Manufacturing Information and Knowledge Models to Support Global Manufacturing Co-ordination

By

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This thesis is dedicated

to my teachers,

parents,

husband, and daughter

for their

encouragement, inspiration, and love

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Abstract

Co-ordination decisions have been recognised as crucial to the success of enterprises to realise global manufacturing strategies. Information sharing and integration between collaborating members is one of the fundamental requirements of global manufacturing co-ordination. This thesis reports the research on information and knowledge model support for global manufacturing co-ordination, and focuses on the understanding of the information and knowledge structure of global manufacturing capability as well as the necessary interaction mechanisms with product and order related information.

A new information and knowledge structure has been explored to represent global manufacturing capability. In addition, a product model and an order model have also been identified to provide product information and order information respectively. The information and knowledge requirements have been explored through a multi-perspective modelling approach including IDEF0 activity modelling, IDEF3 process modelling, and UML. The structure of the main classes in the information and knowledge models has been defined and the relationships between the classes have been specified.

The new defined manufacturing model structure consists of four main classes. It not only comprises process and resource, two basic and important types of manufacturing capabilities demonstrated by a series of applications, but also includes configuration and knowledge classes. The definition of the configuration class in the manufacturing model provides the potential for a global enterprise to access dynamic and unlimited resources on a network, with flexible capabilities to respond to global market requirements. The knowledge class in the manufacturing model enables the retrieval of preferred solutions for global manufacturing co-ordination decisions under different conditions or combinations of conditions, and thus makes the manufacturing model more intelligent. The information and knowledge structures have been tested by experimental systems based on the OODBMS ObjectStore SP8.0 and Visual C++ 6.0, and explored with a case study from the automotive industry. It has been shown that the manufacturing model together with the product model and the order model provide effective support for global manufacturing co-ordination decisions.

Contents

1 Introduction

1.1 Research Context

Over the last several decades, more and more manufacturing enterprises are looking to global manufacturing strategies in order to better meet the challenges and take advantage of the opportunities presented by economic globalisation. On the one hand, economic globalisation has led to an intensification of competitive pressure in most manufacturing industries. On the other hand, economic globalisation has initiated a move toward the creation of global markets. Four types of global manufacturing strategy are widely used in the quest to build a sustainable competitive advantage. These are factor-input strategy, market-access strategy, hybrid strategy, and hub-and-spoke manufacturing/ distribution strategy (Fawcett, 1992; Scully and Fawcett, 1993). Decisions concerning configuration and co-ordination can be distinguished within the decision making process related to the realisation of a global manufacturing strategy (Pontrandolfo et al, 1999).

Regardless of the reason of undertaking a global manufacturing strategy, the key to achieving success rests on the enterprise's ability to co-ordinate its worldwide operations so that all enterprise members perform as a cohesive conversion system (Luis et al, 2001; Kim et al, 2003). In this thesis, the term global manufacturing co-ordination means the management of interdependencies between global manufacturing activities. The co-ordination of global manufacturing can be described in terms of (a) different functions and (b) different geographic areas. A function is defined as a specific logistic stage (e.g. supply, manufacturing, or distribution), whereas a geographical area refers to a region (a country or group of countries) that is homogeneous with respect to such variables as currency and import duties (Pontrandolfo et al, 2002). Decision-making on global manufacturing co-ordination is information and knowledge intensive in that it requires integration and sharing of information and knowledge between different enterprise members. The extent to which information and knowledge is communicated and used depends on how well information and knowledge is represented and organised.

Information and knowledge representation is a complex task. Information and knowledge modelling, which builds information and knowledge models, manifests itself as a powerful tool by representing and providing high quality information and knowledge. Information modelling has been widely accepted in many areas of manufacturing engineering, and is getting more and more important for decision support systems in global manufacturing to simplify the decision making process and reduce the consequences of failure as global manufacturing networks are getting more and more distributed and complex. This thesis is focused on information and knowledge modelling of manufacturing capabilities, i.e. building manufacturing models for global manufacturing co-ordination.

A manufacturing model has been defined as a formal representation of information and knowledge of manufacturing capability of a manufacturing facility. The manufacturing model concept was proposed in the 1990s and has since demonstrated its potential to support manufacturing engineers to make decisions in design for manufacture and process planning at low levels. The research on manufacturing modelling reported in this thesis is related to a high level, i.e. global enterprise level, rather than at factory, shop, cell or station level.

This thesis reports research on the advancement of the understanding of manufacturing information and knowledge models to support global manufacturing co-ordination. Besides a manufacturing model, a product model and an order model have also been identified. The co-ordination decisions that are supported by the information and knowledge models are across both different functions (supply, manufacturing, and distribution) and different geographical areas.

The main contribution of this research that distinguishes it from other related research work is a new structure which can capture global manufacturing capability related information and knowledge and the necessary mechanisms to link the information and knowledge models, to effectively support global enterprise production engineers to make co-ordination decisions. The approach will help manufacturing enterprises to better use global resources and capture the opportunity of global markets.

An object-oriented analysis and design environment has been adopted to support this research work both in information and knowledge modelling as well as the development of experimental systems. A multi-perspective modelling approach has been used in the research to describe a global manufacturing co-ordination domain and represent information and knowledge from different points of view, which in turn allows the information and knowledge to be used for different purposes. The IDEF0 activity modelling method and the IDEF3 process modelling method have been employed to explore the information and knowledge requirements for global manufacturing co-ordination. The Rational Rose visual modelling method and UML have been used to explore the structures of information and knowledge. ObjectStore OODBMS and Visual C++ have been used to build the experimental systems to explore the information and knowledge structures and model applications.

1.2 Aim and Objectives

The aim of this research is to advance the understanding of information and knowledge models to support decision-making on global manufacturing co-ordination.

In order to meet the above aim, ten research objectives have been identified as follows:

(1) to understand the concepts involved in global manufacturing strategy;
(2) to understand the contributions of co-ordination theory and mechanisms;
(3) to understand support tools useful to information and knowledge modelling for global manufacturing co-ordination;
(4) to explore the information and knowledge requirements for global manufacturing co-ordination;
(5) to define a manufacturing capability information and knowledge structure;
(6) to define product and order information structures;
(7) to understand the links between the information and knowledge models;
(8) to construct experimental systems to explore the defined information and knowledge structures;
(9) to construct experimental systems to demonstrate model applications;
(10) to perform case study to evaluate the proposed ideas.

As a basis for the exploration of the information and knowledge structures to support global manufacturing co-ordination, this research has focused on global business in automotive manufacturing.

1.3 Structure of the Thesis

This thesis has been organised in eight chapters as shown in figure 1-1.

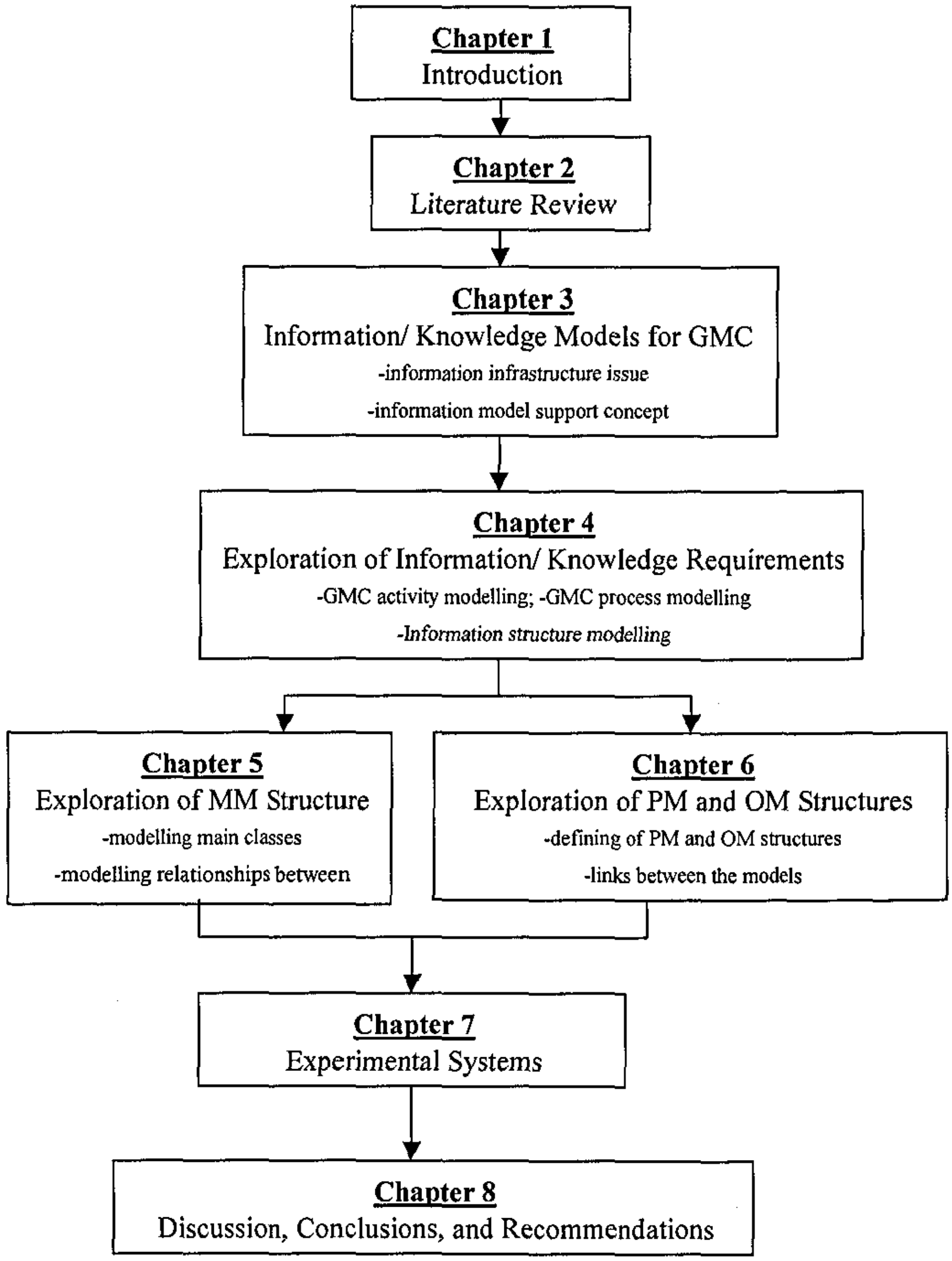


Figure 1-1 Structure of thesis

2 Literature Review

2.1 Introduction

This chapter presents the literature review on three sub-areas that are closely related to this research topic of manufacturing information and knowledge models to support global manufacturing co-ordination. Section 2.2 describes a review on global manufacturing strategy and co-ordination decisions of global manufacturing. Section 2.3 overviews the wide aspects of work that has been done on information and knowledge modelling. Section 2.4 presents the previous research on manufacturing capability information modelling. Finally, section 2.5 summarises this chapter.

The literature review performed in this chapter is to understand the achievements that have been made by other people in related areas, to identify the gap between the proposed research and previous work, and to provide the justification for this research.

2.2 Global Manufacturing Co-ordination

This section has three parts. Firstly, part 1 introduces the concept of global manufacturing and its evolution. Then, part 2 concentrates on global manufacturing strategies. The last part focuses on the co-ordination of global manufacturing.

2.2.1 Global Manufacturing Concept

International business activity is not a recent phenomenon and can be traced as far as the late 19th century when the onset of the industrial revolution resulted in the need for large-scale operations. Over the years the nature of these operations has changed significantly. Moreover, economic globalisation of the past 20 years has had two principal impacts on manufacturing enterprises. First, economic globalisation has led to an intensification of competitive pressure in most manufacturing industries. Second, economic globalisation has initiated a move toward the creation of global markets (Fawcett, 1992). To better meet the challenges and take advantage of the opportunities presented by economic globalisation, more and more enterprises are looking to global manufacturing strategies. The enterprise may be a single multinational enterprise (MNE), or, as is increasingly the case, a set of strategically aligned companies that partner to capture specific market opportunities, termed a global virtual enterprise (Chandra, 1993; Tuma, 1998).

Several theories have been advanced in the literature about the specific aspects of a firm's internationalisation and how global manufacturing has changed over the years in order to respond to revolution in industries, product life cycles, technologies, value chain model and degree of co-ordination. For instance, Porter (1986) proposed the value chain model and focused on the industry characteristic. Bartlett and Ghoshal (1989) studied the co-ordination degree of a MNE's subsidiary network. Lei and Goldhar (1991) revealed how the world has changed dramatically in terms of what competitive strategies are needed to compete successfully, and gave the evolution of both manufacturing and marketing activities over the past several decades (figure 2-1). They divided this time period into four distinct stages where each stage represents a particular way of thinking about manufacturing and marketing as they relate both to the domestic and global marketplace and to each other.

Regardless of the specific theories, global manufacturing seems to be a worthwhile pursuit for enterprises.

Barnevik (1994) suggests three main advantages of global manufacturing:

(1) Offensive advantage, which is achievable by increasing volume through globalisation or, if already operating globally, by applying a broad integrative strategy to existing, country-specific operations;

(2) Defensive advantage, which provides a company with the ability to retaliate against attackers on its home ground;

(3) Economy of scope, which broad-based global competitors may gain over local niche players.

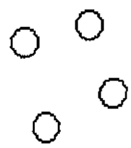
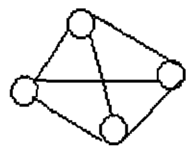
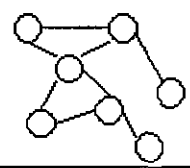
	Stage 1	Stage 2	Stage 3	Stage 4
Strategy	Domestic expansion	Limited overseas expansion	Rationalization	Dispersion and fragmentation; reductionism
Production	Rigid, dedicated, inflexible processes; giant-sized plants; high work-in processes; low variety	Large-scale production in US; decentralized production abroad in smaller but rigid, inflexible factories	World-wide and domestic production; focused factories; integrated networks; global sourcing and transfer of components	Flexible manufacturing systems; high product variety; constant innovation and surge capacity
Marketing	*Domestic* markets; exporting to serve overseas	*Multinational* markets	*Global integrated* markets; homogeneous segments; commonality between certain national tastes and preferences for durable goods	*Marketing* and production become a service business to serve many distinct global segments; faster change and economies of scope predominate
	One market 	Many markets 	Integrated segments 	Dispersed niches 

Figure 2-1 Evolution of global manufacturing and marketing
(From: D. Lei et al., 1991, p.15)

According to Ferdows (1989) manufacturing in different countries provides the following advantages:

(1) access to low-cost production input factors, with particular reference to labour as well as materials, energy, and capital;

(2) proximity to markets, which allows firms to offer better customer severice, lower the uncertainty related to currency and price fluctuations, and derive benefits rather than advantages from trade barriers;

(3) use of local technological resources;

(4) control and amortisation of technology assets, which otherwise would require less effective actions such as technology licensing;

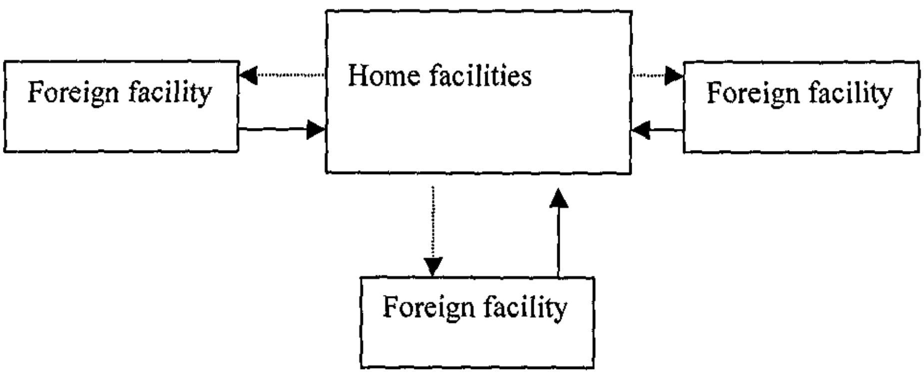
(5) pre-emption of competition, i.e. the ability to maintain barriers for other competitors to entry in new markets such as in developing countries.

Kogut (1990) distinguishes between initial and sequential advantages as a result of foreign direct investments (FDIs). The first category includes access to raw materials, the exploitation of cost and skill differentials, and the penetration of markets. The second category includes advantages that are related to the co-ordinated management of a global network.

2.2.2 Global Manufacturing Strategy (GMS)

Among the four types of global manufacturing strategies, two generic global manufacturing strategies are widely used in the quest to build a sustainable competitive advantage in recent years. One is factor-input strategy, and the other is market-access strategy (Fawcett, 1992; Scully and Fawcett, 1993).

The first strategy, the factor-input strategy, emphasises the acquisition and the use of the 'best'—low cost and/or high quality—mix of factor inputs available (see figure 2-2). The primary objective of this strategy is to enhance the firm's competitive position in its home market through the incorporation of regional comparative advantages into its value-adding system. This factor-input strategy seeks to improve production efficiency through the linkage of various regional economies within a single cohesive



Information, raw materials, components or capital
Finished goods or required inputs

Figure 2-2 Factor-input strategy (*Fawcett, 1992*, p.1094) conversion system. By identifying those countries that have a comparative advantage in one or more of the stages in the conversion process and setting-up operations in these locations, a firm can theoretically develop an economic advantage. In effect, the factor-input strategy allows a company to de-couple comparative advantages from the country/countries of ownership. The electronics firm that sets up assembly facilities in the Pacific Rim to take advantage of low-cost labour fits this type of manufacturing strategy.

Specific examples of factor-input strategy are abundant (Howell and Hsu, 2002; Kim et al, 2003). Intel Corporation first established assembly and test facilities in Penang, Malaysia in 1972 and in Manila, Philippines in 1974. By the mid-1980s, over 40 electronics companies operated facilities in Penang and over 20 had operations in Manila. In general, the high-tech operations such as the fabrication of semiconductor wafers are maintained in the US while labour intensive low and medium-tech operations such as assembly and test are shifted to overseas settings. Maquiladora operations in Mexico are another example of the factor-input strategy. By 1990s, over 75 percent of the US top 500 firms operated one or more maquiladora facilities to take advantage of the very low-cost labour available in Mexico. Many of Western European and Japanese leading manufacturers had also set up maquiladora operations by the late 1980s.

The second type of generic global manufacturing strategy, the market-access strategy (Fawcett, 1992; Scully and Fawcett, 1993), focuses more on increasing the firm's access to foreign markets than it does on attaining a strict comparative economic advantage (see figure 2-3). Many firms are motivated to establish operations in vital markets around the world to develop a local presence and thus reduce negative market perceptions or to overcome protectionist practices such as tariffs, quotas, and domestic content regulations. Also, international market entry and development allows the firm to take advantage of economies of scale as well as diversify its production and market risk. Examples include the manufacture of Honda automobiles in Marysville, Ohio and the rush by both America and

Japanese firm's to establish a presence in Europe prior to the expected European economic unification in 1992.

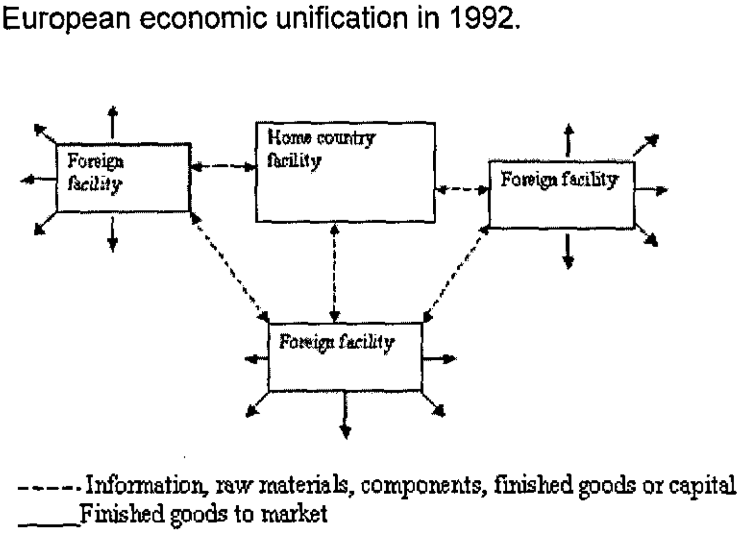


Figure 2-3 Market-access strategy (*Fawcett, 1992*, p.1095)

Pure market-access strategy often begins when a firm has developed some competitive advantage in its home market and evolves as the firm enters and develops foreign markets. If a firm's initial testing of foreign markets proves successful, the firm often increases its commitment to the foreign market. Exporting, licensing, management contracts, joint ventures, and local production are viable market entry strategies. Of course, which market entry and development strategy is developed depends on the firm's global objectives and its resource base. Market-access strategy tends to be more complex than the pure factor-input strategy because of the combinatorial nature of the interactions that are possible among the different facilities and it therefore tends to be more difficult to manage.

In many instances, hybrid global manufacturing strategy develops as firms employ a factor-input strategy demonstrating a global orientation that leads them to move into world markets. The reverse also happens—firms that market globally encounter cost pressures that lead them to establish factor-input oriented manufacturing operations. Ultimately, the truly global corporation will integrate both of the global strategies to improve its competitive position in world markets (Wong, 2002; Howell and Hsu, 2002).

Many examples of firms that have linked factor-input and market-access strategies to become global competitors exist. One such example is Ford Motor Company, which currently operates major production and marketing ventures on five continents. Management at Ford has recognized the need to enhance production efficiency and increase global market share through its global manufacturing network. Ford is presently emphasising the development of operations in key Asian, European, and South American markets.

When the linkage between factor-input and market-access strategies within individual firm's competitive strategies is combined with the current political-economic tendency towards the development of regional trading blocks, a new form of global competitive strategy is emerging. This new competitive approach involves the strategic location of production and distribution hubs within each of the major trading areas in the world - Europe, North America, and the Pacific Basin - to circumvent possible trade restrictions and thus gain access to these key markets. For each targeted trading area, distribution, final manufacturing/assembly facilities are located near critical consumer markets while more labour (factor) intensive manufacturing and assembly facilities are located in peripheral areas where factor-input costs are lower. At the same time, additional production facilities are located in other regions of the world to produce parts and components which can be imported into a trading area in support of local operations to achieve important cost advantages.

An example of this type of hub-and-spoke manufacturing/distribution strategy might involve a US firm seeking to establish a competitive market presence in Europe or the Pacific Basin (Fischer, 2003; Wong, 2002). *Within Europe (figure 2-4), the firm might establish distribution hubs in the* UK and Germany and intensive manufacturing assembly hubs in Spain and an Eastern European nation such as Hungary. The competitive position of these facilities might be further supported by research and design activities being performed in the US and labour-intensive production being performed in a Mexican maquiladora operation. Additional support might come from engineering activities taking place in Japan and low-cost production in Singapore. A similar scenario might occur as the firm seeks to compete in the Pacific Basin—distribution hubs might be located in Japan and Australia with low-cost production hubs located in Malaysia and the Philippines. Moreover, in addition to helping the US firms access markets around the world, the marketing and production advantages achieved through this type of global strategy would be beneficial in the firm's North American home market. It must be emphasised that this type of global hub-and-spoke manufacturing/marketing strategy cannot be implemented effectively or profitably without the development of an advanced logistics support system to assure co-ordinated and integrated operations.

