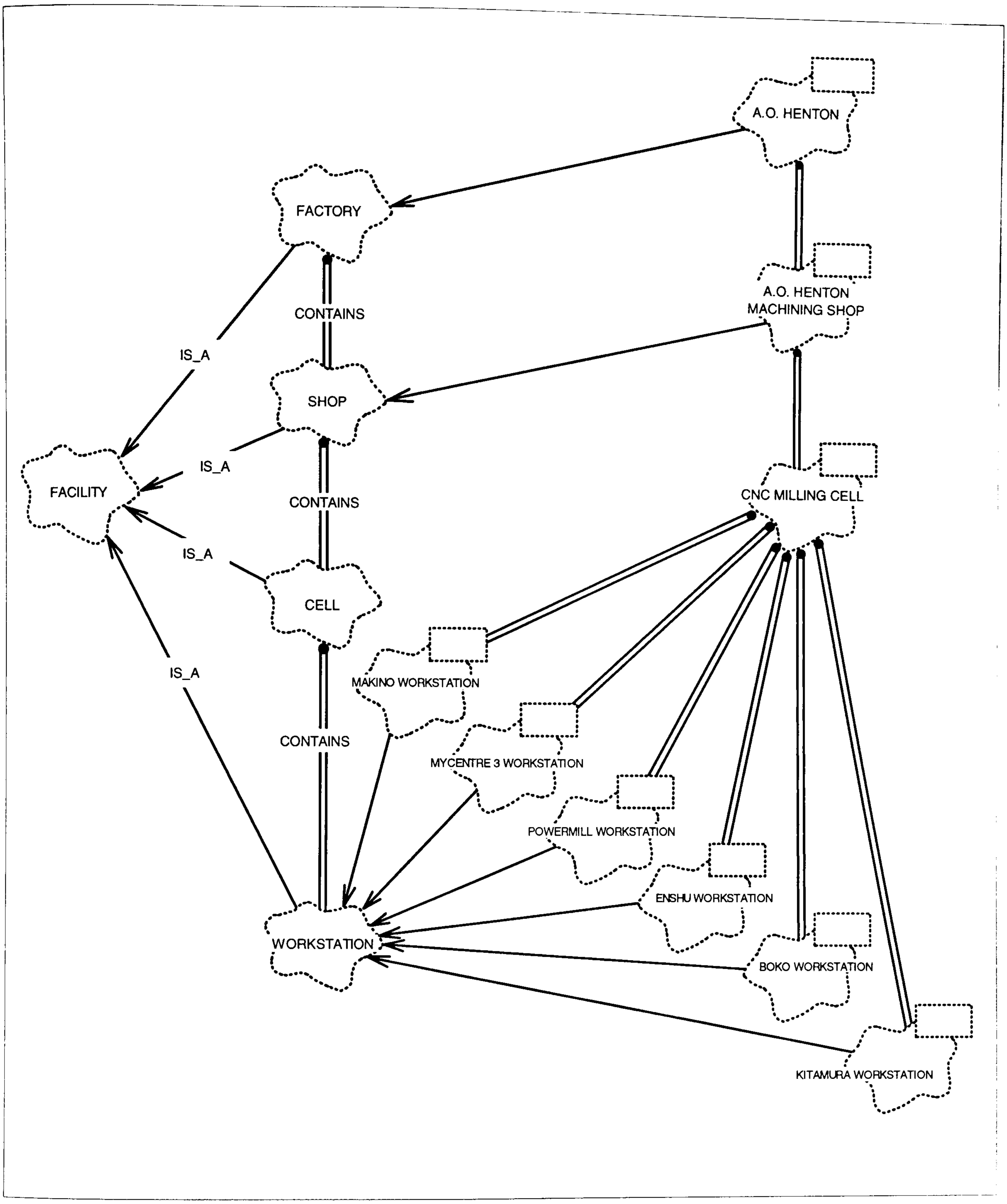


Figure 12.2: The manufacturing facility of Henton: Modelling the CNC milling cell.

12.5.1 Modelling The Factory Resources

The realisation of the manufacturing resource and process description can be derived directly from the taxonomies developed in section 9.4.2.1. The degree of abstraction used to describe the processes and resources of the manufacturing facility can be achieved using any of the classes which best suit the particular constitution and requirements of the company. The taxonomy of the resource objects shown in figure 12.3 identifies the fundamental set of information objects from which the facility description of Henton can be realised. Other specific resource descriptions can be created by deriving from this basic set of objects. For example, a detailed description of production resources such as machine taps, reamers and twist drills can be achieved by deriving from the cutting tool object, this is defined in figure 12.3.

These classes and their associated attributes enable the specification of the information structure which will constitute the manufacturing model. For instance, the machine tool object identified in the taxonomy can be modelled with attributes such as model number, name, description, year of purchase, manufacturer name, etc. These attributes determine the data fields in the manufacturing information model, shown in figure 12.4, which will be populated with particular details of the machine tools existing in the company. The specification of attributes to be associated to a particular class is carried out in conjunction with the third, or organisation-behaviour view of data capture. As shown in figure 12.4, these attribute fields can be subsequently implemented to maintain a record of all the machines in the factory. External schemas, described in section 10.8, are subsequently based on selected elements from these data structures and specified using view formats types such as tables, bar charts, etc.

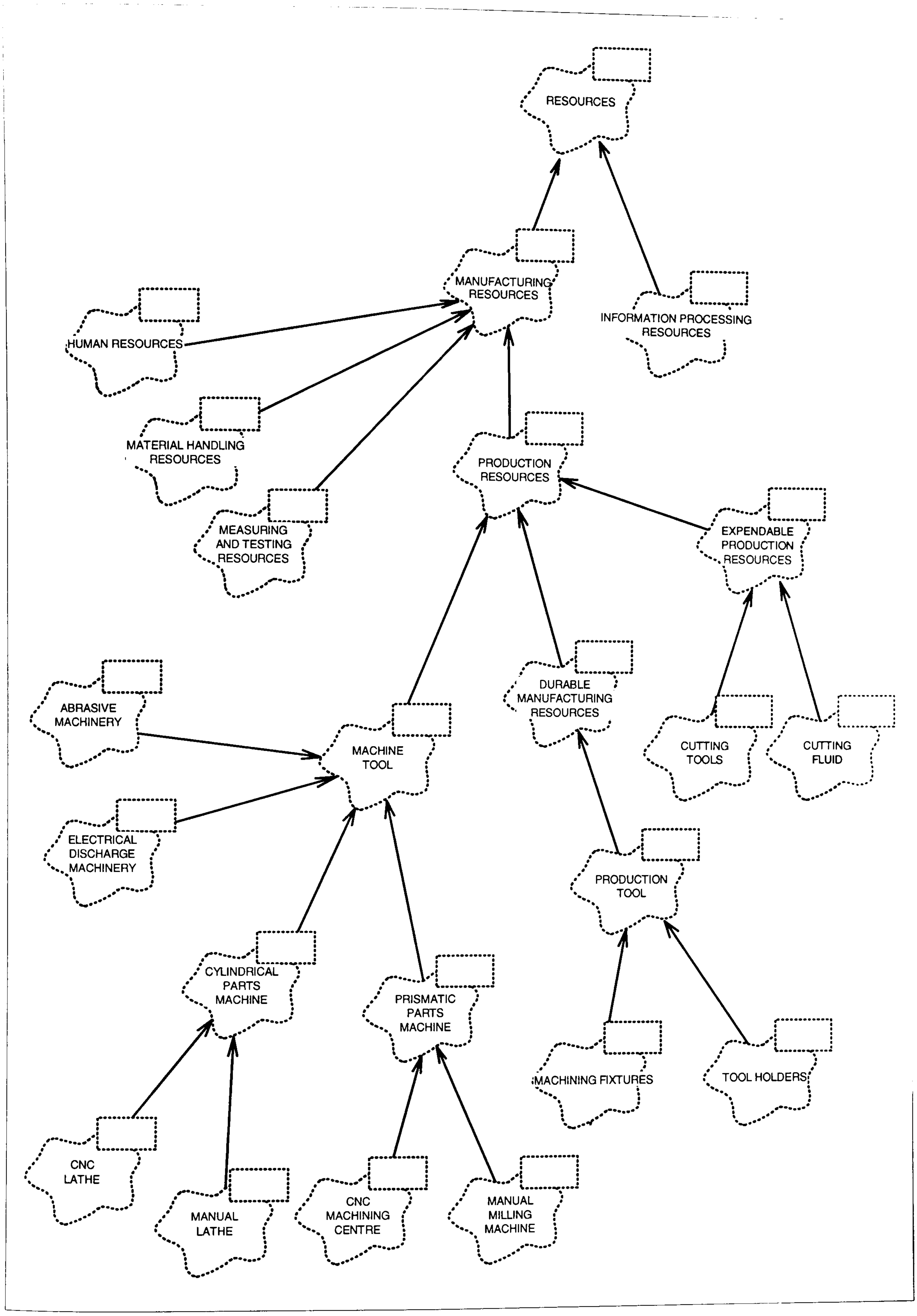
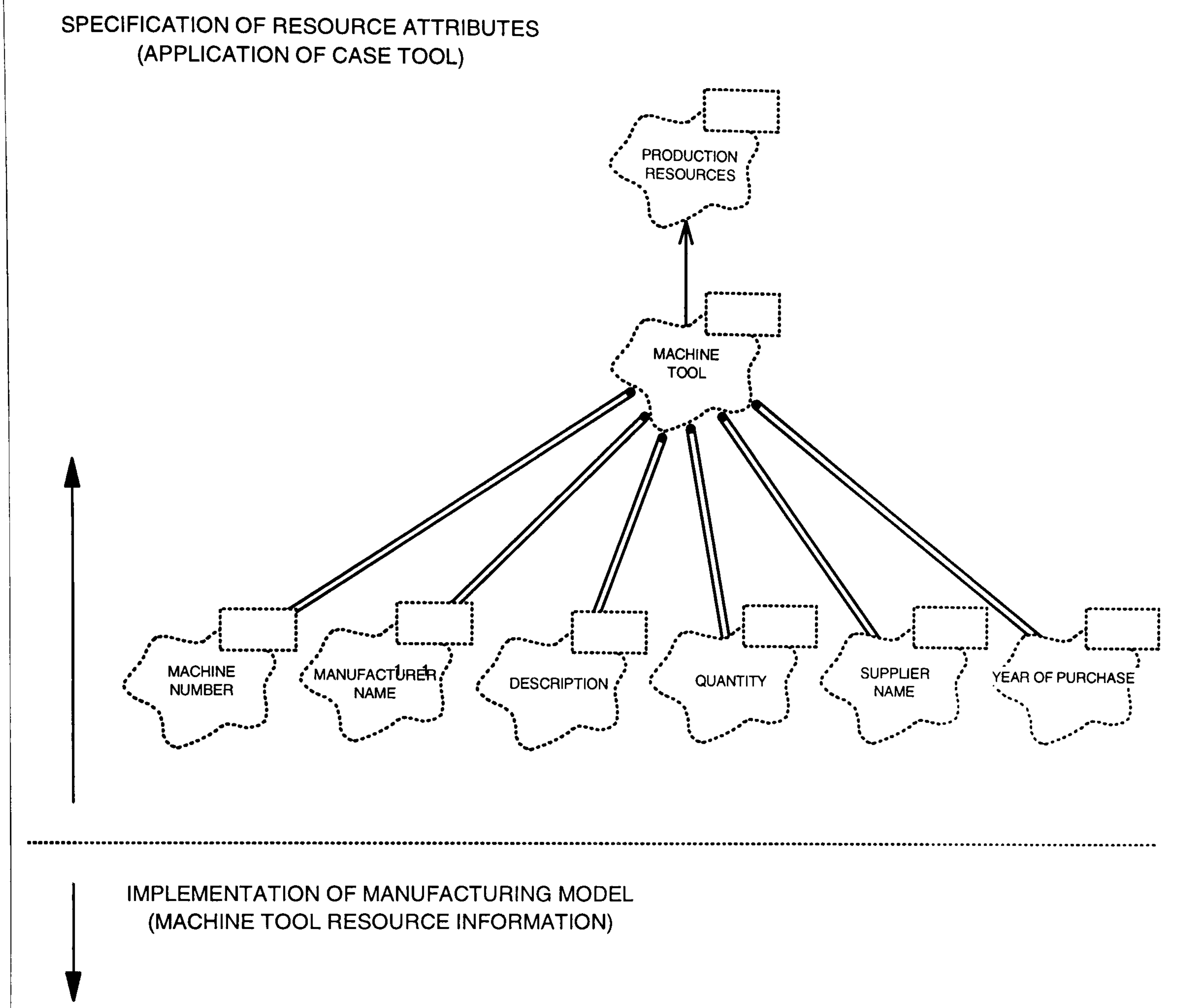


Figure 12.3: The taxonomy of the fundamental resource objects to describe Henton.



M/C No.	Manufacturer Name	Description	Quantity	Supplier Name	Year of Purchase
1	Mori-Seiki	CNC Lathe	01		
2	Colchester	Triumph 2000 Lathe	01		
3	Dean Smith and Grace	Lathe	01		
4	Cincinnati	Horizontal Miller	01		
5	Makino	3-Axis Machining Centre	01		
6	Bridgeport	Vertical Miller	01		
7	Kitamura	Jig Centre	01		
8	Webster and Bennet	Borer	01		
9	Cincinnati	Centreless Grinder	01		
10	Jones and Shipman	Universal Grinder	01		
11	Jones and Shipman	Surface Grinder	01		
12	Jones and Shipman	Cutter Grinder	01		
13	Myford	External Grinder	01		

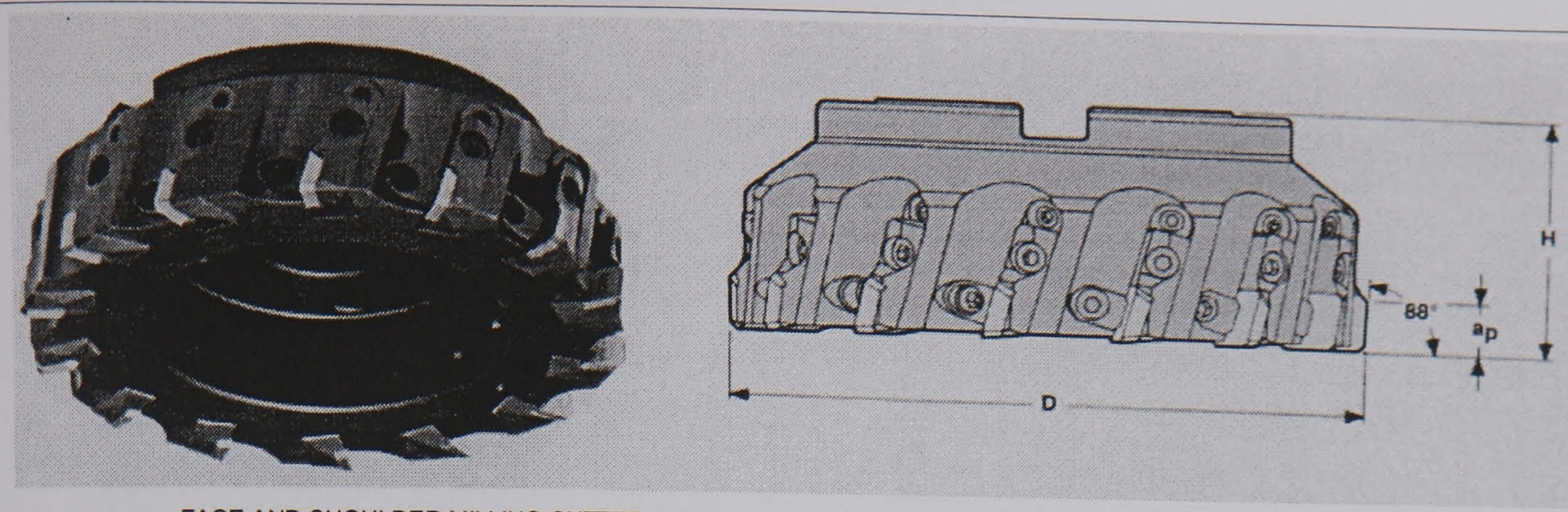
Figure 12.4: Modelling the attributes of a machine tool resource.

Another example is the modelling of the production resources. These are further categorised into durable and non-durable production resources. For example, a face and shoulder milling cutter is a durable production resource, the object model of the cutter (insert holder) is shown in figure 12.5, which lists the attributes which may be associated with the resource. For an expensive resource which may need to be shared amongst a number of machining workstations, an attribute such as the cutter location can provide the basis for tracking the tool around the shop floor. The major items which fall into the non-durable category are cutting tools, such as the milling cutters, turning and milling inserts, machine taps and grinding wheels, etc. The inserts which accompany the tool holders are modelled as non-durable resources, this is shown in figure 12.6, which lists the attributes which may be associated to this class of resource. All the general attributes for the parent cutter insert object can be specified first, these are inherited by the derived milling cutter insert object, where specific attributes such as width and land length can be further defined.

12.5.2 Modelling The Factory Processes

The manufacturing capability of the company is captured in terms of the available processes. In a manner similar to the resource description, the process structure of the shop floor can also be achieved to various degrees of abstraction. Therefore, the same approach is applied to modelling the specific process structure, where a fundamental set of objects are identified in conjunction with the facility view of data capture. The fundamental set of information objects from which the process description of Henton can be established is shown in figure 12.7. Specific instances of manufacturing support processes such as material purchasing or planning can be derived from the information process object shown in figure 12.7.

The information attributes such as the process name, description, associated resource, cost, etc. can be modelled for each process class, an example of which is shown in figure 12.8. This constitutes the process aspects of the manufacturing model and enables the process related information for Henton to be maintained. In addition to attributes such as the process name and the control type, an important attribute which has been identified is the process cost. This can be used to provide information in conjunction with estimated machining times for the purpose of cost estimation.



FACE AND SHOULDER MILLING CUTTER

Right-hand version shown.

Part No.	Dimensions in mm			No. of Inserts	Weight Kg	For Insert
	D	H	Ap*			
R/L220.33-0080-12CT	80	50	11	6	1.6	SE..1203.. SE..1303..
-0010-12CT	100	50	11	8	2.2	
-0125-12CT	125	63	11	10	3.0	
-08160-12CT	160	63	11	14	5.0	
-08200-12CT	200	63	11	18	7.4	
-08350-12CT	250	63	11	22	13	
-08500-12CT	315	80	11	28	35	

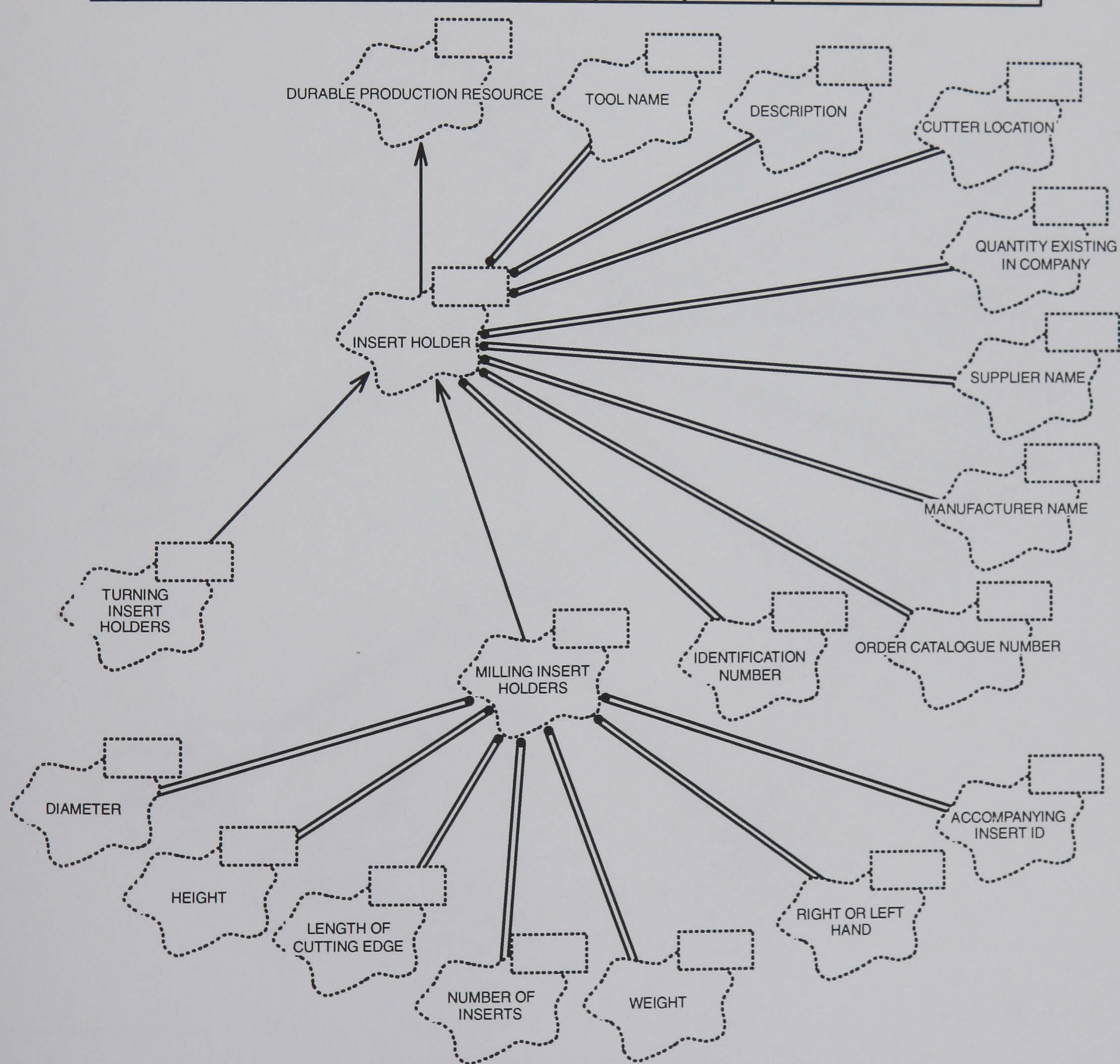
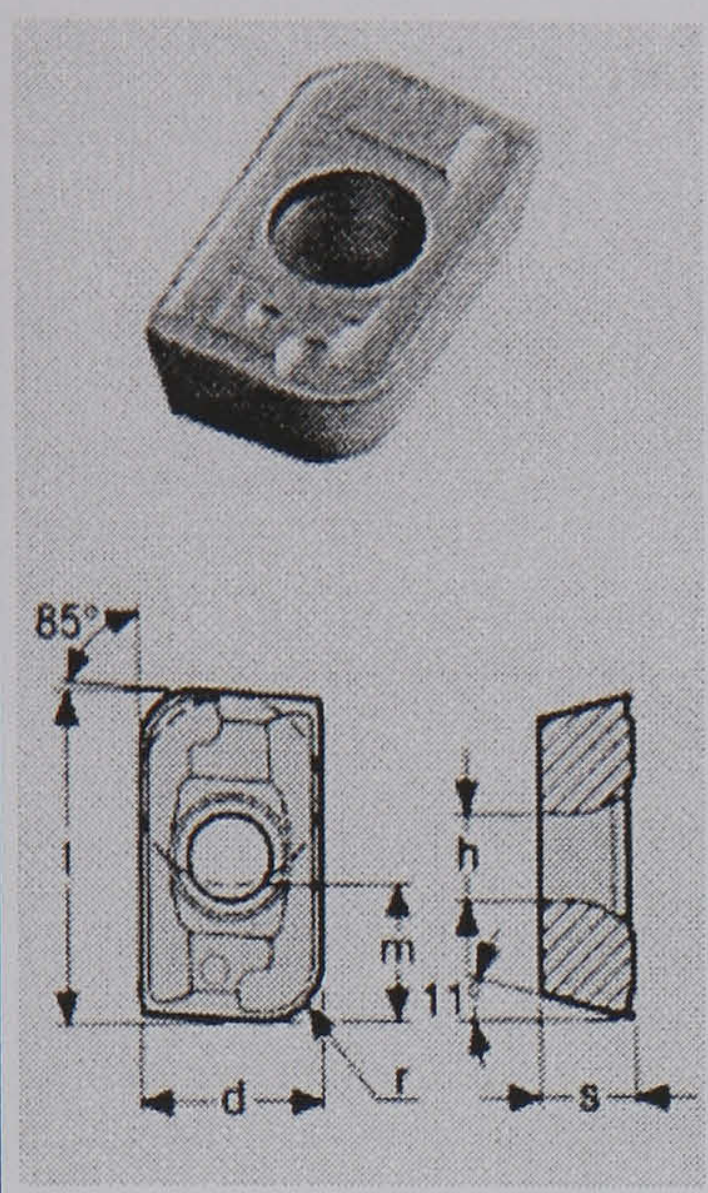


Figure 12.5: Modelling the attributes of an insert holder.

APFT



Tolerances (± mm)
d 0.013
s 0.015
m 0.005

Dimensions in mm

Part No.	d	l	s	r	h
APFT 160416R-M13	9.525	17	4.76	1.6	4.5
160430R-M13				3.0	

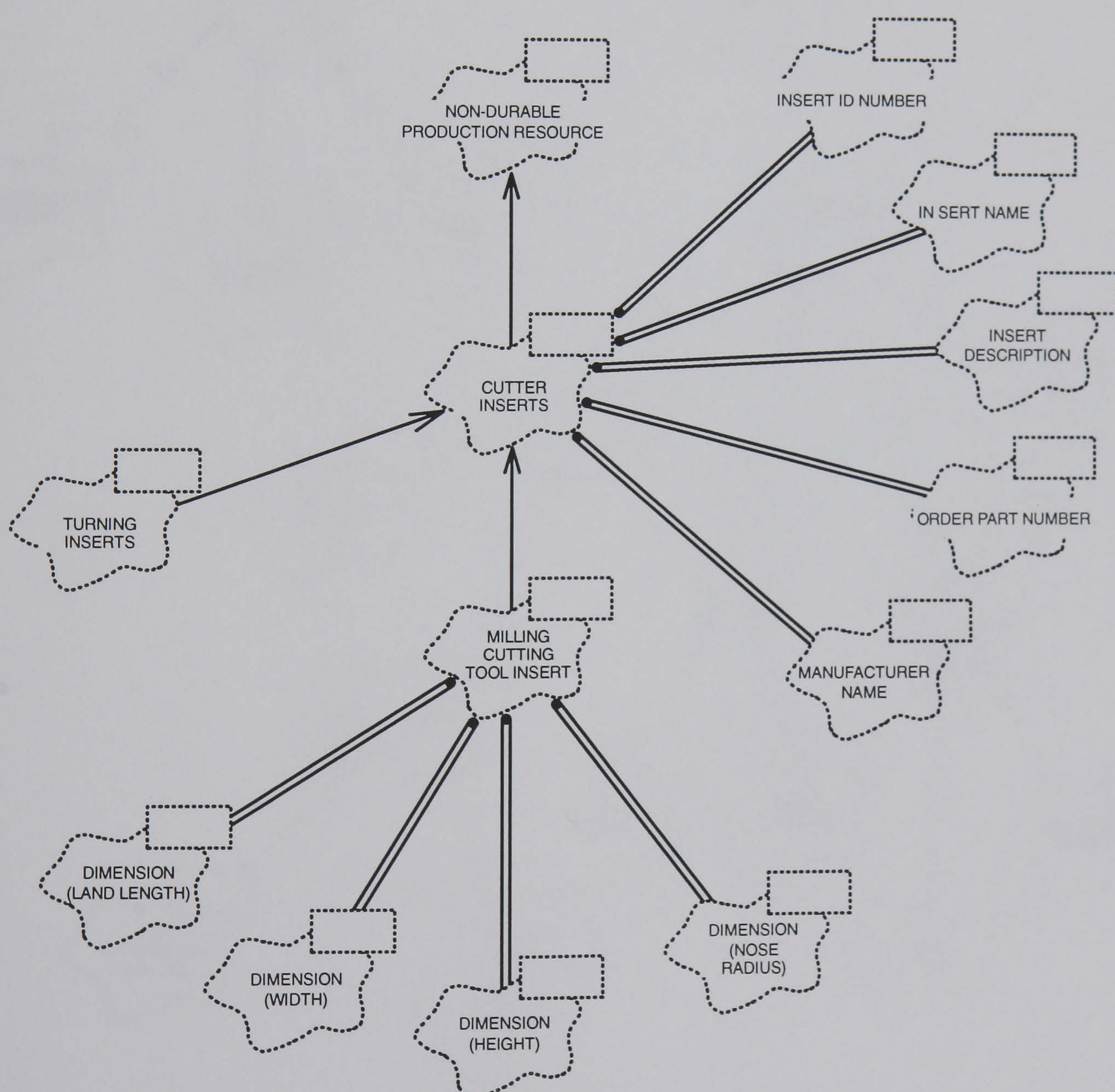


Figure 12.6: Modelling the attributes of the cutter inserts.

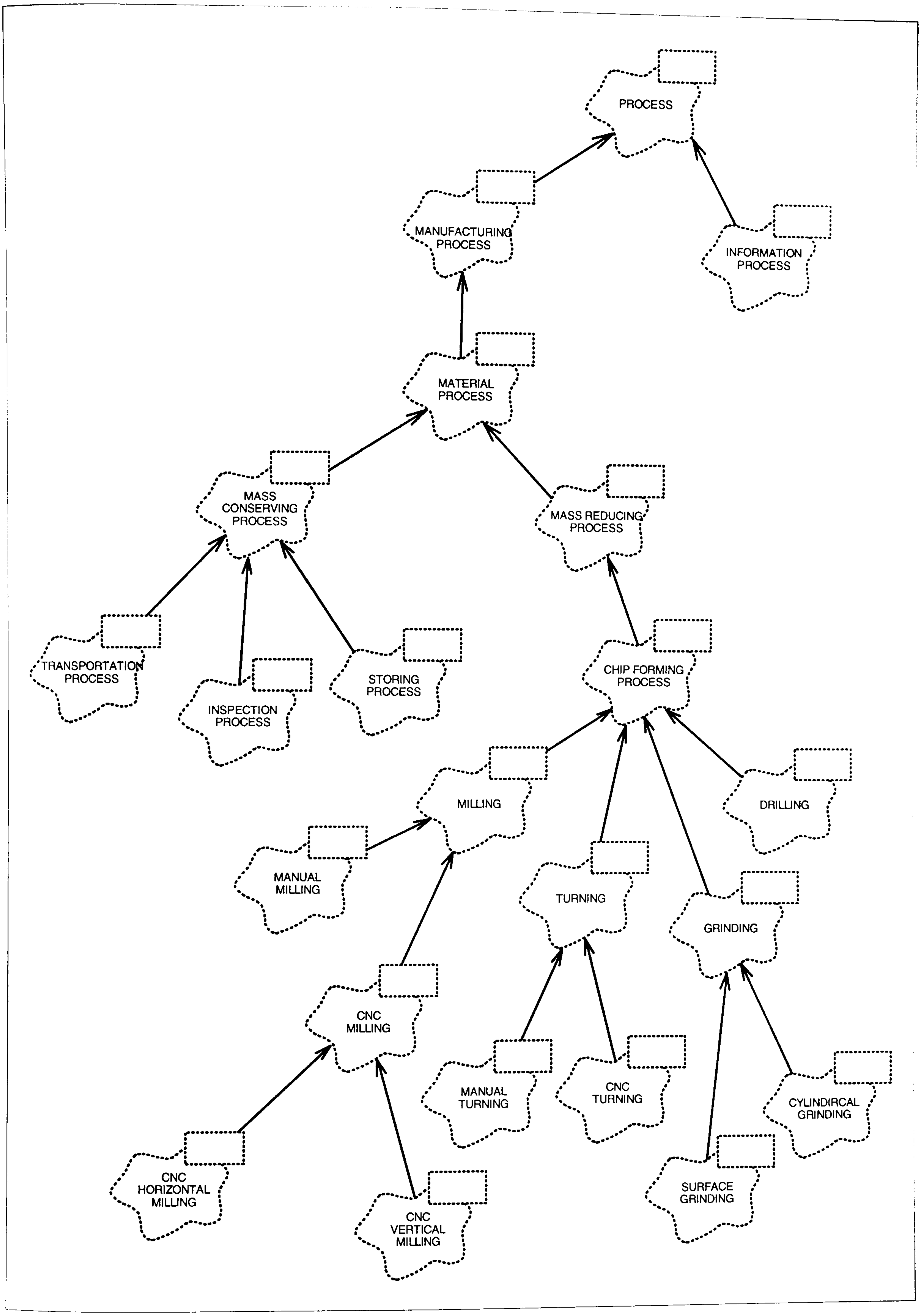
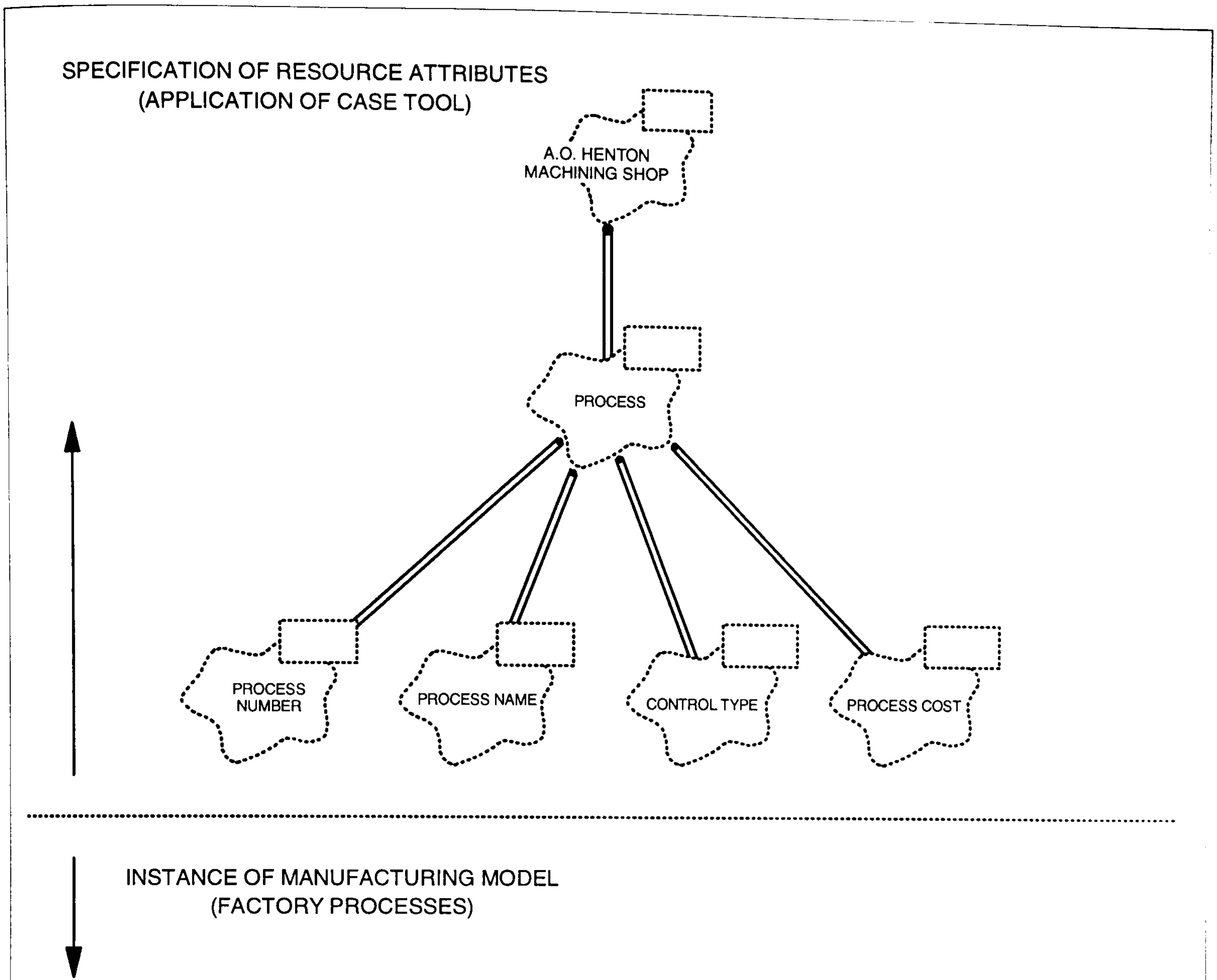


Figure 12.7: Modelling the taxonomy of fundamental process objects to describe Henton.



Proc. No.	Process Name	Control Type	Process Cost
1	Turning	CNC	
2	Turning	Manual	
3	Vertical Milling	CNC	
4	Milling	Manual	
5	Drilling	Manual	
6	Surface Grinding	CNC	
7	Surface Grinding	Manual	
8	Cutter Grinding	Manual	
9	Vertical Boring	CNC	
10	Tapping	CNC	
11	Centreless Grinding	Manual	
12	Electrical Discharge	CNC	

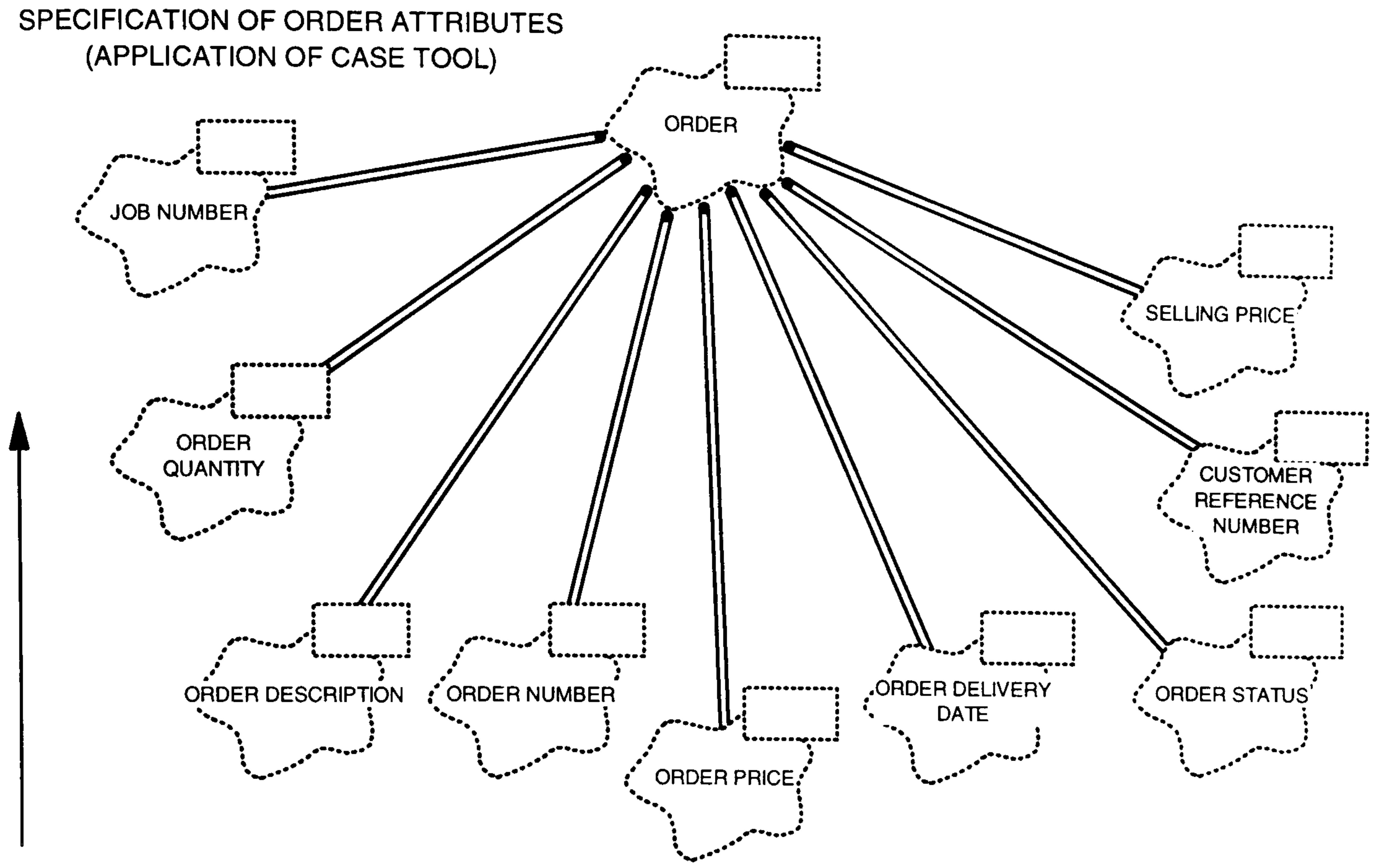
Figure 12.8: Modelling the process attributes.

12.5.3 The Structure of the Order Model

The structure of the generic order model and its constitution based on the order and job classes has been described in section 9.4.4. The relationship between the order and job information classes has been established by the reference information model where an order comprises one, or a number of jobs. The associated attributes which constitute the order and job classes have to be specified, this is illustrated in figures 12.9 and 12.10. These figures show a sample of attributes which have been identified and associated to the order and job classes respectively.

These attributes have been extracted from a number of documents obtained from Henton such as, orders outstanding and orders received registers (Henton, 1994), this is shown in Appendix II. Documentation of this nature represents an example of the external schema which can be specified from the data structures in the order model. In creating the data structure, attributes from the available documentation have been associated to their appropriate information classes. For example, the order due date, customer reference number and order quantity is associated to the order class. An order at Henton may comprise one or a number of jobs, this relationship is established by the link between the order reference number and job reference number, shown in figure 12.9. This allows a list of jobs to be created and associated to a particular customer order.

The job structure in turn, contains a set of attributes which are shown in figure 12.10. The attributes are the job quantity, quantity scrap, date of issue, job due date, job description, etc. The job location provides the information to allow the tracking of work in progress on the shop floor. The operation sequence for individual jobs can also be specified, where details of each operation such as start and complete times, set-up and operation times, etc. can be recorded by the order model. In this manner, the order model provides a source of established processing sequences which can be recalled and amended for repeat or variant work.