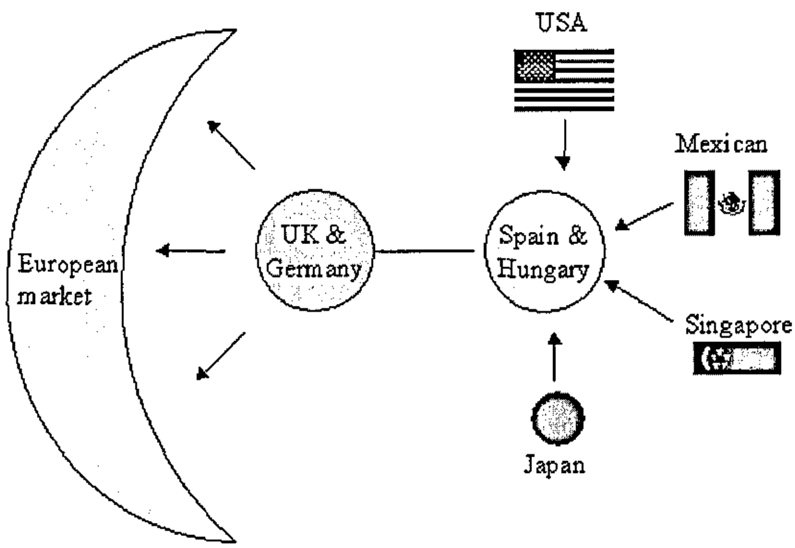


Figure 2-4 Hub-and stroke strategy (based on Wong, 2002)

Within the decision-making process related to global manufacturing activities, two types of decisions can be distinguished: those concerning 'configuration' and those related to 'co-ordination' (Pontrandolfo et al, 1999). Configuration refers mainly to the strategic level of an MNE's decision-making process. It concerns issues such as the building of a network of subsidiaries with particular emphasis on the differentiated structural requirements of different environment. Co-ordination is related to the management of such a network. Its aim is to have an efficient and effective planning of global production activities, involving primarily tactical decisions in different business areas and within several processes. In Fawcett's (1993) opinion, configuration involves the location of facilities and the allocation of productive activities among the facilities, and co-ordination involves the linking or integration of productive activities into a unified conversion and delivery system.

The two aspects of configuration and co-ordination are strictly related. The available literature on global manufacturing looks at both configuration and co-ordination problems. In the next section the issue of co-ordination in global manufacturing will be discussed.

2.2.3 Co-ordination of Global Manufacturing

Co-ordination is a determinant element in global manufacturing. It represents a new and multidisciplinary research area that finds its roots in contributions in many other disciplines such as computer science, and organisation theory. In fact, in recent years, there has been a growing interest in co-ordination theory and co-ordination mechanisms when discussing the activities performed by complex and distributed systems. Different authors have proposed a number of definitions for co-ordination. Some samples of these are:

- Co-ordination is managing dependencies between activities (Malone and Crowston, 1994);
- Co-ordination is the process of building programs by gluing together active pieces (Carriero and Gelernter, 1992);
- Co-ordination can be defined as the study of the dynamic topologies of interactions among interaction machines, and the construction of protocols to realize such topologies that ensure well-behaviour (Arbab, 1998);
- Co-ordination is a property of interaction among some of agents performing collective activities (Bond & Gasser, 1988).

Co-ordination of global manufacturing is a new area that has attracted significant research in recent years. To identify its importance clearly, we need to have a clear understanding of business activities related to global manufacturing, such as international, multinational, and trans-national activities. It is critical to make a clear distinction between these. Stonehouse (2000) stated that a spectrum of international business activity could be identified depending on the nature and extent of a business's involvement in international markets and the degree of co-ordination and integration of geographically dispersed operations.

By Stonehouse's opinion, the term international simply implies that a business is operating in more than one country. A business that is multinational, on the other hand, operates in several countries. Bartlett and Ghoshal (1989) suggest that the term implies some decentralisation of management decision-making to overseas subsidiaries, and little co-ordination of activities across national boundaries. Yet the term global is used to indicate the potentially global scope of all of an organisation's business operations and its ability to compete on a global scale and refers to more than just global markets (Yip, 1992). Also, Bartlett and Ghoshal (1989) use the word trans-national to describe the configuration, co-ordination and control of a global business. Both markets and the ways in which international businesses configure and co-ordinate their activities are becoming global in scope and trans-national in nature. It is co-ordination, which distinguishes global manufacturing from other international business activity, that provides the focus to this research.

Several theories have been advanced in the literature about the specific aspects of global manufacturing co-ordination. Fawcett (1992) proposed a strategic logistics co-ordination contingency theory from a system's perspective. Fawcett (1993) further studied issues on logistics in co-ordinated global manufacturing from the point of Mexico's maquiladora operations. He concluded that several challenges including information sharing and the timely transportation of goods among facilities were inherent in providing true co-ordination within a global facility network.

Bhatnagar and Chandra (1993) provided an extensive literature review of the available models for general and multi-plant co-ordination. The authors distinguished two broad levels of co-ordination, namely a general level (co-ordination of decisions of different functions) and a multi-plant level (dealing with decisions regarding the same function at different places in the organisation). At the general level, decisions focus on the co-ordinated planning of supply, production, distribution and inventory. They argued that currently no unified body of research exists that deals with the co-ordination of production planning among multiple plants in a vertically integrated firm. One year later, Chandra et al (1994) presented a computational study to investigate the value of co-ordinating production and distribution planning. They compared two approaches to manage the operation, one in which the production scheduling and vehicle routing problems were solved separately, and the other in which they were co-ordinated within a single model. The result indicated the conditions under which companies should consider the organisational changes necessary to support co-ordination of production and distribution.

Slats (1995) contributed a review on logistic chain modelling, and summed up three co-ordination levels, namely strategic level, tactical level, and operational level. At the strategic level the issues to be dealt with focus on the development of objectives and polices for the logistic chain. At the tactical level, the issues focus on the means by which the strategic objectives can be realised, such as the determination of tools, approaches and resources for logistic chain management. At the operational level co-ordination should focus on efficient operation of the logistic chain, such as supply chain performance measurement in terms of investment, services level and supplier performance.

Soon after, Thomas et al (1996) offered a literature review addressing co-ordinated planning between two or more stages of the supply chain, placing particular emphasis on models that would lend themselves to a total supply chain model. It is worth noting that Pontrandolfo et al (1999) presented a framework for the co-ordinated planning in global manufacturing based on reviewing alternative approaches on global manufacturing planning.

A few application examples of co-ordination can be also found in literature. Arntzen (1995) introduced a global supply chain model (GSCM) used at *Digital Equipment Corporation.* GSCM is a large, multi-product bill of materials for supply chains with arbitrary echelon structure and a comprehensive model of integrated global manufacturing and distribution decisions. It has saved over $100 million for the Corporation. Martin (1993) reported a large-scale linear-programming model of the production, distribution, and inventory operations in the flat glass business of Libbey-Owens-Food deals with four plants, over 200 products, and over 40 demand centralised planning in a 12-month horizon. It is said that annual savings from a variety of sources are estimated at over $2M.

Approaches and techniques that have been applied for global manufacturing co-ordination include distributed artificial intelligence, multi-agent system, genetic algorithms, fuzzy concepts, rule-based computing, and auction theoretic mechanisms.

An approach used in (Tuma, 1998) is the application of distributed problem solving strategies like contract networks. Motivated by the increasing needs to co-ordinate diverse decision processes and systems, Ertogral and Wu (2000) investigate an auction theoretic mechanism for production coordination in a supply chain. Zelewski (1997) considered a particular type of multi agent systems, namely contract net systems, in which auction mechanisms allowing a market like design of process co-ordination are discussed.

Gyires and Muthuswamy (1996) present a distributed artificial intelligent approach that enables people and computers to work cooperatively as a team in decision-making. Lee and Lau (1999) presented a detailed infrastructure of a multi agent model and how it can be deployed to enhance the performance of a dispersed manufacturing network. Resteanu et al (2000) provided a co-operative production planning method with a specific ruled based computing technique, in the field of continuous process plants. Garavelli et al (1996) proposed a model for the production assignment of global demand to the MNC plants by genetic algorithms. Sauer et al (1998) presented an approach that considers the adequate modelling and processing of imprecise data for global level scheduling within a multi site scheduling systems based on fuzzy concepts.

Adamides (1995) concentrates on a novel framework on co-ordination of distributed production resources for responsibility-based manufacturing. A set of operators associated with the relations is used, in a distributed way, to modify the individual plans. One paper has been found concerning communication-based co-ordination modelling in distributed manufacturing systems (Ceroni et al, 1999).

Therefore, *the importance of the realisation of global manufacturing* strategies has been identified by literature. Different approaches have been developed to facilitate the co-ordination decisions in global manufacturing. However, the information and knowledge support for global manufacturing co-ordination remains a research issue, which will be investigated in this research.

2.3 Information and knowledge modelling

2.3.1 Concepts

Information and knowledge are related but different. According to (Harding, 1996), information is structured data that has some meaning, while knowledge is the information with added value that relates to how it may be used or applied. This definition of information and knowledge is in line with (Hicks et al, 2002).

Information modelling is an important activity in computer-based information system development. It is concerned with the construction of computer-based structures which capture the meaning of information and organise it in ways that make it understandable and useful to people (Mylopoulos, 1998). Information modelling builds the information model, and an information model is a representation of concepts, relationships, constraints, rules, and operations to specify data semantics for a chosen domain of discourse (Lee, 1999).

An information model consists of two main components, the structure model and the process model (Flynn and Diaz, 1996). The structure model describes the organisational and environmental elements about which information is to be recorded, commonly using the concepts of entity, attribute and relationship, and showing these on an entity-relationship diagram. The process model describes the elements concerned with processing the information, using concepts such as process, event and data flow and expressing these in terms of structure model elements. Processing models can be, for example, data flow diagrams, process decompositions or entity life histories. There may be a third component to the information model, i.e. the rule model, or knowledge model, which restricts the values of elements in the structure model, but its scope and contents are presently a research issue (Sprumont, 2002; Zeng and Deng, 2003).

In the research of information and knowledge models to support global manufacturing coordination, the work will focus on global manufacturing capability information and knowledge modelling, product and order information modelling, and software application modelling. Product modelling has been termed by many researchers as capturing product information in a logically structured model to develop an integrated model to support all of the product life cycle aims (McMahon and Browne, 1998). By comparison manufacturing modelling is to capture information and knowledge that relates to manufacturing capability of facilities to support design and manufacture processes. In other words, product models provide a resource and repository for information concerning a product under development, while a manufacturing model represents the capability of a manufacturing facility and can therefore provide manufacturing related input to design and manufacturing decision making (Ellis et al, 1995). While product modelling and manufacturing modelling support the definition of a more suitable data structure for providing integration and information sharing, software applications capture mainly the functionality involved in the engineering process. Applications act as pieces of software, which have knowledge in specific areas of a product life cycle, and that support the design and manufacturing of such a product (Tichem and Storm, 1997). Also, applications are responsible for the main link between the information system and the end user. Depending on the context, different names and definitions are addressed to the applications, such as agents (Harding and Popplewell, 1996; Harrington et al, 1996), actors (Tichkiewitch, 1996) or supporting tools (Tichem and Storm, 1997). The development of software applications into an integrated environment is highly dependent on the information data model with which they share information and is a reason why these applications are also called data model driven applications (Young et al, 1998). Also, these software applications are significantly influenced by user requirements.

2.3.2 Information and Knowledge Modelling Methodologies

According to (Flynn and Diaz, 1996) all information and knowledge modelling methods can be classified into two kinds: traditional and object-oriented methods.

By the "traditional" approach we mean that has been widely used over the past twenty to thirty years and is the majority of software tools currently available to support system development. Three of the methods, SSADM (UK), MERISE (France) and MEIN (Spain), are the most widely used methods in their respective European countries, while the fourth method, Information Engineering (IE), has a wide international use. The main references of traditional methods are IE (Martin, 1990), MEIN (MEIN II, 1991), MERISE (Quang and Chartier-Kastler, 1991), SSADM Version 4.0 (SSADM, 1990). Other SSADM sources used are Downs et al (1992), Duschl and Hopkins (1992), and Hares (1990).

Object-oriented methods have emerged since 1990's, claiming certain advantages over the traditional approach. Object-oriented Analysis (OOA) (Coad and Yourdon, 1991) is a well-known object-oriented method for information modelling. (Booch, 1994) is another useful information modelling method.

However, Lee (1999) pointed out that the underlying methodologies for the recent modelling practices are based on three approaches: the entity-relationship (E-R) approach, the functional modelling approach, and the object-oriented (O-O) approach.

The E-R approach focuses on how the concepts of entities and relationships might be applied to describe information requirements. It is based on a graphical notation technique (Chen, 1976). Various E-R extensions have been introduced since then. The basic constructs in an E-R model are the entity type, the relationship type, and the attribute type. The notation is easy to understand and the technique has been useful in modelling real problems. There are commercial tools available to map E-R models into commercial DBMSs.

The emphasis of the functional modelling approach is placed on specifying and decomposing system functionality. It addresses the system's processes and the flow of information from one process to another. It uses objects and functions over objects as the basis. The approach often uses data-flow diagrams. A data-flow diagram shows the transformation of data as it flows through a system. The diagram consists of processes, data flows, actors, and data stores. This approach has been in wide use.

The O-O approach focuses on identifying objects from the application domain first and then operations and functions. In the object-oriented approach, the fundamental construct is the object, which incorporates both data structures and functions. The building blocks in the O-O model are object classes, attributes, operations, and associations (relationships).

Choosing an appropriate modelling methodology is a judgement that must be made at the beginning of the modelling work. In general, an information model developed in any method, is a representation of entities, attributes, and relationships among entities. However, each information model has a different emphasis. The emphasis often depends on the viewpoint associated with the model. Viewpoints of the model help to decide the type of information modelling methodology to be used. For example, the E-R approach is a better selection if data requirements are at a great level of detail. In the case of where functions are more important and more complex than data, the functional approach is recommended. The O-O approach, however, may provide better extensibility and may be more compatible with the intended implementation environment (Booch, 1994).

In this research, O-O methodology has been used to model the information and knowledge that support global manufacturing co-ordination and the author believes that O-O approach has the following advantages: easier modelling of complex objects, better extensibility, and easier integration with OODBMS and O-O programming code (Adiga, 19930).

2.3.3 Information and Knowledge Modelling Languages

Quite a few information and knowledge modelling languages, for different methodologies, have been developed or are under development. These information and knowledge modelling languages provide various ways of formally representing an information model. In general, the languages are presented in two forms: graphical form and textual form. The former is represented as diagrams being formed by graphic symbols. The structure of the latter is specified by a context-free grammar that includes formal language syntax and semantics. Three modelling languages, IDEF0, EXPRESS, and UML, are widely used in manufacturing areas. There are two reasons for these languages to be chosen. Firstly, they are formal languages. Secondly, they are either standardised or in the public domain.

The ICAM Definition (IDEF0) language was based on SADT from the U.S. Air Force ICAM Program during 1976 to 1982 timeframe (Bravoco and Yadav, 1985). The objective of the ICAM Program was to increase manufacturing productivity through the systematic application of computer technology. The language is in the public domain. It is a graphical representation and is designed using E-R approach and the relational theory. IDEF0 provides a useful model of processes and information that flows between them. It can be used to model the decomposition of any activity into its sub-activities and information flows. Although information flows can be defined with IDEF0, information structures cannot.

EXPRESS was created as ISO 10303-11 for formally specifying information requirements of product data model (Fowler, 1995). It is a part of a suite of standards informally known as STEP. It was introduced in the early 1990s. The language is a textual representation. In addition, a graphical subset of EXPRESS called EXPRESS-G is available. EXPRESS is based on programming languages and O-O paradigm. It consists of language elements that allow an unambiguous object definition and specification of constraints on the objects defined. It uses SCHEMA declaration to provide partitioning. EXPRESS enables information structures to be defined as well as information constraints. However, it is unable to represent information flows, which is a major strength of the IDEF0.

UML is a modelling language for specifying, visualising, constructing, and documenting the artefacts rather than processes of software systems (Quatrani, 1998). UML was originally conceived by Grandy Booch, James Rumbaugh, and Ivar Jacobson, and approved by the Object Management Group (OMG) as a standard in 1997. The language is non-proprietary and is available to the public. It is a graphical representation. The language is based on the O-O paradigm. UML contains notations and rules and is designed to represent data requirements in terms of O-O diagrams. It organises a model in a number of views that present different aspects of a system. The contents of a view are described in diagrams that are graphs with model elements. A diagram contains model elements that represent common O-O concepts such as classes, objects, messages, and relationships among these concepts.

IDEF0, EXPRESS and UML can all be used to create a conceptual model, and each has its own characteristics. In practice, it may require more than one language to develop all information models when an application is complex. In fact, the modelling practice is often more important than the language chosen.

In this research, IDEF0, IDEF3 and UML have been employed for modelling information and knowledge related to global manufacturing co-ordination. The three modelling languages complement each other to represent complete information and knowledge aspects of global manufacturing co-ordination scenario.

2.3.4 Information and Knowledge Modelling Reference Architectures

The flood of information obtained in a free and random way creates confusion and exhaustion with the result that the analysis and synthesis processes become difficult and time consuming. The problem of adopting a free and random way to acquire information can be avoided by employing a proper reference architecture.

Young et al (1998) defined a general information system concept as illustrated in figure 2-5. In order to support information integration and sharing, two elements have been considered into the system. The first element, also named information models, provides an information repository, which is used to capture the information related to the life cycle of an artefact. This element stores company information. To represent this information, well-defined information structures, or information data models, are required (McKay et al, 1996). The second element is responsible for supporting the life cycle functional activities involved in the product development, such as design and manufacturing. This element shares information stored in the information models, and hence it is created based on the first element, i.e. information data model. For this reason such element is also named data model driven applications.

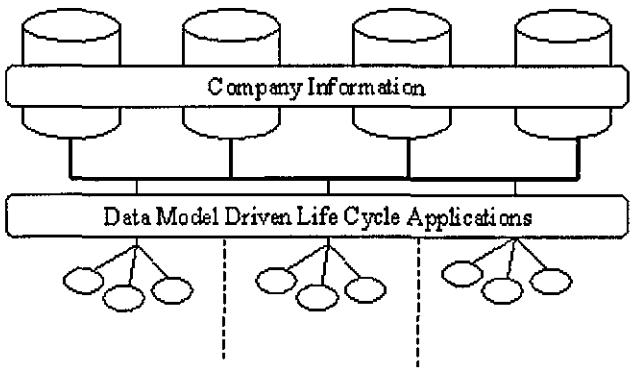


Figure 2-5 The general information system concept (Young et al, 1998)

A number of reference architectures have been developed which are important to information modelling. Some architectures are used for enterprise modelling, i.e. defining the way in which a business enterprise operated, while other architectures are aimed at software system modelling, i.e. defining the way in which software systems are constructed to support the enterprise.

CIM-OSA (Kosanke, 1995; Kosanke and Vernadat, 1999), GRAI-GIM (Doumeingts et al, 1995; Carrie and Macintosh, 1997) and PERA (Purdue Enterprise Reference Architecture) (Williams, 1993; Williams, 1994) allow the description of an integrated system and enable the creation of enterprise models taking into consideration different viewpoints (information, function, resources, organisation etc.).

CIM-OSA (Computer Integrated Manufacturing - Open Systems Architecture) defines an integrated methodology to support all the phases of a CIM system life cycle from requirement specification, through system design, implementation, operation and maintenance, and even systems migration towards CIM-OSA solution (Jorysz and Verbadat, 1990). The

"CIM-OSA" Cube (figure 2-6) represents the CIM-OSA modelling framework.

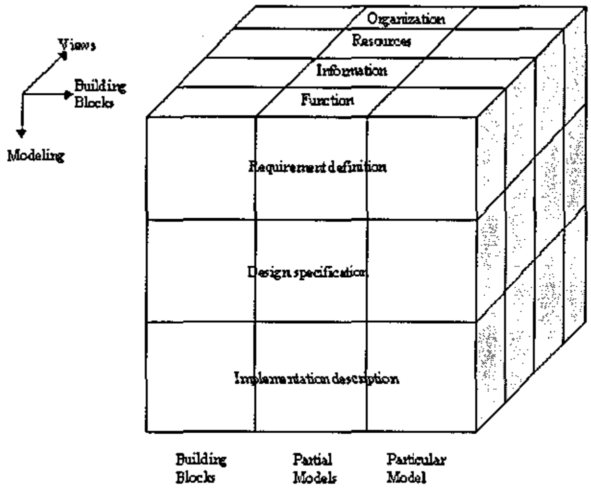


Figure 2-6 CIM-OSA cube

ISO/RM-ODP (International Standard Organization/ Reference Model for Open Distributed Processing) (Raymond, 1994; Farooquik et al, 1995), OMG/CORBA (Object Modelling Group/Common Object Request Broker Architecture) (Greenberg, 1997; Sheu et al, 1999) and OSF/DCE (Open System Foundations/Distributed Computing Environment) (Bloomer, 1995) are some examples of standards for open distributed processing, which aim to enable interaction between systems and applications. Such standards also allow development of system architectures which are open, achieving interoperability among their individual component systems.

RM-ODP was created to produce a reference model for describing open distributed systems and now it is accepted as a de facto standard (*Blair et al, 1996*). It includes five viewpoints of information systems: enterprise, information, computational, technological and engineering, which is described in detail in ISO/IEC 10746-1. The RM-ODP (figure 2-7) establishes the foundations to design and develop open and distributed information system architecture. Each viewpoint represents a different abstraction of the same system to reduce the complexity of any system considered at any one time.

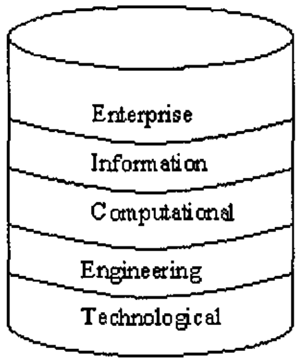


Figure 2-7 Structure of RM-ODP

The model of global manufacturing capability information and knowledge of a global enterprise in this research fits in the CIM-OSA reference architecture, as to be explained in chapter 5.

2.3.5 ISO Standards for Modelling Data

In the International Standard Organization (ISO) the TC184/SC4 group is concerned with standardization in the field of data and languages for manufacturing applications (ISO TC184/SC4 web site). The main activities are concerned with product data with some increasing interest in industrial manufacturing data. Two work areas of the TC184/SC4 are important to this research:

1) Digital Product Data Representation

ISO 10303: *Industrial Automation Systems and Integration - Product Data* Representation and Exchange (Unofficially: STEP), such as

- ISO 10303-1 Overview and fundamental principles;
- ISO 10303-44 Product structure configuration;
- ISO10303-240 Application protocol: process plans for machined products.

2) Manufacturing Management Data

ISO 15531: Industrial Automation Systems and Integration - Industrial Manufacturing Management Data (Unofficially: MANDATE), such as

- ISO 15531-1 Overview;
- ISO 15531-32 Resource model;
- ISO 15531-42 Time model.

Standard for data exchange is very important for global manufacturing co-ordination. The facilities involved in the global manufacturing activities must have no information flow difficulties in communication with each other. ISO standards not only provide the potential for information integration of CAD/CAM (Newman, Allen, and Rosso, 2003; Rahimifard and Newman, 1999), but also for global enterprise members to avoid misunderstanding and collaborate effectively.

2.4 Information and Knowledge Modelling for Manufacturing Capability

In recent years a lot of research works have been reported on information modelling for product design and manufacturing (Czerwinski and Sivayoganathan, 1994; Zhang and Chuan, et al, 1996). However, many of these works are concerned with product data modelling in product development. Ming, Mak and Yan (1998) developed an information model for CAPP by using the object-oriented modelling technique and the Product Data Exchange Step/Standard of Exchange Product Data (PDES/STEP). Zhang and Li (1999) discuss the information modelling for the product development in a "made-to-order" type virtual enterprise. Yeh and You (2000) implement a pilot system for STEP-based PDE (Product Data Exchange) system based on the requirement of product data exchange between and within enterprises. The system incorporates engineering information in the design and manufacturing stages and guarantees the consistency of the product data exchange and sharing.

Many have recognised the need for a neutral information model for sharing product information, however, the modelling and exchange of manufacturing information and order information is equally important (Azevedo and Sousa, 2000; Bagshaw and Newman, 2001). Bagshaw and Newman (2001) identified a structured approach to the design and conceptualisation of a production data analysis framework that was supported by the use of order and manufacturing data.

Most existing manufacturing models concentrate on representing manufacturing resources and their combination into manufacturing processes (Giachetti 1999; Zhao, Cheung and Young, 1999).