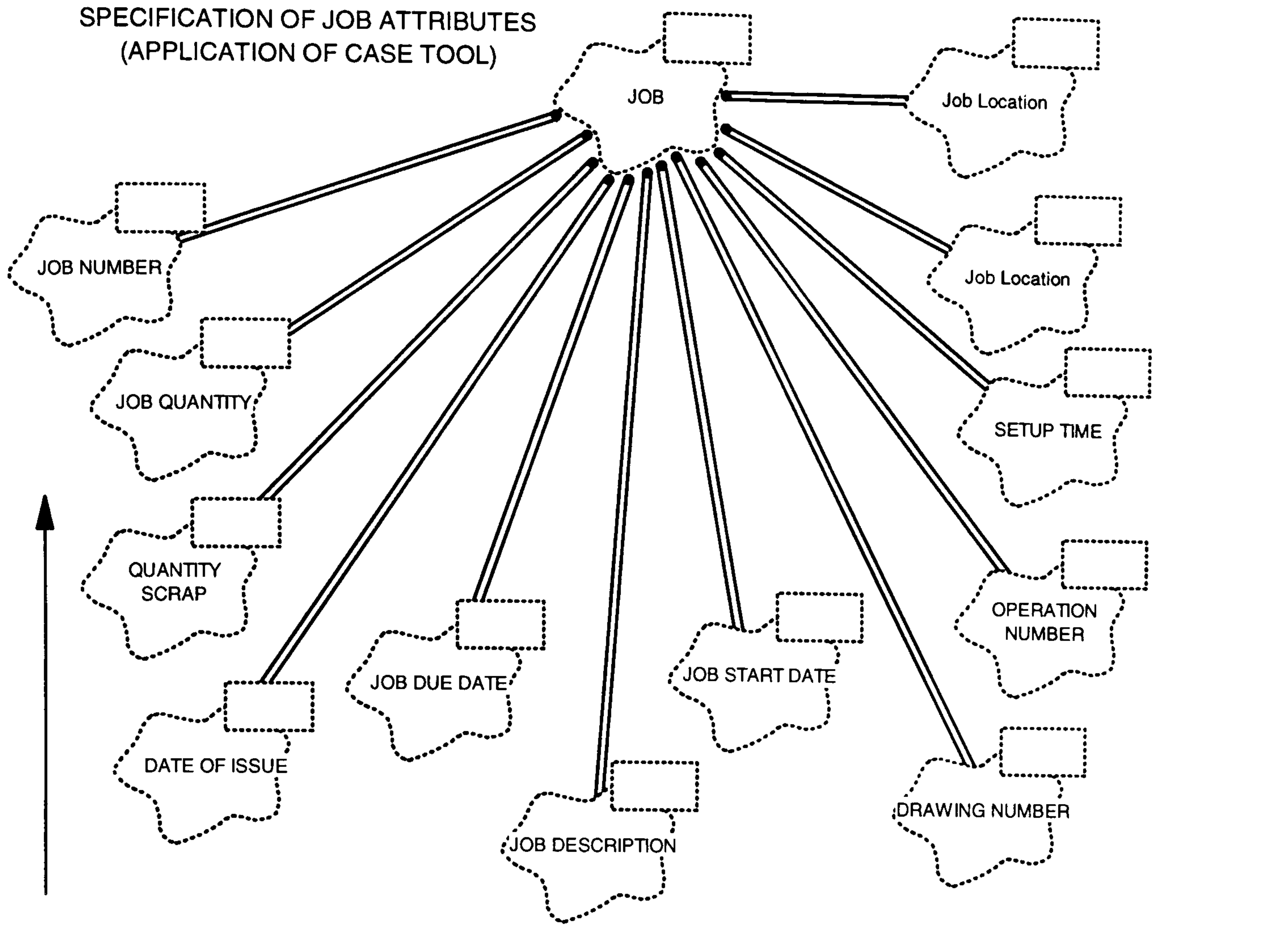


IMPLEMENTATION OF ORDER MODEL
(ORDER INFORMATION)

Order No.	Customer Ref. No.	Order Description	Selling Price	Order Quantity	Order Delivery Date	Order Price	Order Status	Job Number
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								

Order No.	Job Number
1	J1
	J2
	J3
	J4
	J5

Figure 12.9: Defining the order model: Modelling the attributes for the customer order.



INSTANCE OF ORDER MODEL
(JOB INFORMATION)

Job No.	Job Qty.	Qty. Scrap	Date of Issue	Job Due Date	Job Desc.	Dwg. No.	Job Locati on

Job No.	Operation No.	Operation Desc.	Start Date	Compl. Date	Setup Time	Operation Time

Figure 12.10: Defining the order model: Modelling the attributes for the jobs.

12.6 The Representation of the Company as Zones of Activity

The organisation at Henton is classified according to the two categories of business support and manufacturing zones. In accordance with this classification, five business support zones and eight manufacturing zones have been identified, this is illustrated in figure 12.11. Five business support zones can be distinguished, these are (i) Sales and Purchase Order Administration, (ii) Accounts, (iii) Production Control, (iv) Production Engineering and (v) Quality, Goods Receiving, General and Tool Store. Eight manufacturing zones can be distinguished, these are (i) CNC turning, (ii) Manual turning, (iii) CNC milling, (iv) Manual milling, (v) Manual drilling, (vi) Manual grinding, (vii) Honing and (viii) De-burring, finishing and packaging operations.

The classification of Henton into these different zones of activity has been based on the way in which the company is currently structured and does not, therefore, impose any changes to the functional structure of the business. A brief description of these zones is given in the following sections.

12.6.1 The Sales and Purchase Order Administration Zone

The sales and purchase order and administration zone acts as the liaison between the company and its customers, suppliers and sub-contractors. Orders can be of four types, (i) new orders can be encountered, (ii) an existing order quantity may be decreased, (iii) increased, (iv) rescheduled or (v) cancelled. The primary function of this zone is to receive, register, process the customer orders and generate the sales order reports. Other activities performed in this zone are the preparation of invoices, processing of purchase orders for material and tooling, consumable items, sub-contract orders processing or heat treatment.

12.6.2 The Production Control Zone

The production control zone liaises with the sales and production engineering zone with regards to the prediction of delivery dates and queries on customer orders. When customer orders are handed down from the sales zone, production (or batch) quantities have to be determined to fulfil the customer order. This is particularly relevant to the orders which call for separate deliveries of the same item, where the decision would be made to manufacture a batch of items. The determination of material requirements and the requisition of material have to be carried out for new, previously unencountered orders, i.e. orders which have no recorded history in the company. The production control has to maintain a record of all items which have been sent to subcontractors. In addition, it holds a record of all repeat orders in the company to reduce the administrative and planning effort. Production control has to expedite manufacturing to fulfil customer orders and to keep the sales and administration informed of delays.

12.6.3 The Production Engineering Zone

The production engineering zone encompasses the major task of planning the process routes for the individual jobs, this includes setting out detailed instructions for processes such as the parameters for heat treatment. Part drawings and production sketches, set-up sheets and instructions, etc. have to be printed and issued to the shop floor. Special tooling and fixture, and inspection requirements have to be determined, the production of NC part programs for the CNC operations is also carried out. Another activity is the estimation of processing times for the manufacture of the parts, this is essential in the preparation of price quotes to customers. The preparation of quotations requires considerable interactions with suppliers and subcontractors to ensure that material prices and availability are accurately established, so that the correct specifications are produced.

12.6.4 The Quality, Goods Receiving and Dispatch, General and Tool Store Zone

The activities concerned with quality are the inspection of components, the calibration of the measuring equipment and the maintenance of the calibration records. The quality function is also concerned with the production of quality control statistics. The goods receiving and dispatch zone is responsible for maintaining a weekly list of outstanding orders when components are completed, inspected and dispatched. When material is received, a unique designation number for use within the company has to be assigned in order to maintain traceability. The tool store zone is concerned with the purchase, storage and issue to cutting tools. It is also concerned with the generation of purchase orders for non-durable tooling such as milling cutters, machine taps, twist drills, etc. and other expendable items such as cutting fluids, machine coolant and lubricants.

12.6.5 The Accounts Zone

The accounts zone encompasses activities which manage the financial aspects of the company. For example, tasks such as the processing of employee payroll and invoices are carried out. Daily time sheets have to be processed, where times taken for operations are collated for calculation of the employee payroll, reports relating to work centre performance and WIP valuation reports have also to be generated. Material costs and expenses for engaging the subcontract resources have to be allocated to their respective jobs. Following the issue of material from the general store, information relating to the job has to be kept updated for the purpose of job costing. The maintenance of a record of expenses concerning completed jobs for future investigation is also carried out in the accounts zone.

12.6.6 The Manufacturing Zones

The manufacturing zones which have been listed in section 12.6 bounds the eight major manufacturing activity sectors in Henton. As with the business support zones, the identification of the manufacturing zones has been based around the current organisation of the manufacturing shop floor. This reiterates the stance taken in this thesis, that the modelling approach has to be supportive of the preferred business operation and does not necessitate changes to the organisation. Although the classification of the eight manufacturing zones is based around their different process types, the general description of the nature of the activities and their role in the organisation is the same.

In general, the manufacturing zones identify the major interacting activities which have the joint task of producing the components stipulated by the customer orders. These activities employ the range of manufacturing resources to convert the raw material into the completed parts. The main objectives are to meet the demands on quality and order due dates. An individual manufacturing zone requires input from the production engineering zone in terms of the part drawings, fixture and set-up instructions and NC part programs, etc. The sequencing of the jobs at workstations are based on the due date or information on order priority from the production control zone and is subject to the availability of fixtures and tools. Purchase orders have to be raised to the general and tool store zone for cutting tools, machine coolant, etc.

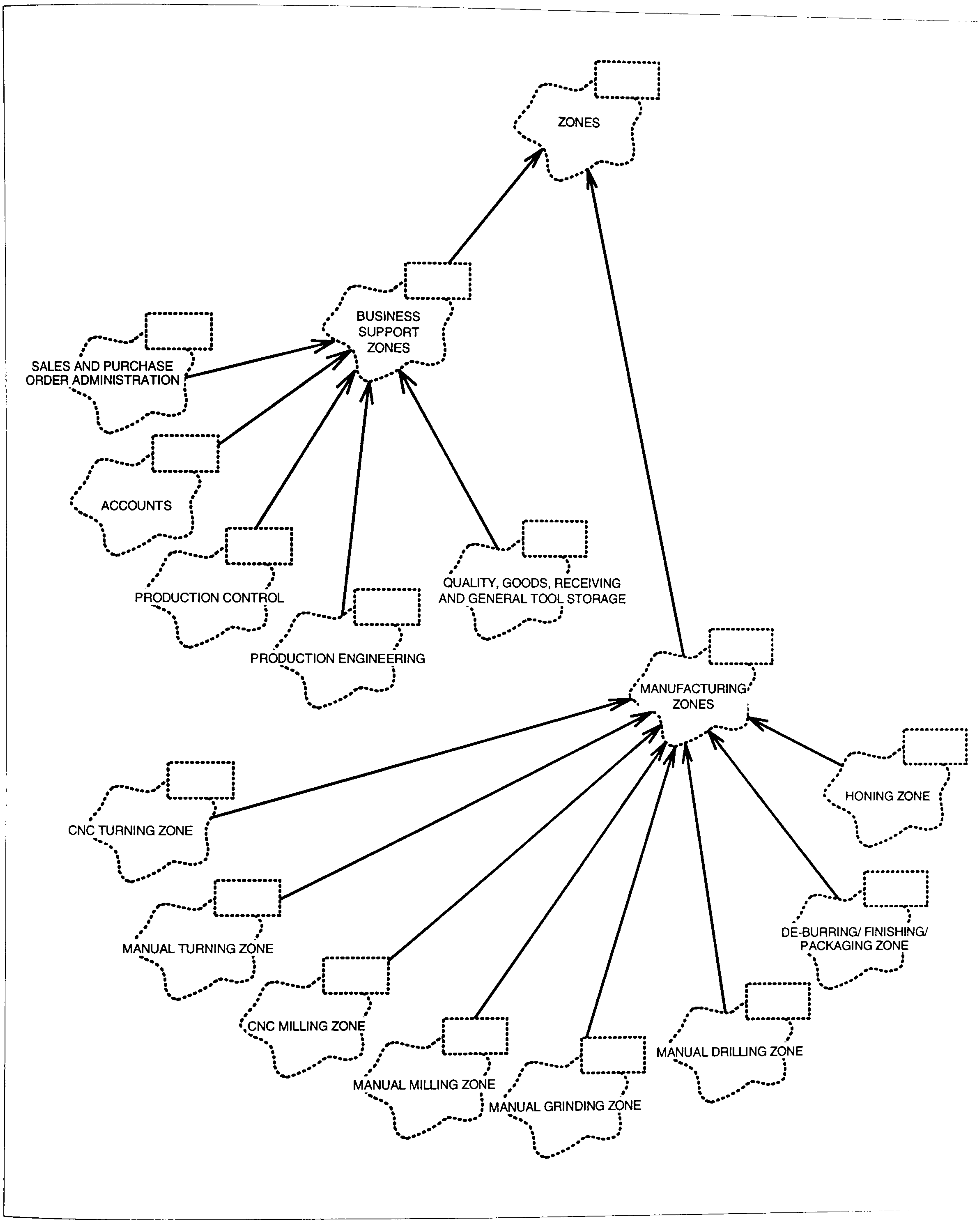


Figure 12.11: Modelling the activity zones of Henton.

12.7 Modelling the Holonic Aspects of the Company

The realisation of the node holon is through its associated zone. To show how the holonic aspects of the company can be modelled, three node holons have been chosen, these are the (i) production planning, (ii) CNC milling and (iii) purchasing node holon. The individual node holons belong to the production planning, CNC milling and the general tool store zones respectively. The realisation of these individual node holons are shown in Tables 12.1, 12.2 and 12.3, where their individual characteristics are modelled as follows:

(i) The production planning node holon is characterised by the production planning process and is a soft node holon, this is shown in Table 12.1 (a). It is further characterised as a shop level node holon, as it oversees the production planning for the shop floor. The primary tendency of the production planning node holon is to cooperate by performing the production planning activity, the analysis of which is shown in Table 12.1 (b).

(ii) The CNC node holon is characterised by the CNC milling process and is further characterised as a workstation level node holon, shown in Table 12.2 (a). The primary tendency of the CNC milling node holon is to cooperate by performing the CNC milling activity, the results of the analysis is presented in Table 12.2 (b).

(iii) The purchasing node holon is characterised by the purchasing process and is also modelled as a shop level node holon, as it oversees the purchasing of material and tools as required by the shop floor, shown in Table 12.3 (a). The primary tendency of the purchasing node holon is to cooperate by processing the purchase orders for the material and tools as required. The results of the analysis of the purchasing activity is shown in Table 12.3 (b).

Analysis of the activities, in accordance to the extended IDEF0 notation, results in the definition of the functional inputs and outputs, control input and output parameters and the resource inputs, the details of which are shown in Tables 12.1 (b), 12.2 (b) and 12.3 (b) respectively for the individual node holons. Table 12.1 (b) shows the results of activity analysis for the production planning activity. The functional input is the sales order and the functional output is the production plans to fulfil the customer orders. The resource input is the production planner who has the responsibility for carrying out the production planning task. Other activities such as the placing of orders for material and special cutting tools are analysed in the same manner. Table 12.1 (b) also indicates that the production planning node has an obligation to cooperate with the purchasing node where the associated activity is the purchase of special tools. With reference to Table 12.3 (c), it can be seen that this situation has originated because the purchasing node holon is unable to raise purchase orders for tooling above a stipulated cost and has, therefore, resorted to imposing this obligation on the production planning node holon.

For every obligation imposed on any of the three node holons to cooperate, there is an accompanying negative contingency situation, these are shown in Tables 12.1 (c), 12.2 (c) and 12.3 (c) for the individual node holons respectively. Each negative contingency situation can be associated to a causal object, which in turn, is identified from the list of functional or resource inputs, upon which the activity depends. When the associated causal objects have been identified, two choices are possible, explained previously in section 10.7. These two situations are:

(i) Where a recourse option can be applied immediately; this is the case for the negative contingency situation "unable to meet due date" affecting the CNC node holon, shown in Table 12.2(c). The causal object has been identified as related to cutting tools and materials, where the shortage of either will result in the contingency situation identified. The cutting tools and material can be traced back to the resource inputs for the CNC milling activity. The recourse option is then to raise an order with the purchasing node to order new tooling and to notify the production planning node of the material shortage.

    In both cases, the CNC node holon also has the autonomy to consider a new processing sequence for the parts, this is subsequently reflected as one of the activities "sequence jobs" which has to be performed, shown in Table 12.2 (b). The CNC node holon therefore has the autonomy to change the priority list and process a job for which there are material and tools available.

(ii) The second possibility is where the recourse option may be governed by conditions, which is the case for the negative contingency situation "unable to issue tooling" affecting the purchasing node holon, shown in Table 12.3 (c). The purchase of tooling is governed by the condition "cost". Two cases have been specified, where the first is if the price of the tool is less than the stipulated amount (cost of tool < £150), it can raise a purchase order. The second case is if the cost of the tool is greater than the stipulated amount (Cost of tool > £150), where the production planning node has to be involved in the purchase. Therefore, in the latter case, the purchasing node holon controls the production planning node, which has to respond by raising the order for special tooling.

Other interactions, which have been shown in Tables 12.1 and 12.3, are those which occur between the purchasing and production planning node holons. The purchasing node holon is subject to negative contingency situations where it may be unable to source the material and tools. The causal object is identified as the absence of supplier catalogues, which will indicate the materials and tools available from the suppliers. The purchasing node holon has to notify the production planning node holon and impose an obligation to respond by investigating other sources of material or tooling. This activity will be carried out in consultation with the customer specifications, which are captured as functional inputs.

The profile of each individual node holon is established in this manner, where its autonomy is distinguished by its column of activities. It should be noted, using the example of the production planning node, that the activity list of a node holon can be extended, when a recourse option involves an activity the node holon can perform on its own. Hence, the recourse activity "sequence job" shown in Table 12.1 (c) is added to the list, thus, characterising the autonomy of the node holon.

12.8 Modelling the Information Support

Analysis of the activities result in the identification of the control input and output parameters, these represent the information support required at the individual node holons. The data parameters are selected to give a supportive insight into the status of the company in terms of order commitments, processes and resources so that employees can respond on an individual basis, with a greater awareness of the company's most pressing customer commitments. The objective, as noted in section 3.3, is to improve the "ad hoc" impulse response to individual priorities as they impinge on individual departments. This requires the specification of information requirements and the presentation of the information in terms of workable, clearly structured lists of data items for individual node holons.

In relation to the concepts introduced by the ARIS modelling approach, these information parameters are the "conditions in the task environment" which provide the support for the processing functions. In the examples shown above, these parameters are related to the jobs to be manufactured, resource inventory status and levels, or information related to the processes employed. It has been emphasised in the examples, that the performance of an activity either requires the support of information, or results in an alteration to the information.

The selection of parameters and their associated information classes are shown respectively in Tables 12.1 (c), 12.2 (c) and 12.3 (c) for the three node holons. The control input parameters specify the information which a particular node holon requires and the control output specifies the information which it needs to update or provide. The classification into technical, administrative and operational attribute types, explained in section 9.4.2, are also shown in the tables.

The production planning node requires information relating to the order due dates specified by the customer and establishes job due dates and routing information. It is required to provide the status of tooling and material on order, in terms of their expected arrival dates and quantity. This information in turn, is accessed by the CNC node holon which has to identify the job priority and sequence the jobs in accordance to the availability of material and tools. To simplify the process planning task, route plans for similar machined components can be retrieved from the order model and adapted for the new job. Such information can be built up by the individual machining node holons as they process any new component.

In performing the machining operations, the CNC node holon builds up information about a job in terms of the start date, completion date and set-up and machining times. It can generate, for future reference, information such as the cutting tools, set-up procedures, fixtures and the parameters used for a particular machining task. These information elements are related to the order model. If the machining node holon has to occupy a shared resource such as a fixture for a particular job, it would be required to specify an expected completion date. Consequently, another machining node holon which may require the same fixture can adapt its work sequence accordingly, until the resource becomes available. Information of this nature is associated to the manufacturing model. Therefore, a machining node holon can be presented with a list of fixtures, and identify from this list, the location and status of a particular fixture which is required. This becomes one of the many possible specifications for an external view format designed for a particular node holon.

Table 12.1 (a)	Node Holon	Characterised by (Level)	Characterised by (Process)
	Production Planning Node Holon	Factory	Production Planning

Table 12.1 (b)	Cooperates (Node Holon)	Activity (Autonomy)	Functional Input	Functional Output	Control Input	Control Output	Resource Input
		Production Planning	Sales Order	Production Plan		Job ID	Production Planner
						Job Due Date	
						Job Quantity	
		Order Material	Part Drawings	Purchase Order	Order Due Date	Material Status	Production Planner
						Expected Arrival Date	Production Planner
	Purchasing Node Holon	Special Tool Purchase	Tool Description	Purchase Order	Order Due Date	Expected Arrival Date	Production Planner
	Purchasing Node Holon	Consider Alternative Material	Customer Specifications				
	Purchasing Node Holon	Consider Alternative Tools	Customer Specifications				

Table 12.1 (c)	Negative Situation	Causual Object	Condition	Case	Recourse Option	Controls (Node Holons)	Autonomy
						CNC Node Holon	

Table 12.1 (c)	Control Parameter	Attribute Type	Associated Information Class
	Job ID		Job Class
	Job Due Date		Job Class
	Job Quantity		Job Class
	Material Status		Material Class
	Expected Arrival Date (Material)		Material Class
	Expected Arrival Date (Cutting Tool)		Cutting Tool Class
	Order Due Date		Order Class

Table 12.1: The profile of the production planning node holon.

Table 12.2 (a)	Node Holon	Characterised by (Level)	Characterised by (Process)
	CNC Milling Node Holon	Factory	CNC Milling

Table 12.2 (b)	Cooperates with (Node Holon)	Activity (Autonomy)	Functional Input	Functional Output	Control Input	Control Output	Resource Input
	Production Planning Node Holon	CNC Milling	Material	Machined Parts	Job Due Date	Job Location	Operator
			Part Drawings		Tool Location	Job Start Date	Fixtures
						Job Complete Date	Cutting Tools
						Job Status	
						Machining Time	
						Number Completed	
						Fixture Location	
						Tool Location	
		Sequence Jobs	Job List	Job Sequence	Job Location		Operator
		Generate Part Program	Part Drawing	Part Program			Operator

Table 12.2 (c)	Negative Contingency Situation	Causal Object	Condition	Case	Recourse Option	Controls (Node Holons)	Autonomy
	Unable to Meet Due Date	Cutting Tools			Raise Order	Purchasing Node	Sequence Job
		Material			Notify Production Planning	Production Planning	Sequence Job

Table 12.2 (d)	Control Parameter	Attribute Type	Associated Information Class
	Job Due Date		Job Class
	Tool Location		Cutting Tool Class
	Job Location		Job Class
	Job Start Date		Job Class
	Job Complete Date		Job Class
	Job Status		Job Class
	Machining Time		Job Class
	Number Completed		Job Class
	Fixture Location		Fixture Class

Table 12.2: The profile of the CNC milling node holon.

Table 12.3 (a)	Node Holon	Characterised by (Level)	Characterised by (Process)
	Purchasing Node Holon	Factory	Purchasing

Table 12.3 (b)	Cooperates (Node Holon)	Activity (Autonomy)	Functional Input	Functional Output	Control Input	Control Output	Resource Input
	CNC Machining Node Holon	Issue Tooling	Tool Supplies	Tool Issues	Tool Level (Quantity)	Tool Level (Quantity)	Purchasing Personnel
	Production Planning Node Holon	Purchase Material	Material List	Purchase Order			Purchasing Personnel
			Supplier Catalogue				
	Production Planning Node Holon	Purchase Tool	Tool List	Purchase Order	Requirement Date	Expected Due Date	Purchasing Personnel
			Expected Due Date			Quantity on Order	
			Quantity on Order				

Table 12.3 (c)	Negative Contingency Situation	Causual Object	Condition	Case	Recourse Option	Controls (Node Holons)	Autonomy
	Unable to Issue Tooling	Tool Supplies	Cost	Cost < £150	Purchase Tool		
				Cost > 150	Special Tool Purchase	Planning Node Holon	
	Unable to Source Material	Supplier Catalogue			Notify Production Planning	Planning Node Holon	
	Unable to Source Tools	Supplier Catalogue			Notify Production Planning	Planning Node Holon	

Table 12.3 (d)	Control Parameter	Attribute Type	Associated Information Class
	Tool Level (Quantity)		Cutting Tool Class
	Requirement Date		Cutting Tool Class
	Expected Due Date		Cutting Tool Class
	Quantity on Order		Cutting Tool Class

Table 12.3: The profile of the purchasing node holon.

Chapter 13

The Information Specification Case Tool Based on the Reference SME Enterprise Model

13.1 Introduction

The purpose of this chapter is to describe the prototype information specification CASE tool which has been developed to support the information specification process and to demonstrate the concepts introduced in this thesis. This chapter will briefly introduce the computational environment of the Microsoft applications development system, Visual C++, which has enabled the creation of the CASE tool. The two principal types of user interfaces which have been developed are introduced and explained. This is followed by a description of the fundamental components of the CASE tool, where major aspects of its functionality will be highlighted using the information from A.O. Henton.

13.2 The Computational Environment for the Development of the Prototype Information Specification CASE Tool

The prototype information specification CASE tool is a windows based application which has been implemented using the Microsoft development system, Visual C++ (Microsoft, 1996). The development system is object oriented, where the visual user-interface objects such as windows, dialogue boxes, dialogue controls and menus are encapsulated as object classes and provided by the Microsoft Foundation Class Library (Microsoft, 1996). The object classes supply the functionality common to most applications developed for windows based operating environments. The most commonly used object class is the dialogue class, which encapsulates the functionality of the Windows dialogue-box and controls. This class is invariably used in conjunction with the control classes such as buttons, list boxes, edit boxes and check boxes, etc. An important feature of the object classes derived from the Foundation Library is the support for object persistence; this is the ability to serialise (or store) the data structures created. This allows a number of SME companies to be modelled and a repository of these separate instances of enterprise data models to be created.

To create any new software application under the Microsoft development system, specific classes have to be derived from the appropriate object class supplied by the Foundation Class Library. Additional functionality can be added to the derived application classes or existing functions in the foundation classes can be overridden to supply new operations. Design of the user interface is thus supported by the set of foundation classes provided by the development system. In addition to the visual aspects of the user interface design, the structure and kernel functionality of the CASE tool itself has to be created.

The structure of the CASE tool is underpinned by the constructs of the reference SME enterprise model, which has been captured in the Booch class diagrams. The kernel functionality of the CASE tool is provided by the methods (or member functions) implemented into the individual classes. During run-time, objects (or instances of the application classes) are created and respond with appropriate action to function calls from other objects. The methods determine how individual classes will respond to user control selections which may be the creation, editing or the deletion of objects. Interaction with the CASE tool is achieved through the selection of items from menu bars, list boxes or the operation of control buttons.

The CASE tool is built around two principal categories of dialogue interfaces. The first category is designed around a list-box which displays a list of objects which have been created and stored. The second category is based on a modelling template which enables instances of classes to be created. Examples of these two categories of dialogue interfaces are shown throughout this chapter. There are other user interfaces, such as message or warning dialogues which, for example, alert the user when erroneous entries are made. This latter group of interface plays an auxiliary role in the CASE tool and will not be discussed.

13.2.1 Dialogue Based List Boxes

The first category of user interface is based around the list-box, an example of which is shown in figure 13.1. List-boxes are a class of common windows based application interfaces. The use of this class of user interface comes from the need to display and browse through lists of data objects, from which any particular item can be identified and selected. This is shown in figure 13.1 by the highlighted item.

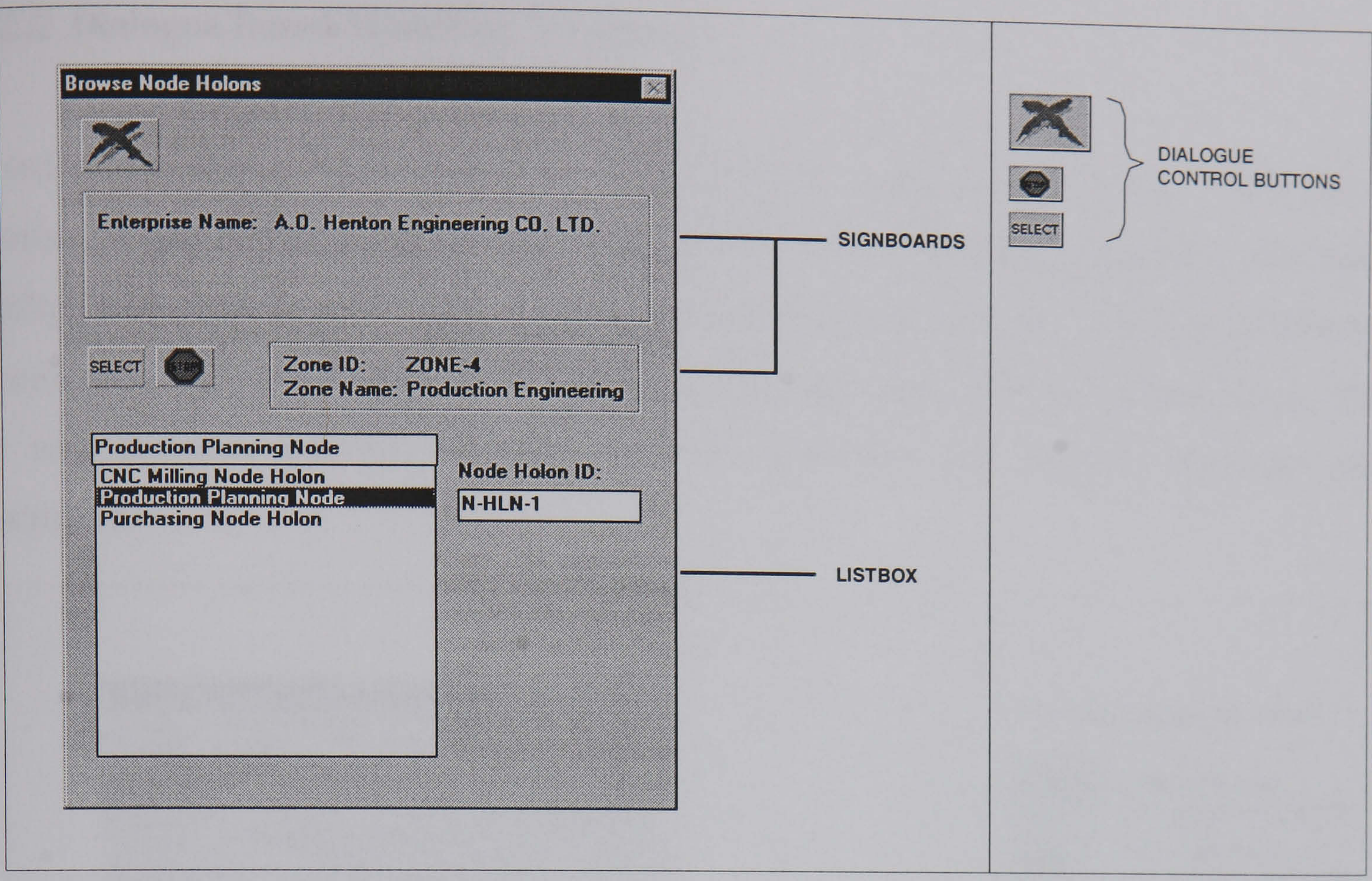


Figure 13.1: An example of a list-box user interface for the CASE tool.

In general, the list box demonstrates the implementation of relations between classes, whose associations are characterised by the one to many relation (1...n), shown throughout the Booch class diagrams in chapters 9 and 10. As the dialogues are invoked, the particulars of the information class are displayed in the signboard above the list box. The data objects in the list box are read in and an index is assigned. The index is an integer which indicates the position of the data objects in the list, this is fundamental to maintaining a current record when items are added or removed. The index of any highlighted item is automatically tracked, which enables the object to be readily identified each time a selection is made.

Class browsers are a major application of dialogue interfaces based on list-boxes, these allow users to view all the data items in the list and make any necessary selection from the list, this is shown above in figure 13.1. A major application of this class of user interface is to enable the relevant process and resource descriptions to be selected from the taxonomy and associated to any facility level. The ability to view the taxonomy of processes and resources is provided by the class taxonomy browser, which is described in greater detail in the following sections.

13.2.2 Dialogue Based Modelling Templates

A series of dialogue based modelling templates have been created for the CASE tool, an example is illustrated in figure 13.2. Examples of other modelling templates will also be highlighted in later figures. The modelling template shown in figure 13.2 is used during the specification of a new facility. Modelling templates are based around text edit fields, where the user provides information such as object identifier (ID), object name and object description.

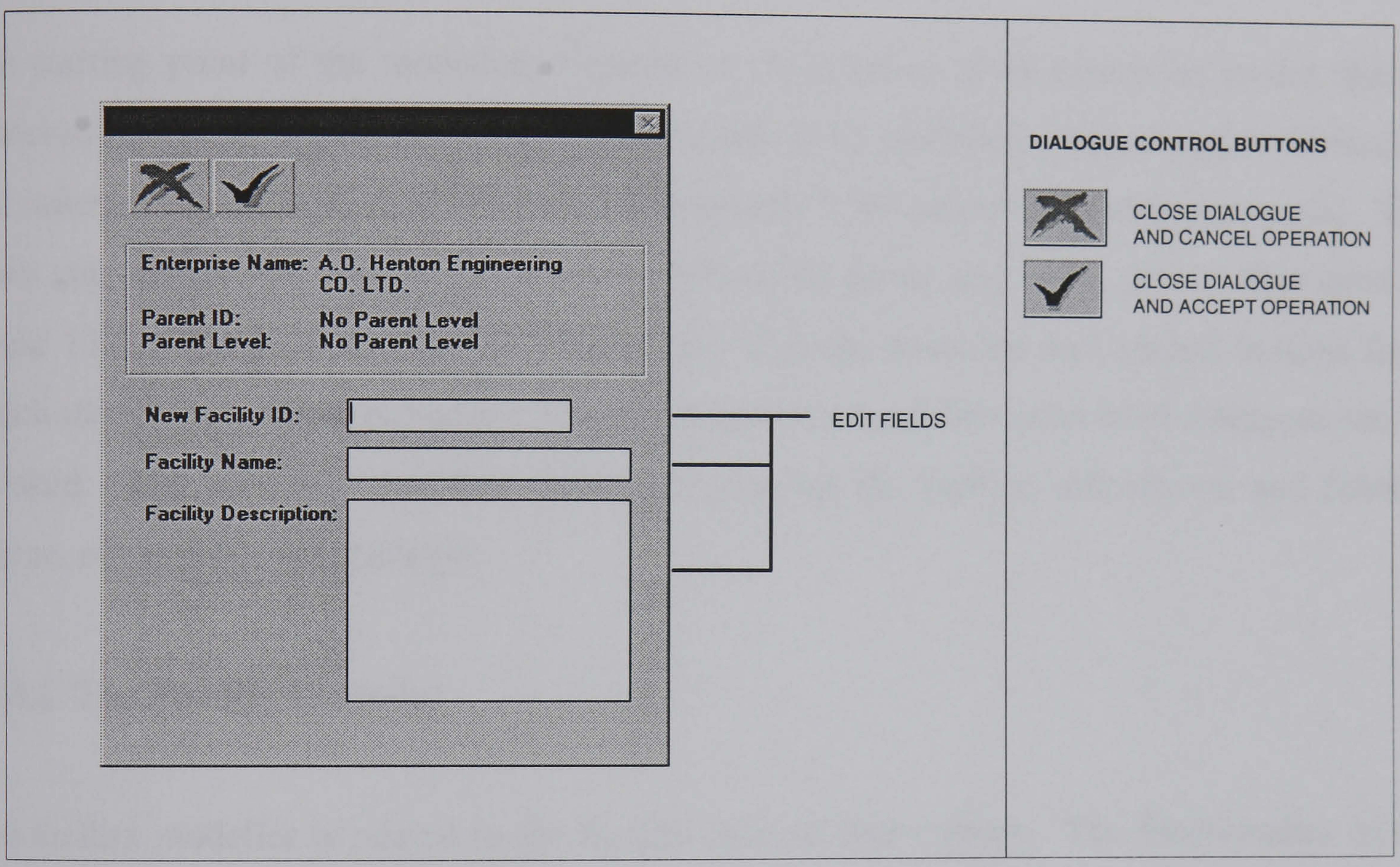


Figure 13.2: An example of a dialogue based modelling template for the CASE tool.

Object identifiers are necessary to provide all data objects with a unique identity. When the text edit fields are filled with the appropriate data, new objects are constructed based on the information provided. In the example shown above, acceptance of the given information within the text fields would result in the creation of a new facility object. Similar modelling templates have been implemented to allow the creation of all constructs which constitute the SME enterprise model, these are invoked for the creation of any new object class during run-time and results in the population of the data structures.

13.3 The Principal Components of the Information Specification CASE Tool

The information modelling tool is based around three principal components which support the modelling process, namely a class taxonomy modeller, a facility modeller and an holonic[7] modeller. The main application interface is illustrated in figure 13.3, which shows the three principal modelling components. There is a direct correlation between the three components of the CASE tool and the three field approach to data capture, previously discussed in sections 7.5 and 9.4.

The starting point of the modelling exercise is the creation of an enterprise model, this is achieved by specifying the details of the enterprise to be modelled. The facility, information and holonic aspects of the company are subsequently built around this enterprise model. The main application interface is based on the Windows frame and view, this is illustrated in figure 13.3. The main application window provides the menu bar and control buttons from which the three principal modelling support components and their associated dialogues can be invoked. The user may therefore choose to populate the facility, information and holonic aspects of the model accordingly.

13.3.1 The Facility Modeller

The facility modeller is related to the facility field of data capture. The functionality of the facility modeller is to enable the manufacturing facility of a specific enterprise to be created. The principal user interface for modelling the facility is illustrated in figure 13.4, which shows the facility dialogue displaying the details of the shop floor facility. This particular shop facility has a number of machining cells which are displayed in the list-box. The user may select a particular facility and use the "navigate down" control button to progress to a lower facility level. In this instance, selecting the navigation button will bring up the list of workstations for the CNC milling cell which has been highlighted by the cursor.

[7] The holonic modeller is a component of the CASE tool which supports the modelling of zones, the associated node holons and their interactions.

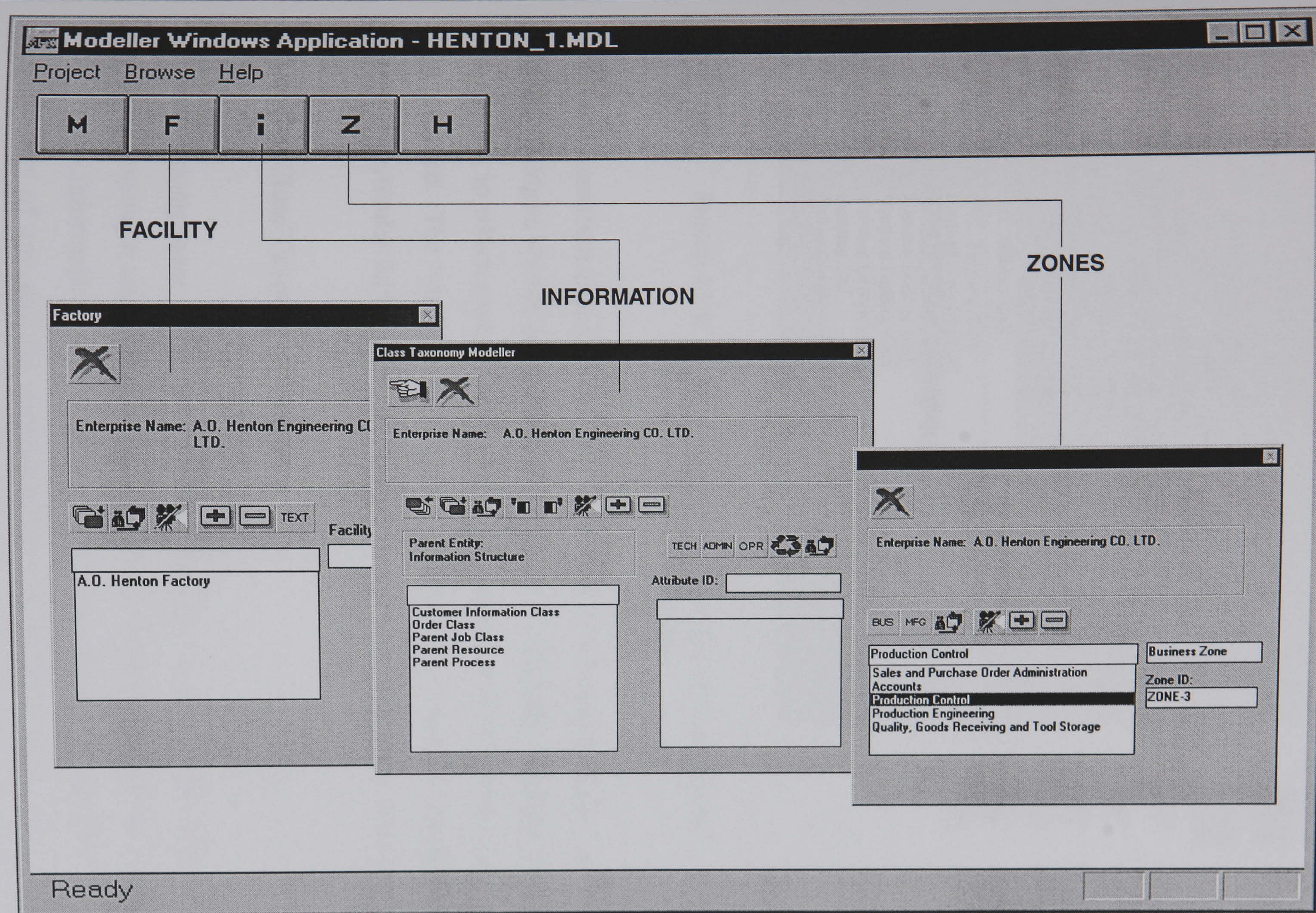


Figure 13.3: The main application interface shows the facility, information and holonic modelling components.