The manufacturing resources are all the elements within a facility which enable product realisation, such as: production machinery, production tools, material handling equipment, storage systems, humans, supply and disposal units, etc. and the different system that results from grouping these elements (Molina, Ellis, Young and Bell, 1995). Jurrens et al (1996) used EXPRESS to Model manufacturing resources for cutting tools. Kjellberg and Bohlin (1996) modelled manufacturing resources for a five axles machining centre. However, manufacturing resources only capture the physical resources and do not model the behaviour of the equipment, tool and fixtures when employed in a manufacturing system. While manufacturing processes do.

The manufacturing processes are those processes carried out in a facility in order to produce a product. There are in general two types of processes, information and material processes. Material processes are mainly concerned with turning, drilling, milling, injection moulding and assembly processes etc (Molina, Ellis, Young and Bell, 1995). Horvath and Rudas (1996) discuss the problem of manufacturing process modelling and present a method for creation models of manufacturing processes of mechanical parts. Generic process model features are defined and related in a four level process model structure. Naish (1996) presented a system module which models cutting process capabilities. Giachetti (1999) provided a review on different approaches used to model various aspects of manufacturing processes and then proposes a standard manufacturing systems information model to support design for manufacturing in virtual enterprises.

It is worth noting that the Manufacturing Information Modelling Research Group at Loughborough University has been working and contributed a lot to this area (Alashaab, 1994; Molina, Ellis, Young and Bell, 1995; Alashaab and Young, 1997; Zhao, Cheung and Young, 1999; Dorador and Young, 2000; Dorador, 2001; Bagshaw and Newman, 2001; Harding, Popplewell and Cook, 2003).

The manufacturing model concept was first proposed by (Alashaab, 1994) and used by (Molina, Ellis, Young and Bell, 1995) to represent the machining capability information. The initial model defined by (Molina, Ellis, Young and Bell, 1995) consists of three types of information, namely: manufacturing resources, processes and strategies. The Manufacturing Model has four levels based on a de facto standard (i.e. Factory, Shop, Cell, Station).

Alashaab and Young (1997) discusses issues relating to the general structure of manufacturing process modelling and examines the use of the information modelling language EXPRESS in defining the content of a Manufacturing Model. It presented the work in building a Manufacturing Model of the injection moulding process. The problems raised in building the model are addressed, and the solutions to them are discussed. In essence, the paper provides an insight into the current capability of information modelling tools and their application in the area of modelling manufacturing process information to provide concurrent engineering support.

Zhao, Cheung and Young (1999) focuses on the definition of an object oriented manufacturing data model that can provide a consistent data structure for the representation of manufacturing capability information which can support the construction of a Manufacturing Model for a virtual enterprise. In order to accommodate the virtual enterprise environment, an extended manufacturing data model, at five levels (Enterprise, Factory, Shop, Cell, and Station) with manufacturing resources, processes, and strategies, was developed.

Dorador and Young (2000) and Dorador (2001) explored the creation of manufacturing model for assembly. The work contributed to the understanding of the general structural requirements of decision support systems based on information models, and to the integration of design for assembly and assembly process planning.

Harding, Popplewell and Cook (2003) took the idea of manufacturing model but applied it, in combination with a "system engineering moderator" to the design of manufacturing systems.

Alternatively, Giachetti (1999) used manufacturing model to support design for manufacturing in a virtual enterprise. The manufacturing information model can provide three types of manufacturing capability information, i.e. resource information, physical process information and process capability information. Giachetti (2001) proposed an EXPRESS object-oriented manufacturing model of the manufacturing equipment and manufacturing process capabilities and applied it to manufacturability analysis of printed circuit board fabrication.

To sum up, information modelling for product design and manufacturing has been highly recognised by many researchers in recent years. Many of the existing works are concerned with product information modelling in product development, while a few are concerned with manufacturing capability information modelling and order information modelling. However, there is no existing manufacturing model that can support global manufacturing co-ordination decisions, which is the main motivation of this research.

2.5 Summary

This chapter has provided a literature survey on three main sub-areas which are closely related to this research.

Global manufacturing has been taken as a strategic approach for most manufacturing enterprises to enhance their competitiveness by providing access to factor inputs and world markets. Many famous companies from different industries, such as Ford Motor and Honda from automotive manufacturing industry, Digital Equipment Corporation from electronic manufacturing industry, have greatly benefited from global manufacturing strategies. More and more manufacturing enterprises are looking for opportunities to take advantages of the global manufacturing strategies. However, the development of global manufacturing networks creates several managerial challenges including co-ordination decision-making which is concerned with the management of inter-dependencies between global operation activities. Co-ordination across both functions and geographical areas has been recognised as the key to successful realisation of global manufacturing strategy. This is one of the reasons why this research is dealing with the co-ordination issue of global manufacturing.

Information modelling has been recognised as a useful approach to represent and provide high quality information and avoid incomplete information, noise, and inconsistent information. Previous work on information modelling has covered wide range of areas including information modelling methodologies, information modelling languages, modelling reference architectures and data exchange standards. All of these areas are important and have attracted a lot of attention from researchers. A lot of work has been done on product information modelling in recent years. Comparatively, less work is attempted to manufacturing information modelling and order information modelling. This work makes a contribution on manufacturing capability information and knowledge modelling to build manufacturing models.

Manufacturing model research has made steady progress over the last ten years. Since its concept was first put forward in early 1990s, the research on manufacturing model has advanced from station level to factory level, from injection moulding process to machining process, and the exploration of its application has ranged from design for manufacturing and machining process planning to design for assembly and assembly process planning. However, there is no existing manufacturing model that can support global manufacturing co-ordination decisions. This is the motivation for this work which aims to present a first attempt to define manufacturing information and knowledge models to support decision-making on global manufacturing co-ordination.

3 Information and Knowledge Models for Global Manufacturing Co-ordination

3.1 Introduction

This chapter discusses the research issue of how to define an information and knowledge infrastructure for global manufacturing co-ordination, and outlines the work done in this research on how to solve this research problem. Section 3.2 first explains the co-ordination issue of global manufacturing and identifies the necessity of information and knowledge support for it. Section 3.3 addresses the issue of an information and knowledge infrastructure for global manufacturing co-ordination. Section 3.4 presents the idea of understanding three information and knowledge models to support global manufacturing co-ordination. Finally, section 3.5 is a short summary of this chapter.

3.2 The Co-ordination Issue in Global Manufacturing

Co-ordination is defined as managing dependencies between activities (Malon and Crowston, 1994). This definition is consistent with the simple intuition that, if there is no interdependency, there is nothing to co-ordinate. While more co-ordination is required if there are more interdependencies between activities (Arbab, 1998). In global manufacturing, all activities in the whole global supply chain have high interdependencies, i.e. more co-ordination is demanded for global manufacturing (Ceroni et al, 1999; Pontrandolfo and Okogbaa, 1999; Ho et al, 2000).

The specific dependencies of global manufacturing activities and the corresponding co-ordination processes that can be used to manage the interdependencies of activities are identified and summarised in table 3-1 (for dependencies of common activities and co-ordination processes please refer to Malon and Crowston, 1994). Two types of dependency addressed here are task assignment, and producer and consumer relationship because they are important but complicated and difficult to manage in global manufacturing as the activities are dispersed and carried out in diverse locations. In terms of task assignment, the coordination processes that can be used to manage it include priority order, "first come/ first serve" and bidding mechanism (Tuma, 1998; Hu, et al, 2001). Producer and consumer relationship can be further classified into prerequisite (precedence) constraints and transfer (Malon and Crowston, 1994). Co-ordination processes for managing prerequisite (precedence) constraints can be notification or tracking. Physical product transfer process includes air shipping, rail shipping, road shipping and ocean shipping (Rugman et al, 1995).

Dependency		Examples of co-ordination processes for managing dependency
Task assignment		"First come/ first serve"; Priority order; Market-like bidding
Producer/ consumer relationship	Precedence constraints	Notification; Tracking
	Transfer	Air shipping; Rail shipping; Road shipping; Ocean shipping

Table 3-1 Examples of common dependencies between activities and alternative co-ordination processes for managing them in global manufacturing (summarised on the basis of Malon and Crowston, 1994; Rugman et al, 1995; Tuma, 1998; and Hu, et al, 2001)

Task assignment is a very important special case of co-ordination in global manufacturing. It allocates the required production tasks to a preferred enterprise configuration (group of factories). For example, as shown in figure 3-1, a key company receives an order from a customer or forecasts the demand for producing cars, when it organises resources to fulfil the order, it has more than one choice to use different enterprise configurations such as configuration i or j. The production engineer must determine which configuration is the best to use for the order fulfilment. The task assignment decision will answer this question. There are obviously many factors to be considered in this kind of decision-making in a particular situation, some common co-ordination processes can be used. For example, one possible kind could be a simple "first come/ first serve" mechanism. Alternatively, a bidding mechanism can also be used. More often, priority order (such as total production cost preference, total production time preference, or collaboration preference) might be used (Malon and Crowston, 1994; Tuma, 1998; Garavelli et al, 1996; Ho et al, 2000).

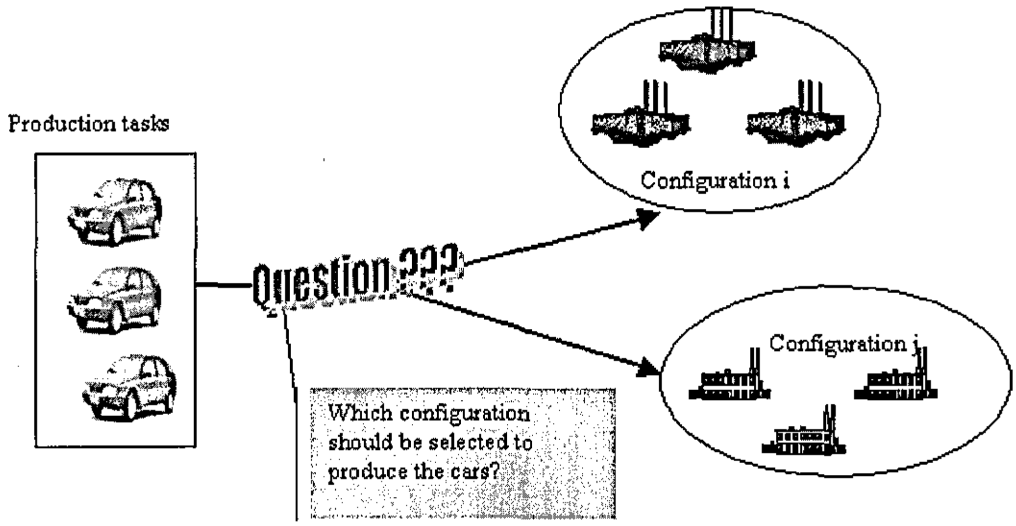


Figure 3-1 Illustration of task assignment issue in global manufacturing

No matter what kind of co-ordination process is used to manage the task assignment issue, there is no doubt that the key to making the right assignment decisions depends on the availability of the right information and knowledge, such as information of the production tasks generated from order information and product information, manufacturing facility information, enterprise configuration information, and task assignment knowledge.

The "producer and consumer" relationship is another extremely common kind of relationship between activities, that is, a situation where one activity produces something that is used by another activity. This relationship clearly occurs in global manufacturing process, for instance, the output of an engine factory is the input of a chassis assembly factory. The producer and consumer relationship often leads to several kinds of dependencies including prerequisite constraints and transfer.

A very common dependency between a producer activity and a consumer activity is that the producer activity must be completed before the consumer activity can begin. A simple process to manage this dependency is notification to indicate to the consumer activity that it can begin. For instance, when an automobile engine factory delivers a completed engine to the chassis assembly factory which will use the engine, the arrival of the engine "notifies" the chassis assembly factory that its assembly activity can begin. Managing this dependency also involves a tracking process to make sure that producer activities have been completed before their results are needed. The ideal alternatives would be a computer-based tracking system that makes it easy for everyone involved in the activities to see state information about all related activities and their dependencies (figure 3-2) (Malon and Crowston, 1994; Herrmann, 1999). Obviously, the above co-ordination decision can't be made without the aid of high quality information and knowledge of all the participated facilities.

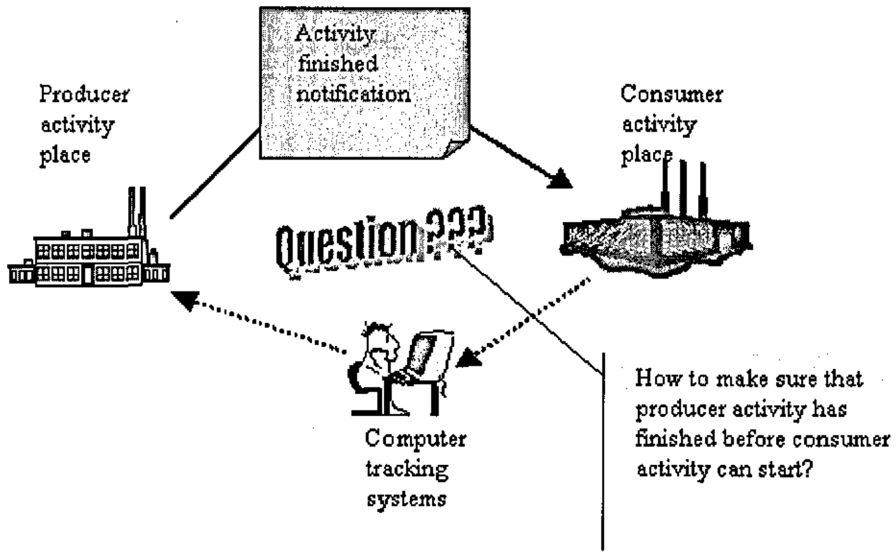


Figure 3-2 Illustration of prerequisite (precedence) constraint issue in global manufacturing

When one activity produces something that is used by another activity, the things produced must be transferred from the producer facility to the consumer facility. Managing this dependency usually involves physical transportation. Widely used transportation processes can be air shipping, rail shipping, road shipping and ocean shipping. In global manufacturing, transportation is even more important because the lead times and costs for the transportation between different areas are much higher than those within the same area. This issue is illustrated in figure 3-3. When there are more than one transportation available to transfer products from the producer activity to the consumer activity, the choice must be made according to specific requirements (Rugman et al, 1995; Pontradolfo, 2002). Undoubtedly, the right transportation decisions require the effective support of information and knowledge of transportation resource, transportation process, and transportation knowledge.

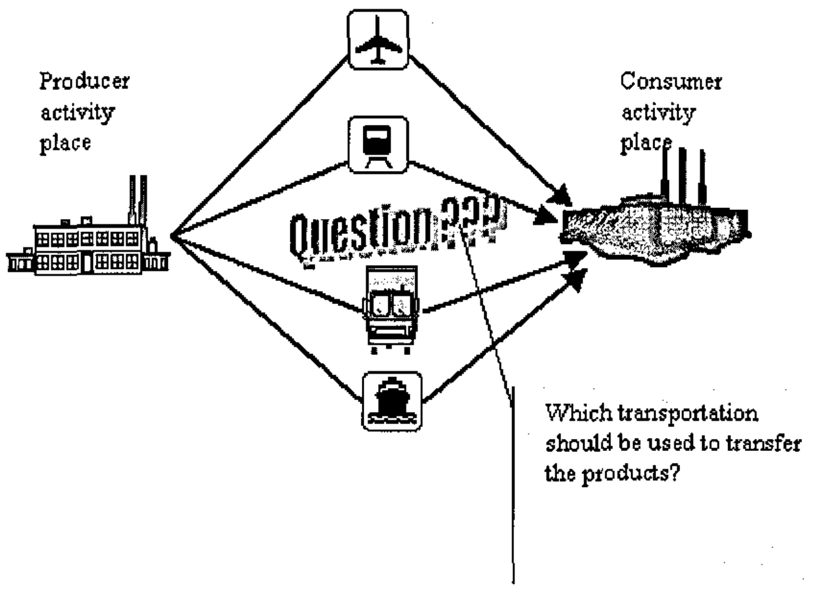


Figure 3-3 Illustration of transportation issue in global manufacturing

In summary, information and knowledge support for global manufacturing co-ordination is important because the co-ordination involves not only cross-functional but also cross-regional activities, i.e. global manufacturing co-ordination is far more complex than ordinary co-ordination within one facility. This demands information and knowledge to be integrated and shared. One of the fundamental requirements to meet these needs is that information and knowledge must be correct, complete, consistent, up-to-date and available when and where needed (Kjellerg and Bohlin, 1996). This work attempts to find an effective way to provide the high quality information and knowledge to facilitate the above co-ordination decisions. Task assignment and transportation are taken as two cases in the exploration of information and knowledge support for global manufacturing co-ordination.

3.3 Information and Knowledge Infrastructure Issues for Global Manufacturing Co-ordination

The information source provision topic has attracted a lot of researchers in recent years. It includes product information modelling, order information modelling, and manufacturing information modelling (Thenemann, 2002; Giachetti and Alvi, 2001). However, most previous work has been concerned with product data modelling. By comparison, less effort has been made on providing manufacturing information and order information. This work is concentrating on manufacturing information representation and provision, particularly in the information and knowledge of global manufacturing capability.

There are different ways to provide information and knowledge of manufacturing capability. Some people such as (Zhou and Besant, 1999; Hardwick et al, 1996; Lin et al, 2000) used a number of database connectivity information management components (modules) that provide database access and data extraction. The information management component is duplicated at some member facilities in a global enterprise. Here, the possibility of redundant and inconsistent information cannot be excluded as each component has its own database with its own proprietary data representation schema. That's why database inconsistency checking modules are introduced to generate missing data reports and reduce the data set to a consistent level (Zhou and Besant, 1999; Hardwick, 1996; Lin et al, 2000). Alternatively, Maropoulos et al (2001) used a resource model separated from a process model to provide specific aspects of manufacturing capability information for all members in an enterprise. Here, a salient problem is how to properly define the close relationship between manufacturing resource and process. This research prefers to use a manufacturing model (MM) as a common repository of manufacturing capability information and knowledge and tries to advance the understanding of manufacturing model following the previous work done at Loughborough University (Molina, 1995; Zhao, Cheung and Young, 1999).

The manufacturing model concept was first proposed by (Alashaab and Young, 1992) and was defined as the model that " captures the information which describes the characteristics, or behaviour, of the process and the knowledge and constraints which govern the use of the process". Molina (1995) carried on the investigation on the manufacturing model and described it as "an information model, which identifies, represents, and captures the data, information, and knowledge, that describes the manufacturing resources, processes, and strategies of a particular enterprise". This enables the provision of the necessary manufacturing information for the support of the machining decision-making and application to design for manufacturing and process planning (Zhao, Cheung and Young, 1999) etc.

The top-level structures of the manufacturing model defined by (Molina, 1995) and (Zhao, Cheung and Young, 1999) are combined and shown in figure 3-4. In this figure, the inheritance relationship presented by an arrow to the Facility class means that either a Station, Cell, Shop, Factory, or Enterprise "is a" kind of Facility. The aggregation relationship presented by a diamond means a "has" relationship. For example, a Facility has Process, i.e. Process is "part of" the manufacturing capability of a Facility. Molina's structure is defined for supporting the machining process at low levels (from factory to station levels), so it does not include the shaded enterprise class.

Zhao, Cheung and Young (1999) extended Molina's manufacturing model to enterprise level by adding an enterprise class before factory class to accommodate the use for a virtual enterprise. Despite the difference of the facility levels, both structures agreed that the manufacturing capability of a manufacturing facility could be embodied as three classes: process, resource, and strategy.

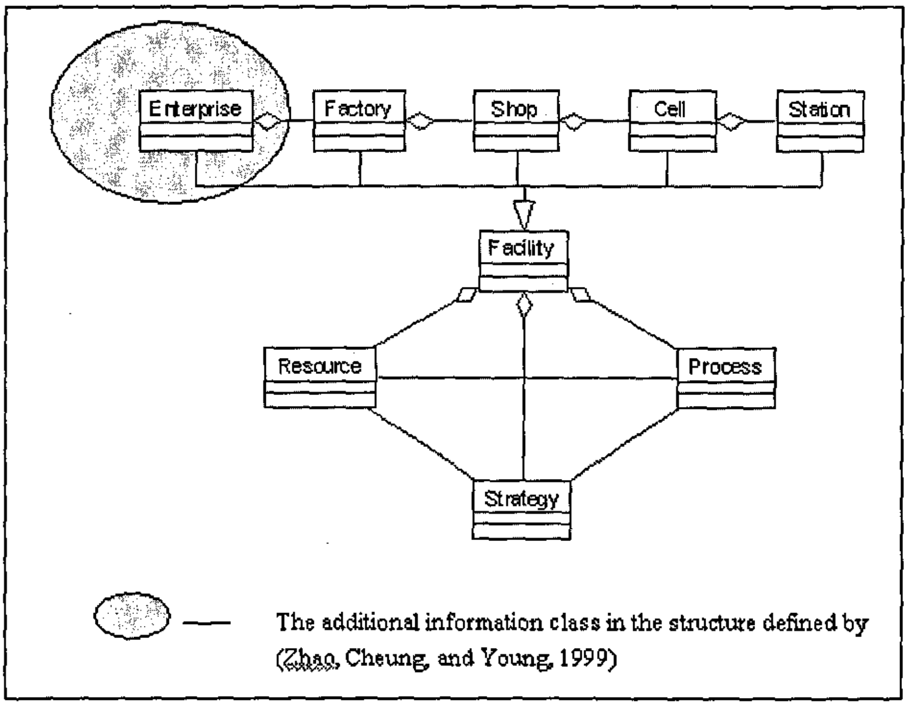


Figure 3-4 MM structure defined by (Molina, 1995) and (Zhao, Cheung and Young, 1999)

The following advantages of using a manufacturing model have been demonstrated by their work:

(1) The relationship between all manufacturing capability elements can be strictly defined.

(2) It's easier to avoid such information as incomplete information (where there are missing attributes or attribute values), noise (incorrect or unexpected values), and inconsistent information (containing attribute and value discrepancies). Incomplete information, inconsistent

information, and noise obviously contribute to inaccurate analysis and incorrect decisions.

However, although the extended manufacturing model structure defined by (Zhao, Cheung and Young, 1999) models the relationship between an enterprise and factories as levels of a facility, it doesn't reflect the characteristics of global enterprise such as flexibility and agility. In fact, a global enterprise must have the capability to organise the required resources over a network to produce hi-tech or hi-value-added products and to avoid unnecessary significant investment and capture the chance of global markets as quickly as possible. The manufacturing capability of a global enterprise should therefore consist of more than process, resource, and strategy. Resolving this issue produces the focus for this research.

3.4 *Information and Knowledge Model Support Concept*

As manufacturing information has typically been collected on an ad hoc basis for applications, there is little consensus on the structure of the manufacturing models (Giachetti, 1999). Therefore, a new manufacturing model structure is demanded for this research to represent and capture the information and knowledge of global manufacturing capability that can support global manufacturing co-ordination applications.

Figure 3-5 shows the new structure of manufacturing model that has been defined in this research to support global manufacturing co-ordination. This new structure of manufacturing model is designed for the global enterprise level rather than factory level or any other low levels (shop, cell, and station). From the structure, we can see that the information and knowledge of global manufacturing capability has been represented as four main classes: process, resource, configuration, and knowledge.

Compared with the existing manufacturing models (Molina, 1995; Zhao, Cheung and Young, 1999), this new structure of manufacturing model has two new classes, i.e. *Configuration* class and *Knowledge* class. It also keeps two classes, *Resource* class and *Process* class, from the existing structures.