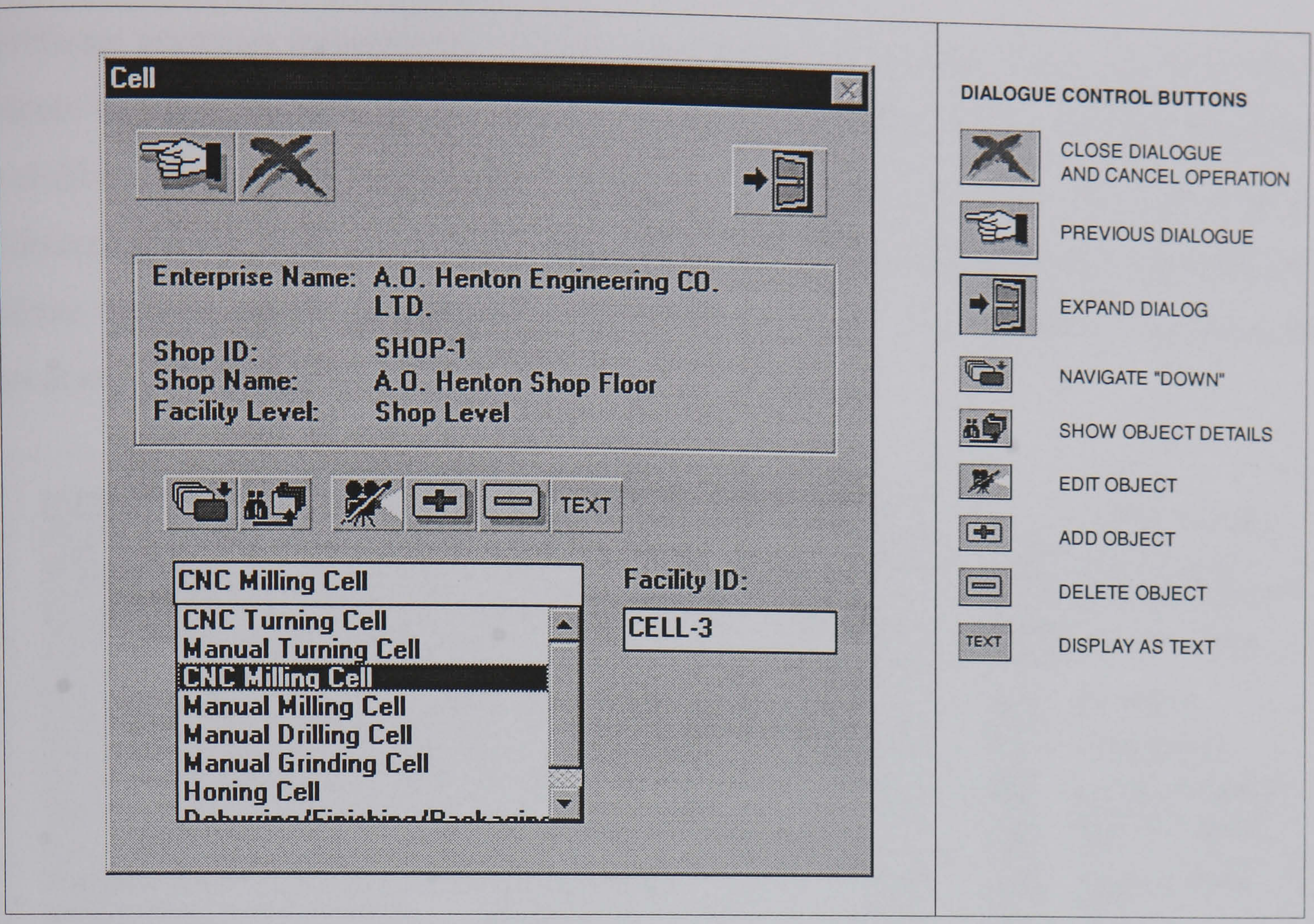


Figure 13.4: The principal user interface for modelling the manufacturing facility.

Additional manufacturing facilities may be added, which would require the facility modelling template dialogue shown previously in figure 13.2. Equally, facilities may also be deleted from the list, in which case, all the associations created with the chosen facility will also have to be removed. The "show object details" control button is used to establish the associations between a particular facility and the resource and process taxonomy structures.

13.3.2 The Class Taxonomy Modeller

The second component of the CASE tool is the class taxonomy modeller which enables the process and resource taxonomies to be created, the interface is illustrated in figure 13.5. This relates to the information field of data capture, where the taxonomy structures can be created independently of any specific instance of manufacturing facility. The taxonomy modeller consists of two list-boxes, the first displays a list of the information classes which have been modelled. The second list box displays the attributes which are associated to the information class. Control buttons have been built in to display the technical, administrative and operational attributes respectively. An important feature of the taxonomy modeller is that any attribute which is added to a higher level class in the taxonomy is automatically inherited by the child class. Therefore, if the attribute "process cost" is specified for a machining process, all derived classes such as CNC machining processes and turning processes also inherit the attribute "process cost". In addition, specific attributes may also be added to an information class at any particular level.

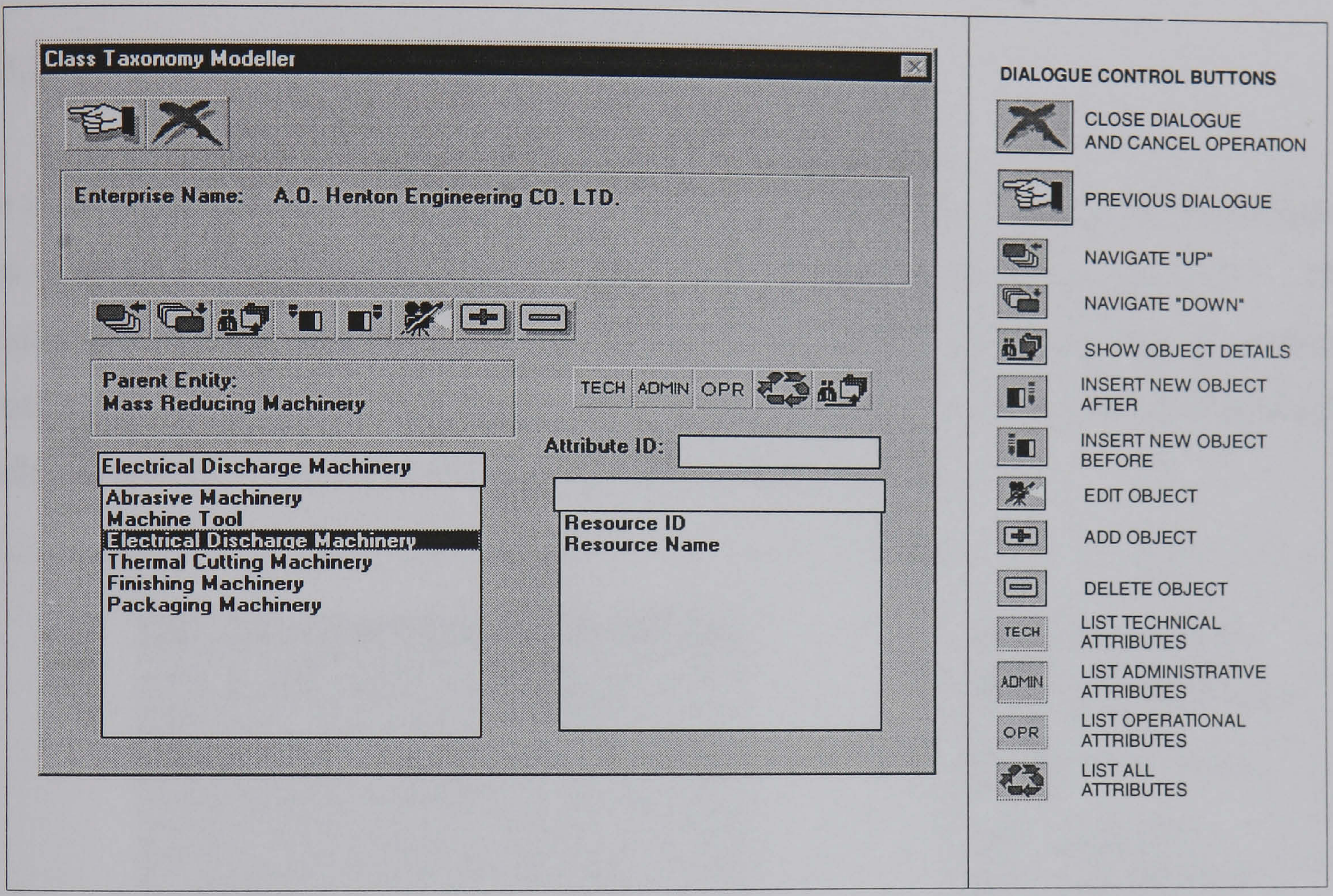


Figure 13.5: The class taxonomy modeller which enables the information class taxonomies to be created.

The class taxonomy modeller includes the "navigate-up" and "navigate-down" controls which provide the means of viewing individual levels of the entire taxonomy. Dialogue controls are also provided to enable the navigation into lower or higher levels of the class structure. New information classes can be added to, or deleted from the list at any particular level of the taxonomy. The taxonomy modeller has to maintain the integrity of the taxonomy when any information class is removed or added at the intermediate levels of the structure, this enables the correct inheritance of information attributes to be maintained as the taxonomy evolves. There are two scenarios which have to be considered, the first is when an information class is deleted from the hierarchy. In this instance, the taxonomy tree of derived classes below the deleted class has to be moved onto the parent of the deleted class. The second scenario involves the addition of a class to the taxonomy, where in this instance, the taxonomy tree of derived classes has to inherit from a new parent class. The taxonomy structure is maintained as each information class is incorporated with a record of its parent classes, i.e. each information class has a record of its genealogy. Any modifications to the taxonomy will result in updates to the genealogy record of the classes affected by the changes.

13.3.2.1 Modelling the Information Attributes

The class taxonomy modeller provides the interface for modelling the information attributes. This is achieved by using the "show object details" control illustrated in figure 13.5. This invokes the attribute dialogue shown in figure 13.6, which displays the list of attributes associated to a selected information class. Attributes may then be modelled accordingly, where the options would be to add, delete or edit individual attributes.

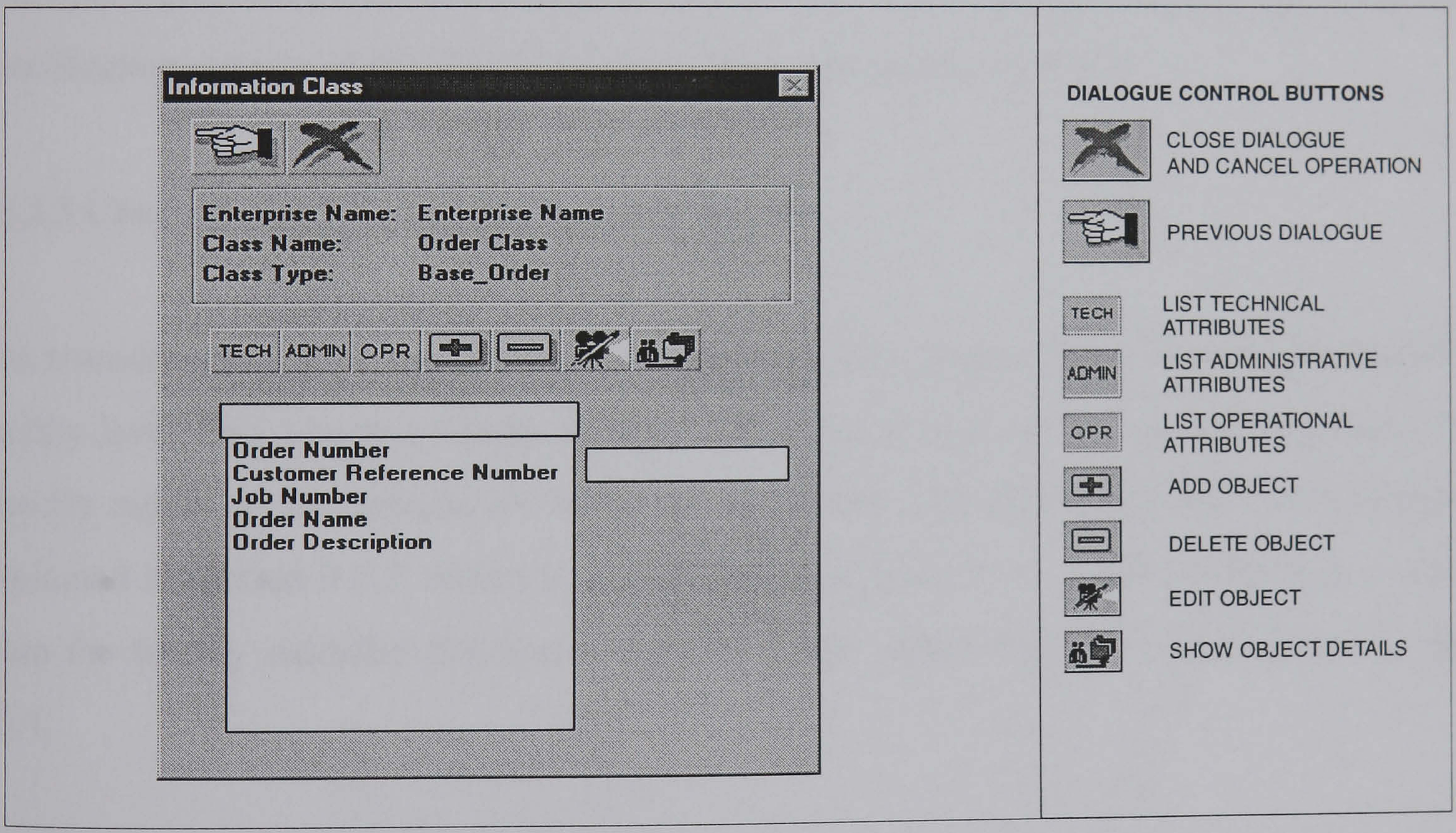


Figure 13.6: The list box interface which displays the attributes associated to a selected information class.

Information attributes may be specified as technical, administrative or operational attributes, these categories have been explained in section 9.4.2. When a new attribute is added, the user is prompted to specify either a compound or simple attribute. The simple attributes which may be specified with the CASE tool are integers, float numbers and character strings.

The set of simple attribute types listed above are seen to provide adequate coverage to satisfy the spectrum of the various information attribute types to be represented. This capability, however, can be readily extended, if required, by deriving other specialised attribute types from the generic attribute class.

Although the information attributes can be modelled solely within the information taxonomy modeller, it is not expected that the attributes specified in isolation from the third view of data capture will constitute a complete or robust specification. The specification of information attributes has to be carried out with a view to providing the most appropriate support for the interactions between node holons. The specification of information is therefore carried out in conjunction with detailed analysis of the activities which are identified using the holonic concepts which have been introduced in this thesis. The implementation of the information specification aspects of the CASE tool is described in section 13.3.4.3.

13.3.3 Creating the Manufacturing Data Model

The manufacturing data model is created by establishing an association between the individual facility levels and selected classes defined within the process and resource taxonomies. This directly relates to the association between the facility and information field of data capture explained in section 9.4.3, which is also depicted in figure 9.11. This relationship is created from the facility modeller dialogue using the "show object details" control shown in figure 13.4.

The "show object details" control invokes a facility dialogue, illustrated in figure 13.7, which displays the process and resources associated to a particular facility. It should be noted that the same dialogue interface applies to all the facility levels. In the example shown, the resources and processes are listed for the CNC milling cell facility. At any one time, a selection can be made to display either the processes related to the processes or the list of resources associated to the CNC milling cell.

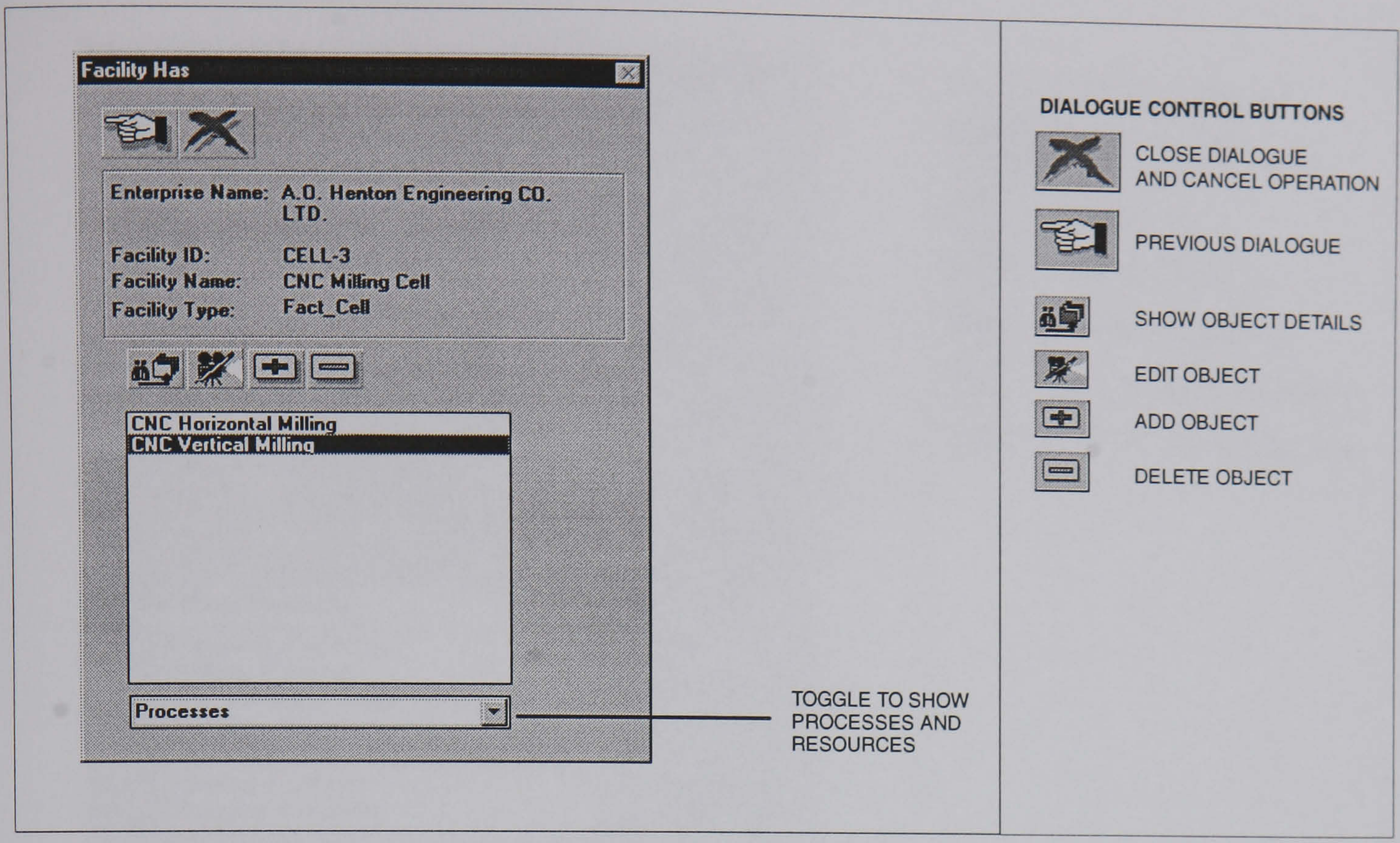


Figure 13.7: The dialogue interface for showing the list of processes and resources associated to a particular facility level.

In order to instantiate a model of any particular manufacturing facility, it is necessary to select a particular information class from the taxonomy structure. The choice is based on selecting a process or resource information class with the most appropriate degree of abstraction, which best describes the facility's resource and process capability at any chosen level, this has been explained in section 9.4.3 and depicted in Figures 9.10 and 9.11. In turn, this requires a class browser dialogue, shown in figure 13.8, which enables the user to navigate through the various levels of the taxonomy in order to ascertain the most appropriate descriptive resource or process class.

Once a suitable descriptive class is identified, the "select" control, shown in figure 13.8, creates an association between the facility level and the chosen item from the class taxonomy. In this instance, the milling process has been selected. As a consequence, the CNC milling cell will be described as having "milling" as an associated process. It should be noted that more than one process can be selected. If a suitable information class is not found, a new class may be created and added to the existing taxonomy. The class taxonomy modeller can be invoked using the "model" control shown in figure 13.8. In this manner, the taxonomies are continually enhanced with the identification of more specialised classes or levels of abstraction.

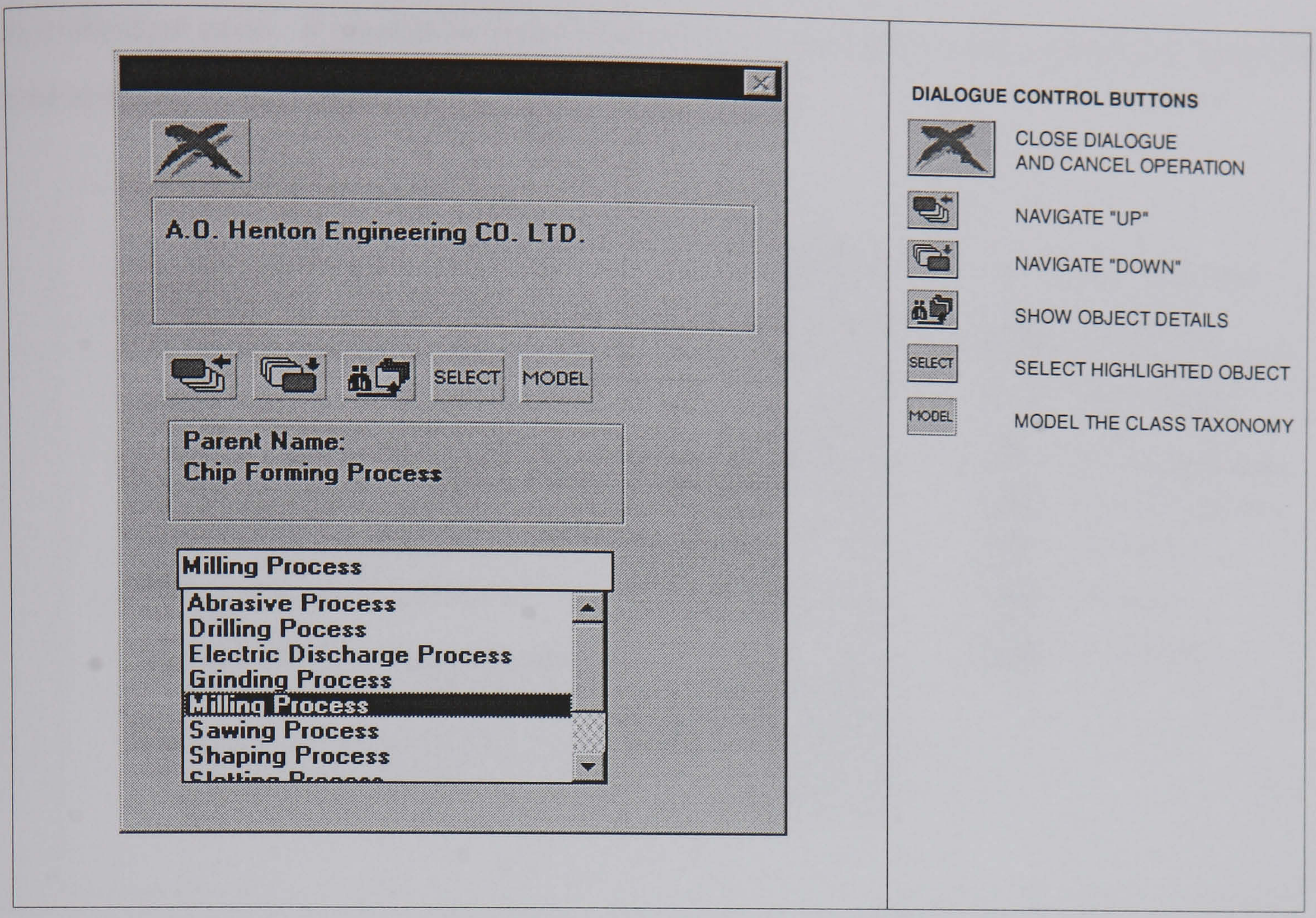


Figure 13.8: The class browser dialogue for navigating through the various levels of the taxonomy.

13.3.4 The Information Specification Modeller Based on Holonic Concepts

The information specification component of the CASE tool corresponds to the third field of data capture which is based on capturing, in holonic systems terms, the organisation and employee interactions within the company. The organisation is modelled as zones using the dialogue shown in figure 13.9, which enables a list of business support and manufacturing zones to be captured. The choice between the list of business support or manufacturing zones can be selected using the appropriate control shown in the figure. Where appropriate, the list of zones can be extended by specifying and creating new zones. The "show object details" control displays the list of node holons existing in any of the zones which have been highlighted.

The population of node holons in an individual zone may be subsequently displayed using the zone dialogue shown in figure 13.10. The dialogue functionality is similar to that used for modelling the business and manufacturing zones. Node holons may be added or deleted from an individual zone. It should be noted that the dialogue also has the controls to show both the hard and soft node holons.

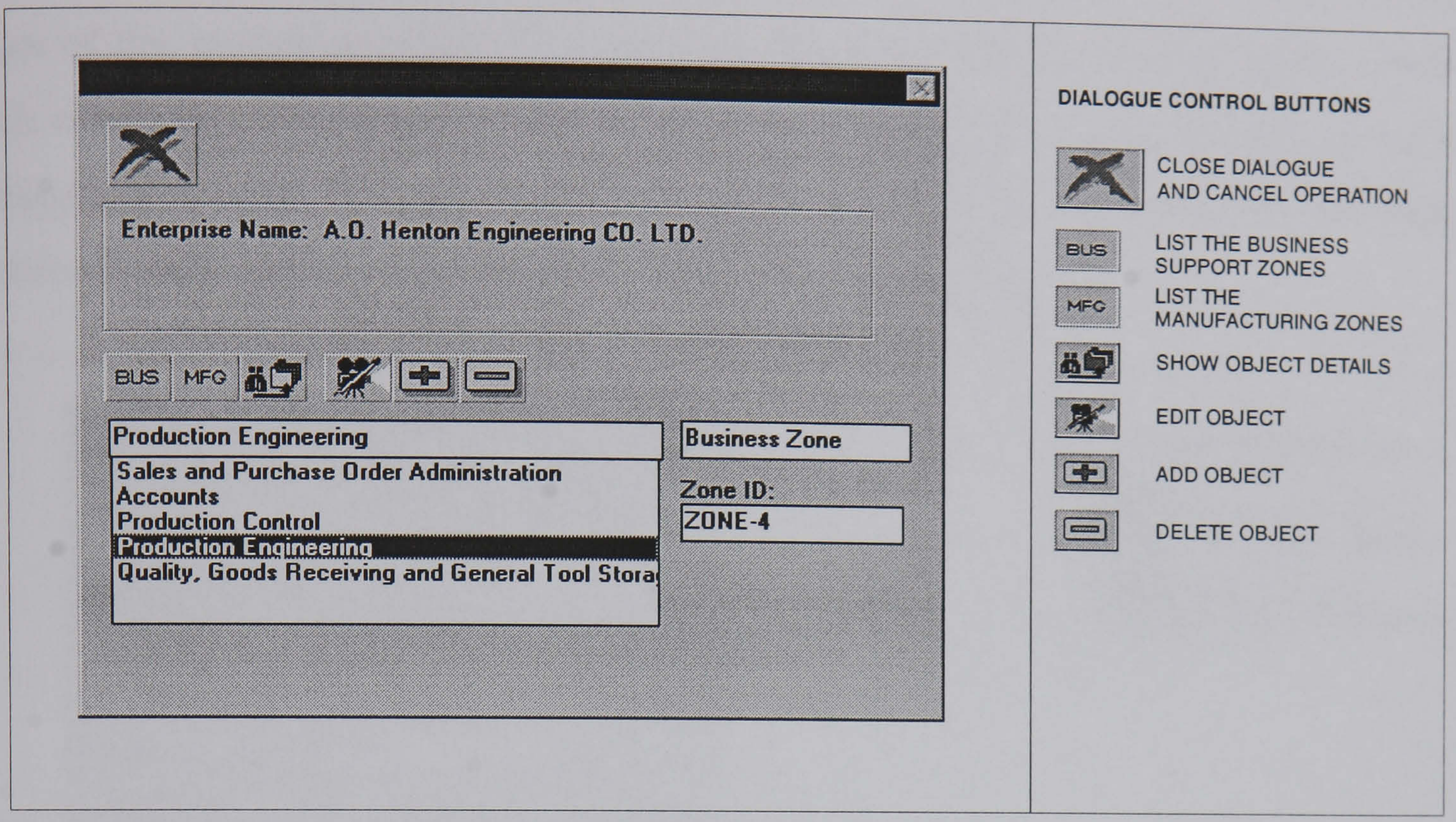


Figure 13.9: The interface for modelling and showing the business support and manufacturing zones.

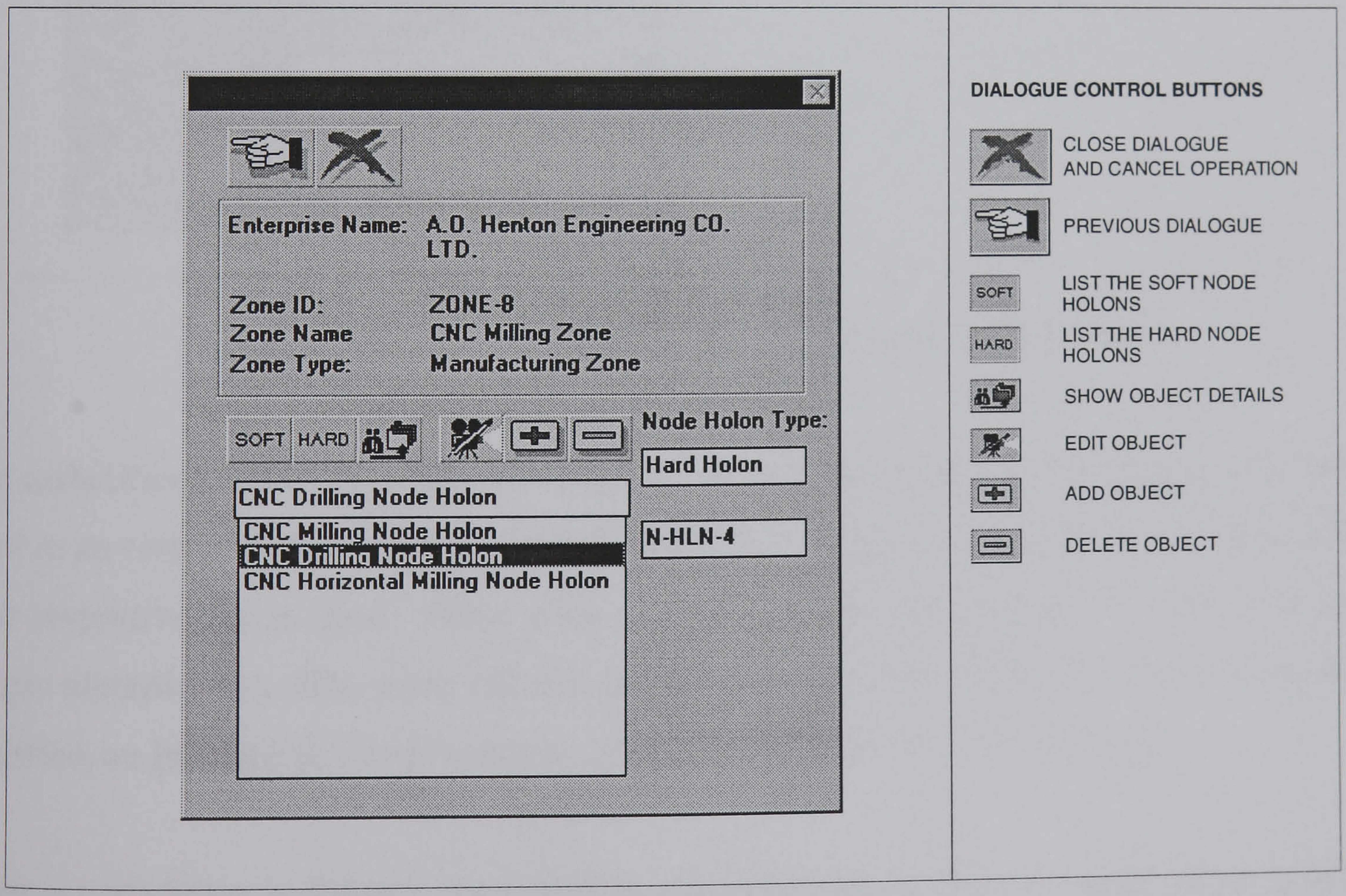


Figure 13.10: The interface for modelling and displaying the node holons in an individual zone.

13.3.4.1 The Creation of a Node Holon

Node holons are created using a modelling template shown in figure 13.11. The distinctive feature of this modelling template is the access it provides to process and facility browsers, which enable the process and facility aspects of the node holon to be defined. It has been explained in section 10.3, that the node holon is characterised in terms of its principal functionality and by the facility level to which it can be associated.

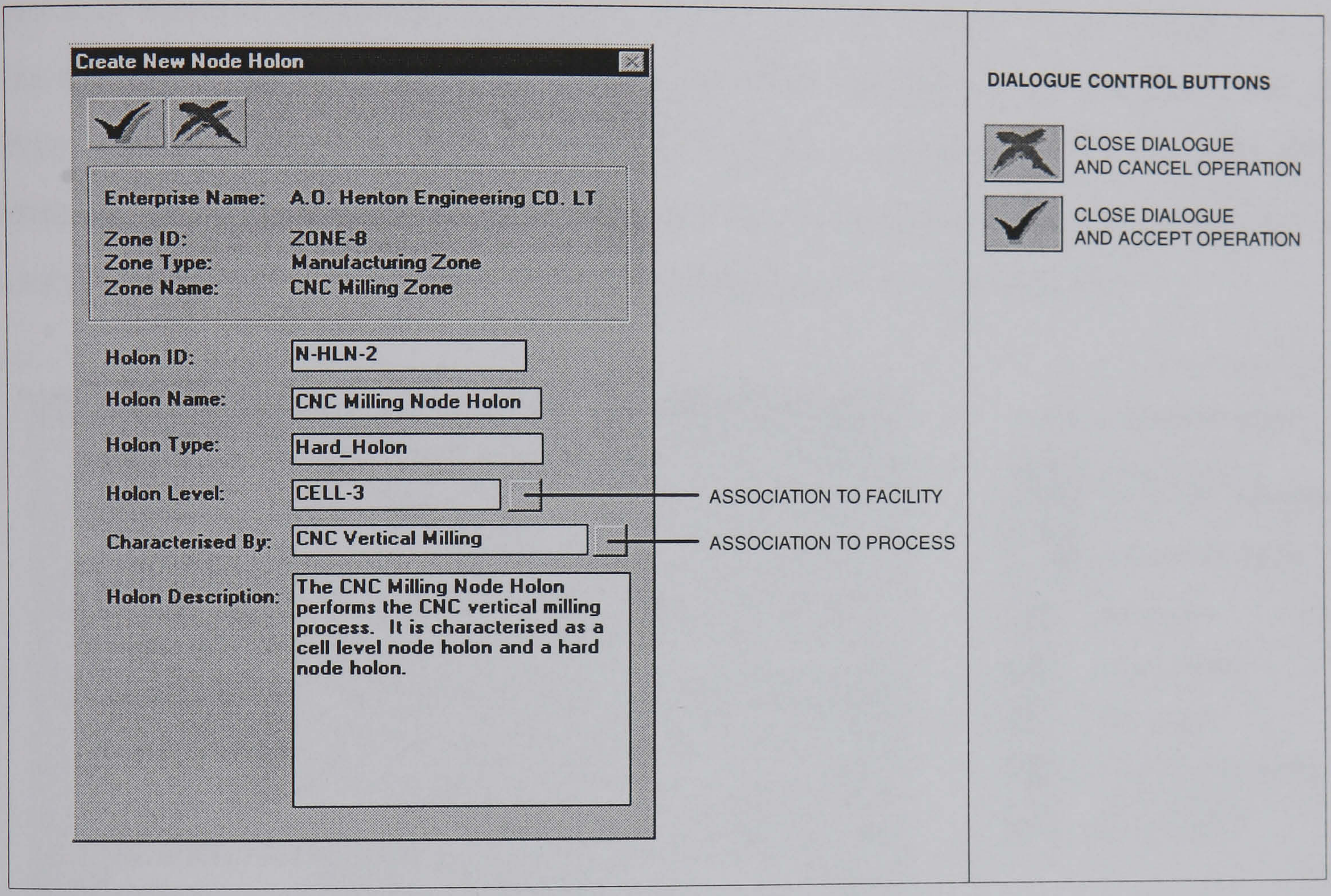


Figure 13.11: The modelling template for creating node holons.

The associations which give the node holon its principal identity and distinguish its facility level in an enterprise are created by choosing the appropriate process and facility classes from their respective taxonomies. Other details which are required to define a node holon are a unique identification (ID), name and description. Once the parameters have been completely specified, an instance of a node holon is created and added to the relevant zone.

When a node holon is defined, the CASE tool automatically creates a cooperation mechanism where the node holon is obliged to cooperate by performing its principal functionality, i.e. if the node holon is identified as a machining node holon, it cooperates by producing machined components. In turn, a negative situation is immediately introduced, this is used to represent the circumstance where the node holon is unable to fulfil its obligation. The modelling of such situation types and their causes with the CASE tool is described in detail in section 13.3.4.5.

13.3.4.2 Activity Modelling using the CASE Tool

Every node holon is responsible for the performance of a set of activities (described in section 10.3); activity analysis is carried out using the modelling dialogue shown in figure 13.12. The activity analysis dialogue is created around the principal elements of the extended IDEF0 formalism, where the functional input-output elements, control input-output parameters and the supporting resource inputs are captured and displayed using combo boxes.

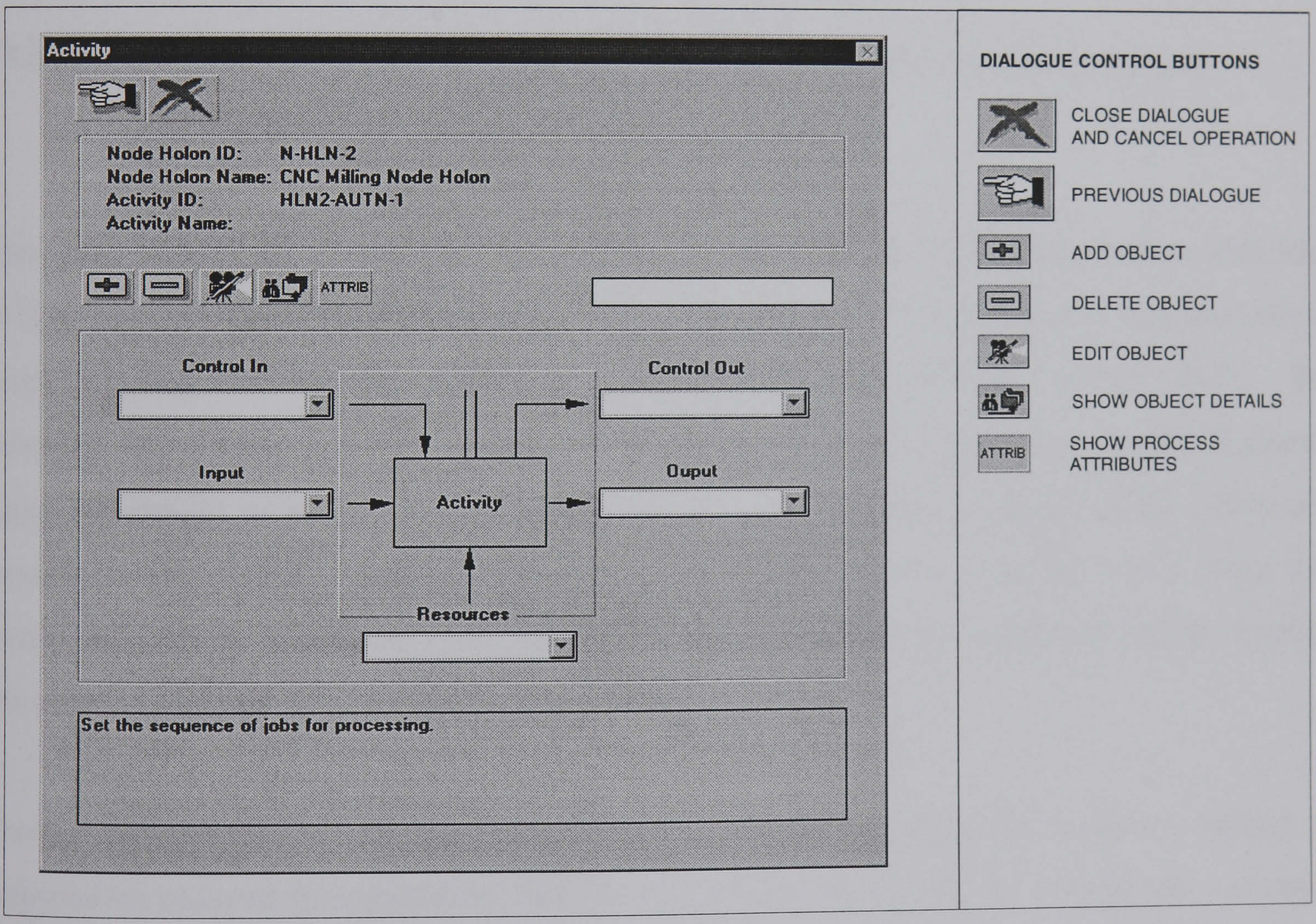


Figure 13.12: The activity modelling dialogue for activity analysis.

The type of objects which constitute the functional inputs and outputs are determined by the activity being modelled. For a machining activity, the functional inputs are the raw material, bought-in components, component drawings, etc. The functional outputs are the completed components. In the case of information processing activities, the functional inputs may be sales order forms, purchase requisition forms, etc. The functional input and output of an activity are specified with modelling templates and the addition of any new item will be reflected in the combo style list-box.

The resource inputs are the machine tool, the human resource (operators), machining fixtures, cutting tools, inspection gauges, etc. A prerequisite in specifying the resource inputs is that the source of objects have to be obtained from the resources identified within the facility. Therefore, the use of resources defined in the manufacturing data model is a necessary, but logical constraint, as not all the resources defined in the generic resource taxonomy may be present in a particular company. The specification of the control input and output parameters is a major objective and is described in the next section.

13.3.4.3 The Specification of the Information Attributes for the Order and Manufacturing Data Models

The specification of the information attributes relating to the information classes identified within the orders and manufacturing data models is carried out in conjunction with the activity analysis using the extended IDEF0 formalism described previously (section 10.5). The relationship between activity analysis and information models is pivotal; elements of control input and output of an activity are derived from the information elements of the orders and manufacturing model. Access to the information attributes is provided via a class and attribute browser, illustrated in figure 13.13, which enables the selection of the required information element for the control parameters.

During the process of activity modelling, there will invariably be instances where an information element is unavailable, here the required attribute may be created and associated to the relevant information class. The procedures and dialogues used for modelling the information attributes are identical to those described in Section 13.3.2.1.

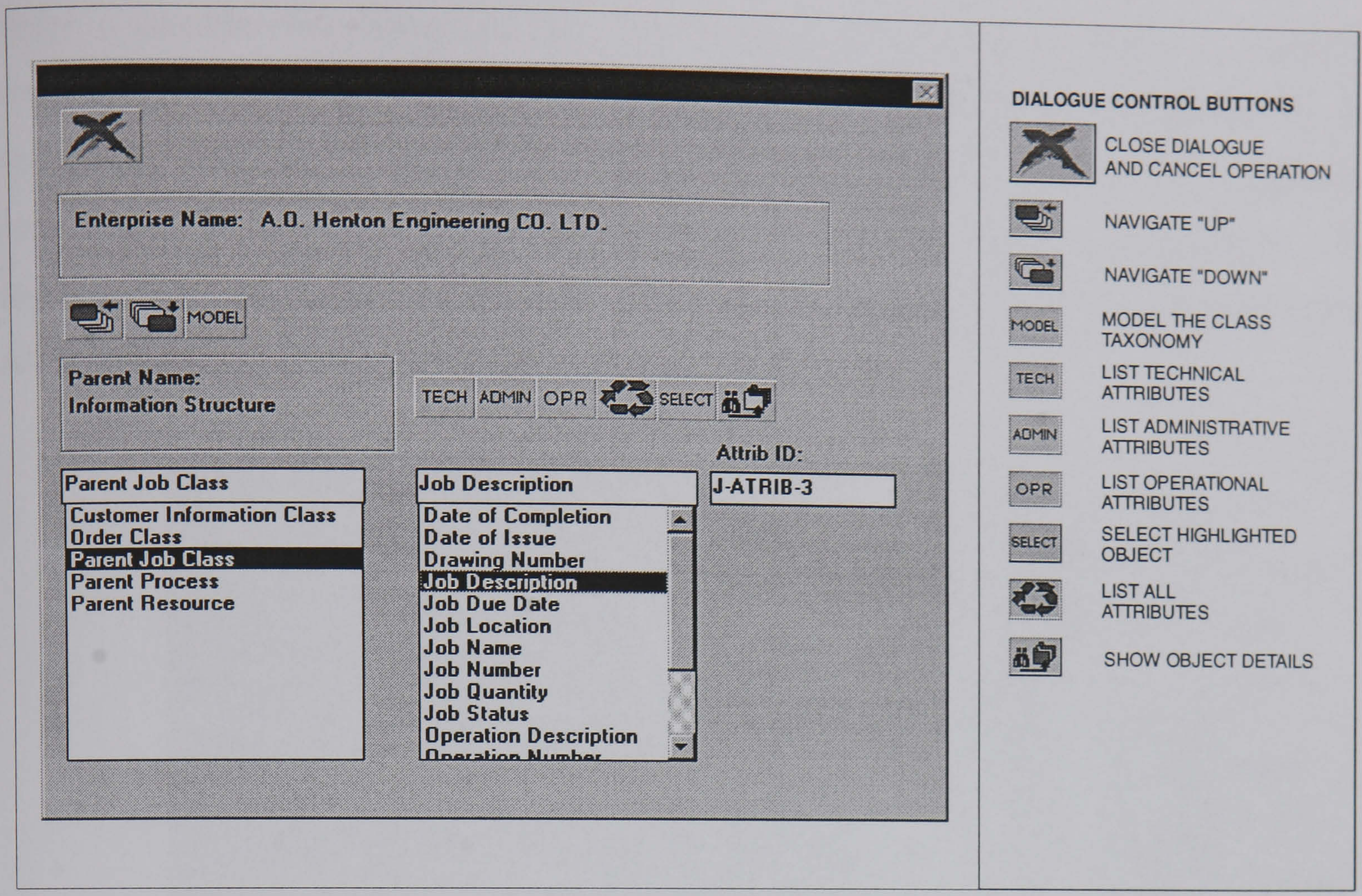


Figure 13.13: The information class and attribute browser which enables the selection of the required information element.

13.3.4.4 Modelling the Profile of a Node Holon

The holonic aspects of a node holon are characterised in terms of autonomy, control and cooperation. The main dialogue interface for a node holon is illustrated in figure 13.14, where selection of the dialogue controls enables the viewing of the respective autonomous, control and cooperative aspects of the node holon. The autonomous aspect lists all the activities for which that particular node holon is responsible for performing and reflects its overall functionality. The control and cooperative aspects define the relationship a node holon has with other nodes in the organisation. The profile of the node holon is drawn from modelling these holonic aspects, a process which has to be carried out in conjunction with the other node holons in the holarchy.

The control aspects are modelled by creating a control mechanism, through which a node holon imposes an obligation on another node holon. The control mechanism may involve a number of responding node holons. Therefore, the process of creating a control mechanism involves identifying the node holons within the holarchy which have to respond cooperatively.

When a suitable node holon has been identified, the CASE tool automatically creates a cooperation mechanism which leads to the definition of a responding activity for the cooperating node holon. In this manner, modelling of the functional aspects of individual node holons is inextricably related to the definition of their roles in the holarchy. The resulting list of activities which a node holon has to perform may be accessed via its autonomous mechanism.

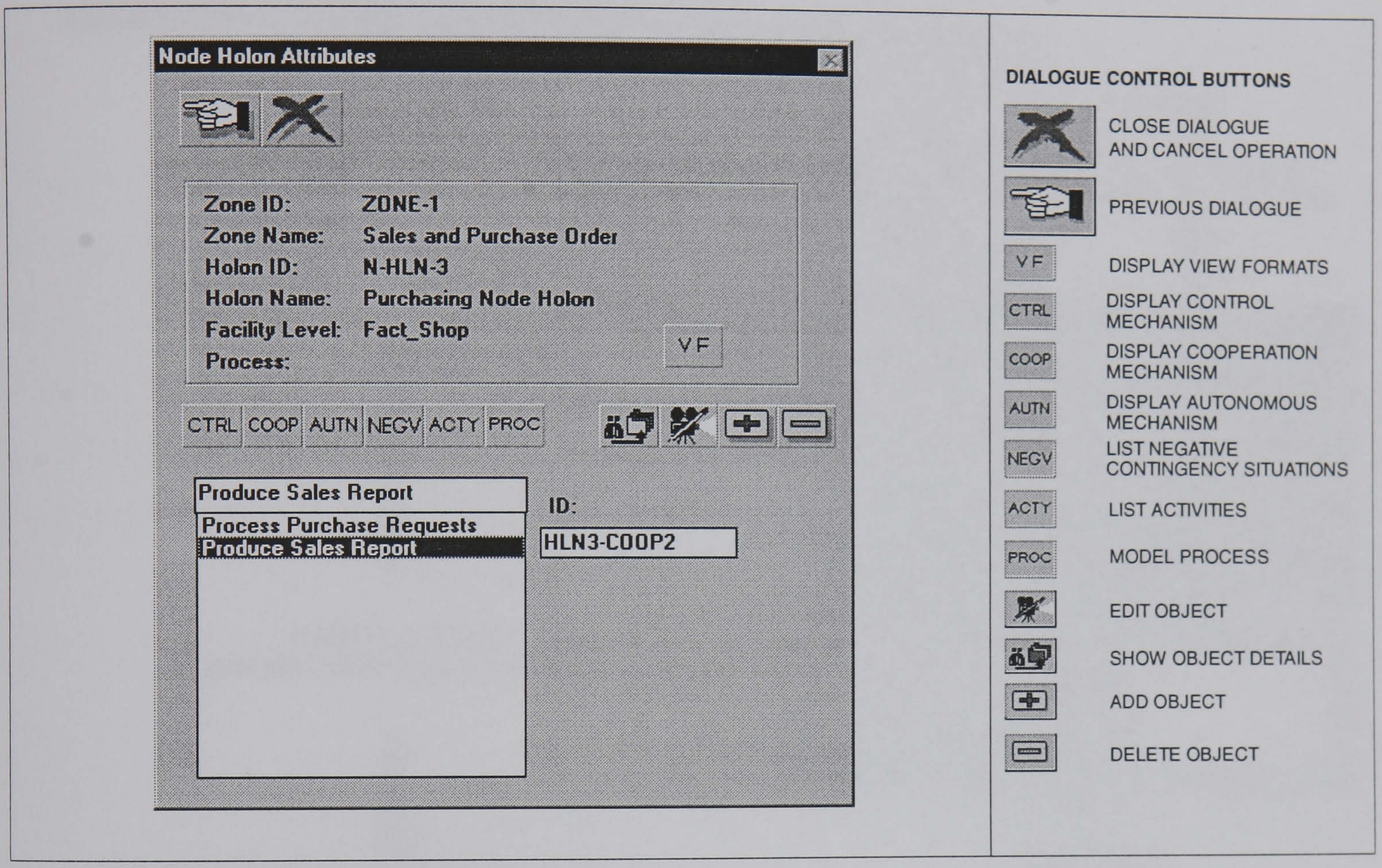


Figure 13.14: The main dialogue interface for a node holon which provides access to its autonomous, control and cooperative aspects.

13.3.4.5 Modelling Contingencies

The modelling of contingencies which impinge on the node holon provides an additional dimension to capturing the interactions and activities which arise in response to the situations. Modelling the reactions to the contingencies relates to the third view of data capture. The series of dialogues used to model the negative contingency situations and recourse options are based on a hierarchy of list-box dialogues, shown in figure 13.15. The failure of a node holon to cooperate is related to either the absence of functional or resource inputs defined through the activity dialogue shown in section 13.3.4.2. A class browser dialogue is used to present the resource and functional inputs relating to the particular activity which is affected, the possible causes of the negative contingency situation is identified from this list.

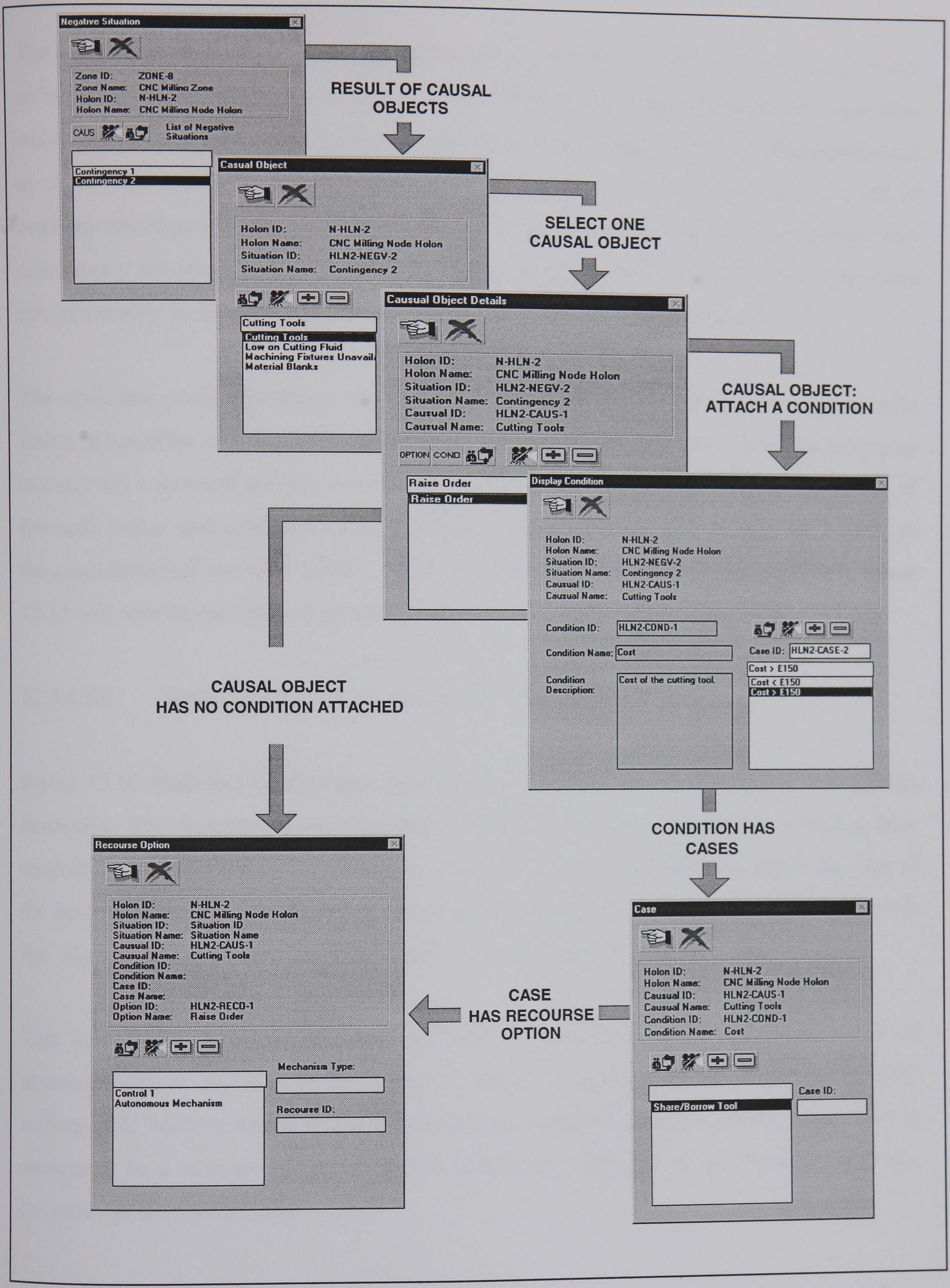


Figure 13.15: The hierarchy of dialogues used to model the negative contingency situations and recourse options.

The user is brought through a succession of modelling dialogues, which ultimately leads to the definition of appropriate recourse actions. The ability to specify any conditions and case rules which determine the recourse option is also provided via dialogue interfaces. The objective is to capture the manner in which individual node holons are known to react in the event of negative contingency situations. The CASE tool which supports this process enables such contingency situations to be recorded and examined systematically in detail, which provides the opportunity for establishing new working procedures between node holons.

The main aim of the systematic study is to provide a means of determining some recourse action in response to a negative contingency. The node holon may either have the autonomy to carry out a recourse activity, or to control another node holon. This adds to the profile of the node holon, and subsequent activity analysis further develops the information content in the manufacturing and data models. The dialogues which have been highlighted in figure 13.15 will now be described in greater detail.

13.3.4.5.1 Modelling Negative Contingency Situations

Figure 13.16 illustrates the dialogue interface which displays the list of negative contingency situations. The dialogue has been invoked for the CNC milling node holon, which has been modelled with two negative contingency situations, shown in the list box, where any one of the items may be selected. To view the causal objects associated with contingency situations, the "show causal object list" control is used for the highlighted item.

This invokes the following dialogue showing the negative contingency situation and its associated causal objects. In this example, the contingency situation is where the CNC milling node holon is unable to fulfil its obligation to perform the CNC milling task. This is associated to a number of causal objects which are displayed in the dialogue interface described in the next section.

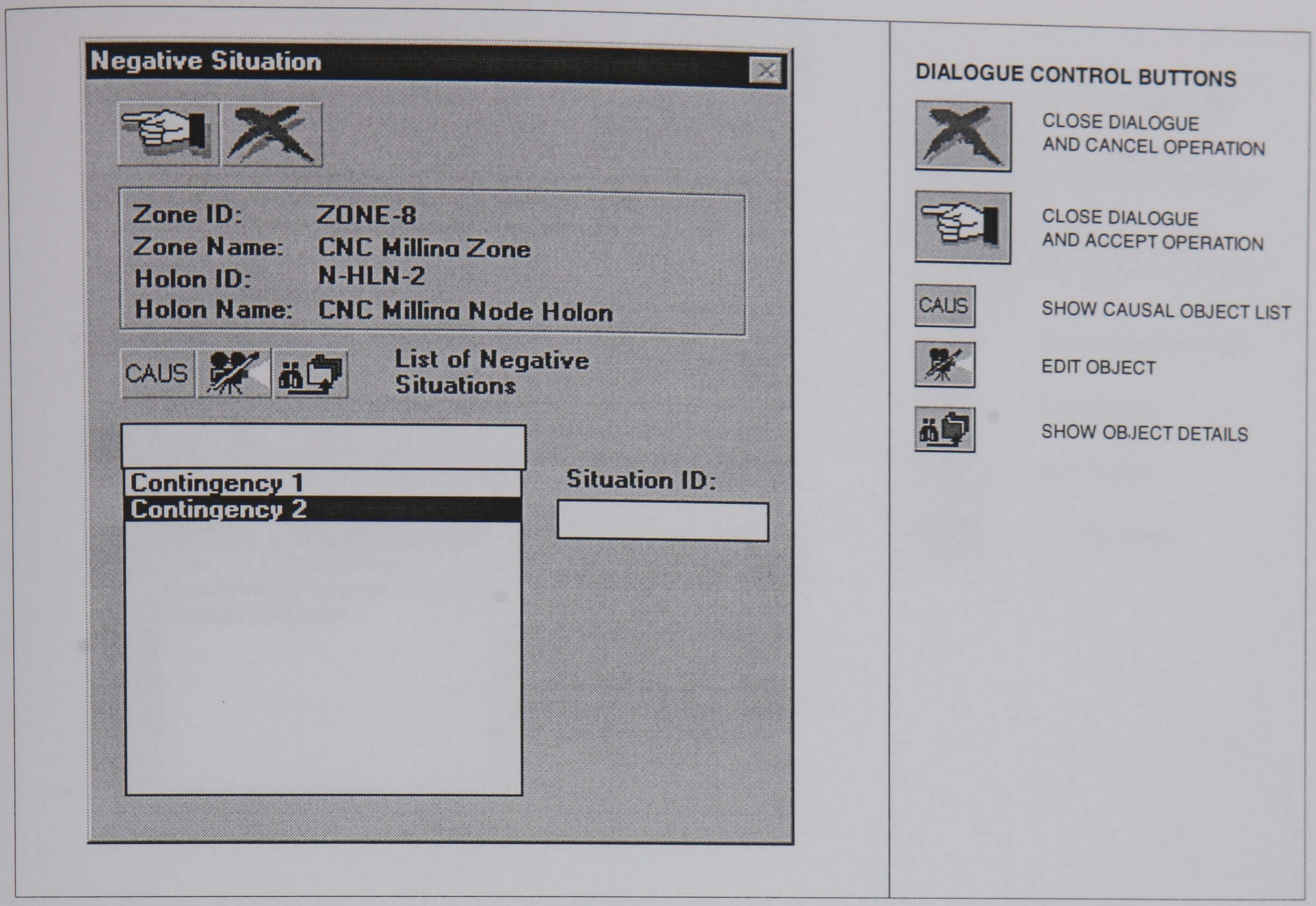


Figure 13.16: The dialogue interface showing the list of negative contingency situations.

13.3.4.5.2 Modelling the List of Causal Objects

The detail of a particular negative contingency situation is shown using the dialogue interface illustrated in figure 13.17. It can be seen that the negative contingency situation may be associated to a number of causal objects, which are shown in the list box. Items in this list are related to the functional and resource inputs specified for individual activities. In the example shown, the causal objects are related to the cutting tools, cutting fluid, unavailability of machining fixtures and raw material blanks. More items can be added to this list and this is accomplished by browsing through the list of functional and resource inputs associated to the CNC machining activity. To view further details of any causal object listed in the dialogue, the item can be highlighted and the "show object details" control is used to bring up the next dialogue in the hierarchy.

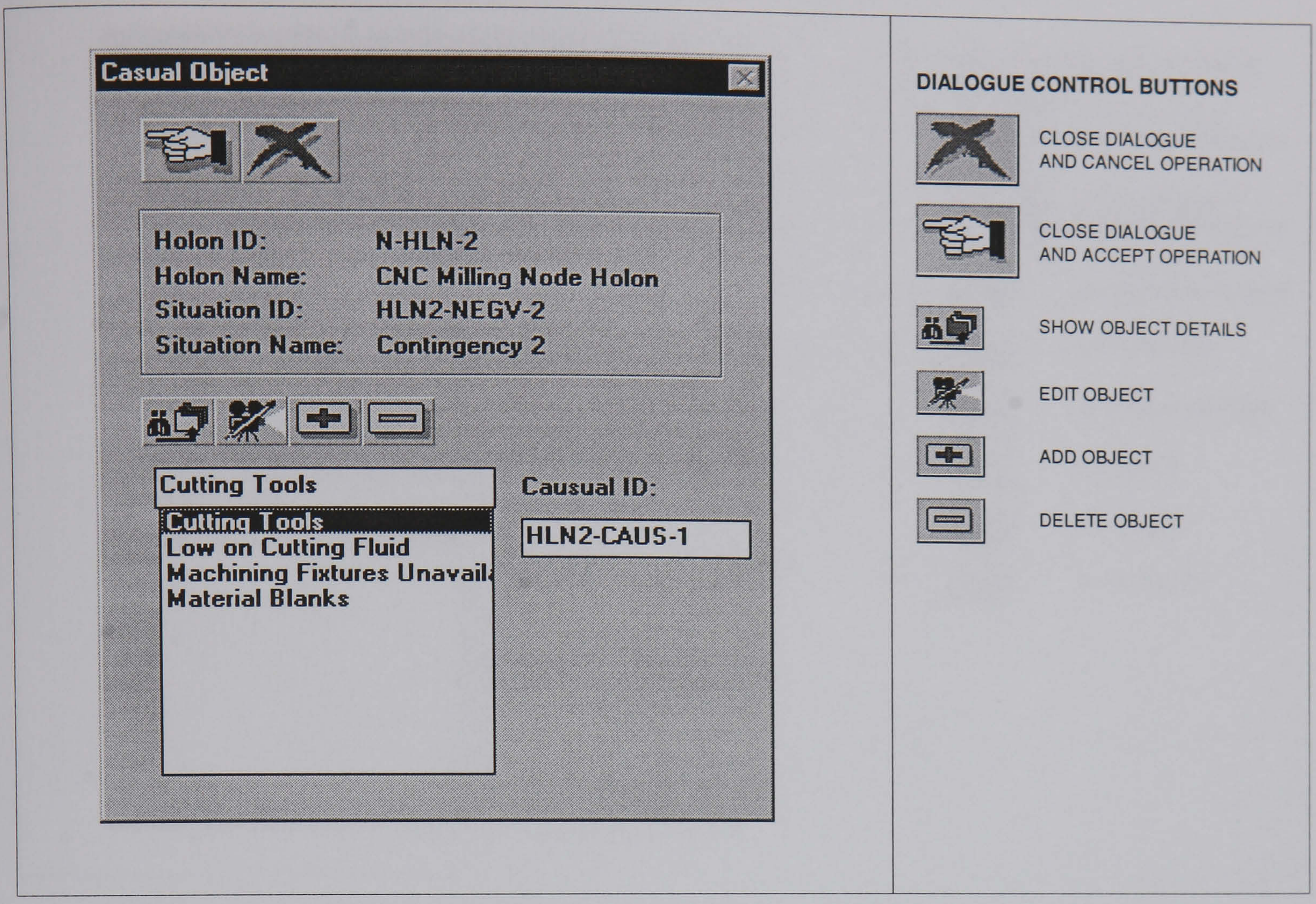


Figure 13.17: The dialogue interface showing the list of causal objects.

13.3.4.5.3 Modelling the Conditions Associated to the Causal Objects

The details of the causal object are modelled using the dialogue interface illustrated in figure 13.18, which shows the list of recourse options or conditions attached to the causal object. For each causal object there is a choice of two alternatives; the first is where a condition can be specified which determines the recourse option. The second is where a recourse option can be identified without any associated condition. The choice between modelling a condition and proceeding directly to specifying a recourse option, is made by selecting the appropriate control button shown in figure 13.18.

As illustrated in figure 13.18, the recourse option "raise order" can be directly specified. This option can be taken by selecting the "list recourse options" control shown on the dialogue, which by-passes the specification of any condition or case scenario. The user may then proceed directly to modelling the details of the recourse option, using procedures described in section 13.3.4.5.5.

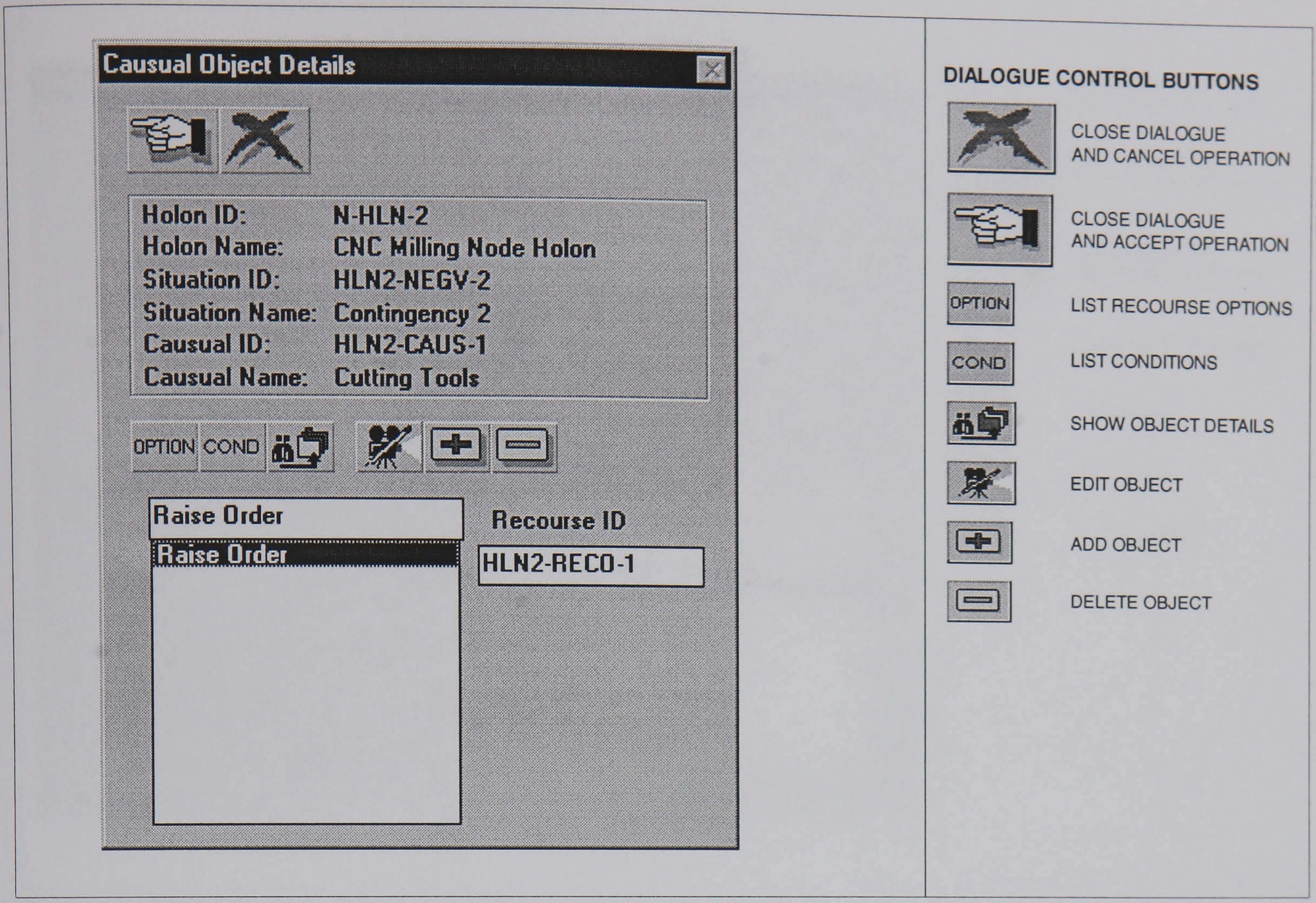


Figure 13.18: The dialogue interface showing the details associated to a causal object where a recourse option is directly specified.

13.3.4.5.4 Associating Conditions and Case Scenarios to the Causal Objects

As opposed to directly specifying a recourse option, a condition can be specified for a causal object using the dialogue interface illustrated in figure 13.19. Access to this dialogue is gained by selecting the "list condition" control shown previously in figure 13.18. The dialogue below shows the details for the causal object "cutting tools" which was identified earlier. This interface shows that the condition "cost" has been associated to the causal object and it can be seen from the figure that the case scenarios can also be specified for a particular condition.

Depending on the particular situation, any number of cases can be specified and added to the list box. In the example shown in figure 13.19, one of the cases specified is where the cost of the cutting is greater than the stipulated amount (cost > £150). The details of the case scenario can be shown by highlighting the item and selecting the "show object details" control button to display the case details. This subsequently leads the user to the next step of the modelling process which is to specify the recourse option.

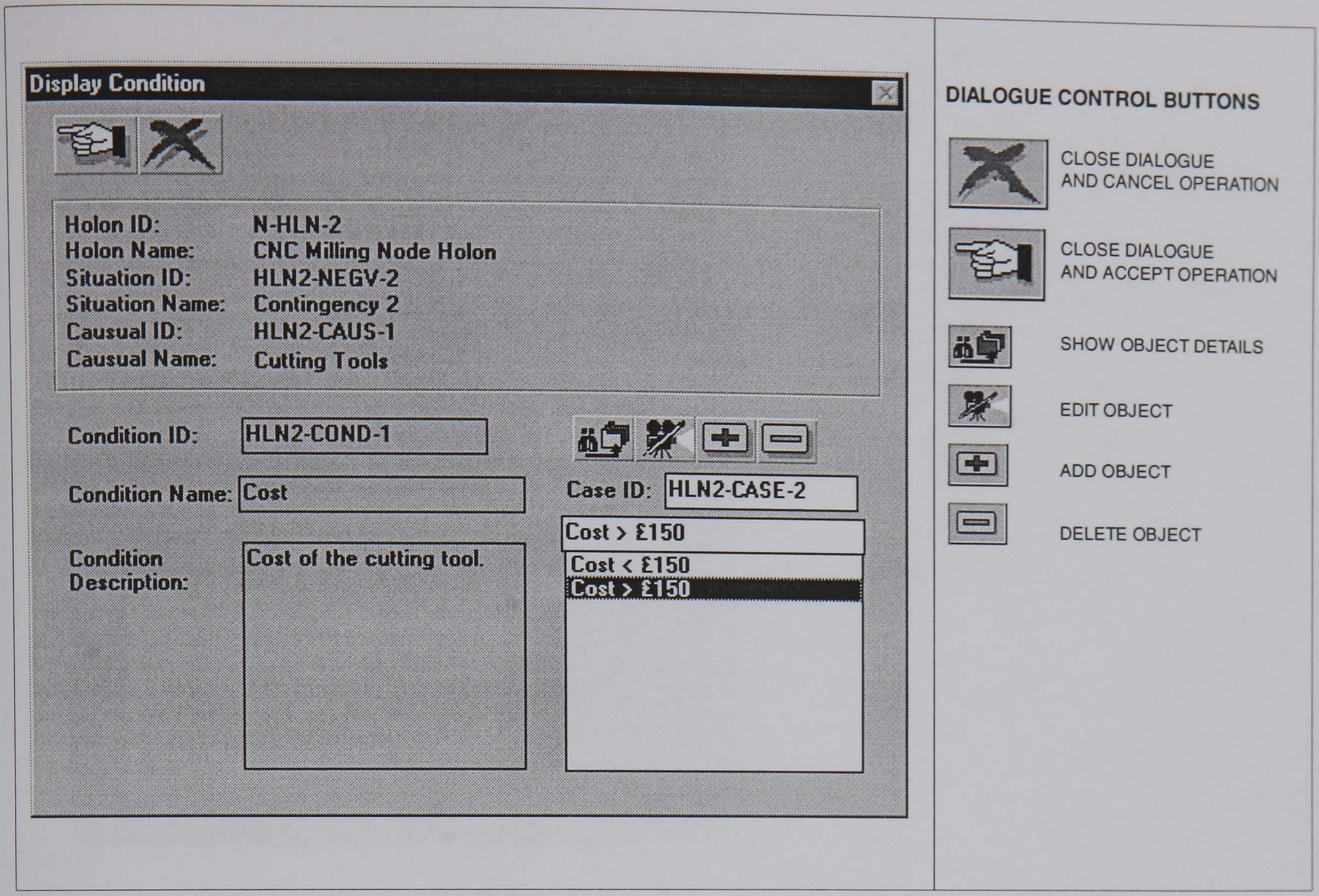


Figure 13.19: The dialogue interface showing the detail of a condition object and the associated case scenarios.

13.3.4.5.5 Modelling the Recourse Options

The details of the case scenario is modelled using the dialogue illustrated in figure 13.20. This shows the list of recourse options which are associated to a particular case. In this example, the case scenario is where the cost of the cutting tool determines that the cutting tool has to be shared or borrowed, this is illustrated in figure 13.21. The recourse option may involve either the autonomy of the node holon or the exertion of control over another node holon.

It should be noted that in either case, a new activity is specified. In the former case, the activities are added to the list for which a node holon is responsible. In the latter case, the control mechanism generates a corresponding cooperation mechanism from another selected node holon which has to respond with an activity. In this manner, the activities are identified and modelled using the activity analysis dialogue discussed under section 13.3.4.2. The new cooperation mechanism generate a corresponding negative contingency situations and the modelling process repeats itself thus.

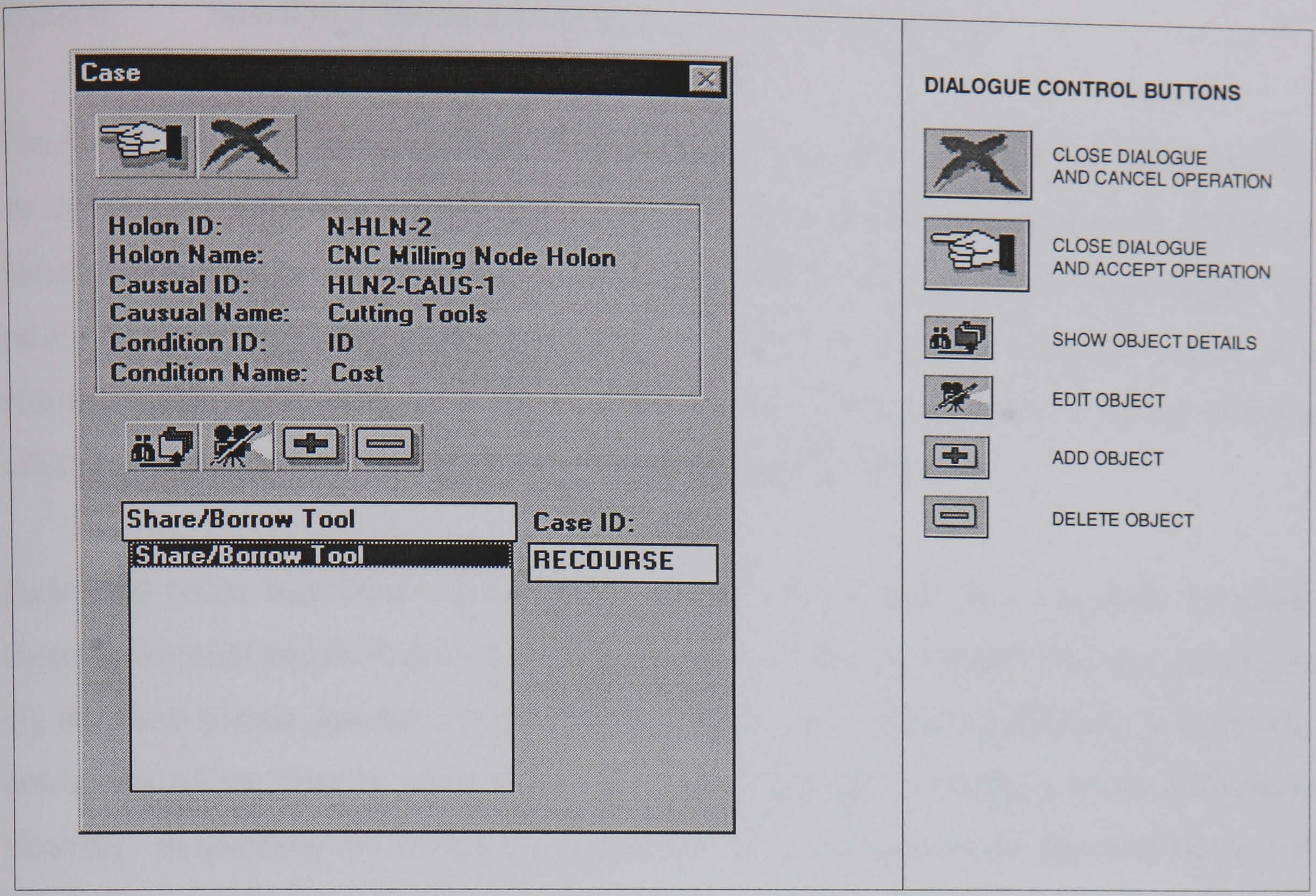


Figure 13.20: The dialogue interface showing the list of recourse options associated to a case scenario.

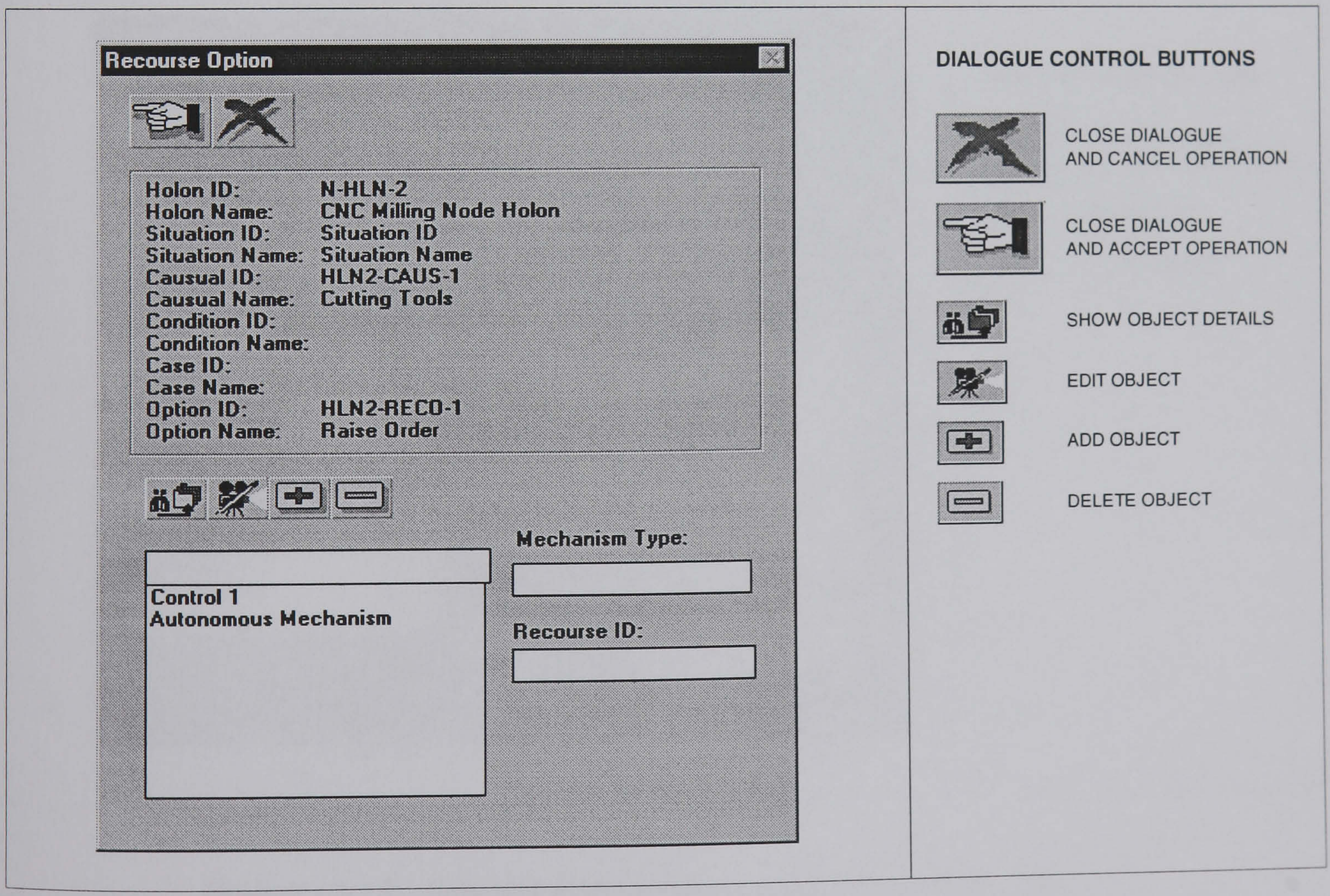


Figure 13.21: The dialogue interface showing the detail of a recourse options associated to a case scenario.

13.3.4.6 Specifying Information Support at the Node Holon

The control input and output parameters modelled during the activity analysis stage identifies the information parameters which play a crucial role in supporting the functions of the node holon. These information parameters constrain the node holon in terms of control inputs. The values of the individual parameters are also changed or altered during the course of an activity. The aggregation of these information parameters constitute external views or schemas to the data held in the manufacturing and order models.

Each node holon may have one or more external views to this data, examples are routing sheets or material and tooling lists, etc. Specification of these external schemas is established via the view format dialogue, illustrated in figure 13.22. The specification is based on a description of the type of view format to be used and the constitution of the information elements. In addition, this includes a description of the changes which are to be made to the information parameters.

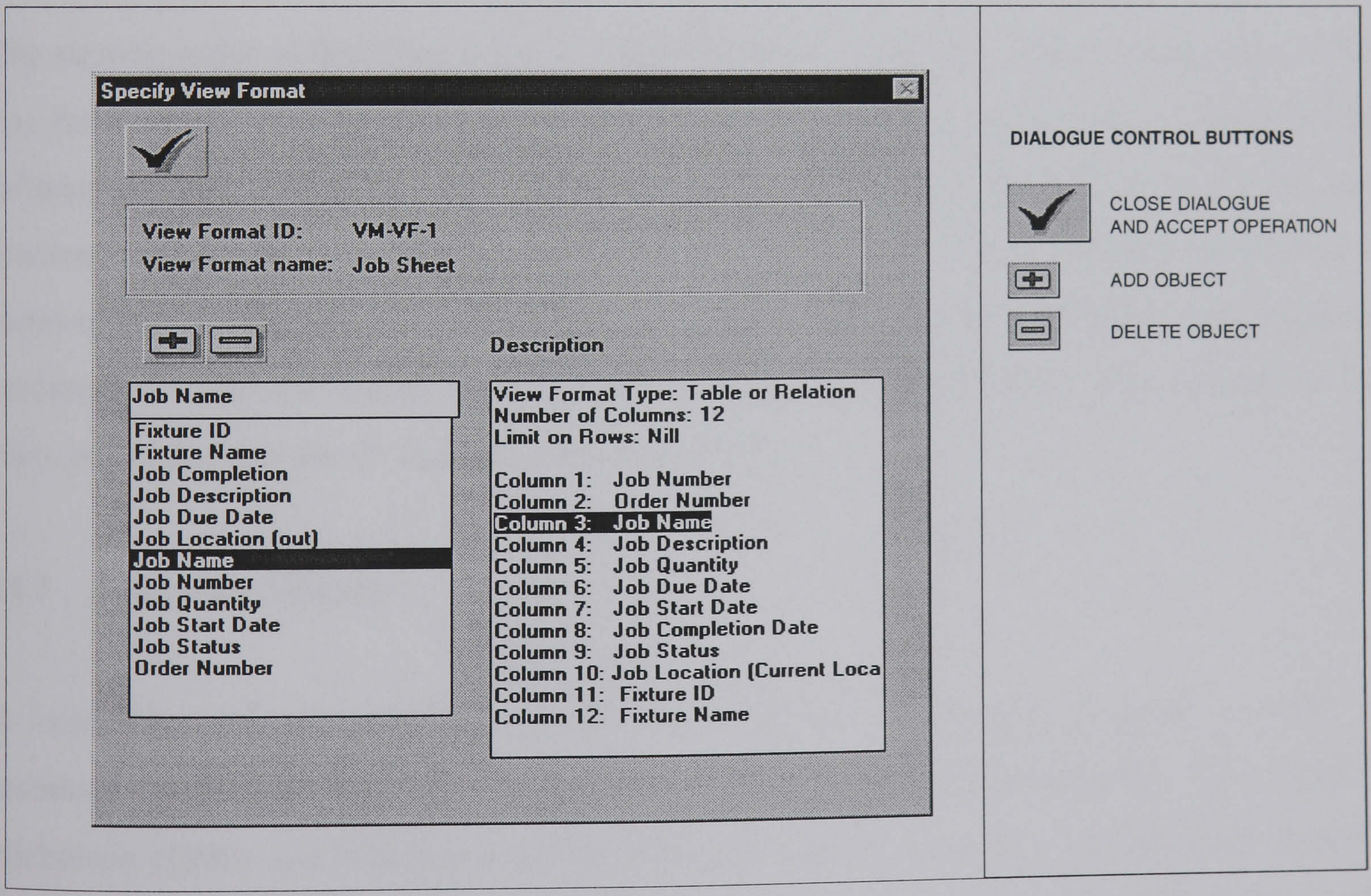


Figure 13.22: Specification of these external schemas via the view format dialogue.