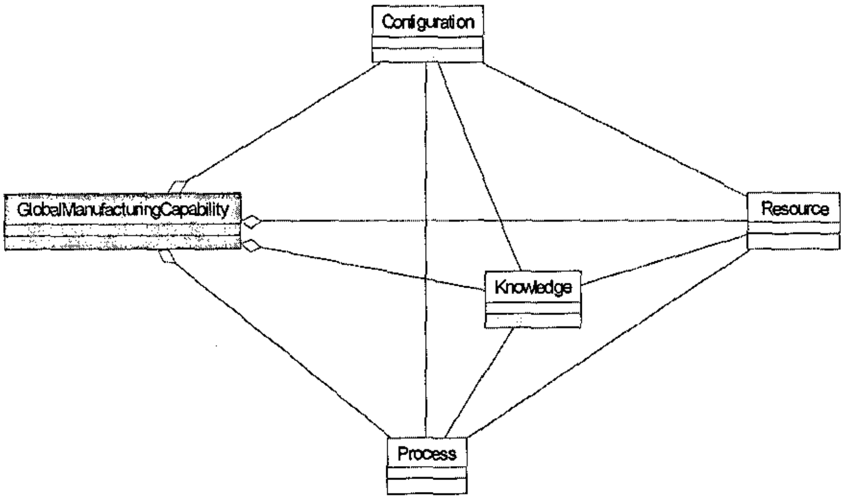


Figure 3-5 The top level of the new MM structure defined in this work

The configuration class is a very important new class in this structure. This is because global manufacturing enterprises are expected to have much more flexible capabilities and operational mechanisms to respond to global market requirements (GMVN, 2002; Tian et al, 2002). A real responsiveness and relevant flexibility might come from dynamic and unlimited resource accessibility, i.e. global resource *configuration*, rather than a rigid company boundary. It is inconceivable to realise such a dynamic and unlimited resource-based manufacturing system under traditional manufacturing and enterprise concepts without consideration of resource configuration capability.

The knowledge class in this structure has a similar function to the Strategy class in the existing structures but with added meaning. An important objective of employing knowledge rather than pure information and data is to facilitate standardisation and relieve the management of routine decision tasks (Chandra and Kumar, 2003). The definition of a knowledge class in the manufacturing model to capture the necessary knowledge means that the required solutions to a problem can be retrieved easily and flexibly in readily usable formats for various global manufacturing applications. This research focuses on co-ordination knowledge, which captures the constraints on the co-ordination process and provides different solutions for task assignment and product transportation under various conditions or combinations of condition. In the existing structures, manufacturing strategies are defined as a restriction imposed upon the use of manufacturing resources and processes.

The process modelled in this structure is focusing on the co-ordination process rather than the machining process (such as milling, turning as in the existing structures). The transportation process between facilities, probably international transportation in order to move products to the next process, is considered as a co-ordination process since it involves managing a dependency between a "producer" activity and a "consumer" activity. Correspondingly, the resource class in this structure includes inter-facility transportation resource as well as transforming facilities. In the existing structures, resources are physical elements such as machine tools and cutting tools.

The detailed exploration of the main classes and their extension as well as the relationships between the classes in the manufacturing model will be discussed further in chapter 5.

Although the main focus of this research is on manufacturing capability information and knowledge structuring, there is also a need for product information and order information to be available before global manufacturing co-ordination decisions can be made. A conceptual view of information and knowledge model support for global manufacturing co-ordination applications can be therefore represented as shown in figure 3-6. Here the applications of task assignment (TA) and producer/ consumer relation co-ordination (PCRC) are illustrated as the global manufacturing co-ordination applications to be considered as described in section 3.2 of this chapter. Therefore, although the main focus of the research is on a manufacturing model (MM), there is also a need to consider its relationship to a product model (PM) and an order model (OM). The exploration of the structures of product model and order model as well as the relationships between three models is documented in chapter 6.

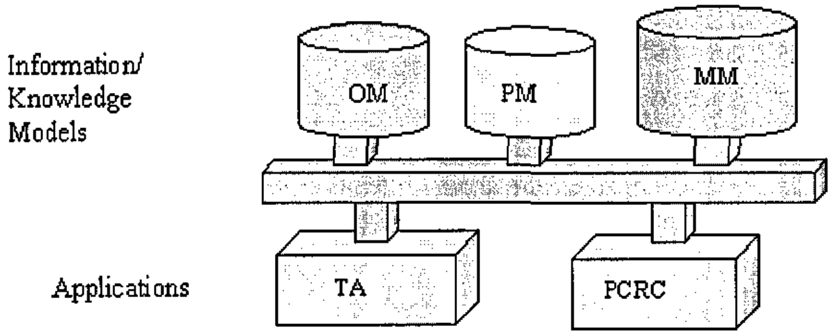


Figure 3-6 Concept of information and knowledge models to support GMC

The understanding developed of the information and knowledge models has been built through iterative and incremental processes, which has involved the following guidelines:

- Define potential functions to be supported;
- Formulate decision processes;
- Identify information and knowledge requirements for various functions;
- Identify the list of objects that need to be classified;
- Define classes for grouping objects;
- Specifying relationships between classes;
- Define the structures of the information and knowledge;
- Investigate the links between three models.

This research proposed the idea of using a multi-perspective modelling approach (Kingston and Macintosh, 2000; Chatha et al, 2003), particularly by the combined application of IDEF0, IDEF3, and UML (Dorador and Young, 2000), where the work involved with the exploration of the requirements of information and knowledge with IDEF0 and IDEF3 (Cho and Lee, 1999) and its relationship to the information and knowledge general structure modelled with UML is discussed in chapter 4.

A global manufacturing co-ordination (GMC) software system has been developed to explore the information and knowledge structures as well as the application of the three information and knowledge models. Figure 3-7 shows the concept of the global manufacturing co-ordination system. The global manufacturing co-ordination system designed here should be able to support the two applications of task assignment (TA) and producer/ consumer relation co-ordination (PCRC).

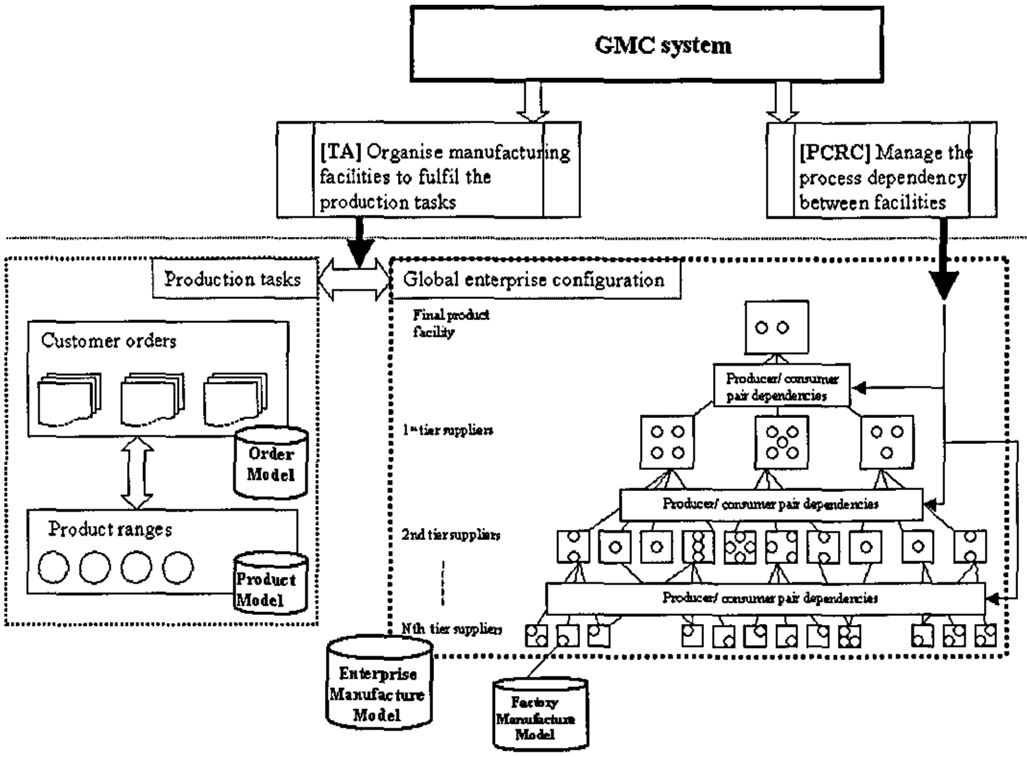


Figure 3-7 Concept of the global manufacturing co-ordination system

The first application of the global manufacturing co-ordination system, task assignment, is to organise manufacturing facilities to fulfil the product orders. Usually, a key facility, i.e. the facility which receives orders from outside customers or forecasts the demand of final products, has many orders which contain many product ranges during a period of time. The key facility will have to organise the most appropriate facilities to produce the products in response to global markets and meet the customer requirements. The global enterprise will consist of facilities at many supply tiers. To manage the process dependency between the producer and consumer pair facilities is the second application of the global manufacturing co-ordination system, which aims to facilitate the co-operation between facilities so that all participating facilities can work synchronously to ensure the final products to be delivered as customers require. Two manufacturing models (an enterprise level manufacturing model and a factory level manufacturing model), together with a product model and an order model, provide different information and knowledge to support the two applications. The development of the global manufacturing co-ordination system is discussed in chapter 7.

3.5 Summary

This chapter starts from the explanation of the global manufacturing co-ordination problem domain. Co-ordination processes with respect to global manufacturing have been identified and classified. The necessity of information and knowledge support for co-ordination decisions has been recognised.

Secondly, this chapter addresses the importance of how to provide quality information and knowledge of global manufacturing capability for the co-ordination decisions, and compares the new information and knowledge structure defined in this work and existing information structures of a manufacturing model.

Finally, this chapter proposes the idea of using a multi-perspective modelling approach to explore the information and knowledge requirements for global manufacturing co-ordination, further discussed in chapter 4 , and applying the manufacturing model together with a product model and an order model to support the global manufacturing co-ordination decisions.

4 The Exploration of Information and Knowledge Requirements for Global Manufacturing Co-ordination through a Multi-Perspective Modelling Approach

4.1 Introduction

The objective of this chapter is to capture and specify the information and knowledge requirements for global manufacturing co-ordination (GMC). To completely represent the information and knowledge for a global manufacturing co-ordination scenario, a multi-perspective modelling (MPM) approach (Yun and Chen, 2001; Abdullah et al, 2002; Kingston and Macintosh, 2000; Chatha et al, 2003) has been used. Multi-perspective modelling enables multiple modelling methods to be used together, each method being the most appropriate for modelling one particular aspect of information and knowledge of the problem domain. The multi-perspective modelling approach is necessary because the global manufacturing co-ordination domain information and knowledge is so complicated and of heterogeneous types that no single modelling method can capture all of the important aspects and present them clearly and appropriately. Thus a multi-perspective modelling approach makes use of multiple modelling methods which complement each other and work as a whole to describe the domain information and knowledge better. In this research, firstly, the information and knowledge contents are identified through IDEF0 function modelling as discussed in section 4.2. Secondly, the IDEF3 process modelling method has been used to describe the dynamic behaviour of global manufacturing co-ordination activities and identify the objects which are involved in the processes as presented in section 4.3. Finally, UML has been used to define the structures of information and knowledge models in section 4.4. These are discussed in the following three sections respectively before a further discussion of multi-perspective modelling applied for global manufacturing co-ordination within the summary of this chapter in section 4.5.

4.2 Function Modelling of Global Manufacturing Co-ordination with IDEF0

This section presents how to capture the information and knowledge contents required by the two functions, task assignment and producer and consumer relation co-ordination, of global manufacturing co-ordination defined in section 3.2 through IDEF0 function modelling (IDEF0 standards). The main reasons for IDEF0 to be used here are:

- As a means for modelling the information and knowledge required by functions (activities) and the functional relationships for global manufacturing co-ordination;
- As a modelling technique which is independent of other modelling tools (such as IDEF3 and UML), but which can be used in conjunction with those methods and tools;
- As a modelling technique based on combined graphics and text that are presented in a systematic way to gain understanding of global manufacturing co-ordination activity integration.

4.2.1 Global Manufacturing Co-ordination Activity Formulation

The activities of the functions must be formulated beforehand for the function modelling. Based on the information collected through literature review and communication with companies, the activities related to global manufacturing co-ordination have been formulated as follows (figure 4-1).

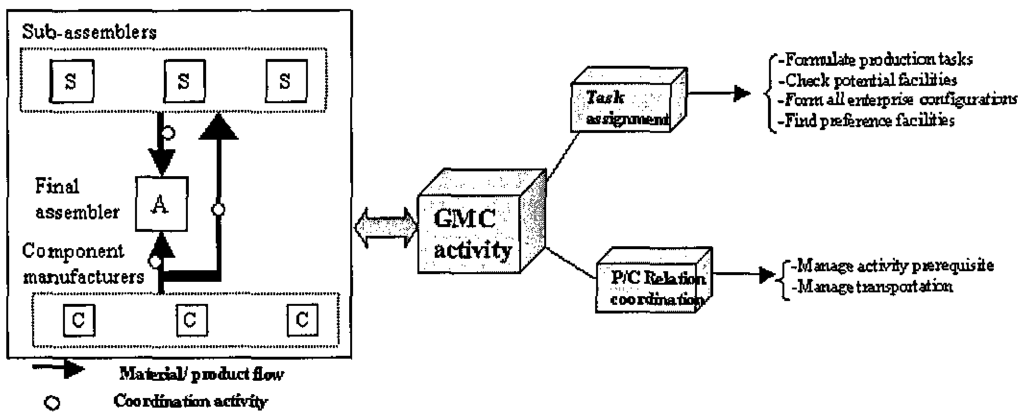


Figure 4-1 Global manufacturing co-ordination activity formulation

The first function, task assignment, has been formulated as four activities (Ho et al, 2000; Garavelli et al, 1996; Chen et al, 1994):

- Formulate production tasks;
- Check potential facilities;
- Form all enterprise configurations;
- Find preference facilities.

The function of producer and consumer relation co-ordination can have a comprehensive list of activities as explained in section 3.2 (Li et al, 2002; Rugman and Hodgetts, 1995; Malone and Crowston, 1994). However this work focuses on process prerequisite and transportation, so the following two activities have been generated for producer and consumer relation co-ordination function:

- Manage activity prerequisite;
- Manage transportation.

4.2.2 Capturing Information and Knowledge Flows of the Global Manufacturing Co-ordination Activities by IDEF0

The information required for the above activities and information flows between the activities need to be identified, to classify the information and knowledge requirements for the global manufacturing co-ordination functions.

With the IDEF0 model, the information and knowledge requirements of the functions (activities) can be modelled as four different types: inputs, outputs, control and mechanisms. IDEF0 diagram is a graphic tool to model function and information flows between activities which starts from a top-level *Context Diagram* as shown in figure 4-2. This *Context Diagram* describes the overall function of global manufacturing co-ordination, and shows that the global manufacturing co-ordination function takes three inputs: product orders, potential facilities and potential transportations. Three ultimate outputs that are created by the global manufacturing co-ordination function are preference task assignment solutions, preference transportation and process prerequisite strategy. Three controls (product structure trees, physical manufacturing capability information, and coordination process and knowledge) are necessary for the function. A mechanism, production engineer, provides the means to perform the function. The top-level *Context Diagram* A-0 can be further broken down into its child diagrams to capture more detailed information that flows between activities. All sets of the IDEF0 activity diagrams of global manufacturing co-ordination can be found in **appendix A** of this thesis, and figure 4-3 is one example of the child diagrams that comes next to top-level *Context Diagram* A-0.

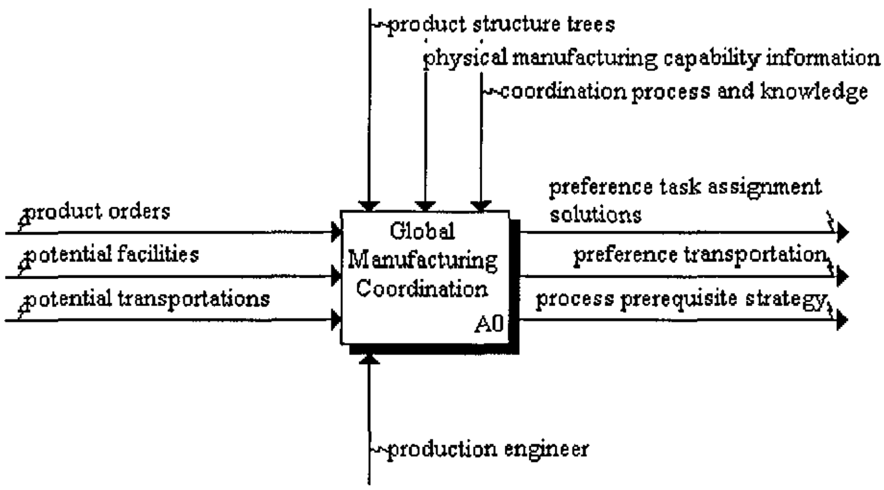


Figure 4–2 A-0 Context Diagram of GMC with IDEF0

The importance of child diagrams is that they present the information flows between activities. This intermediate information shows the interdependency relationship between the activities. For example, in figure 4–3, *selected facility pairs*, the output of the task assignment function, is actually an important condition and circumstance which governs the transformation of producer and consumer relation co-ordination function. That's why it is modelled as the control of the function. Similarly, *process sequence*, the output of the task assignment function, becomes the input of Producer/ Consumer relation co-ordination function. If we track down the lower levels of the IDEF0 diagrams, all information flows between activities can be captured as necessary.

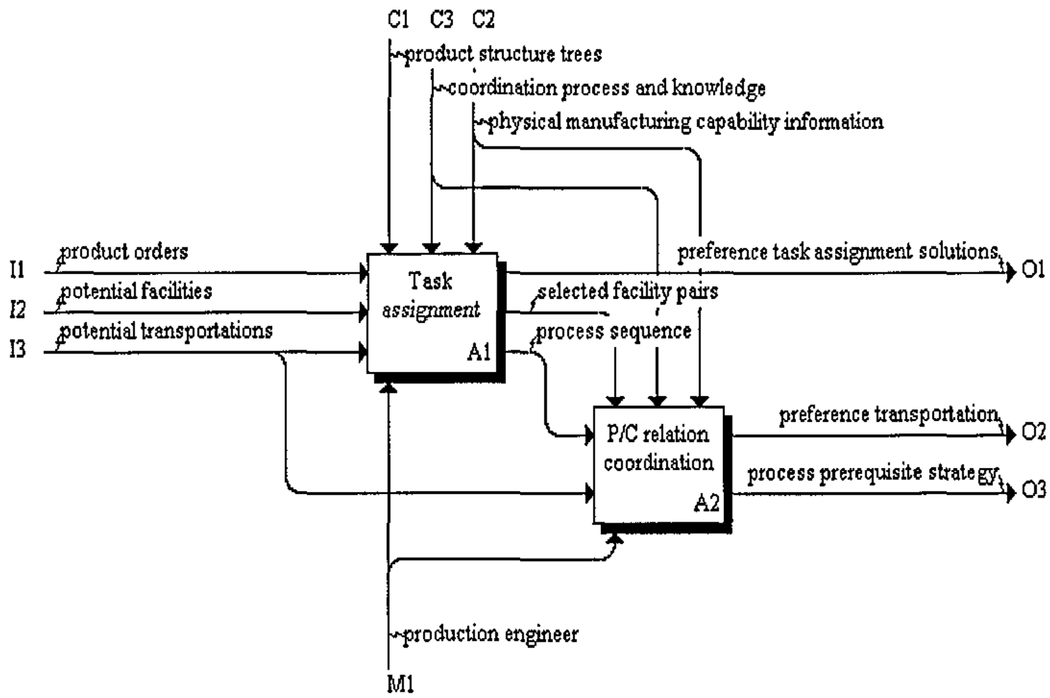


Figure 4-3 Diagram A0 of GMC with IDEF0

Through IDEF0 function modelling, the information and knowledge requirements in terms of global manufacturing co-ordination have been identified and summarised as in table 4–1.

The information and knowledge contents captured here provide more complete requirements for global manufacturing co-ordination compared with similar research work in this area. For example, Ng and Ip (2000) addresses the information of enterprise resources and manufacturing orders for global manufacturing strategy, Azevedo and Sousa (2000) emphasises on the information of sales order and manufacturing processes to support the co-ordination of global networks of manufacturing units and of large complex supply chains, Ho et al (2000) discusses the information of facility configuration for the selection of collaborative partners in global manufacturing. These information and knowledge contents are the key materials for constructing information and knowledge models later.

Information and knowledge types	**Information and knowledge contents**
Inputs	- Product orders - Potential manufacturing facilities - Potential transportation
Outputs	- Preference task assignment solutions - Preference transportation - Preference prerequisite strategy
Control	- Product structure trees - Physical manufacturing capability
Mechanisms	- Production engineer
Intermediate information	- Selected facility pairs - Process sequence - ...

Table 4–1 Information and knowledge contents for GMC captured by IDEF0 model

4.2.3 Limitation of the IDEF0 Model of GMC

Even though above IDEF0 function model shows the strength in representing global manufacturing co-ordination function (activities) and the information flows between the functions (activities), it is important to point out that the IDEF0 model doesn't consider the specific logic or timing associated with global manufacturing co-ordination activities. IDEF3 process modelling method provides this capability and has been therefore chosen as a complementary solution to IDEF0 modelling in this research.

4.3 Process Modelling of Global Manufacturing Co-ordination with IDEF3

This section discusses how to capture precedence and causality relations between situation and events that occur in the global manufacturing co-ordination activities, which have been modelled by IDEF0 in section 4.2. IDEF3 (IDEF3 Ref.) provides two types of models to capture the temporal information:

(1) Process flow description, which captures the timing sequences of activities;

(2) Object state transition network (OSTN) description, which summarises the allowable transitions of an object reference to the activities.

The resulting diagrams comprise a series of IDEF3 process flow diagrams and OSTN diagrams for global manufacturing co-ordination, as attached in **appendix B**.

4.3.1 Capturing Global Manufacturing Co-ordination Activity Sequences by Process Flow Description

This sub-section discusses how to model the dynamic aspects of the activities involved in global manufacturing co-ordination, which is missing in the IDEF0 model. IDEF3 process flow description provides this ability and has therefore been used to capture the knowledge of " how things work" in a problem domain. The following example illustrates how the building blocks of the IDEF3 method can describe a scenario typically found in a task assignment environment. The situation to be described is a process of *finding collaboration preference facilities.* The IDEF3 process flow description shown in figure 4-4 is the graphical representation of the scenario told by an enterprise production engineer when asked to describe "What goes on when you try to find collaboration preference facilities?" According to the process flow diagram, the first activity to do is to *Check all facility pairs*, through a *fan-out* junction the process splits into two paths, *Check collaboration history* or *Check collaboration possibilities.* Only after both activities finish, then *Get collaboration preference pairs* activity can be performed. The junctions (such as J8 and J9) modelled in the diagram capture the knowledge (constraints) along with the information of activities.

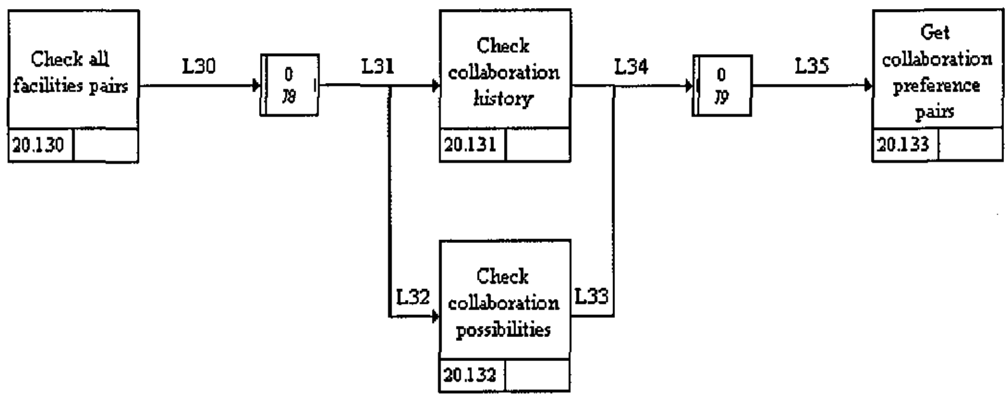


Figure 4-4 IDEF3 Process flow diagram of *find collaboration facilities process*

Process flow modelling is important because the activities identified here are initiators to create, delete, or transform the objects. These objects are key elements for structuring information and knowledge models.