Chapter 14

Discussion

14.1 Introduction

The purpose of this chapter is to discuss and bring together the major issues of the research in order to formulate the conclusions and areas for further work. The discussions have been based directly on the broad headings identified under the scope of the research defined in chapter 2. Major aspects of the reference SME enterprise model will be discussed in the ensuing sections, with the aim of highlighting the key issues which have been addressed and also to contribute some impressions and opinions which have been gained from the research. The final sections of this chapter will discuss the validation and limitations of the work.

14.2 Context of the Research

The starting point of this work was the identification of a particular class of company, which has been termed the metalworking SME. The discussion in section 2.2 highlighted the reliance of these companies on a distinctly flexible nature of operation to meet the daily challenges imposed by a highly volatile order environment. Their operation is distinct in terms of their reliance on skilled employees to plan and manage the allocation of material and resources to meet the highly variable work priorities. An assertion in this research is that there is a major role for IT support in such companies.

14.3 Literature Survey

A comprehensive literature survey has been carried out, which included a study of architectures for planning and control within highly volatile environments. The work of Nicholson (1985) and Westbrook (1993) which addressed production management issues in highly variable order conditions was of particular relevance to the operation of the metalworking SME. The study of holonic concepts and ideas of the fractal factory provided the fundamental principles upon which this research has been based. The literature survey also included a comprehensive study of current enterprise modelling practice, contemporary modelling architectures such as PERA (Williams, 1994a), SSADM (Longworth et al., 1988), CIMOSA (AMICE, 1991), ARIS (Scheer, 1992), etc. The state of the art in manufacturing information systems and the provision of information support was also studied. This part of the review identified the RM-ODP model for IT specification (ISO/IEC, 1995), and the ANSI/X3/SPARC DBMS architecture (Tsichritzis and Klug, 1972). The combination of these major areas of investigation have established the context and framework upon which this research is founded.

14.4 The Role of Architectures in the Information Specification Process

The scope of the research was restricted to the stage of information requirements specification, which can be found within any of the structured approaches of the PERA, GRAI and SSADM methodologies. It was argued that the design and implementation phases which involve the realisation of database implementations are, in general, invariant for the majority of architectures and are well within the capability of contemporary methodologies available. In relation to the scope of the research, the work reported in this thesis has demonstrated a novel approach to information specification, which is distinct from contemporary modelling approaches.

The overall scope was to investigate and develop a method and accompanying CASE tool to support the specification of the information requirements. The primary reason for the use of CASE tools is to provide an identification of the reusable modelling constructs, which would provide more user support and guidance during the model creation process. The CASE tool in turn, has to be based on modelling architectures and their associated modelling viewpoints, concepts and constructs.

At the outset, two modelling architectures namely, CIMOSA and ARIS were identified because of their inclusion of an information viewpoint and their declared goal of formality in all aspects of their architectures. A critical comparison between the two architectures has been carried out and it has been explained that one of the fundamental differences, is the way in which the respective viewpoints are demarcated. To reiterate, both architectures advocate the inclusion of the function, information and organisation as a fundamental set of viewpoints. However, CIMOSA identifies the resource description as a major viewpoint and ARIS subsumes the resource description into the information viewpoint. In addition, it has been noted that the ARIS architecture includes a control viewpoint. The difference implies that each has its own domain of application.

To illustrate this, the author discussed the involvement of these two modelling architectures in the information specification process. This has been presented in detail in chapter 6, where two roles have been clearly identified and explained. The first of the two roles is to provide a means by which the design to implementation process can be captured and the second role is to directly support the specification process. It has been shown that the CIMOSA architecture, with its resource viewpoint is particularly suited as a means for modelling the design to implementation process. This implies that CIMOSA can be used to model the structured approaches of PERA, GRAI or SSADM. This is, essentially, a conversion from one form of representation into another, i.e. a conversion from a graphical or visual form of representation into a computer based representation of the model. Whilst the latter provides a means by which information in the model can be easily updated, shared and stored, it loses the visual impact which is provided by a graphical representation.

For the purpose of creating specifications for the SME manufacturing model, it has been found that the ARIS architecture has the appropriate set of viewpoints where the resources and processes associated to a manufacturing facility is modelled as information classes. The emphasis of the control view to model associations between the viewpoints and individual constructs enables instances of the SME manufacturing models to be constructed from the independent facility and information fields of data capture. Moreover, the relationship between the organisation-behaviour field and the information field of data capture enables information support for node holons to be specified. The ARIS approach has provided the important concept of using the information view to subsume all components of the system which are not described from their own viewpoint. This has resulted in the author's decision to model the resources within the information view.

Each architecture however, has important concepts which have been fundamental to this research. Both advocate the modelling of information in conjunction with the functional and organisational aspects of the enterprise and the use of reference models. The extended IDEF0 formalism, similar to that used by CIMOSA has been used for activity analysis. The ARIS architecture emphasises the creation of an integrated meta-model, this principle has clearly been pivotal for the reference SME enterprise model.

14.5 Identification of Information Requirements for the Metalworking SME

The work of Westbrook has been of significant influence, they recognise that the coordination of manufacturing activities on a day-to-day basis becomes the dominant task in highly volatile environments. The concept of priority management, in response to current pressures on company resources, relies on the communication of the order status to individual employees to give vision and insight to the state of the company's customer commitments from acceptance to dispatch. The order data model, therefore, is one of the major information sources of information.

It has been argued by the author (section 8.2.2) that sole reliance on the order model is insufficient and that the management of the order priority has to be done in conjunction with information relating to the status of company's resources and processes. It was, therefore, decided that the second fundamental component of the information system was a manufacturing model which provides information relating to the manufacturing aspects of the enterprise. In addition, it was also decided that the process and resource descriptions would be modelled as information classes so that information attributes can identified and specified for each.

14.6 The Development of a Novel Representation for the Metalworking SME

The concept of the fractal factory and Koestler's fundamental ideas of the holon have been the basis of this research work. A new perspective is gained by recognising that small companies are inherently holonic in nature, where the daily interactions between individual employees are characterised in holonic terms. This perspective does not impose any changes to the preferred business operation of the company. Rather, this new viewpoint has provided the basis for a novel approach to modelling the interactions within a company and the specification of requirements for information support.

The intrinsically holonic enterprise was therefore termed a casually occurring organisation holon. It was of the author's opinion that a new class of information system had to be designed to perform a greater role in enhancing the capability of the enterprise to respond to work priorities. The research has identified a new class of information support to complement the highly flexible and human dominated nature of operation.

The information system which resulted from this new perspective has been termed the holonic information system (HIS) and its realisation is known as an holonic information network (HIN). As the HIN is designed using holonic concepts, it plays a supportive role for the human interactions and is seen to be more appropriate for the SME. The holonically enhanced organisation was therefore introduced to distinguish this new organisation where there was synergy between the role of the information systems and the employees. The development of a new class of information system also introduces a corresponding demand for a different approach to the creation of its specifications, as conventional information systems, designed using the current modelling approaches, plays a minimal role in representing the interactions.

14.6.1 Modelling the Organisation Based on the Zones of Activity

The introduction of business support and manufacturing zones of activity is seen to provide a more appropriate representation for companies whose organisation is not highly structured in an hierarchical manner. The subsequent division into business and manufacturing zones provides a more sympathetic approach to modelling the organisation of a small, informally structured enterprise. This has been readily applied in the study of Henton, where a representation of the company has been achieved solely on the current organisation of its business support and manufacturing activities.

The representation of zones has been based on the assumption that the top level zone embraces the enterprise, the subsequent division into zones is subject to the complexity of the organisation. There may be further scope in the zone concept for considering the larger organisations which are structured hierarchically into manufacturing cells, where the activities within of one or more cells are human dominated. The application of the reference SME enterprise model to this class of manufacturing industry has not been tested. However, it is the author's belief that the application of the reference SME enterprise model to a human centred manufacturing cell is conceptually possible; this would be accommodated by treating the human centred cell as an SME. In this case, the difference would be in the resulting model of the manufacturing facility, where the definition would be restricted to the workstation level.

14.7 The Development of a Reference SME Enterprise Model

It was realised that a reference SME enterprise model had to be created, which was able to capture the information requirements and the holonic aspects of the enterprise. A three field approach to data capture underpins the enterprise model, with the individual fields identifying the facility, information and holonic aspects of the enterprise which need to be modelled. The development of this meta-model has been explained over chapters 9 and 10, this is necessary in order to create an integrated model where the relationships between the individual viewpoints can be established. In turn, an integrated model was necessary for the implementation of a CASE tool which allowed associations between the individual constructs to be created.

14.7.1 The Development of a Reference Information Model

The author's research is focused on the underlying information component of the information system, which is captured as the order and manufacturing data models. These data models are in compliance with the conceptual schema of the ANSI/X3 SPARC DBMS architecture. One of the major challenges of specifying the information content for the manufacturing model was that process and resource information is used at various levels of abstraction.

The solution to providing a set of abstract descriptions was to create taxonomies of processes and resources independently and subsequently identify the required descriptive levels from the taxonomies, in conjunction with the four level facility model (section 9.4.3). This serves two purposes, the first is to realise a description of the manufacturing facility and the second is to identify the fundamental resource and process information classes. These information classes subsequently act as the carriers for the information attributes, which allow a description of a resource or process to be achieved at any defined level.

To specify the information requirements, the class diagrams of the Booch modelling methodology have been used in place of other established information modelling tools. Although object oriented modelling has been used for information modelling (Joergensen, 1992), Booch has not been widely applied elsewhere as an information modelling formalism. The *is_a* relation, for example, is used to denote inheritance in object oriented programming. As noted in section 9.3, this is not strictly a semantic modelling principle, but is used to convey a particular principle or concept. However, the Booch class diagram has been used in this research as a means for identifying information entities, their relationships and associated rules, for example, resource *has* (1... n) attributes.

This application of the Booch class diagram, as a means for expressing the conceptual information schema, is regarded by the author as an example of the use of Booch as a pseudo-information modelling tool. The Booch class diagram has been found to provide an adequate means for information modelling, moreover, it is within the guidelines stipulated by the SPARC/ANSI/X3 DBMS architecture for conceptual schema specifications (section 5.7.2). There is also a further advantage from this use of the Booch method; whilst the ERA formalism, for example, is used for modelling relational data structures, the use of Booch does not commit the end user to any particular database implementation model. As illustrated in figures 12.4, 12.8 or 12.9, the information entities and attributes modelled using the Booch class diagram can be organised into tables or relations (for relational database). Equally, the entities can be implemented as classes and attributes in an object oriented database.

The development of the order and manufacturing reference models is a significant step to the realisation of the information specifications. This will enhance the information specification task as much of the information requirements for a manufacturing enterprise has been established. The order and manufacturing information structures may then be instantiated in conjunction with the other inter-related viewpoints of the ARIS architecture and implemented after adaptation to the specific situation of the company.

14.7.2 Modelling the Node Holon

A major aspect of the enterprise model is the consideration of the holonic aspects of the enterprise. This is offered as an alternative to the process based approaches which underpin the CIMOSA and ARIS modelling architectures. The introduction of the node holon has provided a powerful abstract representation which enables the modelling of the composite entity comprising human holon, equipment and IT interface.

It has been explained in section 10.3 and demonstrated in section 12.7, how the functionality of a node holon, and its relationships with others within the organisation, can be modelled in terms of the control, cooperation and autonomous mechanisms. This has provided a means to model the activities which are performed by node holons throughout the enterprise. The modelling of contingency situations, their causes and corresponding recourse activities further develops the profile of a node holon. The use of the resources and functional inputs to identify the causes to the negative contingency situations provides considerable enhancement to the modelling process.

The application of holonic concepts for the specification of information requirements reflects a distinctive stance from the work of Duffie (Duffie et al., 1988). Duffie's concept of autonomy stems from the need for fault tolerance in highly automated systems (Duffie et al., 1988). The principle behind achieving autonomy is enforced isolation from other entities in the system. Hence, each entity is encapsulated with its own data source, access to which is restricted.

The distinctive approach in this research is that interactions between node holons are seen, by the author, as essential in order to respond to the pressures of urgent orders. The provision and sharing of information to give the necessary vision and insight into the status of the order commitments, processes and resources is fundamental to supporting these interactions and enhancing the autonomy of the individual node holon. Therefore, the specification of information support is carried out in conjunction with activity analysis, when the control input and output parameters are identified from the information classes. These are subsequently aggregated and view formats are specified in accordance to how the end user wishes the data to be displayed.

Modelling the node holon led the author to realise that one of the limitations of the modelling approach is the inability to model decisions. It may be argued however, that the absence of any restriction on the type of activity which may be specified, means that decision making activities can be included. As a consequence, a node holon may be under the obligation to cooperate by making a decision, or may have a decision making activity specified as part of some recourse action. In the author's opinion, however, the GRAI-NET, which has been developed for modelling decision centres would be more appropriate than the IDEF0 formalism. The ability to explicitly specify and model decision making will enhance the description of the node holon and is discussed in chapter 16.

14.8 Mapping the Reference SME Enterprise Model Against a Contemporary Modelling Architecture

The reference SME enterprise model has been projected against the four viewpoint architecture of ARIS. The purpose of this is to allow easy identification and interpretation of the structure and contents of the model. This has also enabled the reference model to be described in the context of contemporary enterprise modelling practice and to offer an appropriate platform for comparison against other modelling approaches.

The author noted, in section 2.4, that contemporary approaches to systems design and implementation have their origins in the design of computer integrated manufacturing (CIM) systems. It was also argued that their accompanying modelling architectures and methods for specification have been based on the assumption of hierarchical control and a deterministic mode of operation. As such, the direct application of the CIMOSA and ARIS modelling methods are not appropriate for companies whose operations are based around employee interactions. In relation to this, the author discussed that there should be flexibility within individual viewpoints for alternative approaches to data capture (section 6.6.2).

This has been clearly demonstrated by the development of the reference SME enterprise model, which has been subsequently mapped against the ARIS architecture. In doing so, the significance of the multi-viewpoint modelling approach, e.g. modelling the function view prior to the information view, and the formalism which the individual architectures offer have been gained.

The author's approach of reducing an architecture to a bare set of viewpoints (without specific constructs) and subsequently re-populating it with more suitable modelling constructs or reference models, is applicable for any new modelling paradigm which may evolve. The results of the mapping shows, in the author's opinion, how the applicability and uptake of the individual architectures can be significantly increased.

14.9 The Application of the Reference SME Enterprise Model

For the purpose of this thesis, the validation of the research through a rigorous study of a group of companies, with the aim of producing information specifications for each was found to be impractical. However, the availability of a suitable company (A.O. Henton) with well developed information records and working practices provided an opportunity to validate the reference SME enterprise model. This enabled its capability to be tested, by instantiating its major constructs with the available data from Henton.

14.10 The Realisation of a CASE Tool for Information Specification

The development of a CASE tool has also played a role in demonstrating the major concepts behind the reference SME enterprise model. This has been demonstrated by the capability of the CASE tool to instantiate the manufacturing facility of Henton from the generic facility constructs and to establish the link between selected resource and process classes from the generic taxonomy. The use of the class browser dialogues to establish associations between the various data objects captured by the CASE tool has demonstrated the concept of federating the separate viewpoints, as proposed by the ARIS approach.

A major outcome of this approach is the relationship between the holonic field of data capture and the information field of data capture. This important relationship is established through the control input and output parameters and their link to the information elements. This relationship underpins the specification of information support for the node holon, in addition, any missing information element can be easily identified and modelled.

The use of the CASE tool has also shown that it is possible to develop a repository to store instances of the enterprise models using the CASE tool, where the conceptual information structures contained within can be used for further development into design and implementation specifications for the order and manufacturing models.

14.11 Limitation of the Research

It was decided at the outset, that the main focus of the research would be on companies without a product design function, this means that parts are manufactured based solely on part drawings from the customer. The work thus concentrated on providing information support to sustain manufacture in highly volatile environments, rather than support for product innovation. In companies with product design, other issues will surface which are beyond the scope of this work. In order to gain product advantage, a major issue is the need for a new product development strategy, such as concurrent engineering, to constantly reshape and upgrade the product portfolio.

However, the consideration of design support also adds a necessity for accurate and consistent product data and will invariably require the addition of a third model, namely a product model, which has been briefly described in section 4.6.1.1. It has been noted in section 8.2.1, that the order model captures a subset of information relating to the product collected during the manufacturing phase of its lifecycle, which for some applications, may be included into a product model.

14.12 Concluding Remarks

This chapter has been written to provide a balance of arguments based on the research. The conclusions will now be drawn from the discussions and presented in the next chapter.

Chapter 15

Conclusions

15.1 Introduction

The conclusions drawn from the work and the discussions given previously are presented in this chapter.

15.2 Contribution of the Research

The contribution of the research is the development of a new modelling method, derived from fundamental holonic concepts, to capture human dominated interactions within a company and to identify the activities which are performed. The novel application of the research is the incorporation of the new modelling approach as part of the reference SME enterprise model, to realise specifications for information support for metalworking SMEs.

15.3 Conclusions from the Research

The conclusions which have been drawn from the research are as follows:

(i) A novel modelling approach has been developed from the fundamental ideas of the holon and the fractal factory. A major distinction is that the new method is not based on the assumption of a highly structured management hierarchy or a deterministic mode of operation. The use of the new modelling approach for the specification of information requirements is more sympathetic to the needs of the metalworking SME. The process of information specification has been considerably enhanced with the CASE tool, which provides a high degree of user support by supplying a set of well developed modelling constructs based around visual interfaces.

(ii) A new class of information system, the holonic information system (HIS), has been identified for metalworking SMEs. The specifications for the information components, namely the order and manufacturing model, and the information support at the IT interfaces are derived from holonic concepts, as a consequence the HIS will be more supportive of the human dominated activities and interactions throughout the business.

(iii) A reference SME enterprise model for information specification has been developed which is underpinned by a novel three field approach to data capture. This is distinct and identifies the major aspects of the enterprise which are necessary for specifying the information requirements for the metalworking SME.

(iv) The development of the reference SME enterprise model as an integrated meta-model is the result of the consistent application of Booch class diagrams across all modelling viewpoints. The direct implementation of the object oriented CASE tool from the reference SME enterprise model is a powerful application of this concept.

(v) The node holon as an abstract representation of the composite of human holon, equipment and IT interface is a novel concept. This allows the fundamental characteristics of the node holon to be expressed in terms of control, cooperation and autonomy. These fundamental holonic concepts provide a new approach to the modelling of human dominated interactions and the identification of enterprise activities. This offers a competitive alternative to the current methods which are based solely around the modelling of business processes and procedural rules.

(vi) The introduction of business support and manufacturing zones of activity provides an new representation of the organisation for the smaller companies which are not highly structured in nature. The representation of the business from its preferred view of the operation provides the starting point for the subsequent derivation of more appropriate information support requirements.

(vii) The ARIS architecture contains the relevant set of viewpoints for the purpose of identifying the resource and process attributes to create specifications for the manufacturing data model. The mapping of the reference SME enterprise model against the four viewpoints of the ARIS modelling architecture has set the results of the research within the context of contemporary enterprise modelling practice and has also provided a basis for comparison.

(viii) The mapping of the reference SME enterprise model has shown how the ARIS and CIMOSA modelling architectures can be adapted to accommodate new approaches to data capture. This shows how these architectures can readily accommodate new modelling approaches whilst retaining their major advantages, thereby increasing their applicability and potential uptake.

(ix) The applicability of the reference SME enterprise model has been demonstrated by instantiating the constructs of the reference model based on the study of A.O. Henton. The description of the manufacturing facility to various degrees of abstraction and the holonic aspects of the enterprise has been readily accommodated.

Chapter 16

Recommendations for Further Work

16.1 Introduction

This chapter highlights the further work which is required within the overall framework of the SSADM methodology, outlined in section 4.5.3, to realise an HIS implementation. In addition, research is also identified, which can enhance the holonic model introduced in this thesis. Work to further develop the information specification CASE tool is also identified.

16.2 Validation of the Research Context

Further work should be carried out on a number of case studies with appropriate metalworking SME companies. This should include a comprehensive study of the modus operandi of the companies, which will allow the information specification CASE tool to be employed in a number of cases. The studies should be applied to companies which can be adequately represented by a single zone and also include cases of larger companies requiring a multi-zone representation. Further work should also be carried out to study the larger organisation which is structured hierarchically into manufacturing cells and the determine the feasibility of applying the zone and holonic modelling concepts to a cell which is human dominated.

16.3 Realisation of a Holonic Information Network

This work has been set in the context of structured approaches to systems specification and implementation, for this purpose, the SSADM methodology was used. The realisation of an HIN requires two sequential phases, the first phase involves the development of a full body of specifications for the HIS; the second phase involves the realisation of a network implementation. The research work reported in this thesis has been restricted to the first phase, and in particular, to the specification of information requirements for an HIS. Further work should therefore (i) realise a complete body of specification for the HIS and (ii) realise an HIS implementation.

(i) The four viewpoints of the RM-ODP, namely the enterprise, computational, engineering and technological viewpoints have not been explored. Further work should focus on the other stages of the SSADM methodology, which populate the four remaining viewpoints for a complete body of specifications. Studies should establish relationships between the individual viewpoints in order for the relevant data captured in one view, to be used for the development of the other specifications. For example, the information specification CASE tool will identify the number of node holons which have to be supported. This in turn, will determine the number of IT interfaces which will have to be installed and, therefore, affect the decisions made on the hardware aspects specified in the technological viewpoint.

(ii) Further work should also be carried out on the second phase to realise an HIN implementation. The implementation will demonstrate the use of the IT interfaces which have the basis of their design on the holonic concepts. This work will demonstrate the integration of existing software, or vendor products into the HIN and also show the use of bespoke IT interfaces.

16.4 Enhancement of the Node Holon to Include Decisional Analysis

It has been recognised that the present model of the node holon may be used to capture decisions as an activity, where a node holon may be under the obligation to cooperate by making a decision, or may have a decision making activity specified as part of some recourse action. The ability to specify and explicitly model decisions will enhance the descriptive potential of the node holon.

The GRAI-NET (Doumeingts et al., 1987) is an established formalism which has been used to model decisions, further development should, therefore, be carried out to determine how the decision model can be incorporated with fundamental holonic concepts. This will invariably involve the creation of a meta-model of the GRAI-NET and the identification of any relationship which may exist between the constructs of the modelling formalism and the present constructs of the SME reference enterprise model.

16.5 The Modelling of Human Factors

Research should be carried out on the suitability of holonic modelling concepts to support socio-technical design. In order to do this, the areas of socio-technical design and human factors in manufacturing have to be explored in detail. Research should focus on the possibility of developing a taxonomy of human factors, such as human skills, abilities in terms of speed of response, physical strength, job enrichment, job satisfaction, etc. In a similar manner to the resource and process classification structures, a taxonomy of human factors may be developed independently, and be added to the SME enterprise reference model via a fourth view of data capture, i.e. a human factors view of data capture[8].

Studies should identify the relationships between a human factors view of data capture and the holonic view of data capture. The most plausible direction for research is to establish a relationship between decisions, or activities and the human factors field of data capture. This would enable human factors which impinge on particular activities or decisions to be identified and defined. The ability to create such a link would be desirable to establish another dimension for modelling negative contingency situations; this implies that the contingency situation may be linked to a human factor. A model of this nature would be useful to the assignment of tasks which will be fulfilled by people in the organisation.

16.6 The Creation of an EXPRESS Code Generator

The class diagram of the Booch methodology has been used as a pseudo-information modelling tool for realising the conceptual information schema. Further work should be carried out to develop the capability of the CASE tool to generate the order and manufacturing data models as EXPRESS schemas. The manufacturing and order data models can be generated in EXPRESS directly from the Booch class diagrams. The use of EXPRESS also provides a neutral database specification model. The generation of EXPRESS code represents the information in a textual form and verification can be carried out using compilers to ensure that the models are syntactically correct.

[8]These ideas have been proposed, by the author, at the recent ICEIMT '97 workshop on enterprise integration and organisational issues, held in NIST, Gaithersburg, USA (see appendix 5). Publications from the workshop will be presented at the ICEIMT '97 Conference to be held in Torino, Italy, October 28th-30th, 1997.

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Appendix I

The Floor Plan of A.O. Henton and List of Machining Resources

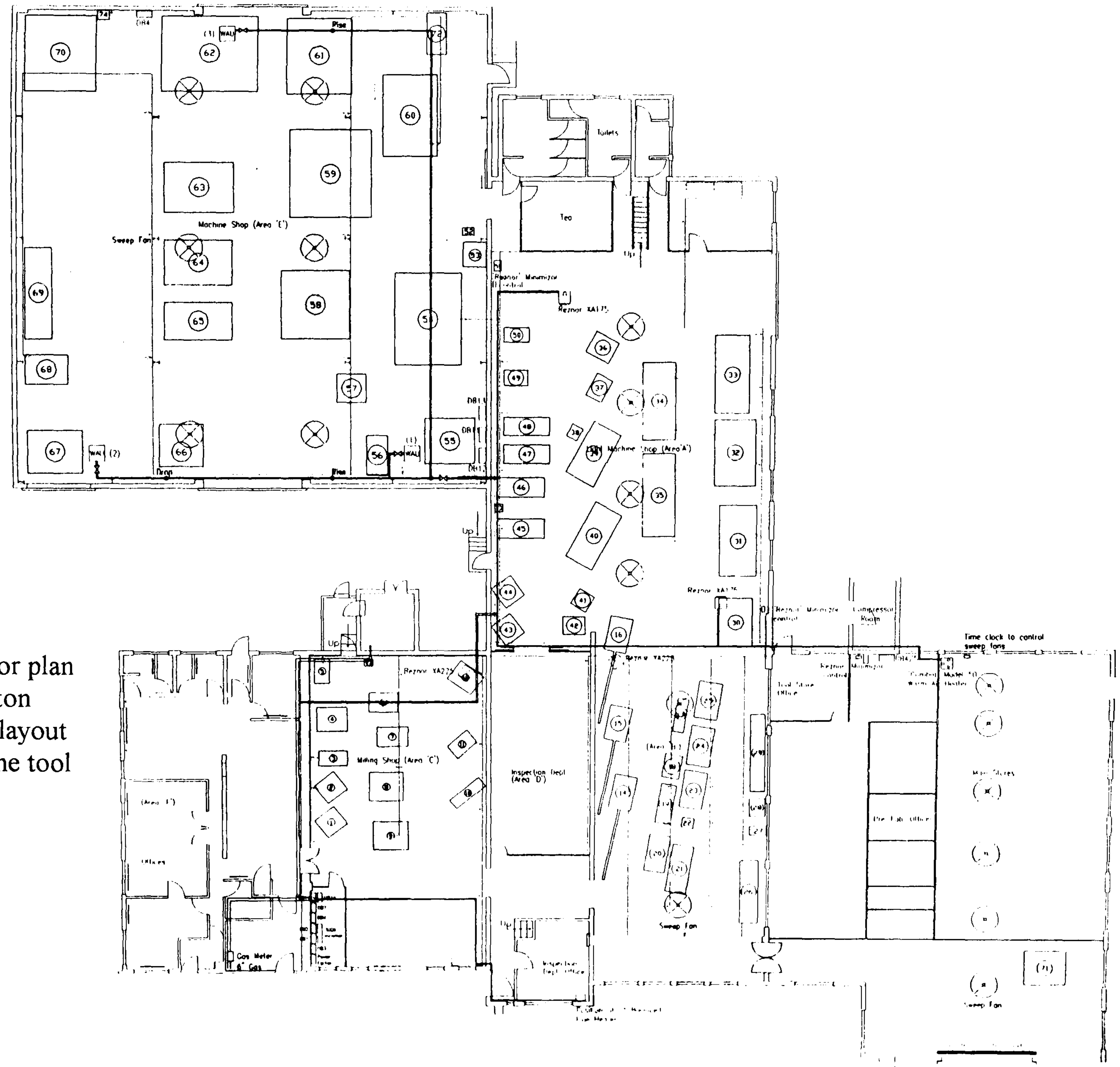

Figure I.1: The shop floor plan of A.O. Henton showing the layout of the machine tool resources.

Category 1
CNC Turning Operations

14 Habegger Automatic Lathe
15 Habegger Automatic Lathe
16 Habegger Automatic Lathe
19 BSA Automatic Lathe
30 Mori-Seiki SL4 CNC Lathe
31 Wickman TS 40/160
32 Wickman TS 40/160
33 Mytum 30 Kitamura
34 Howa CNC 11x
35 Ikegai AT 25U
61 Webster and Bennet 6ft table (CNC)
62 Webster and Bennet 4ft table (CNC)

Category 2
Manual Turning Operations

17 CVA Lathe
18 PeeWee Thread Roller
20 Colchester Triumph 2000 Lathe
21 Dean Smith and Grace Lathe. 15 " swing
23 Herbert 2D Lathe
24 Herbert 2D Lathe
25 Herbert 2D Lathe
26 Dean Smith and Grace Lathe. 21 " swing
63 Webster and Bennet Borer 4ft table
64 Webster and Bennet Borer 5ft table
67 Webster and Bennet Borer 3ft table
69 Swift Lathe

Category 3
CNC Milling Operations

54 Makino Machining Centre 65
55 Mycentre 3
56 Powermill CNC 2800
57 Enshu AM 1547 Vertical Miller
59 Boko CNC WF3/12-NC
60 Kitamura Jig Centre

Category 4
Manual Milling Operations

1 Bridgeport Vertical Miller
2 Bridgeport Vertical Miller
3 Invicta Shaper
4 Startrite 18-T-10 Band Saw
6 Cincinnati Horizontal Miller
7 Archdale Horizontal Miller
8 Kearney and Trecher Horizontal Miller
9 Bridgeport Vertical Miller
10 Bridgeport Slotting Machine
11 Cincinnati Horizontal Miller
12 Cincinnati Horizontal Miller
58 Boko Miller
65 Boko Miller
66 Boko Horizontal Miller

Category 5
Manual Drilling Operations

27 Herbert Tapping Machine
28 Herbert Drill (multi-spindle)
29 4 off Pillar Drills
68 Archdale Radial Drill

Category 6
Manual Grinding Operations

13 Black & Decker Bench Grinder
22 EG Grinder (twin)
36 Excel No 5 Cutter Grinder
37 Jones Shipman Cutter Grinder
38 Brierley Drill Grinder
39 Cincinnati Centerless Grinder
40 Cincinnati Internal Grinder
43 Churchill Ring Grinder
44 Churchill Ring Grinder
45 Jones Shipman Universal Grinder
46 Jones Shipman Universal Grinder
47 Jones Shipman Surface Grinder
48 Jones Shipman Surface Grinder
49 Myford External Grinder
50 Myford External Grinder
51 Tiplap Diamond Wheel
52 Diamond Grinding Wheel
73 Jones Shipman Centre Lapping Machine
74 Jarmac Electric Bench Grinder

Category 7
Honing Operations

41 Delapena Speedhone
72 Delapena Honer

Category 8
De-burring Finishing Packaging Operations

5 Walther Rumbler
42 Orama 500 Shadowgraph
53 De Vlieg Microset
70 Spark Eroder
71 Kasto Power Saw

Figure I.2: The list of machine tool resources at A.O. Henton.

Appendix II

A Selection of Shop Floor Documents of A.O. Henton

```
****************************
*  FINAL INSPECTION CARD  *
****************************
```

JOB NUMBER: 24320 NETWORK REF.: 0-0 DESCRIPTION: RING

CUST. ORDER NO.	092400005	CUSTOMER: RR DRS	
Drawing No.	Revision No.	Description	Quantity
BRR 10578	Dwg 0000A Plg 3	Front Support Ring	2

Operation Number	Work Centre	Description	Set-Up Time	Run Time
990	990	Commercial	0.00	0.00 hrs

QUANTITY GOOD:

QUANTITY SCRAP:

DATE:

SIGNATURE:

Figure II.1: Final inspection card containing information which can be related to the order model.

A.O. HENTON ENG. CO. LTD. **Works Planning Card** **Works Card No.**

DRG No.	DESCRIPTION	CUSTOMER	ORDER No	No REQ	DATE REQ	DATE ISS.	CLASS INSP
JRA 3372	CLAMP SEGMENT	R/R ANSTY	484911005	3	36-5-94	24/11/93	A.I.D.

MATERIAL SPEC. MSRR 6503 HARDEN & TEMP. FORGE RING. (26 5/8 DIA x 24 1/4 I/D x 2 5/16 THK) DRAWING ISSUE 02 Z No 24659

No OF SHEETS 1 OF 4

OP	MACHINE	DESCRIPTION OF OPS AND TREATMENTS	TOOLING	OPERATOR	INSP. REMARKS	EST. T
10	STORES	CHECK & RELEASE MATERIAL.				
	910	1 RING > 8 COMPTS. SIG. HERE.				
20	INSP.	ENSURE MATERIAL IS CORRECT SPEC.				
	930	& CONDITION.				
		INSP. SIG. HERE				
30	W/B.	SET ROUGH M/C'D RING UP TRUE.	PROG No 6 0019		1HR	30
	50	PART OFF INTO 2 EQUAL RINGS	K0097			
		1" WIDE.				
		ENSURE ALL STAMPINGS ARE ON				
		BOTH RINGS.				
		SIG. 1ST OFF.				
40	INSP.	INSPECT PRIOR TO HEAT-TREATMENT.				
	950					
		INSP SIG. HERE				
50	SUB-CON.	HEAT-TREAT TO F25A (STRESS RELIEVE).	JCHT 01182			
	731	650°C ±10°C FOR 1HR. COOL IN AIR.				
	JSC-COV.					

Figure II.2: A works planning card containing information which can be related to both the order and manufacturing models.

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DATE : 30 NOV 93

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PAGE : 1

B A T C H T R A N S A C T I O N R E P O R T

BATCH FILE NUMBER : 06

RECORD NUMBER	JOB NUMBER *DIV CODE*	NETWORK REF	OP No	WORK CENTRE		EMPLOYEE No	EMPLOYEE NAME		---ACTUAL--- SET-UP	RUN	PAY RATE	----QUANTITY---- PASSED	SCRAP	DATE ww.d.yy
1	23711	100-500	90	32	MANUAL MILLING	816	HALLIDAY D	32		5.00	1.00	20	0	47.6.93
2	23475	600-700	125	55	BOKO	852	WESTWOOD R	55		1.00	1.00	0	0	47.6.93
3	23475	600-700	120	55	BOKO	852	WESTWOOD R	55	3.50	1.50	1.00	0	0	47.6.93
4	24309	0-0	70	55	BOKO	854	GOSS A	55		1.00	1.00	2	0	47.6.93
5	24307	0-0	70	55	BOKO	854	GOSS A	55		5.00	1.00	15	0	47.5.93
6	24638	0-0	50	32	MANUAL MILLING	863	WHISTON D	32	1.25	0.75	1.00	3 *	0	47.6.93
7	24625	0-0	50	32	MANUAL MILLING	863	WHISTON D	32	0.50	0.50	1.00	3	0	47.6.93
8	24626	0-0	50	32	MANUAL MILLING	863	WHISTON D	32	0.75	1.00	1.00	4	0	47.6.93
9	23836	200-500	370	70	BENCH/OTHER OPS	908	CHAMBERLAIN J	70		1.00	1.00	2 *	0	47.6.93
10	23836	500-900	430	70	BENCH/OTHER OPS	908	CHAMBERLAIN J	70		3.00	1.00	20	0	47.6.93
11	23744	600-800	125	70	BENCH/OTHER OPS	1145	RIDLEY J	30/70	1.00	1.00	1.00	1	0	47.5.93
12	*21*	MACHINE BREAKDOWN		32	MANUAL MILLING	863	WHISTON D	32		1.00	1.00	0	0	47.5.93
13	*13*	WAITING INSPECTIO		32	MANUAL MILLING	863	WHISTON D	32		0.25	1.00	0	0	47.5.93
14	*31*	SUPERVISION		30	CNC MILLING	1145	RIDLEY J	30/70		5.00	1.00	0	0	47.6.93

TOTAL LABOUR : SET-UP	7.00
RUN	20.75
TOTAL SET-UP + RUN :	27.75
TOTAL DIVERSION :	6.25

There are 14 records on Batch File number 06

Figure II.3: Batch transaction report containing information which can be related to both the order and manufacturing models.

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T I M E   S H E E T   A N A L Y S I S　　　　Page 1

Employee No...... 606
Employee Name.... AIKINS M　　　10

DATE ww.d.yy	JOB NUMBER *DIV.CODE*		DESCRIPTION	PART NUMBER	OP NO	WORK CENTRE	QUANTITY COMPL'TD	HOURS PLANNED	HOURS BOOKED	PAY RATE	DAY TOTAL
47.1.93	* 47 *		TOOL/TLNG SHARP & MAINT			32 MANUAL MILLING	0.00		1.25	1.00	
	24466	0-0	SUCTION BLOCK	98045-848	130	32 MANUAL MILLING	2.00	1.00	3.00	1.00	
	24466	0-0	SUCTION BLOCK	98045-848	120	32 MANUAL MILLING	10.00	2.50	4.00	1.00	8.25
47.2.93	* 47 *		TOOL/TLNG SHARP & MAINT			32 MANUAL MILLING	0.00		0.25	1.00	
	* 13 *		WAITING INSPECTION			32 MANUAL MILLING	0.00		0.75	1.00	
	24457	200-500	HEATER BLOCK	39217-050	80	999 REWORKS/RECT	0.00	0.00	3.00	1.00	
	24466	0-0	SUCTION BLOCK	98045-848	130	32 MANUAL MILLING	8.00	2.00	4.25	1.00	8.25
47.3.93	* 13 *		WAITING INSPECTION			32 MANUAL MILLING	0.00		0.75	1.00	
	* 32 *		PROGRAMMING			32 MANUAL MILLING	0.00		0.50	1.00	
	24466	0-0	SUCTION BLOCK	98045-848	130	32 MANUAL MILLING	5.00	1.25	4.00	1.00	
	24528	100-500	CLAMPING SLEEVE	K 12180001	60	32 MANUAL MILLING	0.50	1.29	2.00	1.00	
	24640	0-0	STUD	A5801-1-80	40	10 LARGE CNC TURNING	0.75	0.25	1.00	1.00	8.25
47.4.93	* 13 *		WAITING INSPECTION			10 LARGE CNC TURNING	0.00		0.50	1.00	
	24629	0-0	LIFTING PLATE	76412614	50	32 MANUAL MILLING	0.00	1.50	1.50	1.00	
	24640	0-0	STUD	A5801-1-80	50	10 LARGE CNC TURNING	8.00	1.60	6.25	1.00	8.25
47.5.93	24642	0-0	STUD	A5801-1-140	40	10 LARGE CNC TURNING	1.00	0.33	1.75	1.00	1.75

Total Productive :	11.72	33.75
Non-Productive :		4.00
Total Hours Booked:		37.75

Figure II.4: Results from a time sheet analysis report containing information which can be related to both the order and manufacturing models.

Report JCS340

M I C R O S S - 7.302 | 01 DEC 93

WORK CENTRE PERFORMANCE REPORT | Page 1

* * * S U M M A R Y * * *

Week 47.93

Work centre		No.of UNITS	PERFM FACTOR	AVAILABLE CAPACITY	------PLANNED----- SET-UP	RUN	TOTAL	------ACTUAL------ SET-UP	RUN	TOTAL	B'DOWN TIME	INDIR WORK	UTILS %	PERFM %
10	LARGE CNC TURNING	3	75	191	31	53	84	59	96	155	0	63	81	54
15	SMALL CNC TURNING	2	79	134	17	27	44	24	41	65	1	32	49	68
17	MANUAL TURNING	2	78	70	3	3	11	3	19	27	0	6	39	41
20	AUTO	3	78	105	0	14	14	0	16	16	0	0	15	83
30	CNC MILLING	3	99	252	32	77	109	45	94	139	0	52	55	76
32	MANUAL MILLING	2	98	88	20	91	111	32	138	170	2	14	193	65
35	CENTERLESS GRINDING	1	86	4	0	0	0	0	5	5	0	0	125	0
40	GRINDING	4	90	184	12	16	28	26	28	54	1	86	29	52
45	SURFACE GRINDING	1	90	40	1	5	6	1	7	8	0	0	20	75
50	CNC VERTICAL BORING	2	92	156	12	95	107	18	80	98	8	8	63	109
52	MANUAL VERTICAL BORE	3	97	131	16	29	45	16	66	82	1	1	63	55
55	BOKO	2	81	105	10	96	106	12	176	188	0	2	179	56
65	EDM	1	86	4	2	0	2	2	0	2	0	0	50	100
70	BENCH/OTHER OPS	4	80	144	6	101	107	6	92	98	0	24	68	109
900	TOOL MAKING	1	100	45	0	0	0	0	2	2	0	0	4	0
901	WORK ON TEST PIECES	1	100	45	0	0	0	0	0	0	0	0	0	0
940	SAW	1	100	75	0	0	0	0	0	0	0	0	0	0
962	N.D.T. (IN-HOUSE)	1	100	75	0	0	0	0	0	0	0	0	0	0
965	PART MARK	1	100	45	0	0	0	0	0	0	0	0	0	0
970	FINAL INSP OPS	1	100	75	0	0	0	0	0	0	0	0	0	0
980	DESPATCH	1	100	45	0	0	0	0	0	0	0	0	0	0
999	REWORKS/RECT	1	100	45	2	0	2	6	11	17	0	0	38	12
9999	APPRENTICES	1	100	45	0	0	0	0	0	0	0	111	0	0
			Totals	2103	164	612	776	255	871	1126	13	404	54	69

Figure II.5: Extracts of a report on work-centre performance containing information which can be related to the manufacturing model.

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*** J O U R N A L S ***

BATCH NUMBER	JOB NUMBER	NETWORK REF	JOURNAL REF	DESCRIPTION	HOURS	LABOUR COST	MATERIAL COST	EXPENSES COST	OVERHEAD COST	TOTAL COST	DATE dd.mm.yy
4	23575		WIP	NOV 93	14.00-	0.00	332.24-	7.50-	0.00	339.74-	26.11.93
4	23735		WIP	NOV 93	8.27-	0.00	12.36-	0.00	0.00	12.36-	26.11.93
4	23916		WIP	NOV 93	16.00-	0.00	41.02-	36.00-	0.00	77.02-	26.11.93
4	23989		WIP	NOV 93	5.85-	0.00	18.34-	39.40-	0.00	57.74-	26.11.93
4	24172		WIP	NOV 93	94.84-	0.00	2057.82-	15.22-	0.00	2073.04-	26.11.93
4	24314		WIP	NOV 93	73.80-	0.00	0.23-	0.00	0.00	0.23-	26.11.93
4	24414		WIP	NOV 93	14.50-	0.00	2.63-	17.85-	0.00	20.48-	26.11.93
4	24422		WIP	NOV 93	19.80-	0.00	98.50-	0.00	0.00	98.50-	26.11.93
4	24440		WIP	NOV 93	3.30-	0.00	0.73-	1.79-	0.00	2.52-	26.11.93
4	24441		WIP	NOV 93	2.50-	0.00	0.73-	1.79-	0.00	2.52-	26.11.93
4	24442		WIP	NOV 93	4.50-	0.00	1.14-	1.79-	0.00	2.93-	26.11.93
4	24459		WIP	NOV 93	39.00-	0.00	70.40-	0.00	0.00	70.40-	26.11.93
4	24467		WIP	NOV 93	11.50-	0.00	12.82-	0.00	0.00	12.82-	26.11.93
4	24476		WIP	NOV 93	12.00-	0.00	12.50-	0.00	0.00	12.50-	26.11.93
4	24586		WIP	NOV 93	27.80-	0.00	50.54-	0.00	0.00	50.54-	26.11.93
4	24605		WIP	NOV 93	14.30-	0.00	5.79-	0.00	0.00	5.79-	26.11.93
4	24612		WIP	NOV 93	20.80-	0.00	0.00	0.00	0.00	0.00	26.11.93
4	24642		WIP	NOV 93	8.00-	0.00	6.57-	0.00	0.00	6.57-	26.11.93
4	24639		WIP	NOV 93	5.30-	0.00	26.87-	0.00	0.00	26.87-	26.11.93
4	24643		WIP	NOV 93	11.30-	0.00	74.78-	0.00	0.00	74.78-	26.11.93
4	24652		WIP	NOV 93	52.80-	0.00	0.00	0.00	0.00	0.00	26.11.93
4	24689		WIP	NOV 93	31.00-	0.00	0.00	0.00	0.00	0.00	26.11.93
4	24715		WIP	NOV 93	9.30-	0.00	68.75-	0.00	0.00	68.75-	26.11.93
Total:	23				500.46-					3016.10-	
Total:	23				500.46-					3016.10-	

Figure II.6: An extract from a job cost transaction report containing information which can be related to the order model.

Appendix III

The future role of DNC in metalworking SMEs

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Received August 1995.

The future role of DNC in metalworking SMEs

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Abstract

This paper provides a framework to describe the current status, and many configurations of DNC that can be encountered today. Major research issues relating to the design and implementation of future DNC are highlighted, in view of new manufacturing paradigms such as the Holonic and Fractal Factory. The characteristics, techniques, beliefs and values that compose these paradigms are already present to a limited degree in the small to medium sized companies. This paper will present a novel view of DNC, and how the latest advancement in PC based controller technology in combination with the manufacturing paradigms, will create a new role for DNC on the manufacturing shop floor.

1.0 Introduction

DNC is widely understood as direct or distributed numerical control, but despite the shared acronym it embodies different concepts of centralised computer control. The evolution of DNC is inextricably related to numerical controller technology, thus the physical appearance and functionality of DNC has correspondingly changed over the years. These changes have been in reaction to the advancement in the associated machine controller technology. A number of reviews have provided a chronology of these different eras in DNC (Testi 1986, Crossley *et al.* 1987).

This paper presents the current status of DNC, and investigates the various factors that are conspiring to change it's role in the metalworking industry. The contemporary term DNC no longer alludes exclusively to the control of NC machine tools. There can be many configurations of DNC systems, and equally as many variations of DNC functionality. In discussing the system configurations and functionalities, the authors have identified a generic three level framework of DNC, which provides a structured approach to describing this technology.

Today, the introduction of DNC in metalworking companies overcomes the basic problems associated with paper tape, reduces lead times and inventory etc., but this is no longer the prevalent justification. Neither is the cost of computing a major concern, this has reduced significantly, epitomised by the introduction of the PC based CNC. Rather, the emphasis has been on integration and centralised computer control of the shop floor.

The strategic potential in implementing DNC in SMEs today is not well understood. The metalworking SMEs are in an ideal position to benefit from the current developments in modern manufacturing paradigms such as the Fractal and Holonic Factory. The authors will highlight the major research issues surrounding the DNC system that have arisen which, if considered, will enable the manufacturing resources of a company to be harnessed as a powerful competitive instrument for the SME.

2.0 Inception of Direct Numerical Control

The inception of direct numerical control can be traced back to the early 70's, in association with the development of conventional numerical control. In addition to the associated paper tape problems with early numerical controllers, there was a need to circumvent the problem of providing costly interpolation computers (Charney and Srinivasan 1971, Spur and Wentz 1971). Direct Numerical Control shared the expensive interpolator across a number of machine tools and effected reliable 'paperless' transfer of control information (Stute and Nann 1971). The prime task of the central computer was the timely provision of all the linked machines with the control information. This task of managing and distribution of NC data is now referred to as the DNC basic function (Kochan 1985).

A number of systems emerged where all the machines were engineered for DNC control, where the individual controllers were 'compatible' for DNC operation. However, the special-purpose hardware and software requirements of such homogeneous or pedigree DNC systems made it difficult, if not impossible to include

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other NC equipment without retrofitting or scrapping the incompatible controllers. The cost of implementing monolithic DNC was prohibitive for the majority of NC users, particularly for those who already had investments in conventional NC equipment.

More often, a mixture of stand-alone NC and DNC compatible machine control units existed on the shop floor (Daly *et al.* 1984, Douglass 1985, Vaice 1986). As opposed to retrofitting a controller, behind tape reader (BTR) interfacing was often used in conjunction with machine interface units (MIU) (Brindley *et al.* 1977, French 1977). This combination is sometimes referred to as *BTR control*, and pertains to older NC machines whose operation systems did not have communication channels, unlike the majority of modern controllers which have an RS-232 interface as a standard I/O port.

3.0 The Evolution of Distributed Numerical Control

The introduction of computer numerical controllers in the early 1970's solved the problem of tape reading to a large extent and therefore the original use of direct numerical control. A transition took place where direct numerical control re-emerged as distributed numerical control, whose acronym is also DNC (Vogel and Schultz 1984, Wainwright *et al.* 1992).

There was a modification to the "DNC basic function", since the substitution of conventional NC with CNC allowed the whole part program to be transferred into the memory of the CNC rather than in an 'on-line' fashion. Today, DNC does not allude to the control of machine tools exclusively, and in some cases, DNC describes a shop floor communications network. In this instance, the data transfer is taken to include not only NC programs, but for example, tool offset files which are needed to execute a specific production task.

Present DNC systems include NC part programming, which comes under the broad auspices of "DNC extension functions" (Quinlan 1988, Kief and Waters 1992, Mitchell 1993). The DNC installation at Westinghouse Electric Corporation, illustrated in Figure 1, is an example of the emphasis placed on the extension functionality, and it can be seen how the basic DNC is overshadowed (Reed 1973). The extension functions increasingly control the process in an automated manufacturing facility and monitor all the equipment and constitutes an important step to the automated "paperless" factory (Lovetri 1983, Tonshoff and Schmiedeskamp 1984, Firm 1987, St. Charles 1987).

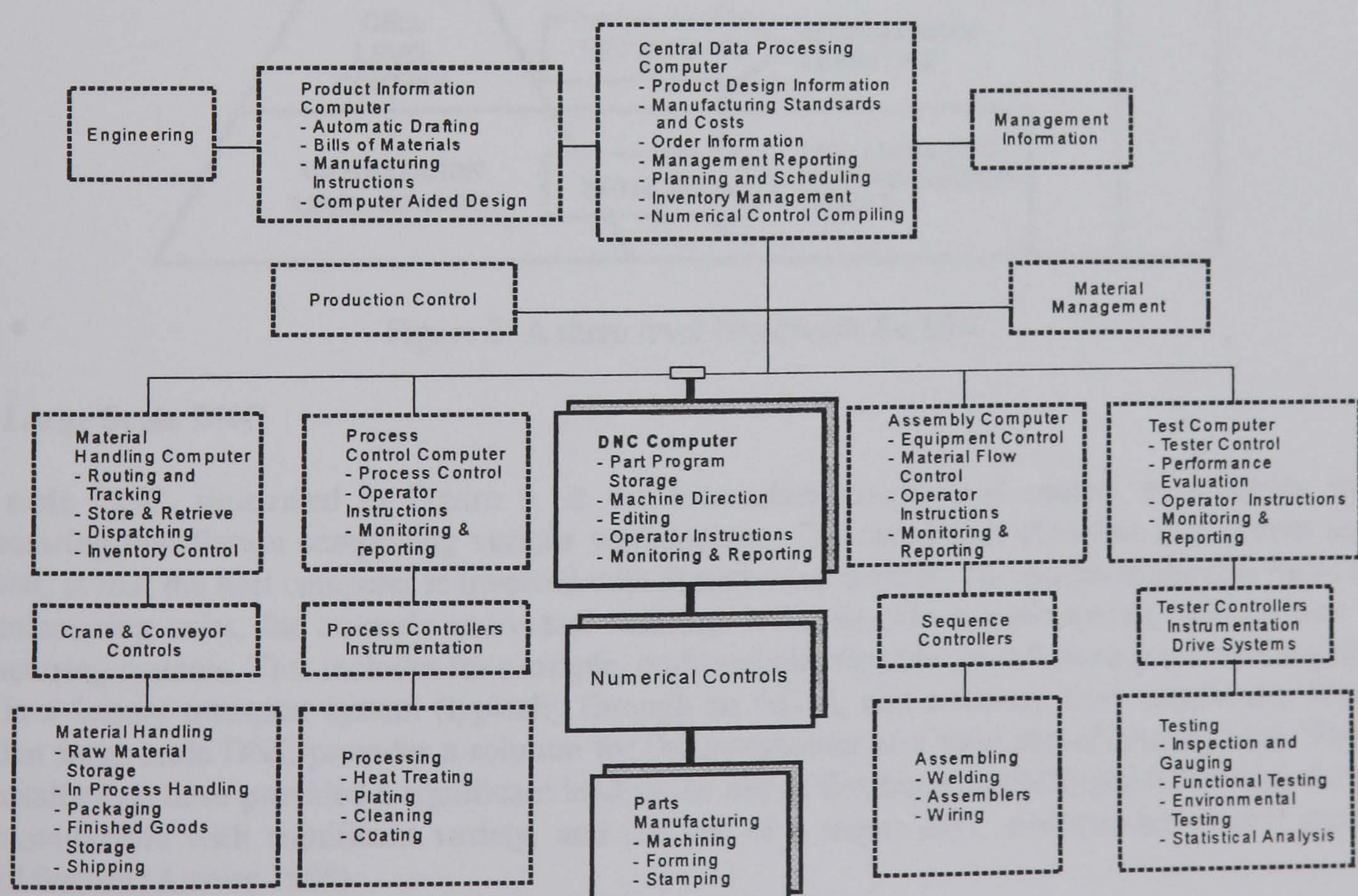

Figure 1: The DNC Installation at Westinghouse Electric.

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The authors have identified two general views of the DNC acronym. The first is where the technology is taken to be a module of a wider shop floor network and where DNC refers to the discharge of the "DNC basic functions" exclusively. This is a "modular" approach which immediately distinguishes for example, the DNC basic functionality of part program management/movement, or data collection as individual constituents. The outcome of this approach is sub-optimisation of the individual modules, where suppliers concentrate on specific areas of expertise. For example, shop floor data collection is popularised as an individual, specialised function.

The second view is to interpret the technology according to the level of control within a hierarchy where all the constituent modules are integral of a DNC network, and the resulting functions fall under the auspices of a DNC system, within which there may exist a "DNC Cell". Wei (Wei 1989) describes monolithic "Large scale DNC" systems, in which DNC is clearly recursive at various levels. In addition, the technology can be further denoted according to it's basic and extended functionality.

The present references to DNC lack a structure against which the various levels of the technology and functionality can be expressed. It is the authors' view, that in order to portray a futuristic view of DNC in batch manufacturing environments or to properly discuss the extension functionalities, a structured approach should be adopted.

4.0 A Framework to Identify the Levels of DNC

Today, hierarchical control architectures underpin many examples of computer integrated factory control, where decisions are made at the top level and controllers at lower levels simply execute the commands. A 3-level structure of DNC has been used by the authors, with a DNC-system title corresponding to each level. As illustrated in Figure 2, the three systems are Large scale, Intermediate level and Low level DNC. These will now be discussed in the context of this framework and it will be seen how this will provide a better perspective of the technology and enable various DNC systems to be identified without the "limitless" boundary of the extended functionality.

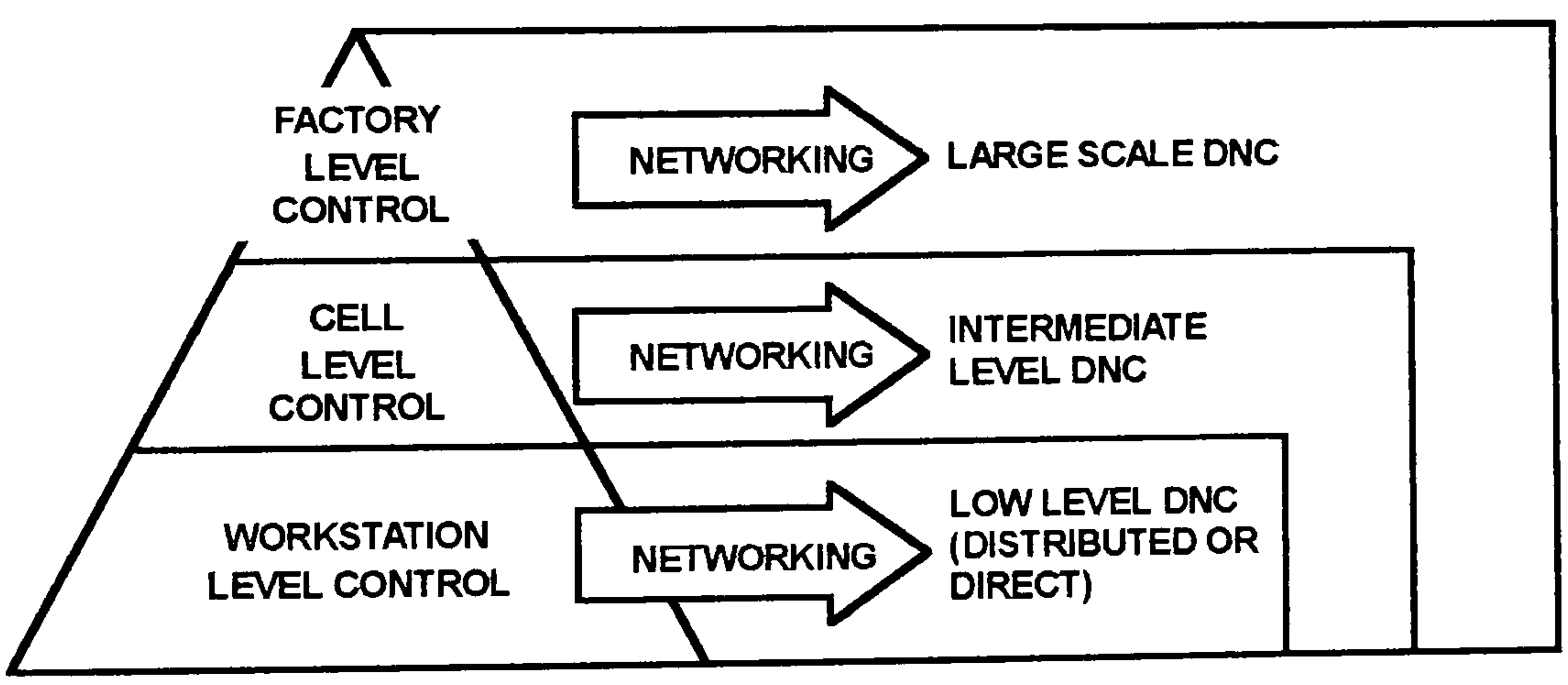

Figure 2: A three level framework for DNC.

4.1 Large Scale DNC

Large scale DNC, illustrated in Figure 3, is the hierarchical multi-level control of a highly integrated manufacturing installation comprising various workstations. The factor that classifies this system as a large scale DNC is that the host computer is involved with factory wide control. The workstations may be in the form of manufacturing units, for example individual machine tools, flexible manufacturing cells or even flexible manufacturing systems. This includes for example, multi-cellular flexible manufacturing systems, supplied with work via a factory transport system (typically through an AGV), and a factory level warehouse. Wei (1989) states that large scale DNC provides a solution for the automation of a total manufacturing area. These large scale installations have provided a significant lead in the use of flexible manufacturing technology for medium batch manufacture with significant variety, and the use of a major DNC network for overall control is a powerful feature (Anstiss 1986).

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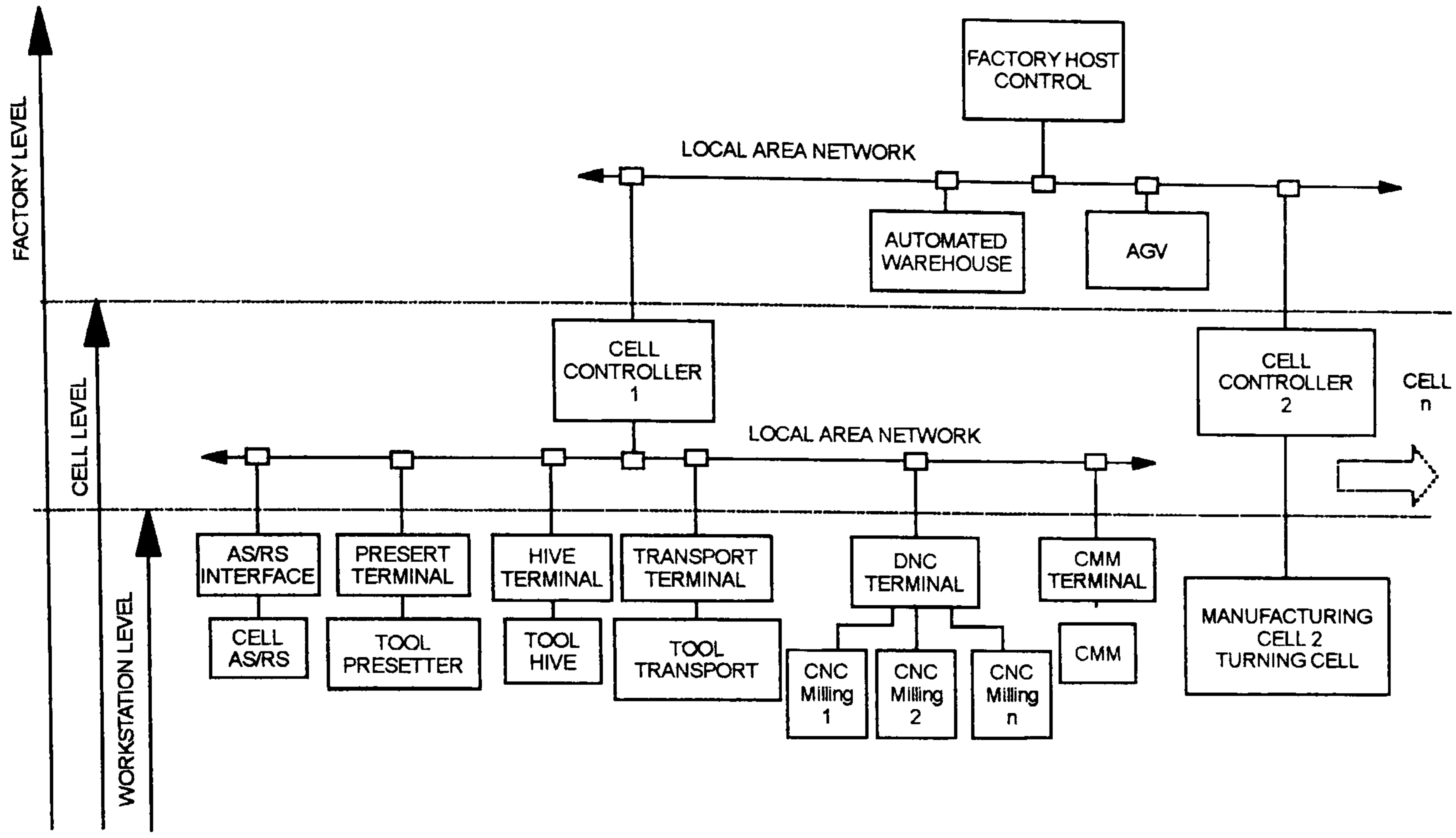

Figure 3: Large scale DNC.

4.2 Intermediate Level DNC

Intermediate level DNC, illustrated in Figure 4, involves the control of a group of machine tools and their immediate environment. It integrates a manufacturing cell consisting of ancillaries such as work and tool storage, a tool-presetter, a coordinate measuring machine. The direction of the intermediate DNC system can be taken to be synonymous to that of cell control. The typical functions include the scheduling of manufacturing orders and coordination of all activities within an integrated manufacturing cell, which involves work and tool flow scheduling at cellular level.

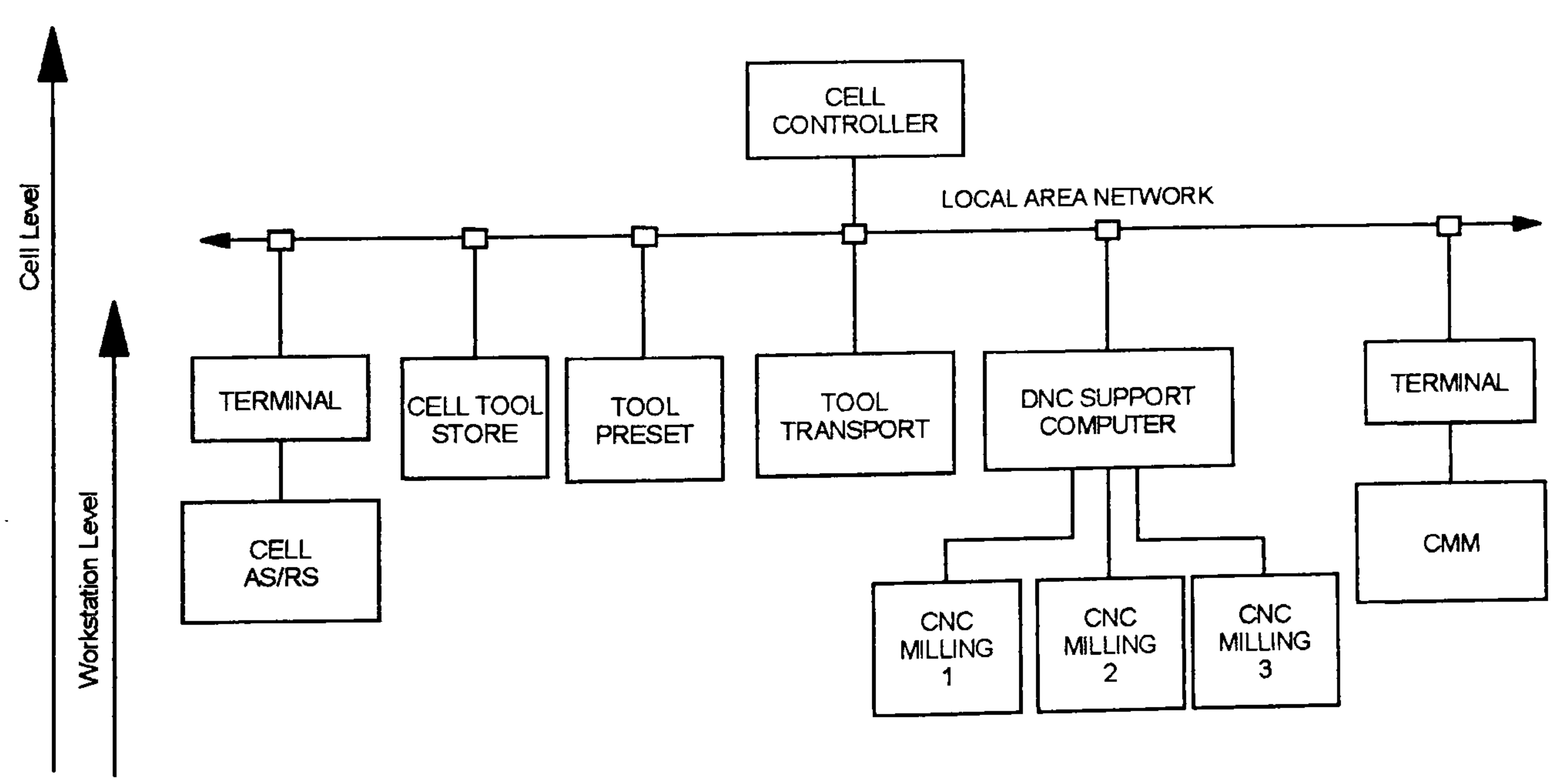

Figure 4: Intermediate Level DNC.

The emphasis of the intermediate DNC system is to keep the operator intervention to a bare minimum through the interconnection of a group of machines both mechanically and in terms of data processing. In this way, highly automated manufacturing cells are created which are capable of handling a number of different workpieces without interruptions to setting-up operations.

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4.3 Low level DNC

A Low level DNC cell involves the control of a group of machine tools exclusively. As illustrated in Figure 5, this excludes the cell ancillaries such as robots, CMMs, tool presetters, etc. The functionality that is typically associated with a low level DNC system is downloading of appropriate part programs to the correct machine tool for machining (Hemphill and Smith 1993). This allows part programs from a programming system to be stored in a machine neutral format until it is decided which machine is to be used. This enables the number of part programs for similar parts to be reduced.

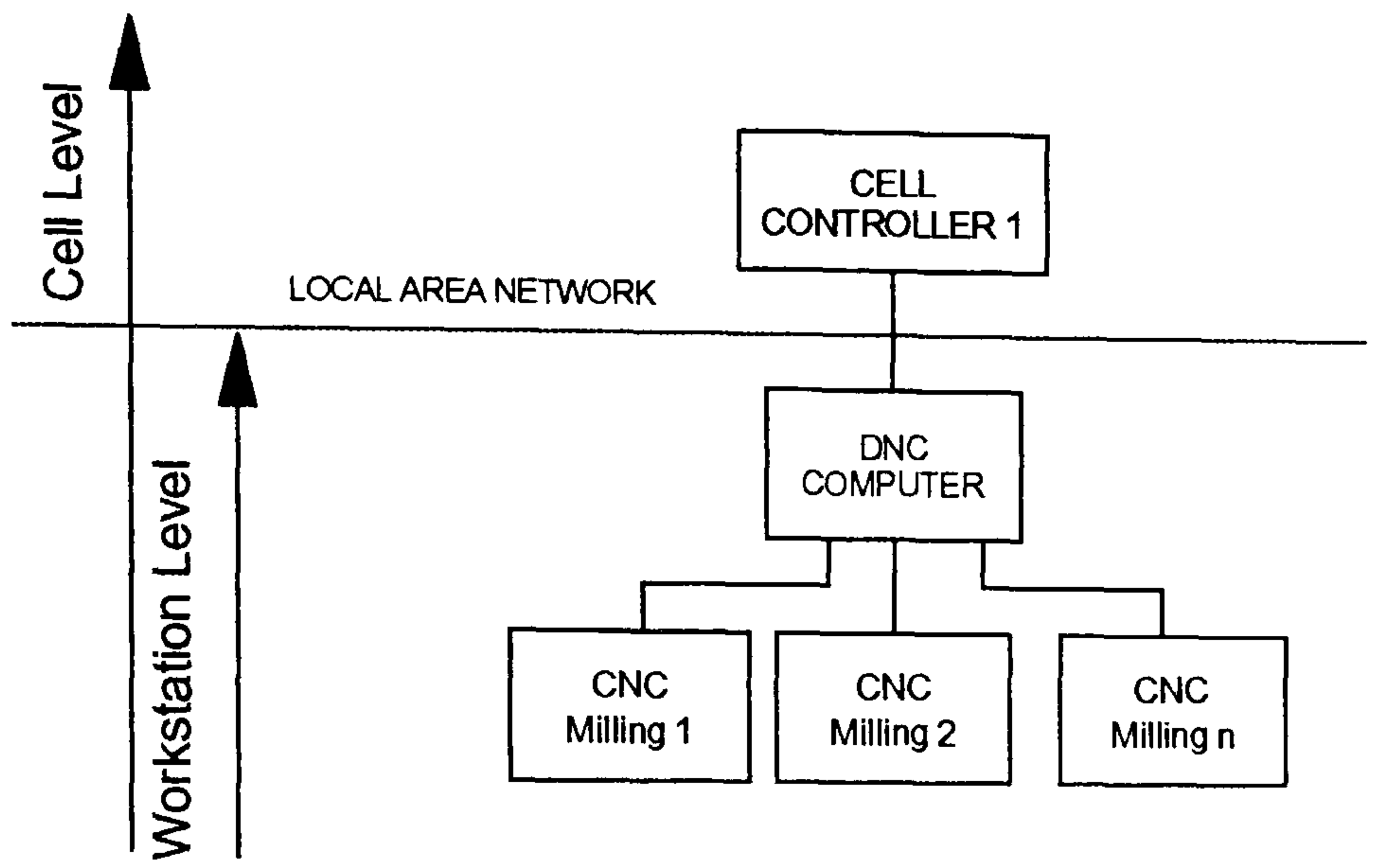

Figure 5: Low Level DNC.

5.0 Non-hierarchical Control Architectures

SMEs, by virtue of their smaller size have inherent characteristics of less complex management, lower manufacturing costs and dynamism. Hierarchical computer control would not be suited in this environment as the relatively small number of people involved justifies only the lowest number of control hierarchies. In view of this, the authors have considered non-hierarchical control architectures for their relevance to the SME.

Duffie *et al.* (1986) propose a non-hierarchical (heterarchical) system. The core of this research centres on a series of design principles that produce a system of cooperating, autonomous entities. The principle of autonomy enforces localisation of information and control and the isolation of entities for fault tolerance in the system. These design principles have been applied for the heterarchical control of a manufacturing cell (Duffie and Piper 1987), where the autonomous cell entities are coordinated in a co-operative manner, based on dynamic part oriented scheduling. In the manufacturing cell, all components to be machined are accorded with individual data records which specify the routing information. These intelligent parts negotiate with the machines and arrange for their own processing slot. The successful integration of humans into non-hierarchical systems for problem solving has also been reported (Duffie *et al.* 1990).

Chaxel et al. (1995) deals with the issue of non-hierarchical manufacturing control by all the products carrying their own information. They investigate and suggest tools and methods for managing the distribution of the information system onto the products, or mobile database nodes circulating in the integrated environment.

The Japanese concept of Bionic manufacturing based on DNA and BN information is a non-hierarchical information centred approach for manufacturing control (Ueda 1992). The analogy of a bionic hierarchy, illustrated in Figure 6, relates to the work piece or a product as it progresses throughout its lifecycle of creation, growth, maturity and death. Throughout the bionic lifecycle, the involvement of BN information on the product increases. This implies an greater amount of interaction with other bionic participants which nurture the product (contribute BN type information) as it grows. The product as a cell comprises of DNA information solely, as it eventually leaves the bionic factory as a mature organ (into society), it carries with it the DNA and BN information. At this stage the DNA and BN information relate to how the product is to be used, maintained and eventually disposed (e.g. user instructions, recycling instructions, etc.).

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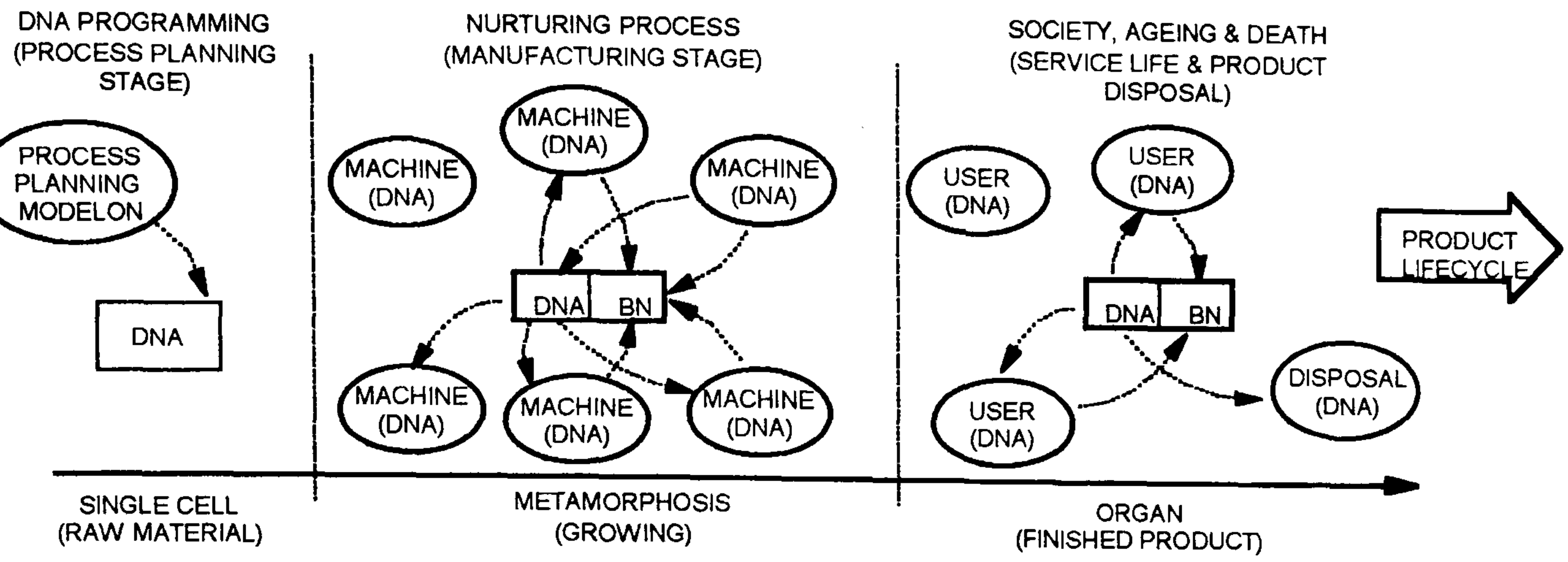

Figure 6: Bionic manufacturing: The product lifecycle based on DNC and BN information.

6.0 Manufacturing Paradigms

The intelligent part oriented control schemas, of non-hierarchical control, may be feasible for the flexible manufacture of a large variety of parts. These parts must consist of a substantial amount of machining content at each operation to justify the time and effort in capturing the manufacturing information. In addition, it may be better applied in cases where the possibility of repeat batch orders is higher. It is the authors' opinion however, that the intelligent negotiation process for shop floor scheduling will not be applicable in the SME environment. Although the inclination is towards a non-hierarchical control architecture, the operator will play the major role in the 'job-to machine' allocation process.

New manufacturing paradigms have now emerged, namely Fractal and Holonic manufacturing, which have direct relevance to how the future SME will be structured and managed, and are briefly outlined below.

6.1 Fractal Factory

The term Fractal was coined to describe organisms and structures in nature which arrive at multiple and complex solutions, albeit task specific ones, by using a number of self imitating elements. Warnecke (1993) adopts this term and introduces the Fractal paradigm for the manufacturing company. As opposed to using a rigid, multi-level control hierarchy, global company goals are formulated in general terms and have to be interpreted and pursued by constituent Fractals as local goals. This forms the basis of autonomous working for the Fractal, whilst the job order comes as a top-down specification, actual planning and implementation planning is based on a bottom-up process. In a dynamic environment, individual Fractals formulate their own goals and methods, for example scheduling and process control and employ appropriate resources to complete their task.

The Fractal factory is an integrating concept and is multi-dimensional, ensuring both horizontal and vertical goal alignment. The paradigm advocates direct communication on the horizontal level of operational levels instead of instructions and information being transmitted through vertical levels of the hierarchy. Individual Fractals are thus networked via an efficient information and communication system and determine their own access to the data.

6.2 Holonic Manufacturing

The Holon is a self-contained entity with the dual persona of assertiveness and an integrative tendency in a wider open hierarchy. Thus if a workstation on the shop floor is modelled as a Holon, it becomes a self-contained unit and also has the awareness of its role as a member of a constellation of peer Holons in a recursive arrangement. Considered to be a solution to the requirement for high variety and variable lot

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manufacturing, the ultimate aim is the development of an architecture for highly decentralised manufacturing systems, built from a modular mix of quasi-standardised, autonomous co-operative and intelligent elements.

One characteristic of the Holonic system is its dynamic organisational structure which is facilitated by a comprehensive information system (Suda 1990). The system is highly distributed with each Holon having functions necessary for production. Examples of these functions are processing, assembly, conveyance, calculation, memory and communication. Human operators in the Holonic factory system are accorded significant prominence, where human intervention is essential via a man machine interface (MMI). It is clearly stated that whilst an operator can operate several Holons, no Holon exists for which man plays no part (Suda 1990).

7.0 Discussion

This discussion identifies the major research themes, illustrated in Figure 7, which have to be considered in the future design and implementation of factory networks for the SME. The introduction of any technological system or software support has to meet the specific requirements of the SME. This avoids stifling the operators with organisational changes to meet the technological solution, and will not compromise the inherent advantages inherent in an SME. The discussion is divided into the following areas:

(i) The specific requirements for shop floor planning and control in the metalworking SME
(ii) Pressure for technological solutions
(iii) The future of DNC in the metalworking SME
(iv) Software support at the autonomous workstation
(v) Socio-technical issues

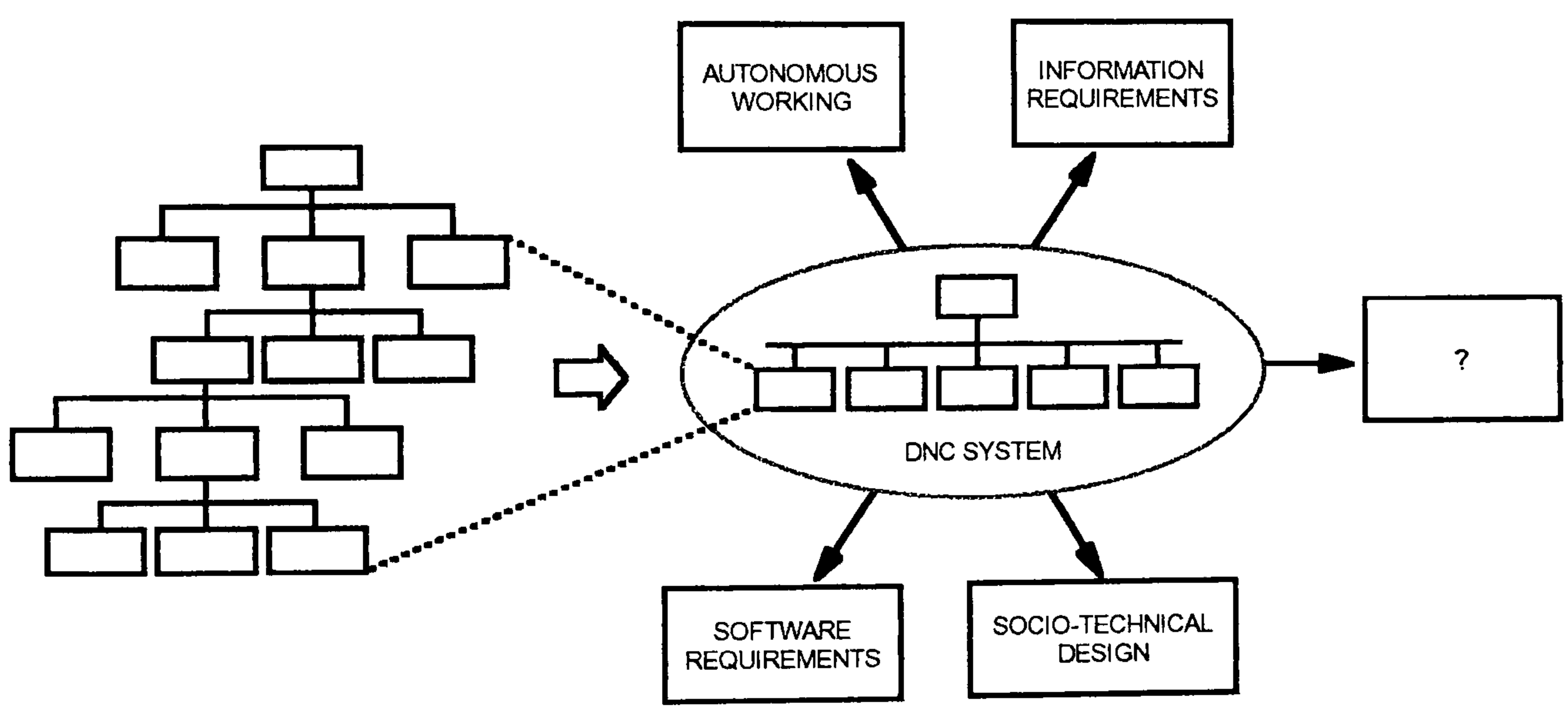

Figure 7: Research issues on a DNC system for the SME.