4.3.2 Capturing GMC Objects by Object State Transition Network

This sub-section discusses how to identify the objects involved with the sequence of activities modelled with IDEF3 process flow model. The OSTN (object state transition network) description has been employed to do this work. The corresponding OSTN description of *find collaboration facilities process* is shown in figure 4–5.

The key elements of the OSTN diagram in figure 4-5 are the object states and the state-transition arcs. Three object states (potential facilities, collaboration preference facilities according to collaboration history, and collaboration preference facilities according to collaboration possibilities) are defined in terms of the facts and constraints which need to be true for the existence of the objects in that state, and is characterised by entry and exit conditions (facts and constraints as well). The arcs represent the allowable transitions between the object states. Elaboration forms have been used to enhance the capture of the above information. One example is the elaboration description for UOB (Unit of Behaviour) of *find collaboration preference facilities* as shown in figure 4-6. The objects section lists the names of all the objects that participate in the process being described by the UOB of *find collaboration preference facilities.* These objects can be either physical or conceptual. Objects can be created, modified, or destroyed during the process. The facts section lists facts about the instances of the UOB of *find collaboration preference facilities.* The constraints field lists constraints (knowledge) on the UOB of *find collaboration preference facilities,* i.e. conditions about what must hold in all instances of the UOB of *find collaboration preference facilities.*

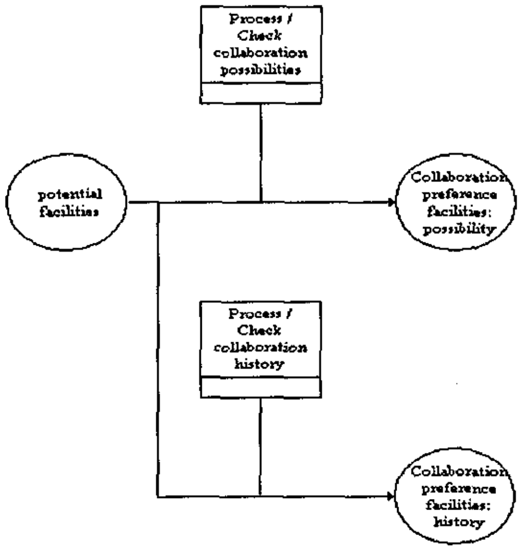


Figure 4–5 OSTN diagram of *find collaboration facilities process*

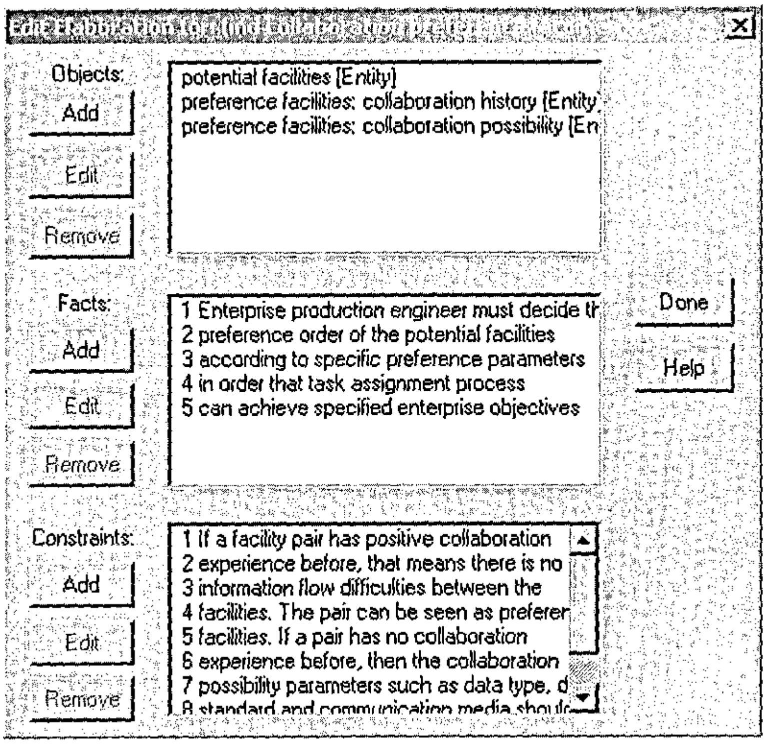


Figure 4–6 Elaboration form about find collaboration facilities process

In summary, IDEF3 models present information from a temporal, dynamic viewpoint. The OSTN description provides a clear idea about how the original objects (or object state) transform into final objects (or object states) as required under the process sequence described in the IDEF3 process flow model. When more and more objects involved with the global manufacturing co-ordination process have been captured, an object pool will be filled with more and more information and knowledge, as shown in figure 4–7, with different kinds of concrete objects that have been captured by OSTN diagrams and UOB elaboration forms. All these objects look a little disorganised but they form the original key information for structuring the information and knowledge models.

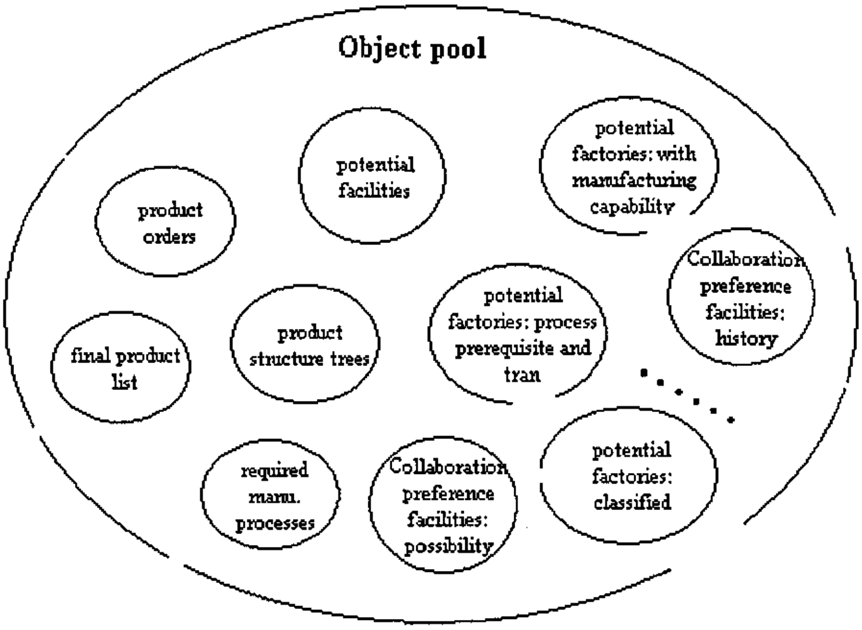


Figure 4–7 Identified objects for global manufacturing co-ordination

4.3.3 Three types of information and knowledge requirements for GMC

Through the above IDEF3 modelling, the requirements of information and knowledge for global manufacturing co-ordination have been identified. According to the properties and behaviour of the objects, by means of information analysis – clustering process (Chang et al, 2001), the information and knowledge can be partitioned relate to three different themes (figure 4-8):

(1) Product-related information such as

- Product structure trees

(2) Order-related information such as

- Product orders

(3) Manufacturing capability related information and knowledge including

- Physical manufacturing capabilities (configuration and manufacturing process capability)
- Co-ordination process and knowledge
- Facilities
- Transportation

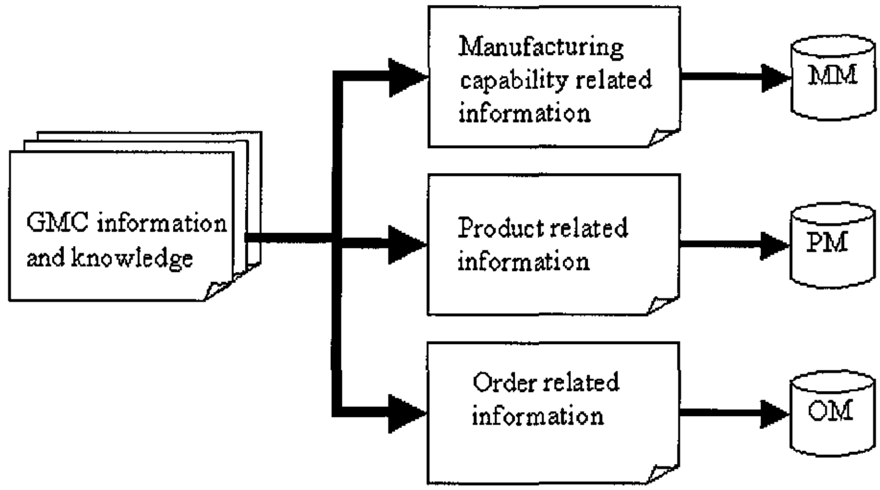


Figure 4-8 Three types of GMC information and knowledge

Therefore, all global manufacturing co-ordination information and knowledge requirements will be constructed in three distinct types of models: a manufacturing model (MM), a product model (PM), and an order model (OM). Similar recent research work (Borja et al, 2001; Giachetti and Alvis, 2001; Thenemann, 2002) addresses one or two of theses models, while this work needs three models working together to provide above information and knowledge required for global manufacturing co-ordination.

4.4 Modelling the Structure of Manufacturing, Product and Order Models Using UML

IDEF0 and IDEF3 models have successfully been used to identify the information and knowledge contents that are involved in global manufacturing co-ordination. However they don't logically organise all the information and knowledge elements in a systematic way. Initially, these descriptions look like simple glossary entries. IDEF0 is strong in function (activity) analysis and IDEF3 is strong in dynamic behaviour analysis, but they both are weak in information and knowledge structuring. UML (Quatrani, 1998) is therefore employed to structure the information and knowledge that has been identified by IDEF0 and IDEF3, as UML is strong in information and knowledge structure modelling.

During the course of the construction of the UML class diagrams, which represent the information and knowledge structures of the manufacturing model, product model, and order model, three crucial steps have been carefully followed:

- Define the classes to group objects;
- Specify the relationships between classes;
- Define the information and knowledge structures.

The initial information has been obtained from the IDEF3 OSTN description and UOB elaboration forms.

4.4.1 Identifying Classes to Classify Global Manufacturing Co-ordination Objects

The problem of information and knowledge element classification has been the concern of countless philosophers, linguists, cognitive scientists, and mathematicians (Booch, 1994). To solve this problem is important to object-oriented design. Three general approaches have been used in this research to classify global manufacturing co-ordination objects that have been identified in section 4.3.

The first approach used is classical categorisation, i.e. all the entities that have a given property, or collection of properties, in common form a category. Mutual homogeneity within objects is implied with them being in a group. For example, objects *ManufacturingFacility* A and *ManufacturingFacility* B have a collection of properties in common (see table 4-2) and therefore can belong to the same class (figure 4-9), but each *ManufacturingFacility* object would have a value for the attributes and access to the operations specified by the *ManufacturingFacility* class, i.e. *ManufacturingFacility* A and *ManufacturingFacility* B can have different facility place, and can be qualified for different processes, etc. Thus, a class

ManufacturingFacility is a template to create objects *ManufacturingFacility* A and *ManufacturingFacility* B. Each object is an instance of some class and cannot be instances of more than one class. A good class captures one and only one abstraction -- it should have one major theme. According to above rules, most objects involved in global manufacturing co-ordination and identified by IDEF3 can be grouped into appropriate classes.

Objects	**Manufacturing facility A** 	**Manufacturing facility B** 
Property 1	Located in UK	Located in Spain
Property 2	Qualified for process a	Qualified for process b
Property 3	Can produce 10 units of product a in a week	Can produce 20 units of product b in a week
Property 4	Can start process a next Monday	Can start process b next Friday
More Properties	......	......

Table 4-2 Manufacturing facility A and B have properties in common

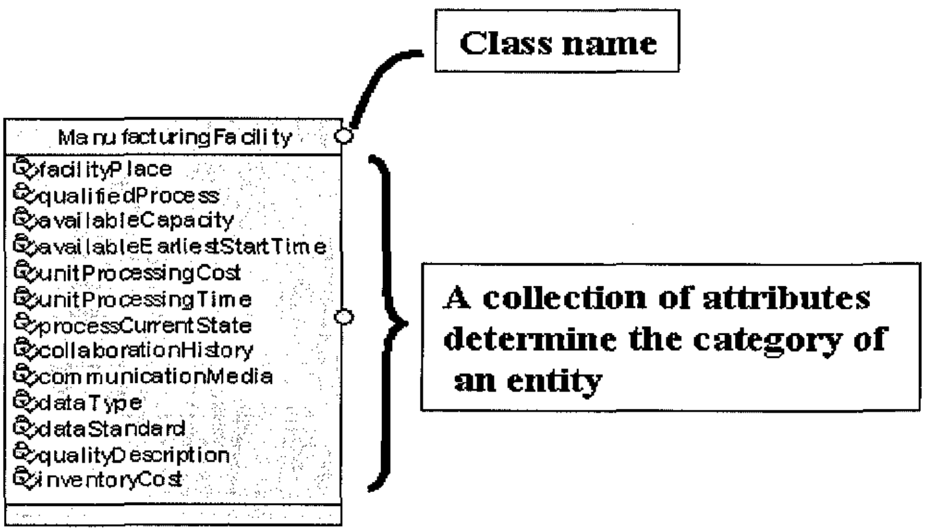


Figure 4-9 Manufacturing facility class created on basis of classical categorisation approach

However, this approach is not always satisfactory because some non-physical categories tend to be messy, for example the co-ordination process. It seems practically impossible to come up with a property list for any non-physical category that excludes all examples that are not in the category and includes all examples that are in the category. These are indeed fundamental problems for class categorisation, which conceptual clustering and prototyping theory attempt to resolve (Booch, 1994).

Conceptual clustering is a more modern variation of the classical approach. In this approach, classes (clusters of entities) are generated by first formulating conceptual descriptions of these classes, and then the entities are classified according to the descriptions. For example, we may state a concept such as " co-ordination process". This is a concept more than a property because the "co-ordination" of any process is not something that may be measured empirically. However, if we decide that a certain process is more of a co-ordination process than not, we place it in this category. Thus, conceptual clustering is closely related to fuzzy (multi-value) set theory, in which objects may belong to one or more groups, in varying degrees of fitness. Conceptual clustering makes absolute judgements of classification by focusing upon "best fit" (Chen and Lu, 1996).

Classical categorisation and conceptual clustering are sufficiently expressive to account for most of the classifications we ever need in the analysis of complex domains (Booch, 1994). However, there are still some situations in which these approaches are inadequate. This leads us to use the more recent approach -- prototype theory where some abstractions that have neither clearly bounded properties nor concepts (Chang et al, 2001). The basic idea of using prototype theory is: a class is represented by a prototypical object, and an object is considered to be a member of this class if and only if it resembles this prototype in significant ways. For example, the creation of a co-ordination knowledge class in this work is based on prototype theory. Comparatively, in conceptual clustering, we group things according to distinct concepts; in prototype theory, we group things according to the degree of their relationship to concrete prototypes.

By using the above three approaches of classification, all objects identified for global manufacturing co-ordination scenario can be grouped into proper classes. These classes are structured in the three models: a manufacturing model (MM), a product model (PM), and an order model (OM).

4.4.2 Specifying the Class Relationships of Information and Knowledge of Global Manufacturing Co-ordination

Objects must communicate and collaborate with each other to achieve the overall behaviour. Class relationships provide a conduit for object interaction. Three important types of class relationship used for global manufacturing co-ordination information and knowledge are association, aggregation and inheritance.

Firstly, if a bi-directional connection, i.e. information may flow in either direction, exists between two classes, an association relationship can be applied (figure 4-10). For example, an association relationship has been specified between *Resource* class and *Process* class, because there is a link between objects in the *Resource* class and *Process* class, i.e. *Process* uses *Resource* and *Resource* performs P*rocess.*

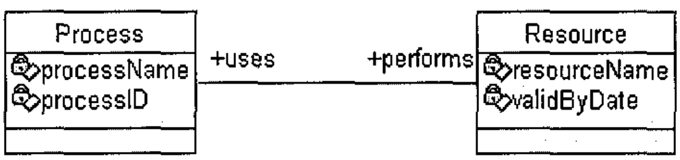


Figure 4-10 Association relationship between Process and Resource

Secondly, if two classes have a "whole" to "parts" relationship, then an aggregation relationship would be suitable. Aggregation is known as a "part of" or containment relationship (figure 4-11). For example, in this research, the relationship between *Order* class and *Product* class has been modelled as an aggregation relationship, because an order can have many products, and each product must belong to an order.

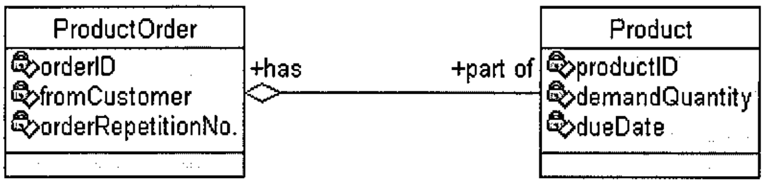


Figure 4-11 Aggregation relationship between ProductOrder and Product

Thirdly, an inheritance relationship can be defined among classes if one class shares the structure and /or behaviour of one or more classes. Inheritance is also called an "is-a" or "kind-of" hierarchy (figure 4-12). For example, *CoordinationKnowledge* is a kind of *Knowledge*.

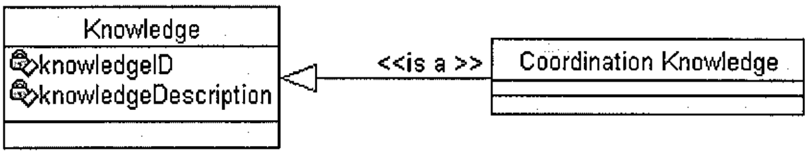


Figure 4-12 Inheritance relationship between Knowledge and CoordinationKnowledge

The classes and class relationships form the basic building blocks of the structures of information and knowledge models.

4.4.3 Structuring Information and Knowledge of Global Manufacturing Co-ordination

After all objects have been grouped into classes and the relationships between classes have been specified, the information and knowledge structures can be defined. Three structures of the manufacturing model (MM), product model (PM), and order model (OM) have been defined in this work (figure 4-13). The information and knowledge structure of the manufacturing model will be discussed in detail in chapter 5, and structures of the product model and order model in chapter 6. UML class diagrams have been created to provide a picture or view of classes in the models. All sets of UML diagrams created in this research can be found in **appendix C** of the thesis.

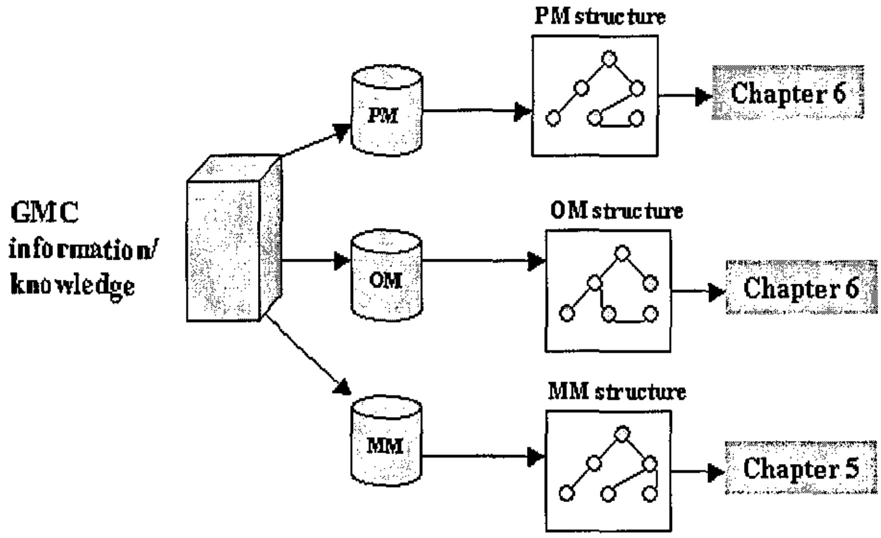


Figure 4-13 Three information and knowledge structures for GMC

4.5 Summary

This chapter presents the exploration of information and knowledge requirements for global manufacturing co-ordination through a multi-perspective modelling (MPM) approach. To maximise the advantages of the approach there are two important points arising from the combined use of IDEF0, IDEF3, and UML.

Firstly, both IDEF0 and IDEF3 have been used to identify the information and knowledge contents required by global manufacturing co-ordination from different point of views, but IDEF3 is not intended to be a replacement for IDEF0. Their complementary relationship can be illustrated as in figure 4-14. The activities (function) in IDEF0 model can be mapped onto processes or UOBs (Unit of behaviours) in the IDEF3 model. The inputs, outputs, and mechanisms of the IDEF0 model reflect the objects of the

IDEF3 model, while the controls in an IDEF0 diagram reflects the constraints in an IDEF3 Elaboration Form. IDEF0 and IDEF3 models work together to capture more complete information and knowledge of the global manufacturing co-ordination problem domain. Moreover, the order of using the two methods can be optional. When the problem domain being analysed is very complex, as global manufacturing co-ordination in this research, activity precedence relations are not evident at first glance. In this case, it is better to start with an IDEF0 model. Such a model is then decomposed to a level where the precedence relations among global manufacturing co-ordination activities become prominent. On the other hand, if the facts collected can be organised into a cohesive process, it would be better to formulate the IDEF3 process description first, and then abstract an IDEF0 model from that description.

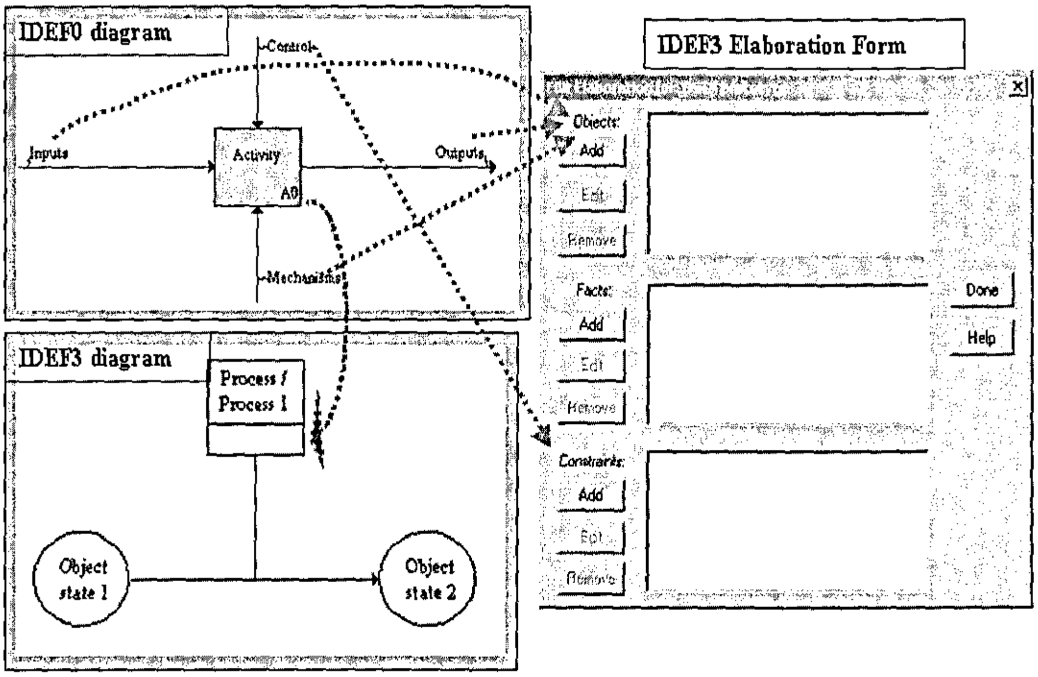


Figure 4-14 Relationship between IDEF0 and IDEF3

Secondly, all chosen modelling methods should be "compatible" with each other so that the models built can achieve a consistent and coherent view of the problem domain. It is easy to understand the compatibility between IDEF0 and IDEF3, as both of them belong to IDEF framework, while UML is not from the same family. However, the "compatibility" of different modelling methods does not simply mean that all methods need to use the same notation and semantics. The compatibility of using UML together with IDEF0 and IDEF3 lies in the basic concept of object-oriented design and analysis – objects and class. This research starts with the analysis of high-level abstraction of the global manufacturing co-ordination with IDEF0 and IDEF3 to obtain the information and knowledge about functions, activities, processes, and objects involved in the processes, followed by the analysis of obtained objects and attributes by UML to abstract classes, definition of class relationships and information and knowledge structures. The objects identified by IDEF3 description are taken as basic building blocks of UML classes. The object and class concept provides a conduit to integrate IDEF3 and UML and thus provides acceptable compatibility between the modelling methods.