7.1 The Specific Requirements for Shop Floor Planning and Control in the Metalworking SME

The planning and control activities in a small manufacturing company present unique challenges, because urgent work demands often overrides synchronised shop floor planning. This is especially prevalent for sub-contract industries where the nature of the business depends on accepting and delivering orders, on short notice, where the larger industries gain little profit.

A significant problem will be in dealing with a large variety of complex components, each requiring multiple work settings and a multiplicity of operations at each machine. This is precisely where the SME must maintain an advantage with its ability to simply channel the work to an operator who processes it without further planning delay. It may not be possible to dispense completely with central planning and administration, rather the autonomous units have to be connected to each other entirely by a comprehensive information system.

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7.2 Pressure for Technological Solutions

Technological solutions such as MRPII, flexible manufacturing systems (FMS) and Computer Integrated Manufacturing (CIM) have affected not only the large companies, but also the SMEs. Moreover, there is prominent emphasis on non-technological solutions such as JIT and TQM. In an information age, the management of computer based documentation is essential, particularly in companies that seek ISO 9000 certification. These standards and their associated certification process confirm that the business is governed by comprehensive, well documented and up-to date procedures which are followed consistently throughout the organisation. This emphasis on computer based information will increase as future versions of ISO 9000 will be stronger and more direct in their treatment of computer based systems (Hales 1992).

These technological solutions have been considered in terms of the benefits offered, but neither a wholesale or measured translation of such manufacturing principles will ensure the survival of an SME. There should be increased use of reference models and engineering tool kits to identify the specific enterprise requirements, and aid the configuration of the multiplicity of complementary software solutions (Hirsch et al. 1994). Reference models are required to capture the specific SME information requirements to support typical planning and control functions, such as:

- Capacity planning, financial planning, project costing, personnel management.
- Computer aided engineering (CAE), part program preparation, tool requirements planning and management.
- Inventory control, work in progress monitoring.

7.3 Future Role of DNC in the Metalworking SME

Stout *et al* (Stout *et al.* 1989) recognise that whilst there are considerable benefits from adopting the concepts behind computer integrated manufacture (CIM), a company must establish that the costs are justified. They suggest that DNC is the nearest technology to CIM and conclude that if CIM was not a cost effective reality, consideration should be given towards introducing DNC with its enhanced functionality.

However, it is important to take into account new manufacturing paradigms, Holonics and Fractals, and their influence on the implementation of an information infrastructure. On a high level of abstraction, the individual paradigms converge to an agreement that the SME should be built upon a collection of autonomous, self-contained workstations. The internal and external structures of the Fractal company are founded on the skills of the workforce and in addition, a holistic approach embodies an increasing regard for human need. Therefore, in the Fractal concept, networking is not solely a technical means of integrating islands of automation, instead it fulfils a subordinate function as a tool. In order to determine the state of the individual Fractals, the information system must support the independently operating, continuous efficiency improvement process of Fractals.
This places additional requirements on the communication system, illustrated in Figure 8, that transcends those offered by contemporary DNC systems. The DNC system in an SME can promote operator autonomy by:

- Providing data to associate operator performance to company performance.
- Providing data for self assessment.

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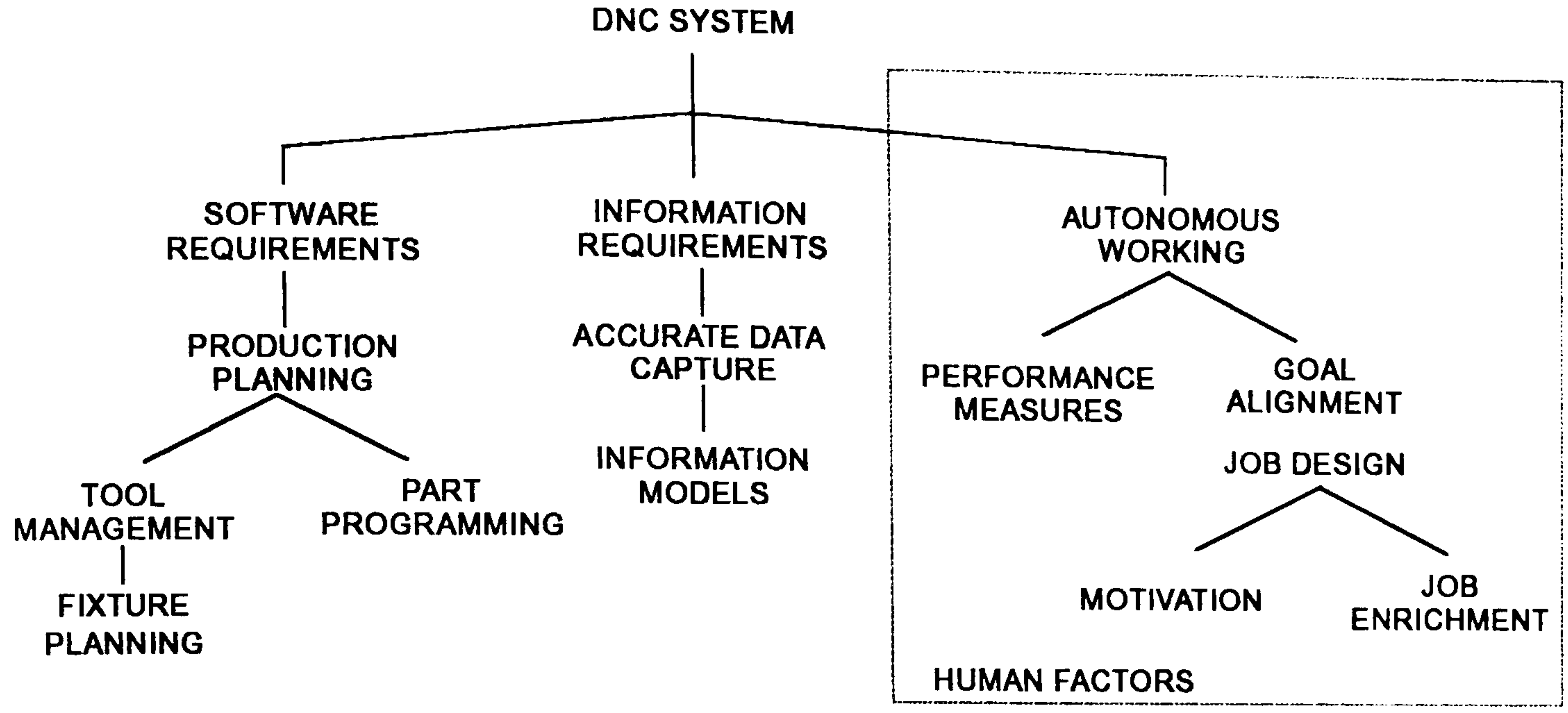

Figure 8: Future challenge for DNC- Incorporation of human factors view.

7.4 Software Support at the Autonomous Workstation

The increase in power and lower cost of today's personal computers are providing a greater opportunity for smaller companies to implement integrated manufacturing at a lower cost, with nearly all of the advantages of the software which was previously only available on powerful computer workstations now becoming of age in the cheaper form of PC's (Toh and Newman 1995). The authors see a new DNC system, illustrated in Figure 9 emerging, in which the PC-based CNC controller (PC-CNC) will play a key role as an enabling technology.

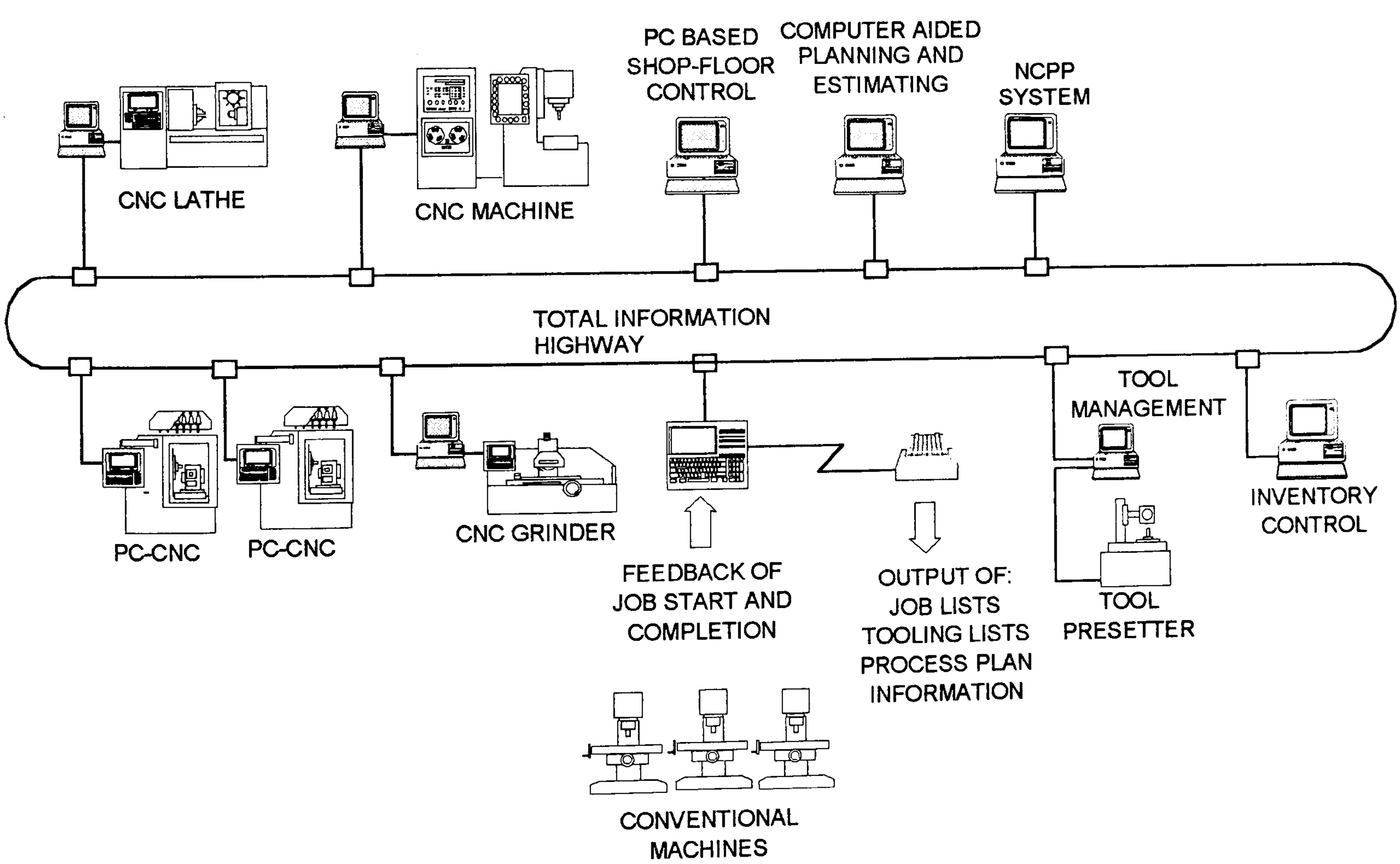

Figure 9: An information network for an SME with PC-Based CNC controllers.

In terms of the software support, the development of hardware has far outstripped the development of software supporting tools. As such there is still uncertainty as to how the end user will utilise the flexibility of installing

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third party choice software at the machine controllers. Future research should focus on the selection of software tools to enhance the autonomy and effectiveness of the individual operator at the workstation.

7.4.1 Sequencing of Jobs at the Shop floor

Without the benefit of larger batch quantities, longer and predictable planning lead times, an SME depends on a highly skilled work force to plan and sort through the work on a daily basis. Skill is not the only requirement for the work force, the ability of the SME to react to an urgent customer order is contingent upon their dedication and flexibility in meeting the due dates for customer orders. Planning for the rushed order often does not go beyond the detail of a route specification, with operations planning at the machine level often delegated to the skilled operator.

The requirements of shop floor managers have to be identified, and software solutions created to help with the shop floor loading for both manual and CNC machine tools. Where, in the past the NC part programs have been downloaded to the machine controller together with the tooling data, thus firming the job sequencing. However, tool breakages, or tool/fixture unavailability often disrupt the planned work sequence machine utilisation becomes adversely affected. It will become possible for the operator to perform sequencing at machine level to:

- Maximise the utilisation of the resident tooling and to minimise tool-changeover.
- Minimise the change over for fixtures, particularly for jobs with long set-up times.

7.4.2 Tool Management Software Support

A significant proportion of the work accepted by the SME would not have been designed externally. As such, the SME would not have control over the tooling selection. Without the benefit of longer lead times, tool management solutions specified for highly automated manufacturing facilities would be unsuitable for the majority of SMEs. To maximise the loading flexibility, the working practice would typically be to maintain a distributed store of standard issue tools. In order to react to urgent work, it would be desirable to maintain a large variety of tooling at the individual workstations thereby increasing the chances of an urgent job being successfully processed.

However, the information relating to what tools are available, the quantity of these tools and the rate of expenditure are typically not available to the managers. Often, a job order may require special tooling which is duly purchased, which upon completion of the work may still have remaining useful life. These are kept either on the shop floor with the good intention of being used should another job require the tool. However, the availability of these tools may not be known to other operators and over time, their existence may become forgotten.

This problem is exacerbated by a lack of information on tooling availability and in the rush to meet the urgent demands, tool tracking or inventory checking takes on secondary importance. There is a requirement for future support in this area of tool management, which considers tooling inventory at manual workstations as well as CNC machines.

- Tool purchasing.
- Information on tool costs.
- Information on tool availability.
- Feed-back to sales for project costing.

7.5 Socio-Technical Issues

The SME is in an ideal position to assimilate the principles of the Fractal factory and isolated elements of Fractals can already be identified; the typical SME may consist of a collection of CNC and manual machine tools where the operator generally has the autonomy of planning his work and operation sequences. This will provide high flexibility in product and production reconfigurability and will enable the integration of customer needs with flexible processes. Design of future DNC systems should avoid the failure of computer based shop

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floor control, caused when individuals have no opportunity to influence the design of their working environment and the operating staff are unable to supervise the manufacturing complexity.

A Japanese SME, the Horiuchi Cylinder manufacturer (Anon. 1989), is an example where a technical approach has not compromised the autonomy of individuals, work groups, their roles and the social structure of the company. A major emphasis of this company is in the reduction of supervisory intervention, were the task of purchasing parts, tools and raw material is relegated to the leader of an individual section. A consequence of the distributed management is that the leaders can directly convey to the suppliers or subcontractors their exact requirements. Changes in suppliers can also be made, as if the section were a business unit and was responsible for the task of supplier appraisal (Anon. 1990a). This case study illustrates the feasibility of non-hierarchical control in the SME and highlights the need for a DNC system which supports operator autonomy.

The ingredient which underpins the success of future companies is the utilisation of the skills of the people to create a condition where ideas can be contributed and implemented. The skill requirement of the machine operator has to be evaluated in terms of the increased computing literacy required. It will necessary to explore the human aspects of integrated manufacturing for the SME, such as:

- Goal alignment through the dissemination of company goals.
- Operator autonomy.
- Skills development in the new DNC environment.

8.0 Conclusions

The contemporary status of DNC has been presented in this paper, the authors have used a three level framework to demarcate the various forms of the technology. The amount of computer domination diminishes with each reducing level of DNC. Large scale DNC implementations are founded on the basis of total control, where the decision making is reduced at lower levels of the framework. All the activities under the Large scale and intermediate level DNC control are scheduled by the factory host or cell controller. In contrast, for low level DNC installations, the decision to start machining can be left to the operator, where the central program store serves primarily as a supply of part programs. Although the interpretations of DNC can be varied, it appears that the SME is more predisposed to accepting a low level implementation technology because it does not carry the connotation of CIM, and its associated high cost. Therefore, continued existence of DNC will be expected, but there is significant scope for a greater role, especially in areas relating to the integration of human factors in an SME.

However, current advances in the functionality of a PC-CNC control will have ramifications on the way operators will play a greater role in reacting to real time disturbances. The role of DNC on the shop floor will transcend that of shop floor control, rather it will play an important role in providing both information and software support for harnessing the manufacturing resource as a competitive and strategic tool. The emergence of new manufacturing paradigms will have an influence over the information infrastructure of companies, where the application of appropriate technology, coupled with effective use of human resources can improve the efficiency of a company and enable autonomous operation with minimal management intervention.

9.0 Acknowledgements

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Appendix IV

An Architecture for Information Specification Based on an SME Enterprise Model

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An Architecture for Information Specification Based on an SME Enterprise Model

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ABSTRACT

This paper describes a CASE tool architecture for a manufacturing information specification. The objective of this is to establish a new approach to the specification of information requirements for an SME IT system. An enterprise model for an SME metalworking company is introduced and mapped onto the ARIS architecture, this enables the modelling tool to be described in the context of enterprise modelling, which highlights the important relationship between enterprise models and information specification.

INTRODUCTION

The metalworking industry consists of a wide spectrum of companies, amongst which small to medium-sized metalworking enterprises form a significant proportion. Whilst some may possess a niche market, others frequently play the role of being the company at the end of the supply chain. As a consequence, many SMEs work in a volatile environment, employ small numbers of operators and are heavily dependant on their dedication and flexibility. The information flows and information storage requirements are different to those found in larger companies, who out of necessity operate in a more hierarchical and deterministic structure.

The generation of specifications for the IT system is compounded by the inherent complexity of manufacturing systems. Furthermore, the particular needs of individual companies have to be fully taken into account, with user driven specifications for the information system. In order to ensure the implementation of an information system that is appropriate for an enterprise, a structured approach should be used where individual phases of the design to implementation process should be precisely defined and based on a standardised project structure. Enterprise modelling tools can thus be used to provide a fundamental bridge between the user and the IT vendor.

Explicit models of the enterprise are an important enabler of understanding, which focuses directly on the activities and objects within the company. The main assertion in this paper is that much of the data necessary for designing the new system exists in enterprise models, as a consequence, enterprise modelling should be linked to the creation of information systems specifications.

A REVIEW OF INFORMATION SYSTEMS SPECIFICATION AND ENTERPRISE MODELLING

Structured approaches such as the Structured Systems Analysis and Design Methodology (SSADM), have been widely applied for information systems implementation. SSADM begins from the study of an existing system to the implementation of a new one, taking into account evolution objectives and specific constraints. The methodology applies entity-relationship (ER) modelling, data flow analysis and modelling techniques for mapping entity life histories (1). Systems analysis methods are being enhanced with engineering methods based on modelling formalisms used in conjunction with a modelling architecture. These provide improved capabilities for modelling as a means to identify problems, simulate changes and give direction to managing change and integration (2). The process of requirements definition then transforms the available knowledge, via a modelling framework, into more formal descriptions.

Generally, the primary reason for constructing a model of the enterprise is to supply an explicit method for the analysis, understanding and the control of some selected aspect of the company (3). The result is a symbolic representation of individual facts, objects and relationships that occur within an organisational entity. The use of modelling frameworks thus greatly reduces the modelling effort and can be computer based. Examples of frameworks for enterprise modelling include CIMOSA (Open Systems Architectures for Computer Integrated Manufacturing) (4) and ARIS (Architectures for Integrated Information System) (5). These systems modelling methods may be applied as some form of a CASE tool. Other architectures for enterprise modelling include the Purdue architecture (6) and GRAI (7). The Purdue enterprise reference architecture does not as yet, require specific modelling formalisms to support each step of the development process (8). The GRAI structured methodology for enterprise integration is supported by modelling tools, namely the GRAI-GRID and the GRAI-NET (7). The former identifies the major decision centres in a company, which the latter (the GRAI-NET) models in detail.

In recognition of the need to define standards for IT and computational systems, ISO/IEC have developed a reference model for open distributed processing (RM-

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ODP) (9). The RM-ODP reference model is an organising framework for the substantial body of specifications which is typically associated to large and complex systems. The reference model comprises five parts, which enable the IT system to be specified in terms of its enterprise, information, computational, technological and engineering viewpoints (9). The information viewpoint is of the prime interest in this paper, it specifies the information held by the ODP system, in terms of information objects, their relationships and behaviour.

THE USE OF ARCHITECTURES FOR THE SPECIFICATION OF INFORMATION REQUIREMENTS

A major part of the information system design process is the specification of the information requirements. Vernadat states that in order to correctly capture information requirements, the functionality and behaviour of the enterprise must first be modelled (3). Hence it is appropriate to emphasise this fundamental bridge between enterprise modelling and the creation of information systems specifications, so that a unique understanding of the information requirements can be derived from an appropriate modelling framework such as CIMOSA or ARIS. The main characteristic of these architectures is the inclusion of an information viewpoint which is accompanied by the necessary methods and constructs for information specification. The currently accepted solution for realising IT support based on these architectures is to model the enterprise, generate the information network specifications and proceed to implementation.

To realise a complete information specification, a choice has been taken (10) to generate the specification in accordance with the ANSI/X3/SPARC three level architecture for database management systems (11). This architecture, which comprises the conceptual, internal and external schema, has been chosen as it has gained a wide level of acceptance and forms the basis of modern database architectures. The architecture has reached a relatively stable state, in so far as the schema levels are concerned, and that future refinements are not expected to result in the addition of new levels.

THE ARIS ARCHITECTURE FOR INFORMATION SPECIFICATION

The ARIS architecture comprises four views, namely: function, organisation, information and control view. ARIS supports the modelling process from design specification to implementation. The first three views of the architecture are directly associated to the model of the process chain; the function view models business processes in terms of functional and goal structures. The organisation view models the organisational units responsible for the tasks defined in the process model. The information view of the ARIS architecture models the parameters for the process functions (5). These parameters might be, for example, related to the number of products to be created, inventory levels, or parameters related to the resources employed. The relationship between the function view and information view, is that the performance of any activity or task results in an alteration to the conditions in the information environment.

The control viewpoint models the relationships between the three views (5). The difference between ARIS and CIMOSA is that the latter demarcates the resource model through a major viewpoint, whilst the former architecture subsumes the resource description into the information view. The ARIS architecture takes into consideration that the resource entities may have information parameters that are used during the performance of a task. An example of this may be the status or location of the manufacturing resources (e.g. machining fixtures, cutting tools, etc.) on the shop floor, cost of the resource, or the available quantity.

THE NEW APPROACH TO INFORMATION SPECIFICATION FOR THE SME METALWORKING COMPANY

The objective of this research was to establish an approach to the specification of information requirements for a shop floor IT system. Invariably, a large proportion of the information requirements relating to the operational issues of shop floor control involves the manufacturing resources. Moreover, the capacity of the manufacturing plant, which directly affects its ability to accept an order, does not remain unchanged, it varies according to the combination of machine and resource commitments at any particular time.

The information associated to the resource structure plays a pivotal role; managers make decisions to accept orders, or to invoke sub-contract resources by reviewing the level of factory capacity in terms of manpower and machine resources. The resource information structure has, therefore, to contain parameters relating to the level and location of material, expendable inventory, job sequences, and the impact of job relocation on the capacity loading at machines. As such, the authors decided that the resources would be better modelled within the information viewpoint which allows the specification of the necessary information attributes to the factory resource entities (10).

It is important to note that this does not disprove the CIMOSA architecture; the resource information exists

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2nd-4th April 1997, Cambridge, U.K., pp. 456-463.

within the model, but mapping the information structure to the ARIS architecture does not demarcate the resource model nor emphasises its prominence as a major viewpoint. This reiterates the assertion, that the constitution and organisation of the enterprise model should be driven by its intended application. For this purpose, the architecture of ARIS has been used to place the relevant viewpoints into context for information specification. However, this research has identified two aspects that need to be addressed. Firstly, there is still a need for generic models of information structures which would greatly enhance the use of these modelling architectures. Secondly, there should be flexibility within the individual viewpoints for alternative approaches to information capture. This paper proposes an enterprise model based on holonic systems concepts and a basic information structure for small manufacturing companies, these are discussed in the next sections. The contents of this enterprise model is subsequently mapped against the ARIS architecture which will form the basis of an information specification tool. The results of this mapping will highlight the relationship between enterprise modelling and information specification and show the applicability of the modelling architectures for this particular purpose. The architecture will set the enterprise model in perspective and will provide a basis for comparison against other modelling tools.

THE SME ENTERPRISE MODEL

The contemporary architectures have been intended for deterministic systems, and are based on the premise that all enterprises can be functionally decomposed into business process chains, where operational rules impose the unconditional execution of enterprise activities. This is regarded to be unsuitable for the majority of SME companies which work in volatile environments. Out of necessity, larger companies operate with more formal, hierarchical and deterministic operational structures, coupled with highly developed production control and process planning. On the other hand, sub-contract companies at the end of the supplier chain work under volatile external pressures, utilise informal organisational structures, employ small numbers of operators and are heavily dependant on their dedication and flexibility. The specification of information requirements must capture the management style of the business and must be supportive of the patterns of work on the shop floor. It is, therefore, important to point out that the wide spectrum of businesses cannot be supported by the same approaches to information specification.

This work involves the development of a new, generic SME reference model which enables the specification of information requirements. The enterprise model must be capable of representing the basic systems functional and information requirements of the company. An information modelling tool can be subsequently developed to allow an instance of the enterprise model, and consequently, the information specifications to be realised. The contents and structure of SME enterprise model has been founded on a novel holonic systems concept which underpins the process of information capture (12). The following sections of this paper will introduce the research work and a new approach to information specification based on holonic systems concepts.

A Three Field Approach to Information Capture

Three interacting fields of data capture, illustrated in Figure 1, are needed in order to develop an adequate representation of the SME enterprise and instance of the information requirements. This three field approach to data capture underpins the contents of the reference model and is used to illustrate the author's approach to the process of instantiating the information requirements. The first field of data relates to a description of the factory facility of the enterprise. The second field of data involves the holonic dimensions of the enterprise, which captures the human dominated interactions, which are characteristic of the SME. The third field of data involves a specification of the information which needs to be held within the information system. The following sections will explain the three individual fields of data capture for the SME enterprise model.

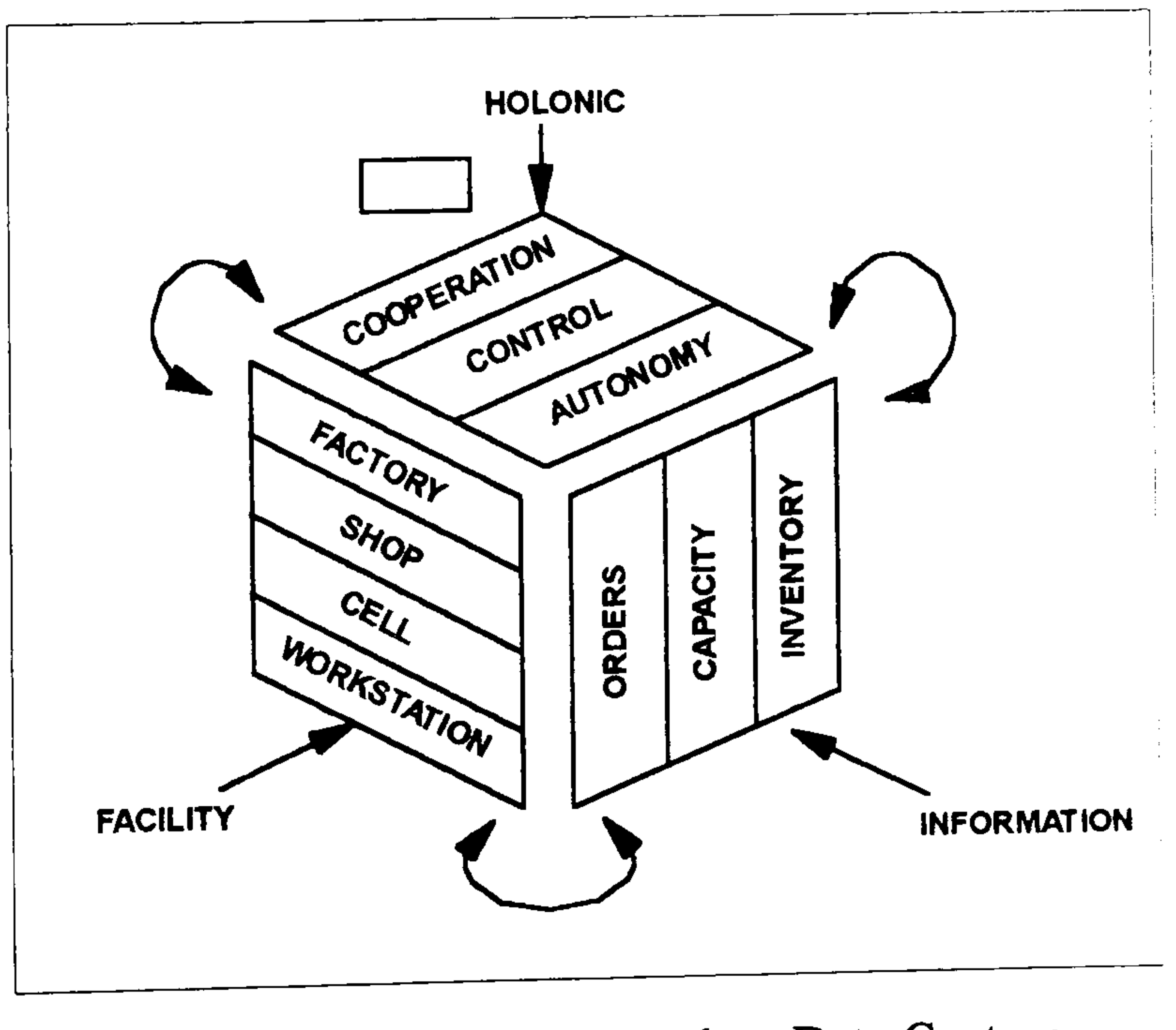

Figure 1: A Three View Approach to Data Capture

The Facility Field of Data Capture. The first field of data relates to a description of the organisation of the enterprise facility in terms of a generic four level factory, shop, cell and workstation structure. This generic structure will enable the factory facility to be mapped against the four levels to produce an instance of the facility description; this level is essential in order to obtain a model of the organisation of the enterprise facility for which the information system is to operate. At this level, the model of the factory is that of an empty facility which does not capture any aspect of its manufacturing resources or processes. The manufacturing resources and processes, which a facility has, need to be described; this is carried out within the second field of data capture.

The Information Field of Data Capture. The second field of data relates to the information structures which need to be captured by the SME enterprise model. This second field of data must be associated to the first in order to produce a model of, for example, the process capability and manufacturing resources contained within a manufacturing facility. The manufacturing processes and resources are identified and modelled as information entities, which will enable information attributes to be associated to the information classes. The second field of data may be modelled independently of any specific enterprise, where the generic structure of information classes may be developed. The class taxonomy of the SME enterprise model is realised in the CASE tool using a class taxonomy modeller, which enables the hierarchical tree of the information entities to be defined.

The Holonic Field of Data Capture. The third field of data involves the holonic dimensions of the enterprise, which captures the human dominated interactions, which are characteristic of the SME. The nature of the interactions are classed accordingly into autonomy, cooperation and control. In order to model the holonic dimensions, the concept of the holon is used to model the functional entities which perform the processes and activities in the enterprise. The third field of data underpins the process of instantiating the generic information structures, it establishes the relationship between the information structures and the holons. The CASE tool allows individual holons to be modelled.

Realisation of the SME Enterprise Model Using the Class Diagrams of the Booch Methodology

To describe the functional, information or organisational aspects of an enterprise, any appropriate modelling formalism can be chosen. However, in order to create an integrated modelling tool, a meta-model of the individual modelling formalisms has to be created to abstract from the specific modelling constructs. Accordingly, selected modelling formalism have to be decomposed into their constituent elements and represented in terms of objects and relationships. The different formalisms may then be represented in a uniform manner across the individual viewpoints. If a uniform descriptive language is chosen throughout the individual viewpoints to create a meta-model, a common semantic framework is maintained and the interdependencies between the individual components of the SME enterprise model can be explicitly established. This is an important concept as the meta-model of the individual constructs ensures a model that is integrated across all four views and thus enables the ARIS architecture to be directly implemented as a CASE tool (13). A computer based modelling tool for the specification of manufacturing information requirements has been founded on this principle of employing a meta-information model.

The contents of the SME reference model are captured using the descriptive formalism of the Booch class diagrams (14). The Booch modelling methodology describes the existence of classes and their relationships in an object oriented applications system. The methodology has an established set of object oriented modelling semantics based on *inherits*[1], *has*, *uses*, *metaclass* and *instantiates*, to enable the conceptualising and modelling of relationships or associations between classes. For instance, the *inherits* relation is used to denote inheritance in object oriented programming. This is not strictly a semantic modelling principle, but is primarily used to model a programming mechanism which reduces redundant programming code.

The Booch class diagram establishes the conceptual schema for instances of the viewpoints within the architecture. Hence, the class diagrams are used in two contexts; firstly, it has been used to establish the class structure for instances of the SME enterprise reference model. As there is a direct correlation between the modelling constructs and the structure of the modelling software, the implementation, which is based on the object oriented programming paradigm, can be carried out directly based on the class structure of the SME enterprise model. Secondly, with extension to the semantics, the representation using the Booch class diagram becomes an effective communication tool. Relations such as *is_a*, *describes*, *performs*, *invokes*, *determines*, *subject_to*, or *accesses* are used to described, unambiguously, the concepts and relationships behind the enterprise model

AN ARCHITECTURE FOR AN INFORMATION SPECIFICATION TOOL

The contents of the information specification tool, illustrated in Figure 2, are shown mapped onto the viewpoints of the ARIS architecture. The architecture

[1]The semantic relations will be shown in italics within the rest of this paper.

of the information modelling tool is based on three principal components, namely an information class taxonomy modeller, a component for the capture of the organisational structure and an activity modeller which is based on holonic systems concepts.

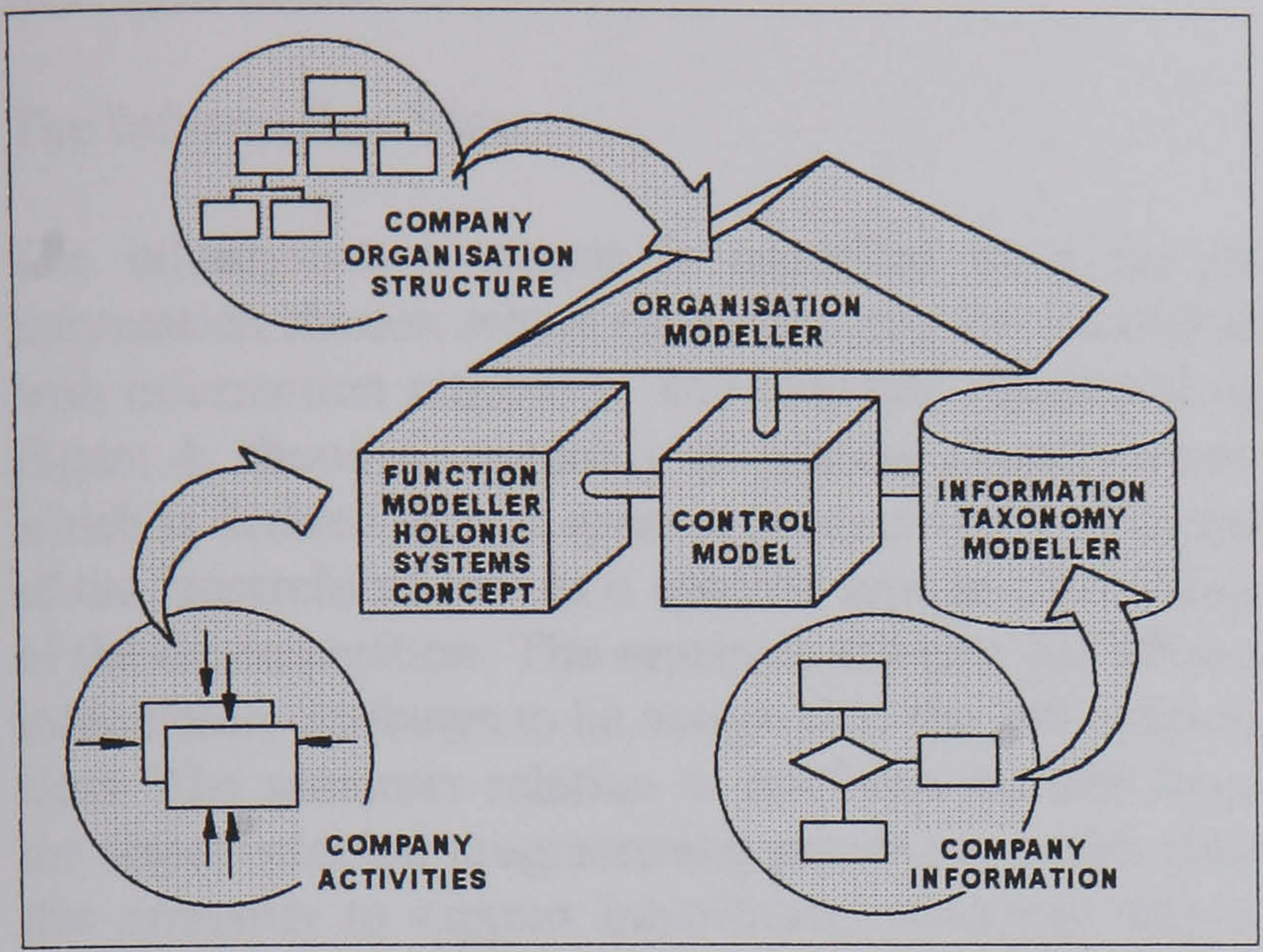

Figure 2: The architecture of the information specification CASE tool mapped onto the ARIS architecture

The Function View

The starting point for modelling the function view is a need for a new form of representation where the organisational structures within a company are less structured and more informal. This is followed by an assertion that the human dominated interactions which occur within the organisation of SME companies may be characterised in holonic terms. Koestler's fundamental study included social organisations consisting of hierarchies of semi-autonomous sub-wholes, branching into intermediaries of a lower order (15). The entities existing within the SME hierarchy might, for example, consist of the executive holon of the company and the operator holons working in the machine shop. The human holons operating in this holarchy are expected to display relative autonomy in their work. The executive holon represents the ultimate decision-making individual who may be actively involved in the planning and adjustment of work sequences and in the execution of manufacturing activities. This representation is the simplest configuration of an SME holarchy.

The characteristics of the holon have been influenced by Koestler's definition of the holon (15) and from Suda's application of the holon for highly automated manufacturing (16). Suda characterised the holon into hard and soft holons; those holons which perform information processing tasks are categorised as soft holons and those which perform manufacturing tasks are categorised as hard holons. The holon is a functional entity, its functionality is modelled using the semantic relation *performs*. A holon therefore *performs* information processing or manufacturing tasks. In order to identify the primary functionality of the holon, the semantic relation *characterised_by* is used to associate the holon with a process which is defined in the manufacturing model. Hence, a holon with a vertical CNC machining centre may be *characterised_by* vertical CNC machining *is_a* hard holon which performs vertical CNC machining tasks. The relationship between the information specification model and the information structures, as depicted by the second and third field of data capture, is established by modelling the functionality of the holon.

Elements of the IDEF0 activity modelling construct are used within the functional viewpoint for operational analysis, the formalism has been selected because it is easily understood and has been widely applied for activity modelling (17). Figure 3 demonstrates how the Booch class diagram enables the creation of meta-models of the constructs used in the IDEF0 based activity modelling formalism.

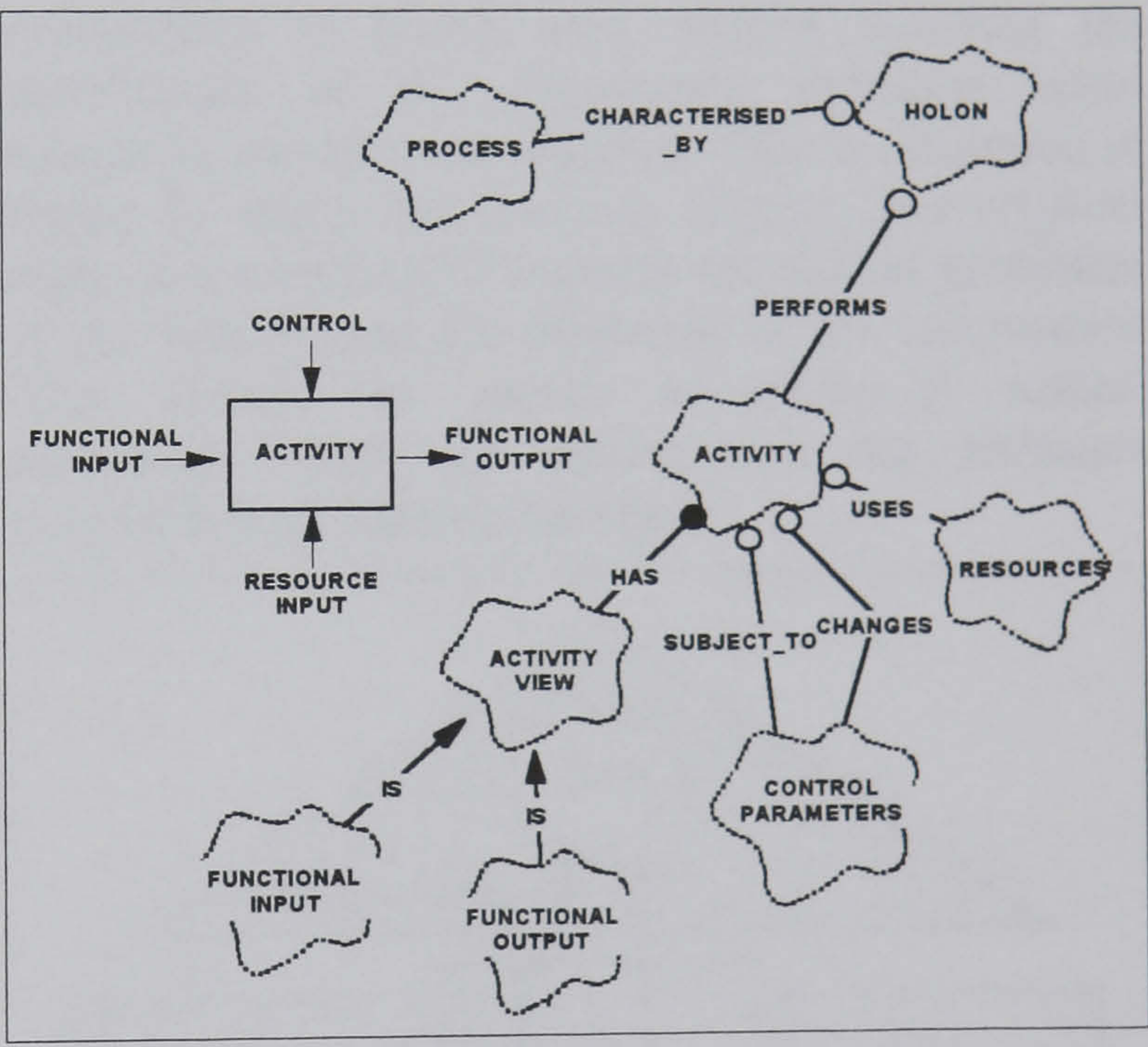

Figure 3: The creation of a meta-model of the IDEF0 activity modelling construct using the Booch class diagram

As shown in the figure, the semantic relations *subject_to*, *uses* and *has* are used to define the IDEF0 constructs. Hence, an activity is *subject_to* control parameters, *uses* resources and *has* functional inputs and outputs. This demonstrates how the meta-model is created for the modelling constructs of the IDEF0 modelling formalism.
The holon is distinguished through its capability for working in an autonomous manner and its capability to interact with other holons via control and cooperation. Therefore, the holon *has* autonomy, control and cooperation mechanisms. The holon is expected to have

a degree of autonomy in performing the supporting activities. The more activities which the holon is given the responsibility to perform, the more autonomous it becomes. The assignment of these autonomous activities is carried out during the modelling of an individual holon.