The application of IDEF0, IDEF3, and UML methodologies have been successfully used in the creation of information models for assembly decision support systems by (Dorador and Young, 2000). Similarly, The emerging multi-perspective modelling approach has been found as a suitable approach to illustrate the essence of the domain of global manufacturing co-ordination, since it is able to capture different aspects of the domain and allows the presentation and analysis of concerned model concepts that is required for this work.

5 The Exploration of Manufacturing Capability Information and Knowledge Structures for Global Manufacturing Co-ordination

5.1 Introduction

This chapter explores the information and knowledge representation of global manufacturing capability of a global enterprise. Firstly, section 5.2 presents the understanding of information and knowledge structure for each element of global manufacturing capability. Then section 5.3 addresses the relationships between the classes in the information and knowledge structure of the manufacturing model (MM) defined in this work. Finally, section 5.4 is a short summary of this chapter.

The information and knowledge structure presented in this chapter has been built on the understanding of the global manufacturing co-ordination issue discussed in chapter 3 and based on the information and knowledge requirements modelling in chapter 4. All information and knowledge structure diagrams in this chapter are represented with UML. The manufacturing model structure defined in this chapter is also seen as the main contribution of this research.

5.2 Modelling the Information and Knowledge Structure of Classes of Global Manufacturing Capability for Global Manufacturing Co-ordination

As manufacturing information and knowledge in a manufacturing model is quite application dependent, the structure of the manufacturing model has to be designed carefully to accommodate the specific problem domain. In the case of global manufacturing co-ordination, a manufacturing model is supposed to capture all classes of the information and knowledge of global manufacturing capability as well as the relationships between the classes.

This section defines the information and knowledge structures for the main elements that should be captured in a manufacturing model for global manufacturing co-ordination. Most manufacturing models concentrate on representing manufacturing resources and their combination into manufacturing processes (Giachetti, 1999). However, some manufacturing models can capture manufacturing resources and manufacturing processes as well as manufacturing strategies (Molina, 1995; Zhao, Cheung and Young, 1999). Based on the understanding of existing manufacturing models and the exploration of new requirements of global manufacturing co-ordination, four main classes have been identified and evaluated in the manufacturing model for global manufacturing co-ordination, as shown in figure 5-1. They are *Resource*, *Process*, *Configuration*, and *Knowledge*. Among which *Resource* and *Process* classes are inherited from the

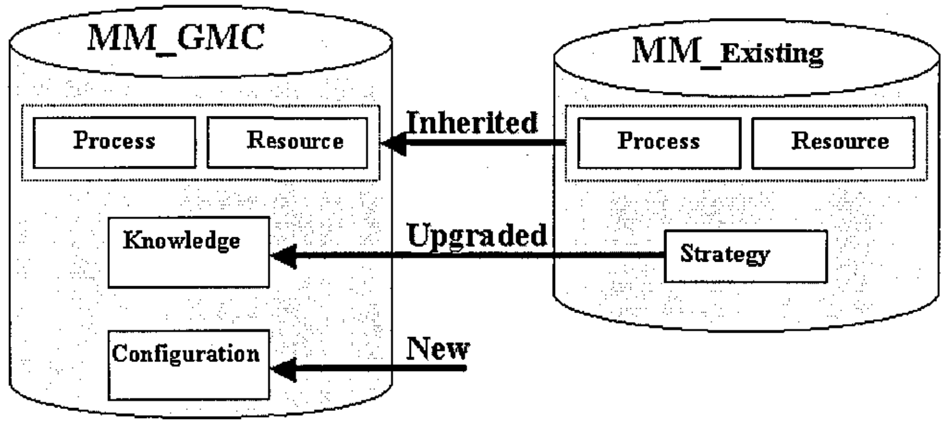


Figure 5-1 Main classes of global manufacturing capability in MM_GMC

existing manufacturing model structures (Molina, 1995; Zhao, Cheung and Young, 1999; Giachetti, 1999) because they have been demonstrated by different applications as two basic types of manufacturing capabilities for manufacturing organisation at any levels from enterprise through factory to shop, cell, and station. The *Knowledge* class was upgraded from the *Strategy* class in the existing manufacturing model structures (Molina, 1995; Zhao, Cheung and Young, 1999). The reason for this change is that while *Strategy* represented constraints on the use of *Resource* and *Process* defining a *Knowledge* class instead of the *Strategy* class in the new structure enables the retrieval of the most appropriate solutions for a problem under different conditions or combination of conditions, which makes the manufacturing model more intelligent. *Configuration* has been added as a new class in the manufacturing model structure to reflect the fact that global manufacturing should be able to organise manufacturing resources throughout the network to perform the required manufacturing processes and fulfil product orders to catch the best market opportunities.

The identification of the above four classes for the manufacturing model is also compatible with the reference architecture of Computer Integrated Manufacturing – Open Systems Architecture, i.e. CIM-OSA (Kosanke, 1995; Kosanke and Vernadat, 1999), as shown in figure 5-2. The CIM-OSA modelling framework addresses four views of an enterprise: function, information, resource, and organisation. The manufacturing model starts from the *Information* view and focuses on the information of manufacturing capability of an enterprise. The *Process* capability allows the realisation of enterprise functionality addressed by the CIM-OSA *Function* view. The capture of *Resource* and *Configuration* capabilities in the manufacturing model reflects the views of *Resource* and *Organisation* in the CIM-OSA respectively. *Knowledge* in the manufacturing model is based on the *Information* view and tries to provide added value on the information of *Process*, *Resource*, and *Configuration*. Therefore, there is a good fit between the manufacturing model with the four classes and the CIM-OSA reference architecture.

During the course of the exploration of the information structure of each element of the global manufacturing capability, described in the subsequent sections, first the domain problem is explained, then what needs to be understood within the information and knowledge structure is discussed, and finally the UML representation of the information and knowledge structure is presented.

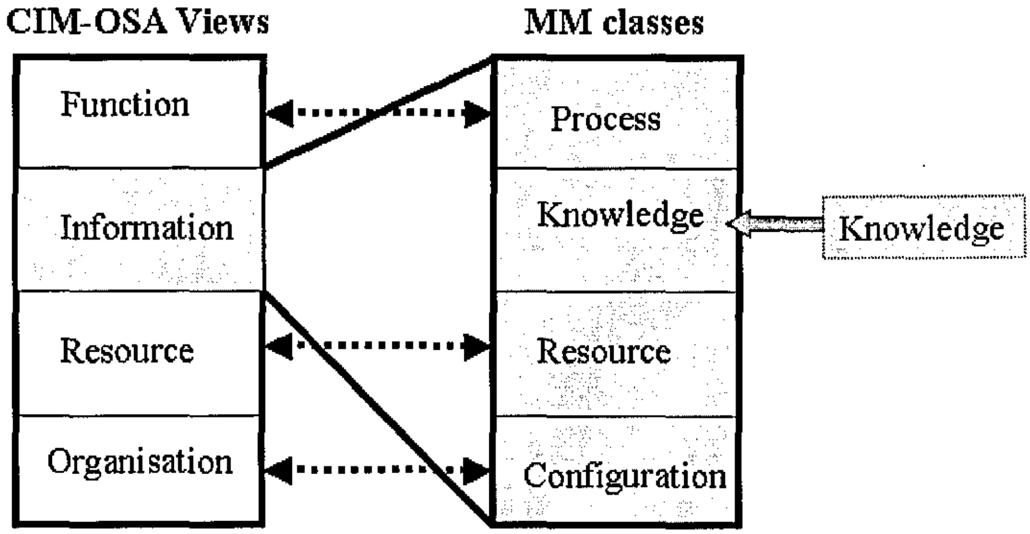


Figure 5-2 MM fits in the CIM-OSA reference architecture

5.2.1 Modelling the Information Structure of Resource

According to the definition given by the International Standard Organisation (ISO) on Industrial Automation System and Integration – Industrial Manufacturing Management Data: Part one (ISO15531-1), resource is "any device, tool, and means at the disposal of enterprise to produce goods or service". This is a very general definition. To apply this open definition to the case of global manufacturing co-ordination, specific constraints are necessary. Considering that both manufacturing factories and transportation resource are resources of a global enterprise, resources have therefore been defined in this research as any physical entities at global enterprise level that perform transformation processes or transportation processes. Thus, two types of resource have been modelled in this research: manufacturing facility and transportation resource.

5.2.1.1 Modelling the Information Structure of Manufacturing Facility

In this research, manufacturing facilities are factories that can perform specific manufacturing process(es). Because this research is focused on *global enterprise level activity and the direct interaction with enterprise* is restricted to factory level instead of further lower levels (shop, cell, and station). For example, as shown in figure 5-3, five facilities (factory F_1 to F_5)

are involved with three types of manufacturing processes *i*, *j*, and *k* (*i.e.* process for changing physical property, machining process, and joining process). In order to attach the process information of the facilities, each facility has a second suffix, i.e. a letter after the first suffix (facility number). For instance, F_{1i} means facility NO. 1 can perform process i. A facility may be able to perform more than one process, for example, factory F_3 can perform both machining process and joining process. The manufacturing facilities have to be understood correctly before they are organised to form into proper enterprise configurations.

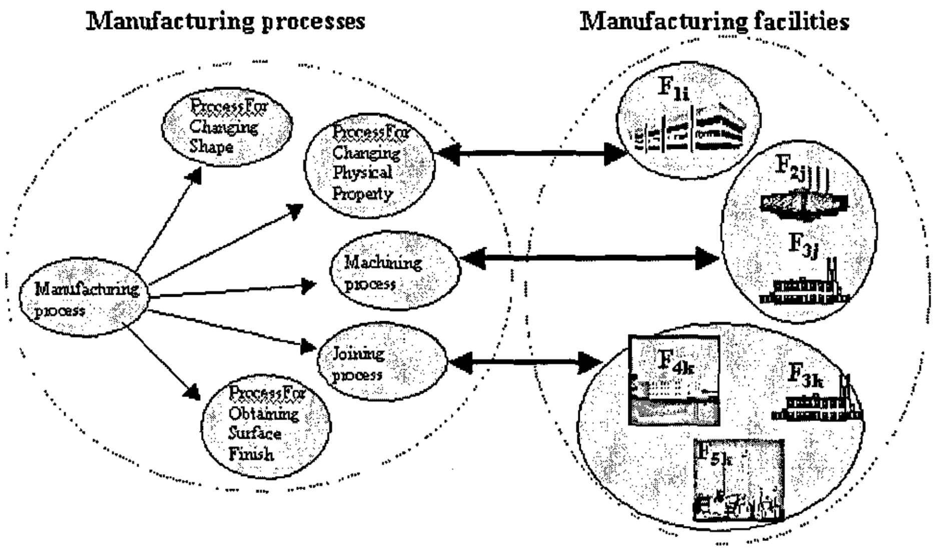


Figure 5-3 Examples of manufacturing facilities required for specific processes

In order to make a full understanding of a manufacturing facility, a series of information with respect to answering the kinds of questions shown in figure 5-4 should be available.

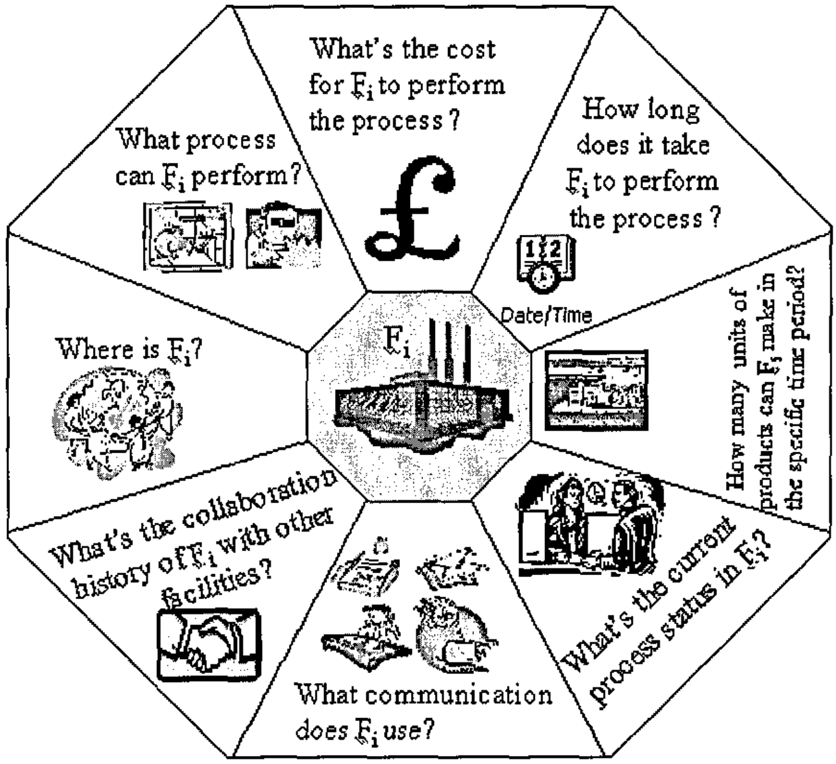


Figure 5-4 Examples of questions leading to the information needed for a manufacturing facility in GMC.

The answers information includes:

- Facility place, for example, F_i is located in the UK, Europe mainland, or America etc.;
- The process capability of the facility, for example, F_i can perform both drilling machining process and welding joining process;
- When using F_i to perform a specific process, the unit processing cost;
- When using F_i to perform a specific process, the unit processing time;
- When using F_i to perform a specific process, the units of the products in a specific time period;
- The current process status in F_i: on schedule or late;
- The facility F_i uses specific medias to communicate with other facilities: multi-media, Internet, World Wide Web, ISDN, telephone, or email;

- The facility F_i has collaboration history with some other facilities: positive or negative.

The availability of the above information can be made by properly structuring the information. The structure of an object is described by the attributes of the information class (Quatrani, 2000). The resource information structure should reflect the abilities, occupation and condition of all the facilities at any given time (Streppel et al, 2000). In this context, the following aspects of properties need to be considered in a manufacturing facility information structure (Ho et al, 2000; Streppel et al, 2000): identity property; capability property; capacity and occupation property; collaboration property; and timing property.

The identity property establishes the identification aspect of a manufacturing facility, e.g. each facility is unique. This aspect including facility name and facility location has to be understood in the manufacturing facility information structure.

The capability property reflects technological aspects of a manufacturing facility. The qualification of a facility to perform some process(es) is the first requirement to be considered in a potential facility. The process qualification of a facility has been evaluated at a factory level before a factory is put into global enterprise level as a potential facility. Once a facility is qualified for a process, the performance of the process in the facility becomes important. Three parameters are usually used to assess the process performance: unit processing cost (as well as inventory cost, if necessary), unit processing time, and product quality (Taylor, 1997; Gayretli and Abdalla, 1999; Minis et al, 1999).

The capacity property is defined to register the logistic consequences of the use of a certain facility. Each facility should be equipped with an attribute that contains a time schedule. In this time schedule, such information for the following questions should be recorded: when the facility is allocated to a certain process? How long is it occupied by this process? How many units of product this process can perform? Hence, it is clear when a facility is available for a certain process. If the current process state is under monitoring, the process capacity for next time period can be known easily.

As a global enterprise might be in the form of a dynamic partnership, the collaboration between facilities is critical. The collaboration property can be seen from two aspects. On the one hand, if a facility has a positive collaboration history with another facility, which means there's a priority to collaborate again. On the other hand, if two facilities have no collaboration history, there is a need to look for the collaboration possibilities in terms of the information flow techniques. For example, what kind of communication media do they use? Do they use the same data type and data standard to describe product information and manufacturing information?

As a manufacturing facility has its dynamic behaviour, any information about the facility is time-dependent. Out-of-date information will cause incorrect decisions and all information has to be updated in time. According to "Industrial manufacturing management data: Time Model" (*ISO 15531-42*), transaction deadlines or timing constraints must be designed to maintain the transaction consistency (Ozsoyoglu and Snodgrass, 1995). The timing property is a mark used to prevent the use of those manufacturing facilities for which information is out-of-date.

As a result, the attributes for the information structure of a *ManufacturingFacility* class have been identified and summarised in table 5-1:

Attributes identified	Meaning of the attributes	Properties reflected by
facility name	The name of a manufacturing facility	Identity property
facility place	Location of a facility	
qualified process	The process a facility is qualified for performing	Capability property
unit processing cost	The cost to produce one unit of the product using the process at the facility	
unit inventory cost	The cost to inventory one unit of the product at the facility	
unit processing time	The time to produce one unit of the product using the process at the facility	
quality description	The quality of the product produced at the factory	
available capacity	The quantity of products that the facility can make in a period of time	Capacity and occupation property
available earliest start time	The earliest starting time to produce a product at the facility	
process current state	The current status of the process at the facility that might affect the earliest start time	
collaboration history	The collaboration record between facilities in the past	Collaboration property
data type	The data type used by the facilities to communicate, such as text, pictures, sound, binary files etc.	
data standard	The data standard used by the facilities to communicate, such as ISO standard, European standard, National standard etc.	
communication media	The media used by the facilities to communicate, such telephone, fax, Internet, ISDN, multi-media etc	
information valid by date	The moment before the information in the models becomes out-of-date	Timing property

Table 5-1 Attributes identified for a manufacturing facility

Based on the above discussion, the information structure of a manufacturing facility class has been defined and represented by UML as in figure 5-5 (a). A series of attributes have been created to reflect the properties of the facility in the above list except for the facility name and information valid by date, because these two attributes can be inherited from the super-class of the *ManufacturingFacility*. Each attribute can have its own data type and value. Figure 5-5 (b) depicts the UML representation of an instance of the *ManufacturingFcility* class. The attributes of both *facilityName* and *informationValidByDate* in *ManufacturingFacility* class that are inherited from its super-class *Resource* have been marked with an arrow on the left side.

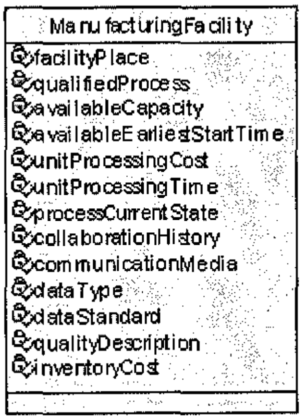


Figure 5-5 (a) Manufacturing facility information structure with UML

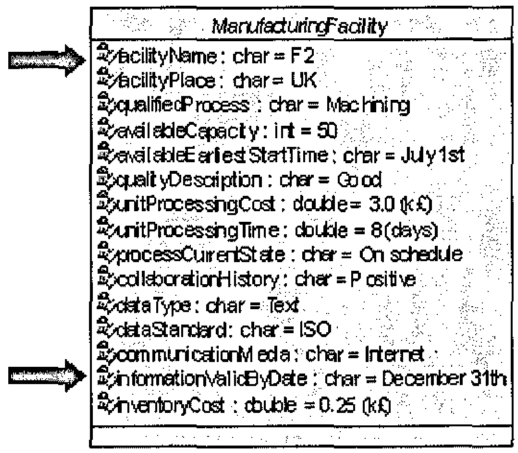


Figure 5-5 (b) Instantiation example of a manufacturing facility

5.2.1.2 Modelling the Information Structure of Transportation Resource

With the distribution of global manufacturing activities, transportation between facilities has become more significant as transportation time and cost between different areas are much higher than those within the same area. As illustrated in figure 5-6, four main types of transportation resource (flight, train, truck, and ship) are usually used to transfer materials/ products between two manufacturing facilities such as between a producer and consumer pair.

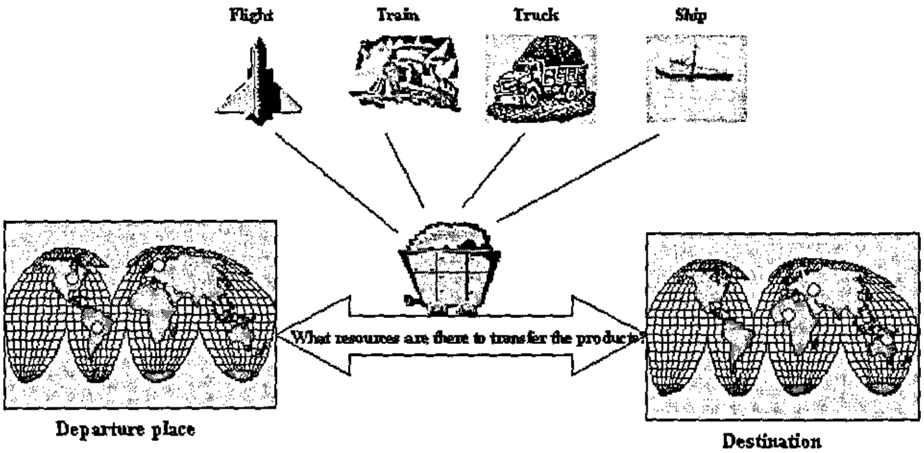


Figure 5-6 Transportation between manufacturing facilities

In deciding the best transportation mode to use, global enterprise tends to focus on some important criteria. Therefore, transportation resource information structure should reflect those important properties (Pontrandolfa, 2002; Rugman et al, 1995):

- Identity property: departure place and destination;
- Criteria property: transportation time, transportation cost, reliability, and availability.

The departure and destination properties are important because the use of transportation is highly dependent on the infrastructure of the area. For example, rail and motor carriers are of importance in some regions (such as EC) because of the extensiveness and quality of the region's road system and railway network. But in some other regions, if the infrastructure is poor, then the use of them is greatly limited.

The period between departure and arrival of a carrier can vary significantly between an ocean freighter and an aircraft. So one of the questions the enterprise will have to answer is: How quickly is delivery needed? The capture of this information will help the enterprise to make the right transportation decision. For example, products from a producer factory can be brought into a consumer factory by ship because the length of the trip will not negatively affect the succeeding activity at the consumer factory.

The expense associated with shipping is another major consideration when choosing an international transportation mode. Since air freight is significantly more costly than shipment by water, the cost must be economically justifiable. Typically, a global enterprise will use air shipments only when time is critical and / or the product has high value. On the other hand, if the merchandise is bulky or the cost of air freight is a significant portion of the value of the product, it will be sent by water.

Even though all transportation modes are basically reliable, they are subject to the vagaries of nature especially for air and water transportation. For example, bad weather can close an airport, inadequate seaport facilities can slow down the loading and unloading of cargo. However, certain carriers are more reliable than others, and the global enterprise will use its experience in determining which companies to choose for delivery. Reliability is particularly important for air shipments, where the difference of one day could significantly influence the saleability of the product.

Availability is the basic attribute that has to be captured about transportation. During busy time periods, the preferred transportation may not be available when required, sometimes a queuing time is necessary before a specific transportation service is available.

Therefore, a *TransportationResource* class should capture the following attributes:

- from facility (departure place);
- to facility (destination);
- transportation cost;
- transportation time;
- availability;

- reliability.

The information structure of the transportation resource has been defined by UML as in figure 5-7. *TransportationResource* has been designed as a super-class with all necessary attributes including *fromFacilty*, *toFacility*, *transportationCost*, *transportationTime*, *availability*, and *reliability*. All four sub-classes, i.e. *Flight* class, *Train* class, *Truck* class, and *Ship* class, will inherit attributes from *TransportationResource* class as necessary.

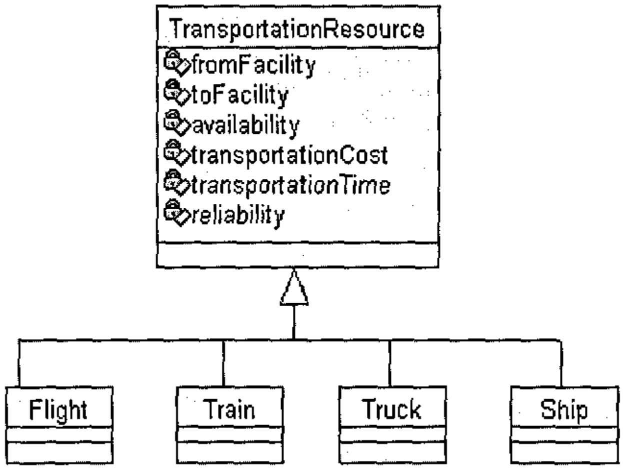


Figure 5-7 Transportation information structure

5.2.2 Modelling the Information Structure of Configuration

In this research, by configuration we mean the capability of organising resources to enable the required manufacturing processes to be performed. Under the current global-market driven situation, to produce demanding new products, it generally requires expensive and special resources (such as NC machines). For each company, these resources demand significant investment and high technology. In order to provide the required manufacturing resources and proprietary technology and avoid unnecessary investment, it is a good idea to organise the manufacturing resources around the world to form dynamic enterprise configurations (Tian et al, 2002). Figure 5-8 is an example of the configuration of manufacturing facilities. The five facilities defined in figure 5-3 can form six possible configurations to accomplish three required processes. Similarly, the two suffixes to each facility indicate the facility number, i.e. the first suffix, and the process (the second suffix of the letter) the facility can perform.

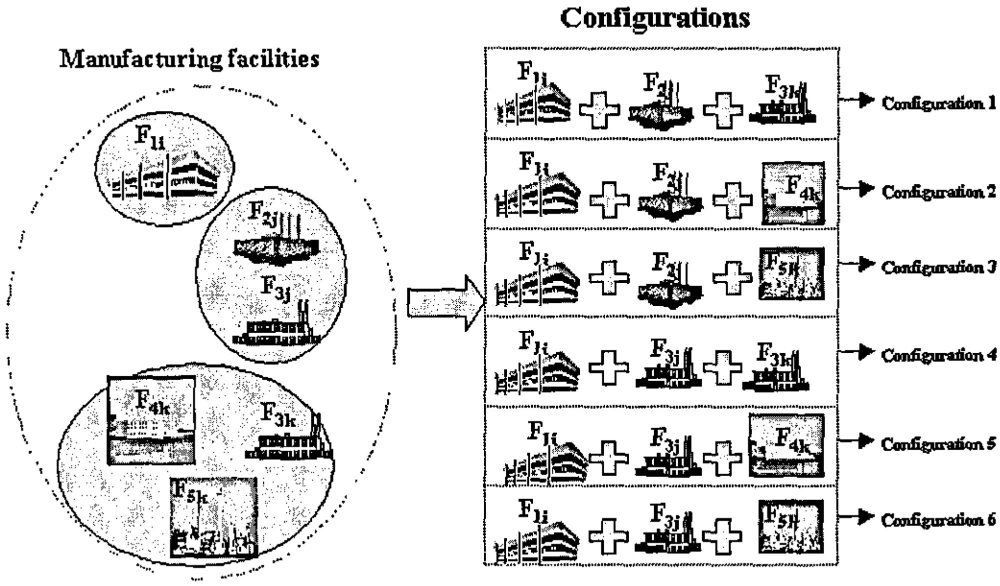


Figure 5-8 Examples of configuration of manufacturing facilities

In global manufacturing, general configuration options may exist depending on the characteristics of the product, facility, and market (Chakravaty, 1999). For example, whether products are customised or global, whether the worldwide market is segmented by regional concentrations, and whether facilities are product or process specific. Product-specific means all the processes from fabrication to assembly are performed in the same facility, but only for a single product. While process-specific means the facility may specialise on a specific process, e.g. final assembly, for more than one product. The relationship between configuration and types of product and facility can be summarised in table 5-2.

Except for the configuration type, other attributes need to be considered in a configuration structure. Such information of a configuration as total processing cost, total processing time, collaboration history or collaboration possibility should be available to evaluate the performance of the configuration.

The quantitative parameters such as total processing time and cost of a configuration can be obtained through general mathematical calculation, which is easily handled by computer programming. However, the collaboration history and collaboration possibilities between facilities is not so straightforward, even though the importance of collaboration possibilities in terms of information flows between facility pairs in global manufacturing has been addressed by other researchers (Ho et al, 2000). Therefore, how to enable this property to be captured in the manufacturing model and used to support global manufacturing co-ordination decisions is an issue to be solved.

Products	**Manufacturing facilities**		
	Centralised	**Decentralised**	
		Product specific	**Process specific**
Global	A single large facility producing large quantities, for export as well as home consumption	Identical manufacturing facilities located close to market concentration to reduce cost of transportation	Specific manufacturing processes (e.g. component manufacturing) located where manufacturing costs (e.g. labour and materials) are cheap
Customised	Several dedicated facilities, one for each product; or a large flexible facility producing a variety of products	Specifically designed facilities producing specific products in specific locations	Process common to several unique products grouped and located in a country with cost and/ or skills advantages

Table 5-2 Configuration options depending on types of product and facility (Chakravaty, 1999)

The difficulty to solve this problem is in that many factors can affect the collaboration possibility between the facility pairs, and it's not necessary for a facility pair to use particular data type (e.g. text, pictures, sound, binary files), data standard (for example international standard such as ISO 10303 for product data representation and exchange, ISO 15531 for manufacturing management data, European Standard, or any other standard), or communication media (e.g. telephone, fax, Internet, ISDN, or multi-media). The fact is that only if both the facility pairs use the same data type, the same data standard, or the same communication media, then they might be able to collaborate. In order to reflect this situation and properly represent the collaboration parameter, a credit awarding mechanism has been designed in this research to record corresponding credits.

As shown in figure 5-9, the credit awarded mechanism follows the pre-defined rules. In terms of collaboration history, the rule is that: if a producer

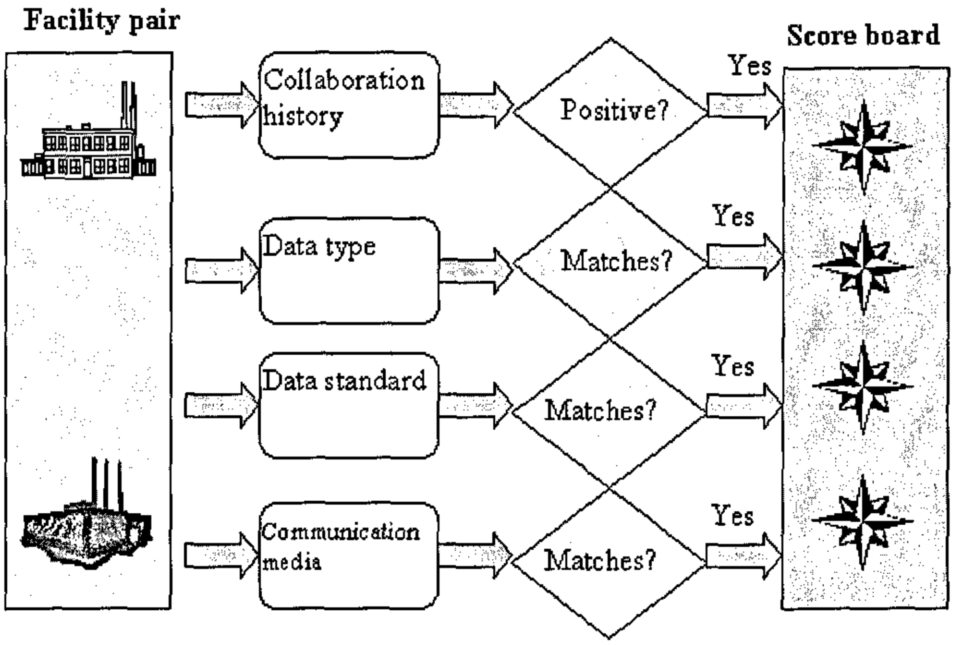


Figure 5-9 Credit awarding mechanism to record collaboration between facility pairs

and consumer pair had collaboration history before, then score one point for " positive" history to encourage to re-collaborate, minus one point for "negative" history to discourage to re-collaborate. Score zero point for no collaboration history. In terms of the data type, if the output data type of a producer facility matches the input data type of a consumer facility, that means there is a possibility for data flowing between them, score one point. Similarly, if the facility pair uses the same data standard, score one point. If the facility pair use the same communication media, score one point. This credit awarding mechanism provides a way to quantitatively evaluate the collaboration performance of the configurations. The credit awarding mechanism developed in this research is quite simple, the level of the complexity could be increased when more factors affecting the collaboration between facilities need to be taken into account, or when the different aspects of the collaboration possibilities are of different importance in specific situations. However, the credit awarding mechanism is good enough when the author believes that: (1) collaboration history and collaboration possibility are two important aspects that reflect the collaboration between facilities; (2) data type, data standard, and communication media are the basic three factors of collaboration possibilities for most global manufacturing co-ordination situations.

Moreover, existing configurations should be allowed to delete when a manufacturing facility is withdrawn, or a new configuration should be added if a new facility is available. These functions have been captured by class behaviour.

As a result, the attributes designed for the *Configuration* class are:

- configuration ID;
- configuration type;
- facilities involved;
- total processing cost;
- total processing time;
- collaboration history credit;
- data type credit;
- data standard credit;
- communication media credit.

Two operations designed for the *Configuration* class are:

- add a configuration;
- delete a configuration.

To meet the above requirements, a *Configuration* class has been defined and represented with UML as shown in figure 5-10.

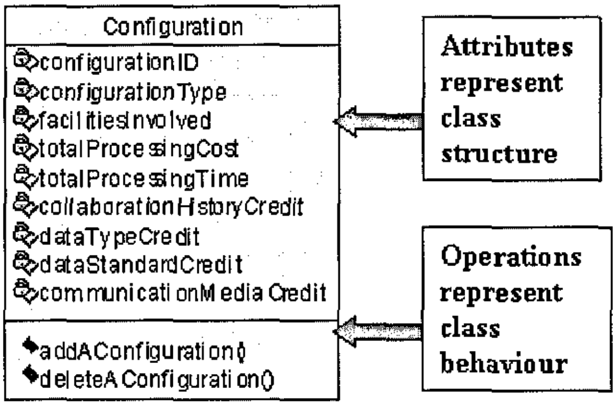


Figure 5-10 Configuration information structure with UML

5.2.3 Modelling the Information Structure of Process

Generally, process is defined as a structured set of activities involving various enterprise entities (ISO 15531-1). Applying this generic definition to the context of global manufacturing, processes have been embodied in this research as actions that transform materials and/ or products, or manage the interdependency between the above processes to consider the situation that all processes performed in different facilities and areas must be synchronised and co-operate to meet the global enterprise overall objectives. Two types of processes have been modelled in this work, manufacturing processes and co-ordination processes. The co-ordination process has been defined as the management of the interdependency between manufacturing processes (Malon and Crowston, 1994). The task assignment process and producer and consumer relation co-ordination process have been taken as two examples of co-ordination processes in this work.

5.2.3.1 Modelling the Information Structure of Manufacturing Processes

At global enterprise level, the information structure of manufacturing process is focused on the class relationships rather than the detailed attributes definition for each class. A few references can be found about manufacturing process class structures (Zhao, Cheung, and Young, 1999; Giachetti, 1999). In terms of classification of manufacturing processes, this work takes the ideas from Professor Hayes in Harvard University and Professor Wheekwright in Stanford University (Hayes and Wheelwright, 1984), as summarised in table 5-3.

<table>
<tr><td rowspan="6">Manufacturing Process</td><td colspan="2">Processes for changing physical properties</td><td>chemical reactions, refining/ extraction, heat treatment, hot working, cold working, shot peening</td></tr>
<tr><td colspan="2">Processes for changing the shape of materials</td><td>casting, forging, extruding, rolling, drawing, squeezing, crushing, piercing, swaging, bending, shearing, spinning, stretch forming, roll forming, torch cutting, explosive forming, electro-hydraulic forming, magnetic forming, electroforming, powder metal forming, plastics moulding</td></tr>
<tr><td rowspan="2">Processes for machining parts to a fixed dimension</td><td>Traditional chip removal processes</td><td>turning, planing, shaping, drilling, boring, reaming, sawing, broaching, milling, grinding, hobbing, routing</td></tr>
<tr><td>Nontraditional machining processes</td><td>ultrasonic, electrical discharge, electro-arc, optical lasers, elctrochemical, chem-milling, abrasive jet cutting, electron beam machining, plasma-arc machining</td></tr>
<tr><td colspan="2">Processes for obtaining a surface finish</td><td>polishing, abrasive belt grinding, barrel tumbling, electroplanting, honing, lapping, superfinishing, metal spraying, inorganic coatings, parkerizing, anodising, sheradising</td></tr>
<tr><td colspan="2">Processes for joining parts and materials</td><td>welding, soldering, brazing, sintering, plugging, pressing, riveting, screw fastening, adhesive joining</td></tr>
</table>

Table 5-3 Technical classification of manufacturing processes

The relationships between different processes can be reflected by a class inheritance relationship. Figure 5-11 is the UML class diagram of the manufacturing process part modelled in the manufacturing model. The *ManufacturingProcess* class is a sub-class of the *Process* class, and it has five sub-classes: *PFChangingPhysicalProperties* class, *PFChangingShapeOfMaterials* class, *PFMachiningParts* chass, *PFJoiningParts* chass, and *PFObtainingSurfaceFinish* class. All the sub-classes of the *ManufacturingProcess* class can inherit the attributes of *processName* and *processID* from the *Process* class to mark their unique identification.

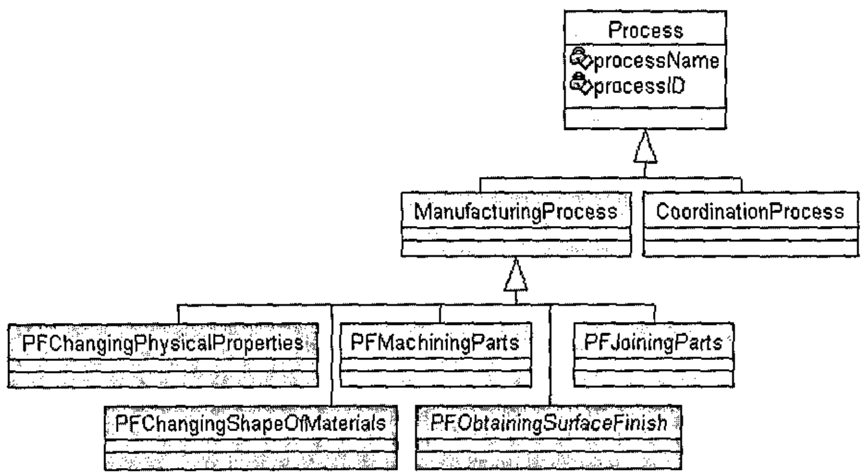


Figure 5-11 UML representation of *ManufacturingProcess* class and its sub-classes

5.2.3.2 Modelling the Information Structure of the Task Assignment Process

The task assignment process is concerned with the allocation of production tasks to the most appropriate enterprise configurations. In principle, the task assignment process can be based on priority rules, pure trading mechanisms, or mixed strategies (Tuma, 1998; Hu, et al, 2001).

Priority rules are especially interesting in the case of a global competitive environment. Priority parameters can be based on total production cost, total production time, total quality, or collaboration etc. (Ho et al, 2000) as illustrated in figure 5-12.

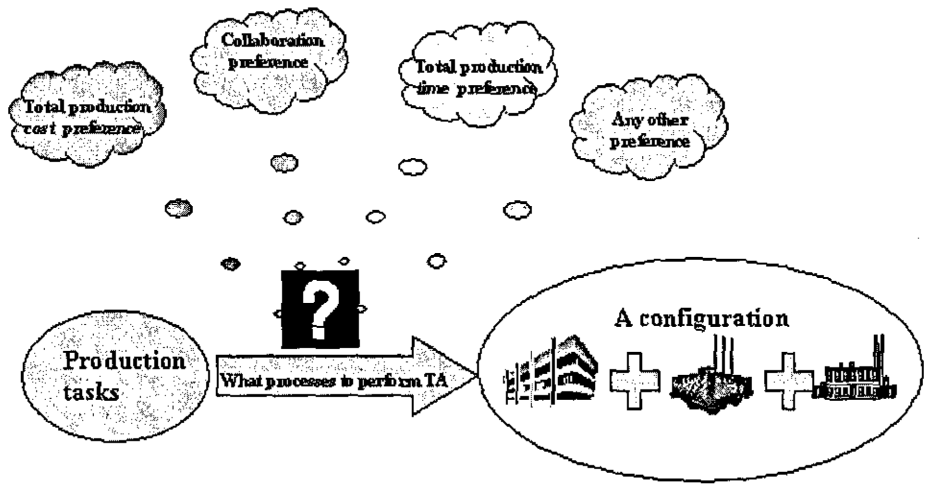


Figure 5-12 Examples of task assignment process- priority order

Total production cost is one of the most important criteria for any product manufacturing activity. In global manufacturing, as manufacturing factories qualified for the processes can be located in different geographical countries, total production cost includes all the costs associated with implementation of all processes in a global enterprise faced with global manufacture and transportation networks. Consider the general cost notation in table 5-4 which is extracted from (Taylor, 1997). The total production cost includes all three aspects: processing cost CM_{ijklm}, transportation cost CL_{ijklm}, and inventory cost CI_{ijklm} as illustrated in figure 5-13.

Variables	Description
CP_{ijklm}	The processing cost associated with producing one unit of product i, using process j, at facility k, in period l to satisfy forecast demand in region (country) m. This cost includes four sub-components as follows:
- CP_{ijklm}	The process cost associated with producing one unit of product i, using process j, at facility k, in period l to satisfy forecast demand in region (country) m.
- CS_{ijkl}	The cost associated with setting up for production of product i, using process j, at facility k, in period l.
- CT_{ijk}	A one-time charge of design of tooling for a specific facility k, if selected for production of product i, using process j, during any production period.
- CC_{jkl}	The cost of procuring additional capital equipment at process j, in facility k, during period l.
CL_{ijklm}	The cost of logistics and transportation associated with product i, process j, in period l, from at facility k to region (country) m.
CI_{ijklm}	The cost of inventory to support product i, process j, facility k, period l, and region m.

Table 5-4 Description of total production cost

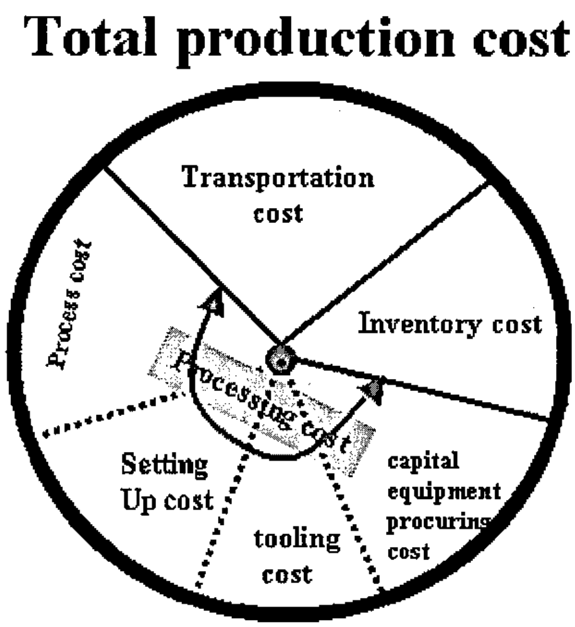


Figure 5-13 Total production cost composition in global manufacturing

Similarly, total production time consists of processing time, inventory time, and transportation time.

The collaboration between different factories can be viewed from two aspects. Firstly, if there is a collaboration history between the factories, the existing collaboration history record should be available. If there is no collaboration history, then the collaboration possibility should be evaluated before a task assignment process is performed. The parameters for collaboration possibility can be based on the type of the data that needs to be communicated, the standard of the data, and communication media used by the factories as explained in section 5.2.2.

In order to capture the above information for the task assignment process, a four-level structure has been defined to represent the classes and class relationships involved (figure 5-14). *TaskAssignmentProcess* has three sub-classes: *FirstCome/FirstServe* process, *PriorityOrder* process, and *Bidding* process. *PriorityOrder* process has further got four sub-classes: *TotalProductionCostPreference*, *TotalProductionTimePreference*, *TotalQualityPreference*, and *CollaborationPreference*. Both *CollaborationHistory* class and *CollaborationPossibility* are sub-classes of *CollaborationPreference* class. A blank class designed in the figure 5-14 implies the extensibility of the structure when more types of task assignment processes will be identified. Required attributes have been designed for specific classes.

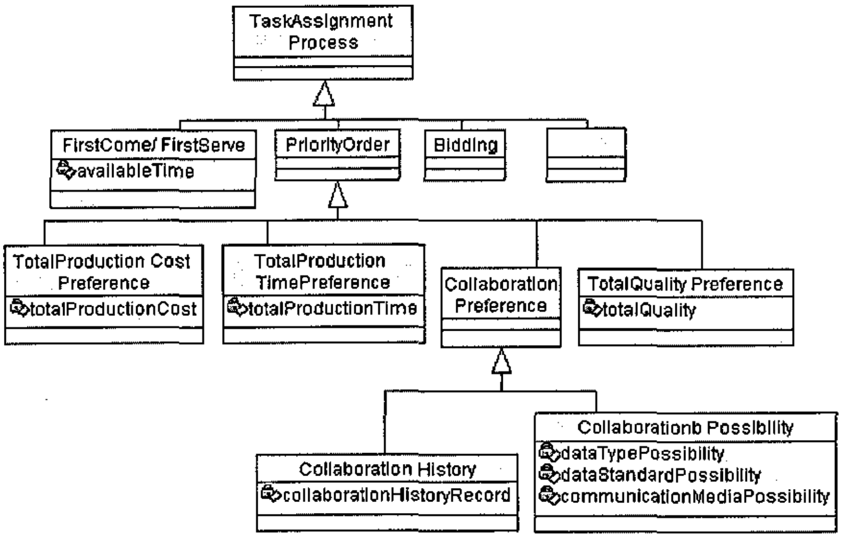


Figure 5-14 Class diagram of task assignment process

5.2.3.3 Modelling the Information Structure of the PCRC Process

In a global manufacturing network, the close co-operation between each producer and consumer pair is the key to ensure the on time delivery of products to outside customers. As explained in section 3.2, transportation and prerequisite are two important cases in global manufacturing co-ordination.

According to the classification of co-ordination process, transportation process and prerequisite process (Malon and Crowston, 1994; Rugman et al, 1995; Ho et al, 2000), the information structure of P/C relation co-ordination process has been defined and represented with UML as figure 5-15. This structure clearly presents the hierachy relationship between associated classes. *TransportationProcess* further has sub-classes of *AirShipping, RailShipping, RoadShipping, and OceanShipping. PrerequisiteProcess* is the super class of *Tracking* class and *Notification* class.

In the course of the information structure definition of the *PCRC Process*, a special type of attribute has been introduced for the *TransportationProcess* class. As there is the fact that only those transportation processes which can be associated with qualified manufacturing facilities will be meaningful. Therefore both *fromFacility* and *toFacility* attributes have been defined as the type of Facility* rather than ordinary *Characters*. The two attributes have to refer to the manufacturing facilities that have been modelled in the *Resource* class to avoid the inconsistency of the information and maintain the relevance of the information.