The Information View

The information structure is modelled as a set of information classes, where each class may be associated with information attributes. The example illustrated in Figure 4, shows a taxonomy of process classifications which is derived from a generic process type at the top of the hierarchical tree to a specific type at the bottom of the decomposition. The semantic relation *has* allows information attributes to be assigned to the information class. The semantic relation *is* has been derived from the object oriented programming paradigm, which uses this primarily to support inheritance. Although this is not strictly an information modelling principle, it enables all instances of resources, customer records, orders and jobs to be modelled as information classes, facilitating the specification of the information attributes for each.

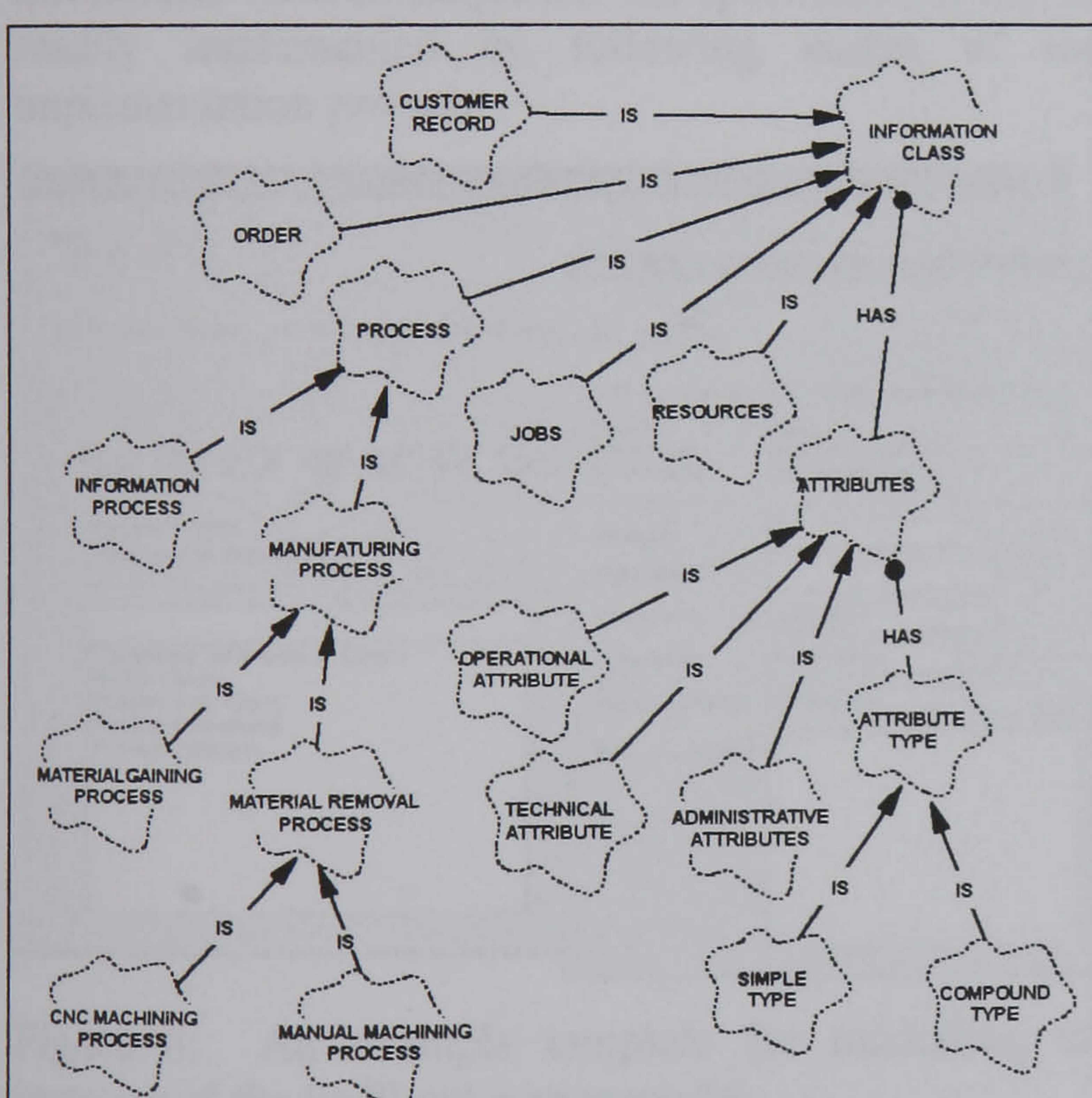

Figure 4: The class taxonomy structure of the information viewpoint modelled using the Booch class diagram

Figure 4 shows how the process and resource taxonomies are modelled in the information view. A process has associated information parameters which may, for example, help in the identification of an alternative process route. An instance of this might be the process cost, or the quality of surface finish which relates to the capability of the process. The process taxonomy may be defined in a top down fashion, from a generic level description to a detailed process description using the semantic relation *is*. Hence, a CNC machining process *is* a material removal process which in turn *is* a manufacturing process.

Similarly, the taxonomy modeller allows the creation of resource taxonomies where resources are instances of information classes. Again, the semantic relation *is* can be used to model cutting tools or cutting coolant as expendable resources, which *is* an operational resource, which in turn *is* a manufacturing resource. The taxonomy modeller is designed such that attributes assigned to the upper level, or parent class is automatically inherited by child information classes. This enables generic information attributes to be specified at the top levels of the class taxonomy, reducing the modelling effort required for the child classes.

The Control View

The control view has been introduced to federate the hitherto independent viewpoints and identifies the relationships to bridge each, thereby allowing the specification of the information attributes when enterprise activities are modelled. This is illustrated in Figure 5, where the semantic relation *derived_from* captures the association between the control parameter of the activity and the attributes of the information class. Hence, the activity is *subject_to* control parameters which are *derived_from* the attributes associated to an information class.

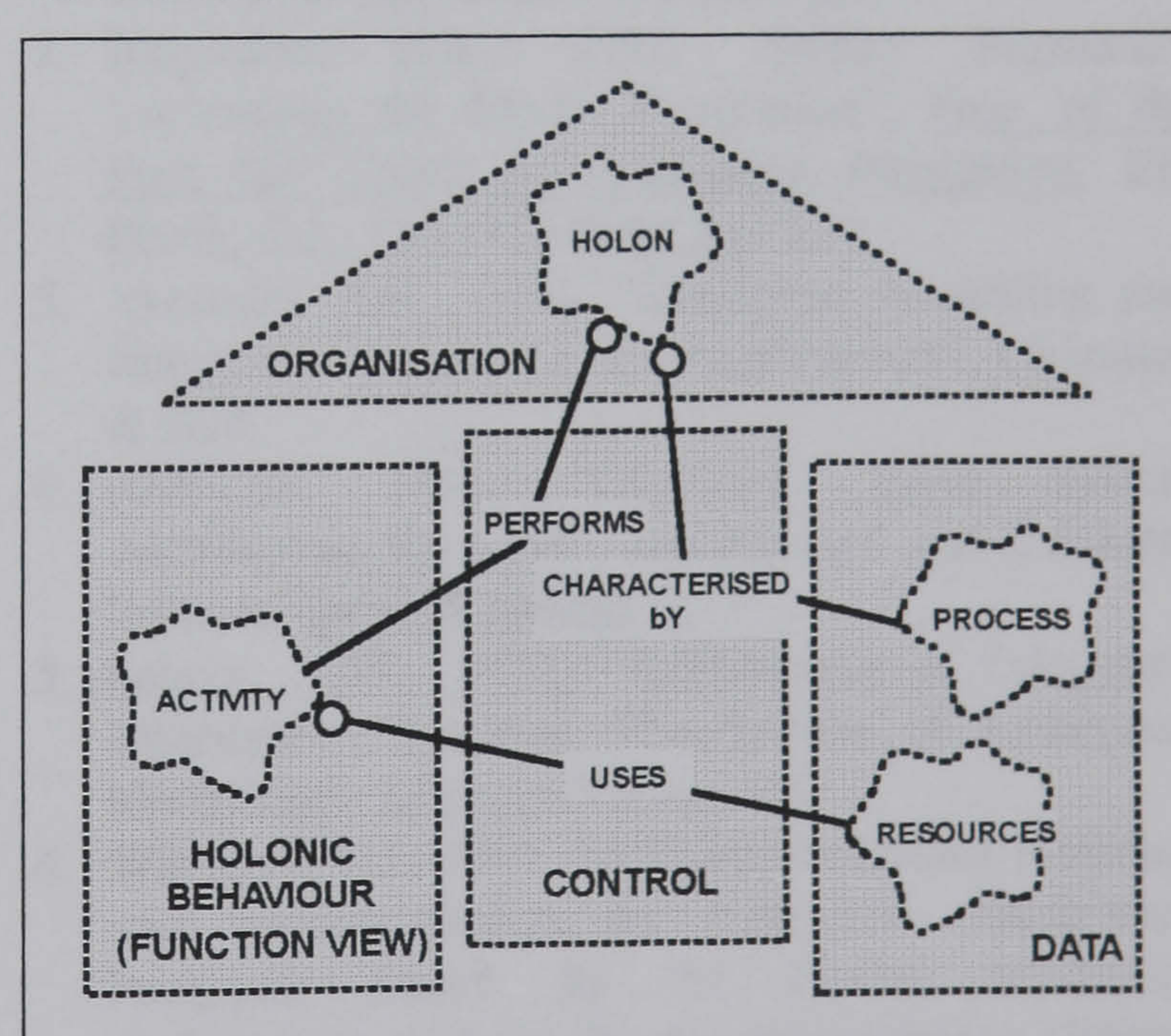

Figure 5: Modelling of the control view to establish the relationship between the individual views

The control viewpoint captures the relationships between the classes allowing the associations to be created in the modelling software. As a consequence of the links, class browsers can be designed to view, from within any viewpoint, the list of classes in another. This is the basis for information specification, where a relationship between the function viewpoint may be established with the information viewpoint via the control parameters.

The architecture of the CASE tool has been implemented using an appropriate application, such as Visual C++. Through a series of dialog templates and menu selections, the CASE tool guides the user through the process of creating a particular instance of the information models. Modelling templates can now be based on the constructs of the functional viewpoint, these are used to populate the details of the activity, which in turn, provide access to the information structures via a class browser. In the process of activity modelling, there will invariably be instances where information is incomplete, here the missing attribute may be identified and created for the relevant information class structure. The CASE tool written for this methodology may be used to produce a set of information specifications consistent with the specifications of the information viewpoint of the RM-ODP and the requirements of the ANSI/X3/SPARC framework. As a consequence, the specifications can be readily implemented by following stages of the implementation process.

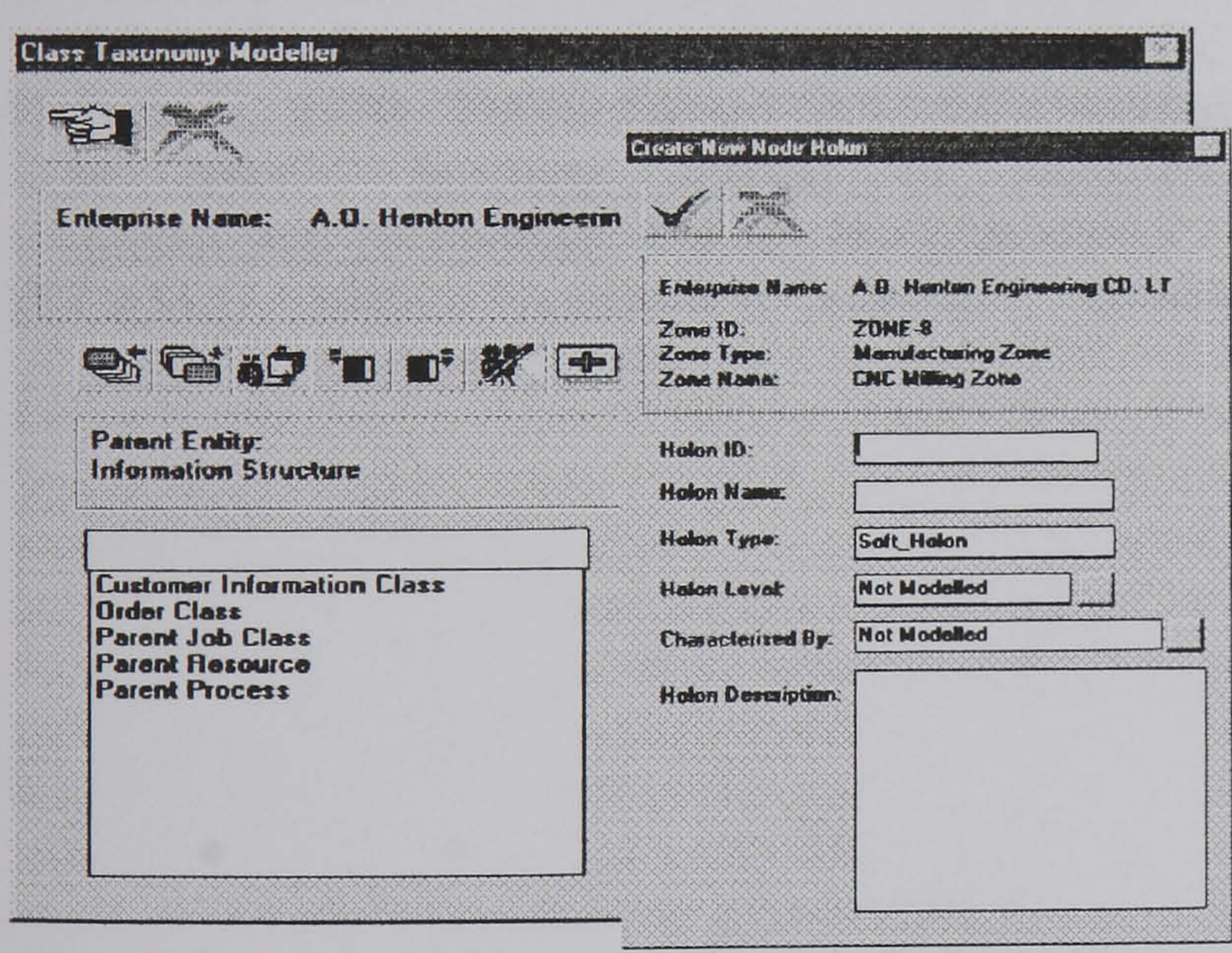

Figure 6: An example template for modelling an instance of the SME enterprise model.

CONCLUSIONS

The starting point of this paper was the assertion that manufacturing industries can be best supported by an information system which is based on a IT specification architecture. In addition, it was stated that the process of enterprise modelling should be capitalised on to provide the basis for information specification. An SME enterprise model has been developed for information specification based on a three field approach to data capture.

For this particular application, the structure of the software tool is mapped onto the viewpoints of the ARIS architecture. This allows the company resources to be modelled within the information viewpoint as a set of information classes with associated attributes.

This work will be followed by a number of case studies with collaborating companies and a report of the experience will be generated at a later date. Due to the constraints imposed on the length of this paper, it has been impossible to go into further detail over the implementation of the CASE tool. This however, will be discussed in later publications. Further work will include both a comprehensive study of the modus operandi of some thirty companies and will allow the object oriented modelling tool to be employed in a number of cases.

ACKNOWLEDGEMENTS

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Appendix V

The Capture of Human Interactions in Enterprise Modelling

ICEIMT'97 Conference, Torino, Italy, To be published,
October 28th-30th, 1997.

The Capture of Human Interactions in Enterprise Modelling

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Abstract

This paper discusses the inclusion of the human element in enterprise modelling as a possible means to support socio-technical design. Particular emphasis will be placed on the role of modelling architectures in the derivation of information specifications for shop floor information systems. The need for including the human element in enterprise modelling is identified and an approach to modelling the human interactions in a company is proposed. This work is set in the context of contemporary approaches to enterprise modelling.

1.0 Introduction

Enterprise modelling provides a means through which a selected aspect of the enterprise is captured and analysed. In general, the reason for conceptualising various aspects of an enterprise in terms of formal models is to supply an explicit method for the understanding, controlling and monitoring the enterprise. Many modelling architectures and methodologies have been developed recently, some have their origins in CIM systems, where the modelling approach is based on an assumption of a deterministic and hierarchical model for planning and control. There is a need for a new approach which accommodates the human element within an enterprise.

This paper address the role of modelling architectures in the specification of information requirements for shop floor information systems. It can be argued that much of the data necessary for designing the new system exists in enterprise models, as a consequence, enterprise modelling should be linked to the creation of information systems specifications. There is however, no correlation between the degree of computer integration and the degree of human integration and there is an increasing recognition that these two issues will have to be inextricable linked. The implementation of any information system, therefore, has to be preceded by some consideration of the "soft" aspects of the company, which plays a major role in business performance.

This paper discusses the capture of human interactions as a first step to the modelling of the human element in enterprise modelling. This paper has been influenced by the experience gained from the authors' research in the specification of information systems for metalworking small to medium enterprises. The approach used in this work involves the use of holonic systems concepts for the derivation of information systems requirements, in conjunction with the use of contemporary modelling architectures **(1)**.

2.0 Literature Survey

Enterprise modelling is a rapidly developing technical field and is becoming part of a systematic engineering approach called enterprise engineering, which encompasses modelling, analysing, designing and implementing integrated enterprise systems **(2)**. An enterprise model is a symbolic representation of individual facts, objects and relationships that occur within the enterprise, these definitions and descriptions may apply at any scale **(3,4)**. As an abstract, simplified representation of some specific aspect of the system under consideration, an enterprise model amplifies the important characteristics and conceals the details which are considered to be of low or no importance at a given abstraction level **(5,6)**. Many of the modelling architectures were originated for the design and the implementation of CIM systems **(7)**. These are based upon describing the invariant elements and relationships which the individual CIM system was conceptually composed of, and their functionality **(6,8,9)**. Moreover, these models also described specifications which could be transformed into the working system **(7)**. Generally accepted architectures could be supported by reference models and a range of appropriate modelling products which make the entire modelling endeavour efficient in time and cost **(10)**.

Examples of enterprise modelling architectures include CIMOSA (Open System Architectures for Computer Integrated Manufacturing) **(11)** and ARIS (Architecture for Integrated Information Systems) **(12)**. These systems modelling approaches may be implemented as some form of a CASE Tool. Other architectures for enterprise modelling include PERA **(13)**, GRAI **(14)**, GERAM **(15)** and SSADM **(16)**. The PERA architecture and associated methodology guides the steps of an enterprise integration programme from conceptualisation to implementation. The GRAI structured methodology for enterprise integration is supported by modelling tools, namely, the GRAI Grid and the GRAI-NET **(14)**. The former identifies the major decision making centres in a company, which the latter (the GRAI-GRID) models in detail.

In addition to the enterprise integration technologies, there is an increasing need to consider the human element in the enterprise. The work on human centred advanced manufacturing technology (AMT) was pioneered by Rosenbrock (1983) at the University of Manchester Institute of Science and Technology **(17)**. This work was subsequently incorporated into ESPRIT 1217 (1199), titled "Human Centred CIM Systems". The objective of human centred technology or socio-technical design, is to produce human centred CIM building blocks, in which people are given responsibility for those tasks best performed using human skills **(18, 19)**. The concept of human-centred manufacturing relies on skill enhancement rather than skill replacement, moreover and the development of human-computer based tools provides people with assistance in the management of complex situations **(19)**. The tasks within the factory must be organised such that, in all areas, people in people are able to apply a substantial range of their skills rather than just a small "useful" part. The work of Slatter (1990) in the human centred design and implementation of a flexible human-centred turning cell, concentrated on the development of a framework of human-centred design criteria to guide the design of both hardware and software to assist operators in the management of the cell **(20)**.

The design of human centred systems has wider implications, it encompasses the important component of human factors engineering, which focuses primarily on abilities, limitations and other human characteristics. Chapanis (1996) states that human factors engineering is the application of human factors information to the design of tools, machines, systems, tasks, jobs and environments for safe, comfortable and effective human use **(21)**. An exemplar of this approach can be found in the development of a man-machine interface by the controller manufacturer Keller Ltd., where matching the needs of operators and users is the main theme **(22)**. A human centred approach, on the other hand, takes full advantage of the potential increases for productivity, better quality and greater flexibility provided by the better utilisation of human skill, experience and the power of modern computer technologies **(19)**.

Recently, manufacturing paradigms such as the fractal factory **(23)** and holonic systems **(24)** concepts have been the subject of much interest. The holonics systems concepts have their origins in ideas developed by Koestler in 1967 **(24)**. These may be used to communicate an overall sense of direction and carry the internal values or corporate culture of the company.

3.0 Architectures for Enterprise Modelling

In general, the reason for conceptualising various aspects of an enterprise in terms of formal models is to supply an explicit method for the understanding, controlling and monitoring the enterprise **(4)**. The major effort involved in collecting the data about an ongoing activity for subsequent review and analysis, itself contributes to a better understanding of enterprise activities and their interactions. The application for enterprise models are not only for the improvement of organisational structures; the construction of enterprise models may embrace overall system architecture, product design, project management, software specification or to establish the information requirements for database design. Therefore, it important to state that models would already be in existence in various forms which can address virtually any aspect of an enterprise, these components of the company are not purchased; rather, they are built over time by the enterprise.

No single modelling technique is adequate for all situations; to express all the constituents of a complex system, more than one modelling method has to be used. Within an individual viewpoint of an enterprise model, modelling formalisms should provide sufficient scope and modelling capability.

in terms of constructs and notations (i.e. rich or extensive in semantics), to capture the concepts and factual information **(2)**. Modelling architectures are therefore, used to allow easy identification and interpretation of the structure and contents of a model, e.g. views, levels. An architecture is used to organise the relevant viewpoints and the multiplicity of models (e.g. specification, design and implementation models) which may result from enterprise modelling.

4.0 Enterprise Modelling for Information Specification

The design and implementation of an information system a protracted task which involves diverse areas of expertise throughout all stages of the project. The requirements of the individual company have to be considered, along with the various enabling technologies and highly competitive range of contemporary products available. To ensure the implementation of a system that is appropriate, a methodology should be used where individual phases of the design to implementation process is precisely defined. Methodologies are generally accompanied by a set of guidelines, techniques and procedures which the end-user can follow in order to carry out the project. This may involve the use of structured approaches, reference architectures and their associated modelling formalisms and graphical tools **(6)**.

Structured approaches cover all aspects of the project which is typically divided into phases (analysis, design, development, implementation, operation), this is illustrated in Figure 1. The reason for using structured approaches, as opposed to ad hoc methods, is that a complex project is organised into small, well-defined activities; by specifying the sequence of and interaction of these activities, project planning and control becomes more effective. Exemplars include the structured approaches of the Purdue **(13)**, GRAI **(14)** and SSADM **(16)** methodologies.

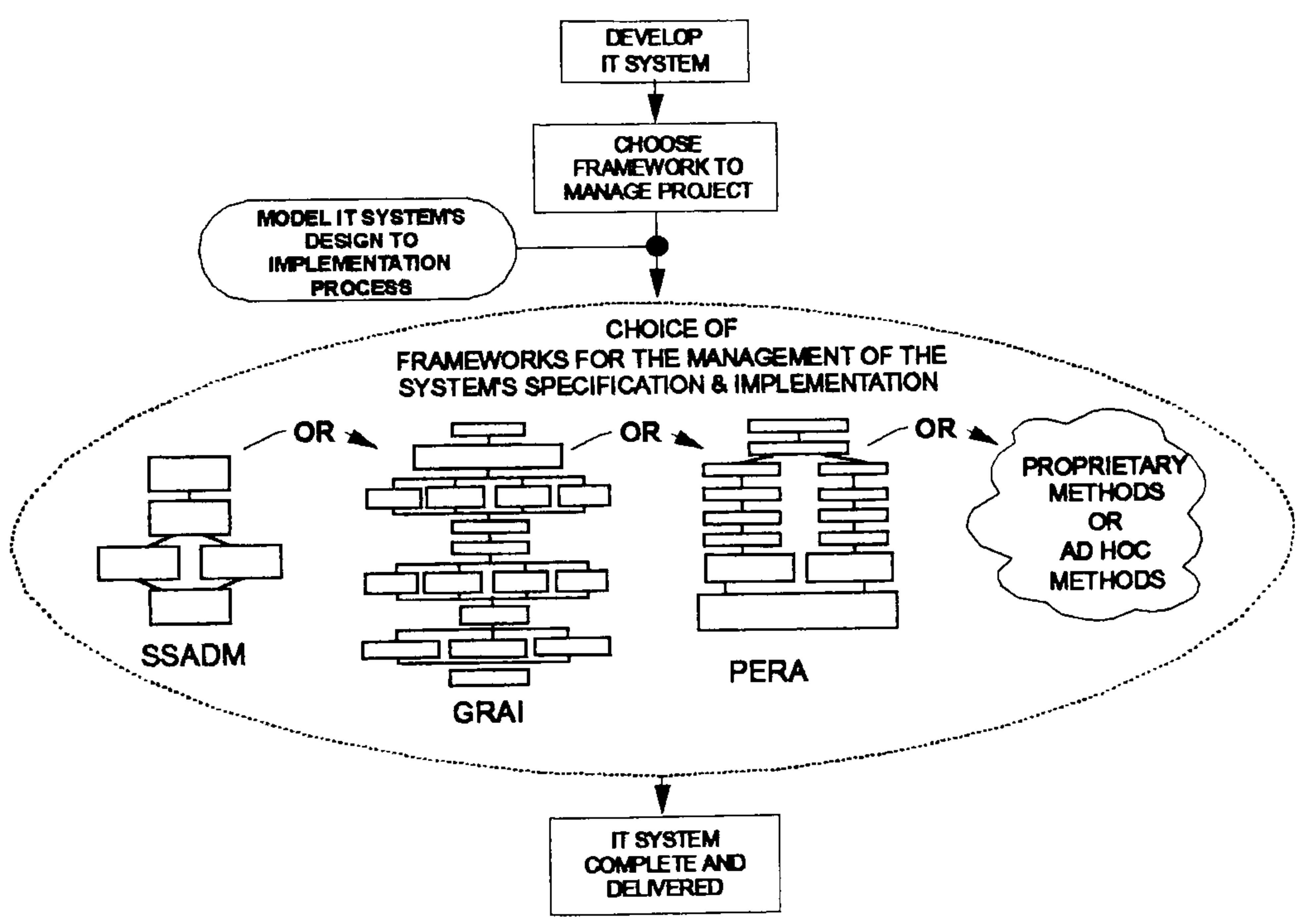

Figure 1: A choice of modelling frameworks to manage the systems implementation process.

4.1 The Role of Modelling Architectures in the Realisation of Information Systems Specifications

Two main involvements of the modelling frameworks, within the design of an information system, can be distinguished. The first is where the modelling architecture captures the design to implementation process itself, this is illustrated in Figure 1. The documentation role is where the modelling framework captures the design and implementation process for the system. From the time a decision is made to install an information system, modelling architectures can be chosen to document the stages of the project from specification to implementation. It can be seen from the figure that the structured approaches of PERA, GRAI, SSADM can be used to manage the implementation from conceptual design to implementation. It is noted in the figure that other ad hoc or proprietary methods can be used as well. Regardless of which modelling framework is chosen, a fundamental task in implementing any information system is the specification of its information requirements.

Information which is stored, shared and processed by various applications and employees throughout the enterprise is a fundamental component of the information system and particular emphasis must be placed on its modelling and specification. The second application of the modelling architectures is in the derivation of the information specifications for the new system. This is illustrated in Figure 2, which shows a detailed view of the specification stage, where in particular, a major activity is the definition of information requirements. The output in terms of a model of the information specifications can subsequently be used by design processes to create implementation schema and software modules for the systems realisation.

4.1.1 Modelling Architectures for the Specification of Information Requirements

The process of information requirements specification can be considerably enhanced through the use of systems engineering methods based on modelling formalisms. Vernadat (1996) states that in order to correctly capture information requirements, the functionality and behaviour of the enterprise must first be modelled **(2)**. Therefore, the information specifications are usually developed with modelling architectures in conjunction with other relevant modelling viewpoints to capture the enterprise in terms of function, resource and organisation.

The currently accepted solution for realising IT support is to first create a model of the enterprise using an appropriate modelling architecture. The modelling process transforms the available knowledge into more formal descriptions of the information network specifications. The impetus for the involvement of CASE tools in the modelling engineering process is to provide an identification of those reusable modelling constructs already established in the system **(10)**. The CIMOSA and ARIS architectures, shown in Figure 2, have been chosen as the candidate architectures as each has a declared goal of formality in their definition and description of all aspects of their architectures. Both architectures were designed with the ultimate aim of achieving complete computer executability of all constructs, models, techniques associated with the architectures **(11, 12)**. Moreover, they contain within their framework methods which guide the process from model creation to execution[1].

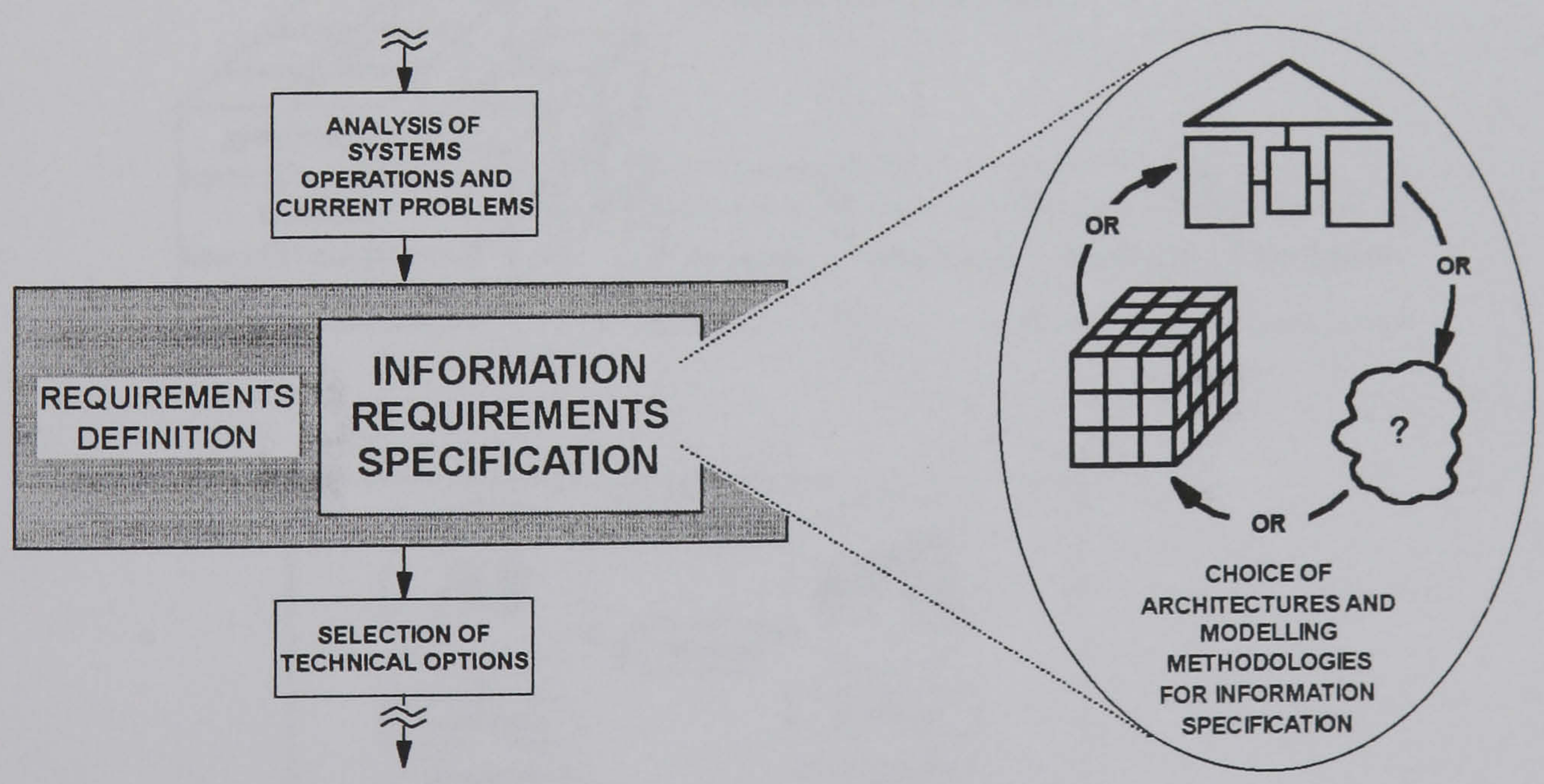

Figure 2: A detailed view of information specification: A choice of modelling architectures.

[1] Model creation to execution is not a seamless process and a broader view should be taken of the term "execution". This process is better characterised by the term "model enactment", which is viewed as the ability to let the model evolve over time [21]. In information design, model execution is the further development or engineering of a model which has been produced and adequately validated by an upstream model building process. The final execution of the conceptual information models is the implementation of the information system.

5.0 The Need for Human Factors in Enterprise Modelling

The implementation of any information system has to be preceded by some consideration of the "soft" aspects of the company, which plays a major role in business performance. The use of shop floor information systems, which are specified through conventional or ad hoc methods provides, limited enhancement to the performance of the company as no method currently takes into consideration the interactions which are human dominated. The performance of the company can be enhanced if appropriate information support is given, this requires an accompanying new methodology for specifying the information system requirements which is sympathetic to the human interactions.

An example of an architecture which provides the scope for considering the human role is the PERA architecture. However, PERA does not provide the capability to model the human component, rather, it gives the scope to discuss and define the tasks which will be fulfilled by people in the organisation **(10)**. The actual degree of involvement of human and technology in the final implementation of the information or manufacturing system is indicated by the extent-of-automation, which is subject to economic, social laws and directives. The humanisability line indicate the extent to which human involvement may possibly be implemented, subject to human skills, abilities in terms of speed of response, physical strength, etc. The automatability line indicates the extent of technology in terms of its capability in actually automating the task **(13)**.

6.0 The Modelling of Human Interactions in an Enterprise

Whilst there is still much to accomplish in this field, work has been undertaken to model the interactions within a company using the fundamental concepts of the holon introduced by Koestler in 1967 **(25)**. The starting point of this concept is the assertion that the human dominated interactions which occur within the organisation may be characterised in holonic terms. This work is based on the fundamental concepts from Koestler's study **(25)**, which included social organisations consisting of hierarchies of semi-autonomous sub-wholes, branching into intermediaries of a lower order. A model of the interactions can be subsequently associated to one of the established modelling architectures for information specification, illustrated in Figure 3. For the purpose of this paper, the CIMSOA architecture has been chosen as a particular exemplar.

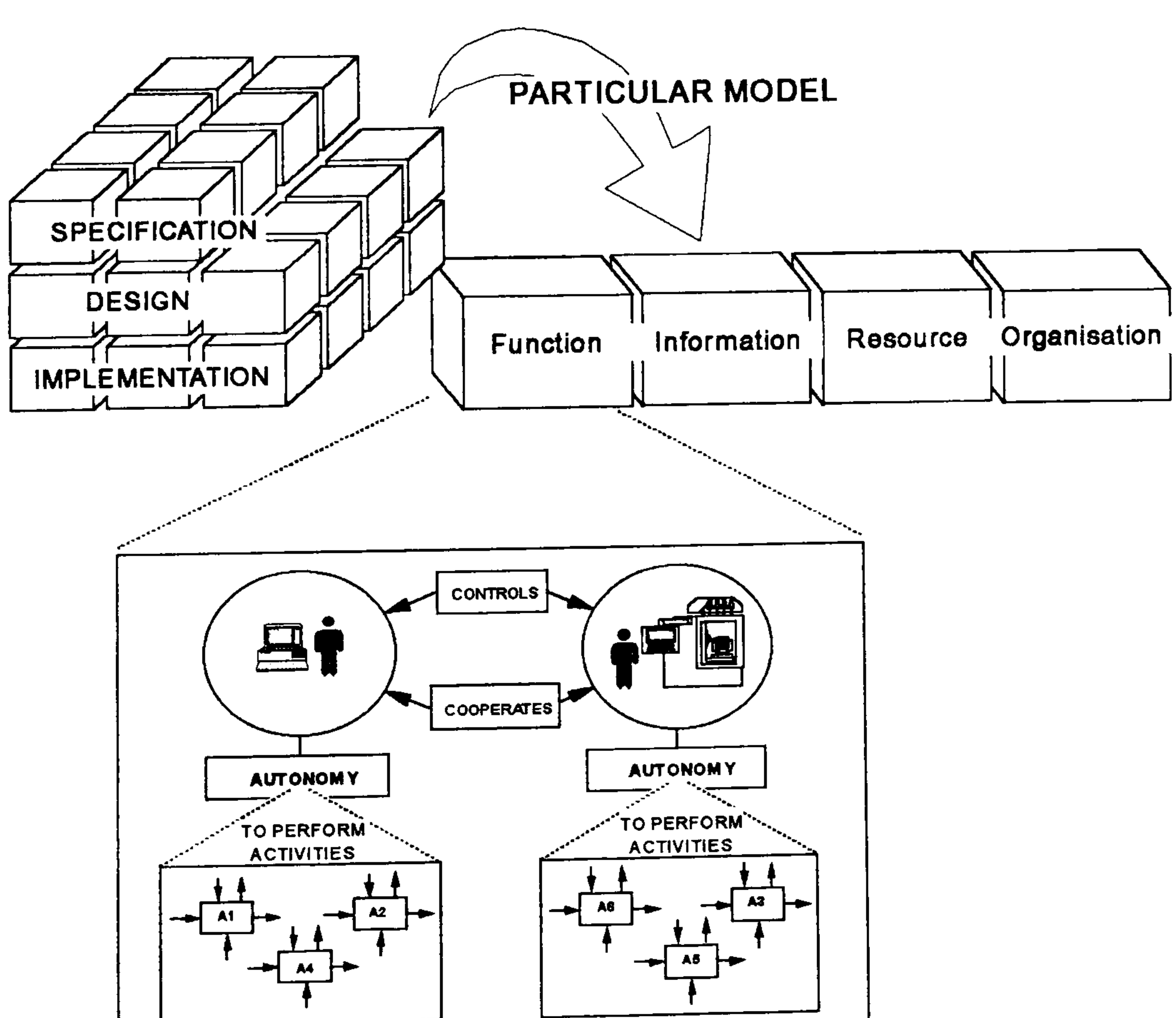

Figure 3: The use of holonic systems concepts to characterise the human interactions and the identification of enterprise activities in relation to the CIMOSA modelling architecture.

Based on these concepts, entities in the shop floor can be modelled with autonomous, cooperative and control aspects. The autonomy captures the self assertive tendency of the human entities, hence, it has the autonomy to perform a defined set of activities. The cooperative dimension captures the integrative tendency; the primary tendency of the human entity is to cooperate, e.g. a turning operator cooperates by accepting jobs from the production planner and produces completed components. A third dimension of control is needed, where at a particular instance, one entity may assert itself and control another. When one peer entities controls another, the controlled party has a corresponding cooperative mechanism to meet the demand. When an interactions occur between two entities, activities are identified and analysed. The results of activity analysis enables the identification information requirements.

A further enhancement of the concept is the capability to model contingencies. Many of the interactions between employees occur out of necessity when shop floor contingencies are encountered. In order to further instantiate the behaviour of an enterprise, the modelling of disturbances is introduced. Any human entity is subject to disturbances, which occur when one party is unable to fulfil the requirements stipulated by the control component. Causes to these disturbances are usually the result of some aspect of the activity. For example, a machining operator requires cutting tools, raw material, or machining fixtures to perform a machining task. A disruption can occur where the machining node is unable to fulfil this obligation to cooperate. The causual object may be that the machining fixtures are absent, a shortage of cutting tools or raw material.

The modelling process may identify that the machining operator has the autonomy to perform additional activities such as generate an alternative job sequence, to reallocate raw material from another job. In additional, the machining operator may invoke its control mechanism over the production planner node holon to purchase new cutting tools. The production planning node will then have a corresponding cooperation mechanism and a new activity is generated which is to purchase new cutting tools.

7.0 Concluding Discussions

In this paper, it has been argued that new approaches are needed to model the human dominated interactions in an enterprise, the inclusion of such a model will provided an additional dimension for describing the company. The function view of the enterprise can be captured in terms of holonic systems concepts, where control, cooperation and autonomy are used to characterise the behaviour and relationships between the individual functional entities. The holonic systems concept provides a novel approach to the modelling of interactions between employees in a company for the identification of enterprise activities. The incorporation of such a model, or other alternative approaches to data capture, into an existing modelling architecture will further enhance the applicability and uptake of enterprise modelling, architectures and their associated methodologies.

The socio-technical design approach provides a framework for the allocation of responsibilities between humans within a manufacturing system. The fundamental concepts of the holon, introduced by Koestler, is seen as a way by which the human dominated interactions can be characterised and modelled in terms of control, cooperation and autonomy, with the aim of capturing current and improving business practices. However, the question of whether the holonics based modelling concept may be considered to support socio-technical design must be left as an issue for further research.

The main objective in the consideration of human factors in enterprise modelling is to accommodate human factors, rather than constrain them. This may be done by the inclusion of the human factors explicitly in a modelling architecture rather than assuming it is part of a deterministic structure. Research should be carried out on the suitability of modelling concepts to support socio-technical design. In order to do this, the areas of socio-technical design and human factors in manufacturing have to be explored in detail. Research should focus on the possibility of developing a taxonomy of human factors, such as human skills, abilities in terms of speed of response, physical strength, job enrichment, job satisfaction, etc. One plausible direction for research is to establishing a relationship between decisions, or activities and the human factors field of data capture. This would enable human factors which impinge on particular activities or decisions to be identified and defined. The ability to create such a link would be desirable to establish another dimension for modelling shop floor contingency situations; this implies that the contingency situation may be linked to a human factor. A model of this nature can become useful to assignment of tasks which will be fulfilled by people in the organisation.

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