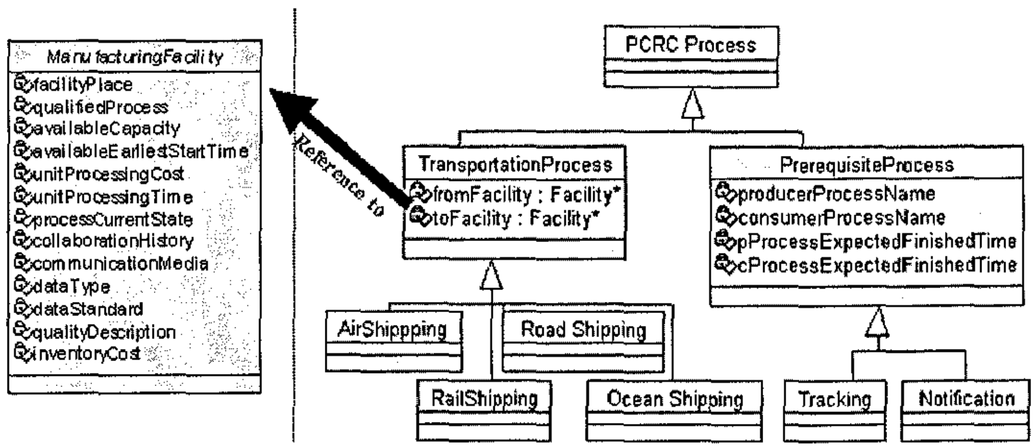


Figure 5-15 Producer and Consumer Relation Co-ordination (PCRC) process information structure

5.2.4 Modelling the Knowledge Structure in the Manufacturing Model

Basically, knowledge consists of relations between facts and decisions (Deneux and Wang, 2000; Klein and Methlie, 1995). With respect to the global manufacturing capability modelled in the manufacturing model, knowledge can be seen as a structured set of information, providing the solutions for the global manufacturing co-ordination decisions based on specific constraints to process, resource, and configuration and relations. This research is emphasised on co-ordination knowledge, which captures the constraints to the management of the interdependencies between manufacturing processes. Therefore, two types of co-ordination knowledge have been addressed. One is task assignment knowledge. The other is transportation knowledge.

According to the nature of knowledge, three sets of information should be considered in the knowledge structure, i.e. constraints, relations, and solutions.

5.2.4.1 Modelling Constraints in Knowledge Structure

Constraints for co-ordination knowledge should include all the constraints both for the task assignment process and the transportation process.

The analysis process shown in figure 5-16 is helpful to identify the necessary constraints. If a factor is important for making co-ordination decisions, then a constraint should be imposed to get the required solutions.

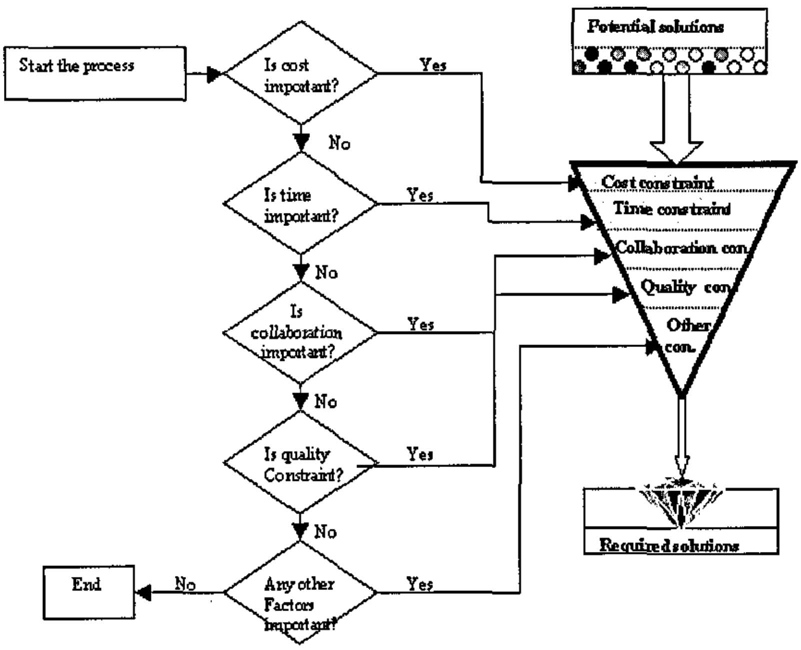


Figure 5-16 The process of constraint identification for co-ordination knowledge

Through the above constraint identification process, the necessary constraints for task assignment and transportation knowledge have been identified and summarised in table 5 – 5. The total performance constraint means the combination of all the constraints that have been identified.

<table>
<tr><th>Knowledge</th><th colspan="3">Constraints</th></tr>
<tr><td rowspan="8">Task assignment knowledge</td><td colspan="3">Total production cost constraint</td></tr>
<tr><td colspan="3">Total production time constraint</td></tr>
<tr><td colspan="3">Total quality constraint</td></tr>
<tr><td rowspan="4">Collaboration constraint</td><td colspan="2">Collaboration history credit constraint</td></tr>
<tr><td rowspan="3">Collaboration possibility constraint</td><td>Data type credit constraint</td></tr>
<tr><td>Data standard credit constraint</td></tr>
<tr><td>Communication media credit constraint</td></tr>
<tr><td colspan="3">Total performance constraint</td></tr>
<tr><td rowspan="2">Transportation knowledge</td><td colspan="3">Transportation cost constraint</td></tr>
<tr><td colspan="3">Transportation time constraint</td></tr>
</table>

Table 5-5 Constraints identified for co-ordination knowledge

To properly represent all the constraints required for the co-ordination knowledge, five classes have been created under the Constraint class: CostConstraint class, TimeConstraint class, QualityConstraint class, CollaborationConstraint class, and TotalPerformanceConstraint class. Further classification of collaboration constraint has been modelled by the creation of sub-classes. Figure 5-17 is the UML representation of the Constraints modelled in the Knowledge structure. Three operations have also been defined for the Constraints class. If a solution proposed by the system is obviously wrong, existing constraints must be modified. New constraints should be created for new situation, and obsolete constraints should be deleted from time to time to avoid the waste of space in a manufacturing model.

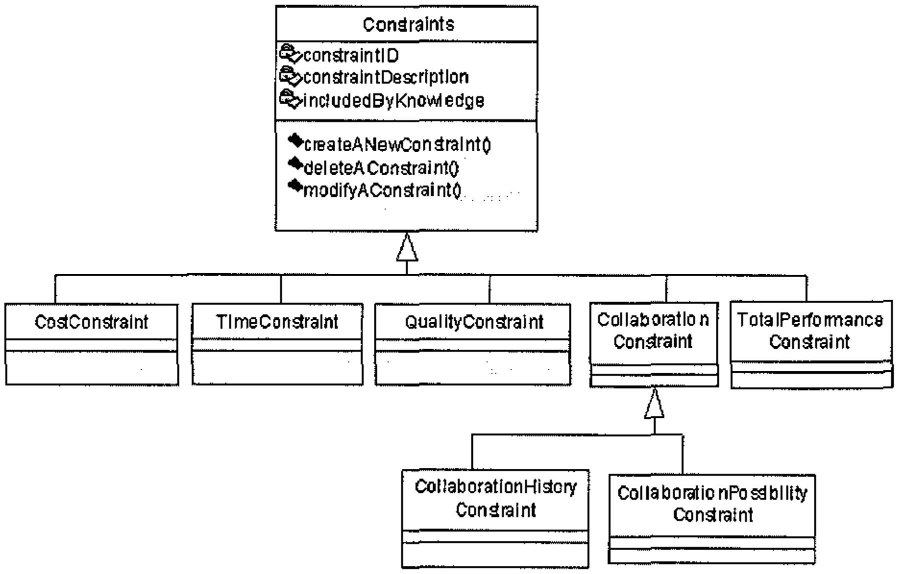


Figure 5-17 Constraints in the Knowledge structure with UML

5.2.4.2 Modelling Relations in the Knowledge Structure

Relations in the knowledge structure can exist in two ways. They can exist between constraints and solutions, so as to express the idea that constraints directly influence the solutions of the problems. For example, a simple numerical constraint – "total production cost less than C_0" -- can leads to task assignment solution No. X -- " production task should be allocated to configuration No. Y". Relations can also exist between two constraints so as to express the idea that a constraint works together with other constraints to lead to a solution, such as AND_Relation and OR-Relation defined in the figure 5-18 to perform the Boolean operation (Costa, 2000). For example, if a cost constraint and a time constraint are both required for a specific task assignment decision, the solution might be completely different from the above solution No. X.

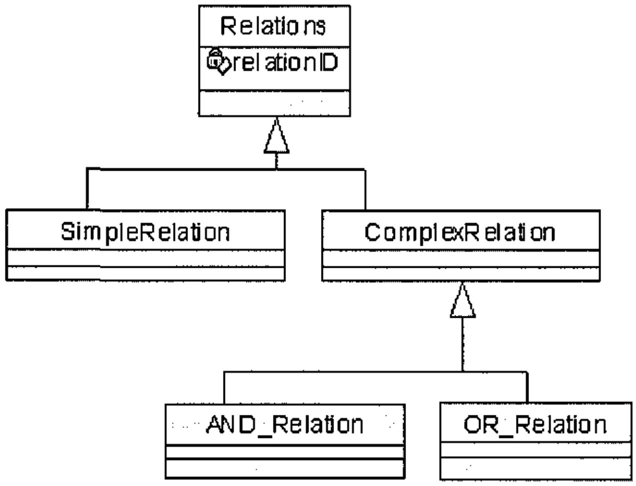


Figure 5-18 Relations in the Knowledge structure with UML

5.2.4.3 Modelling Solutions in the Knowledge Structure

In this research, two types of solutions about global manufacturing co-ordination are task assignment solution and transportation solution. Figure 5-19 shows the structure of the solutions. Each solution is unique and has a special ID, which can be indexed by the system. Similar to the constraint structure, three operations have been defined to add a solution, delete an unwanted solution, and modify an existing solution.

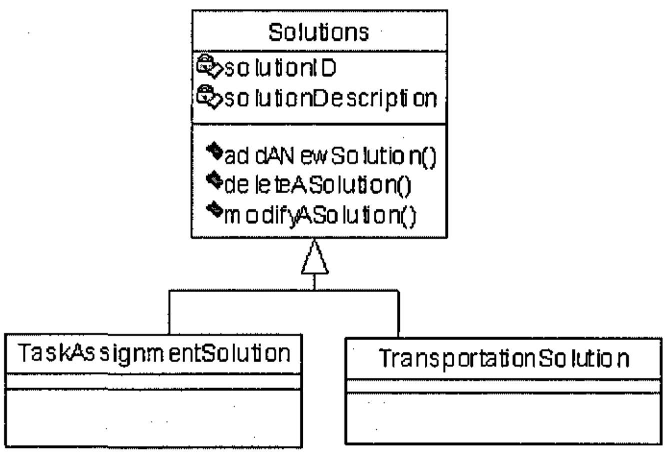


Figure 5-19 Solutions in the Knowledge structure with UML

5.2.4.4 The Knowledge Structure

The important idea in the knowledge structure is that the Knowledge class has to find the appropriate Solutions according to the specific Constraints and Relations. In order to do this, the right Constraint, Relation and Solution has to be captured. This has been realised by the definition of proper attributes for the Knowledge class and the relationships between the Knowledge class and the Constraints class, Relations class, and Solutions class.

Aggregation relationships between the Knowledge class and the Constraints class, Relations class, and the Solutions class have been defined to ensure that a piece of knowledge includes appropriate constraints, relations, and solutions. Furthermore, multiplicity has been specified for corresponding classes. The multiplicity indicators 1...* with the Knowledge class and Constraints class indicate that one Knowledge object may use one to many Constraints objects, and one Constraints object can be used by one to many Knowledge objects. The same situation applies to the Knowledge class and the Relations class, i.e. one Knowledge object may use one to many Relations objects and one Relation object may be used by one to many Knowledge objects. However, in some unusual cases, there may be no appropriate solutions according to the existing Constraints and Relations, that's why a 0...* multiplicity is specified for the Solutions class.

The attributes knowledgeID provides the unique identification for each knowledge element, and the knowledgeDescription holds the main points for each knowledge element so that it can be retrieved in a direct way.

As TaskAssignmentKnowlsdge class and TransportationKnowledge class have been designed as the sub-classes of the CoordinationKnowledge class, which in turn is a kind of Knowledge, they both will inherit all the attributes of the Knowledge class. Figure 5-20 shows the knowledge structure in the manufacturing model.

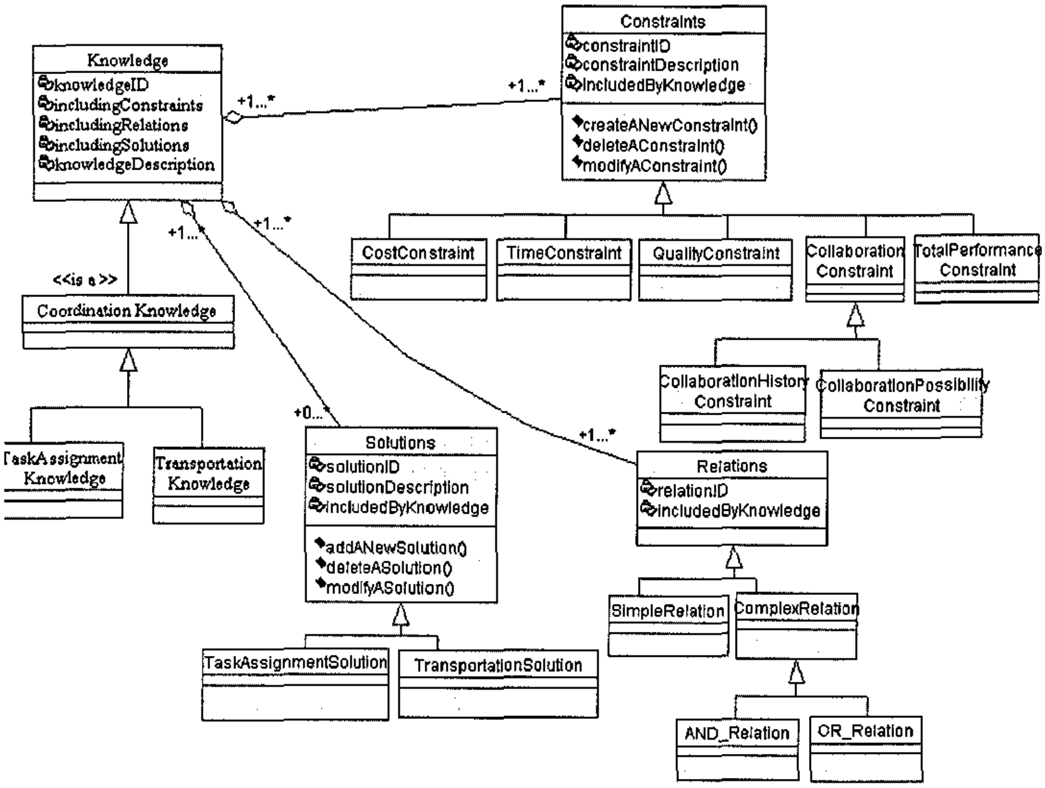


Figure 5-20 Knowledge structure in the manufacturing model

The manufacturing model is intelligent because it has knowledge within it as well as information. The information part consists of process information, resource information, and configuration information. The knowledge provides the potentials to retrieve required solutions based on the constraints to specific problem related information. This situation can be illustrated in figure 5-21.

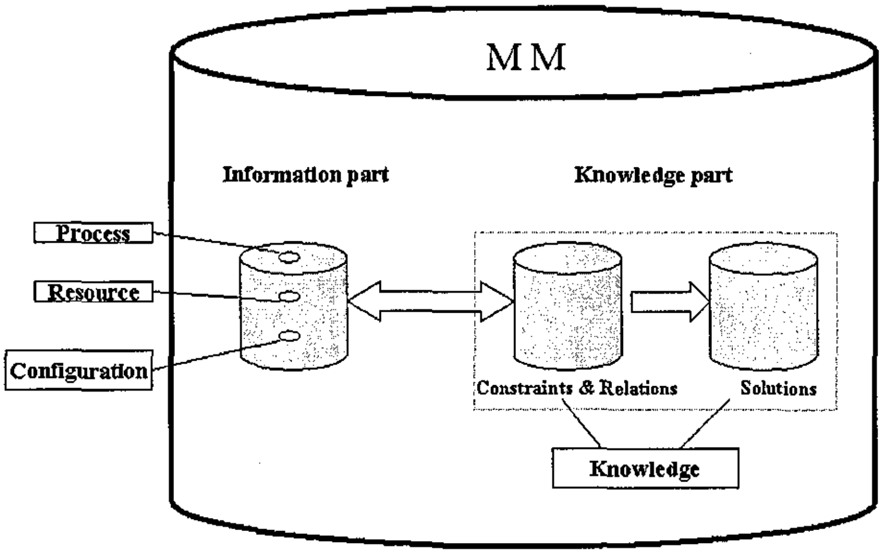


Figure 5-21 Nature of the manufacturing model

There is always an argument about how much knowledge should be captured and stored, because despite all the flexibility desired, there are constraints on information that can be extracted from the knowledge base and this has to be planned on a priori basis (Chandra and Kumar, 2003). In this research, only the knowledge that is frequently used and requires effort for retrieval has been designed and captured in the manufacturing model under the *Knowledge* class. In principle, storing too much knowledge on a priori basis should be avoided as it unduly complicates knowledge updating. However, if properly designed, the manufacturing model will offer more consistent solutions to satisfy routine and complex decision situations.

5.3 Modelling the Relationships between Classes in the Information and Knowledge Structure of the Manufacturing Model

This section discusses specifying the relationships between the classes of the four elements of global manufacturing capability (modelled in section 5.2) and their details to build the whole information and knowledge structure of the manufacturing model (**appendix C**). This section uses the relationships explained in section 4.4.2.

5.3.1 Modelling the Relationships between the Main Classes in the Top-level Structure of the Manufacturing Model

The top-level structure of the manufacturing model is concerned with only the four main classes: *Process, Resource*, *Configuration*, and *Knowledge*. To define the relationships between these four classes it is necessary to understand the basic links between different elements of global manufacturing capability. This process can be split into two steps: (1) understanding the links between process, resource, and configuration; (2) understanding the links between knowledge and process, resource, and configuration.

The links between process, resource, and configuration can be described by a triangle for global manufacturing co-ordination as in figure 5-22 (a). All three facets are needed to perform global manufacturing co-ordination. Manufacturing processes cannot be accomplished without the necessary resources. Without configuration, resources cannot be organised in a proper way to perform the required manufacturing processes. Without co-ordination processes, the interdependency between the activities in a configuration cannot be managed effectively. Therefore, lack of any one of process, resource, or configuration, a global manufacturing strategy will probably fail.

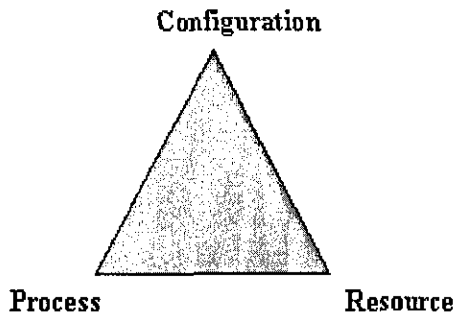


Figure 5-22 (a) The triangle relationship between Process, Resource and Configuration

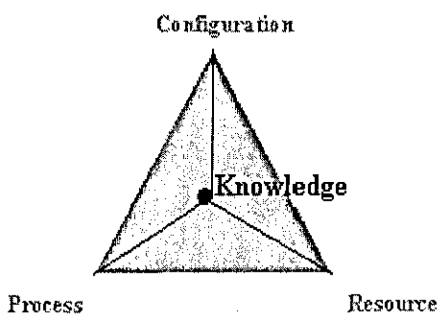


Figure 5-22 (b) The Relationship between Knowledge and Process, Resource, Configuration

However, to successfully implement a global manufacturing strategy, proper rules have to be set on process, resource, and configuration. This has been realised by the definition of knowledge which captures the constraints on process, resource, and configuration. The role of the knowledge in the triangle of global manufacturing co-ordination is the centroid of the triangle as shown in figure 5-22 (b) because without the knowledge the retrieval of preferred solutions cannot be realised.

Based on the understanding of the links among process, resource, configuration, and knowledge within global manufacturing capability, class relationships have been defined for the top-level manufacturing model structure shown in figure 5-23, which presents the four main classes and the relationship between the classes. *Global manufacturing capability* includes *Process*, *Resource*, *Configuration*, and *Knowledge*, i.e. either *Process*, *Resource*, *Configuration* or *Knowledge* is part of the global manufacturing capability. Further more, an association relationship has been specified between the four main classes to indicate that there is a bi-direction communication between any two associated classes. For example, *Process* uses *Resource* and *Resource* performs *Process*, *Configuration* arranges *Resource,* and *Resource* affects *Configuration.*

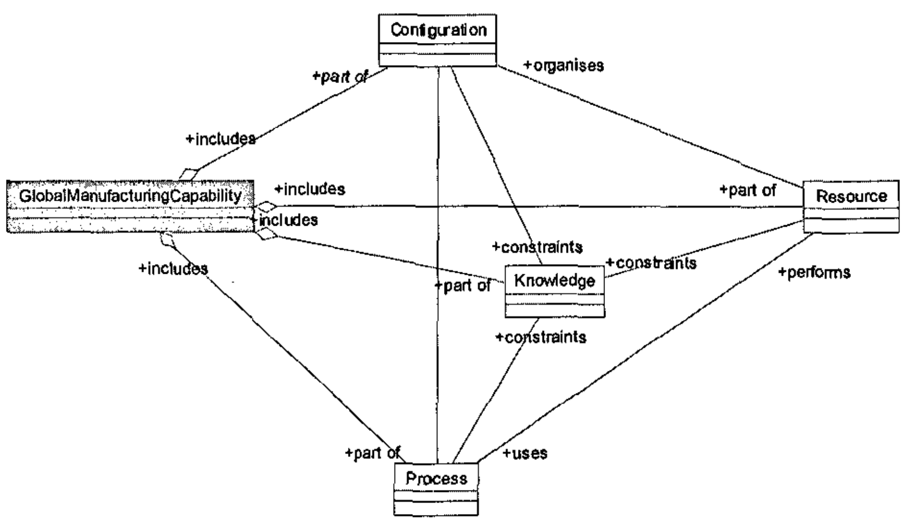


Figure 5 – 23 Class diagram of top-level structure of the MM

5.3.2 Modelling Relationships in the Extended Structure of the Manufacturing Model

In the detailed structure of the manufacturing model, the relationships between objects across different main classes should be captured for objects communication and interaction. Three ways have been used to model the relationship in this work. (1) by class inheritance; (2) by attribute value definition; (3) by reference to specific attribute type.

Many classes in the manufacturing model communicate with each other making use of class inheritance, i.e. a very important advantage of object-oriented analysis and design technology. Once an inheritance relationship has been created, a sub-class will inherit all attributes, operations, and relationships defined in any of its super-classes. Figure 5-24 is an example of illustration of the relationship between the classes of *CoordinationProcess* and *CoordinationKnowledge* through class inheritance.

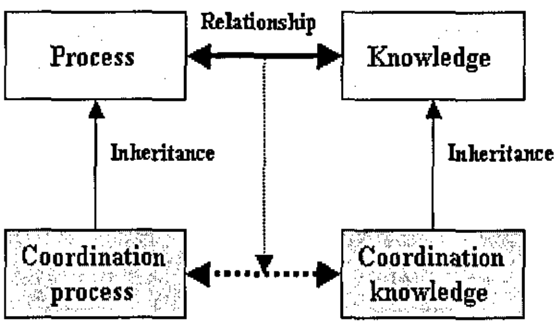


Figure 5-24 The relationship inherited by sub-classes of Process and Knowledge

Relationship can also be passed by attributes value definition. When an attribute is given different values, the call of this attribute will link to different objects of another class. In figure 5-25, the value of attribute *qualifiedProcess* can make the link from manufacturing facilities to manufacturing processes.

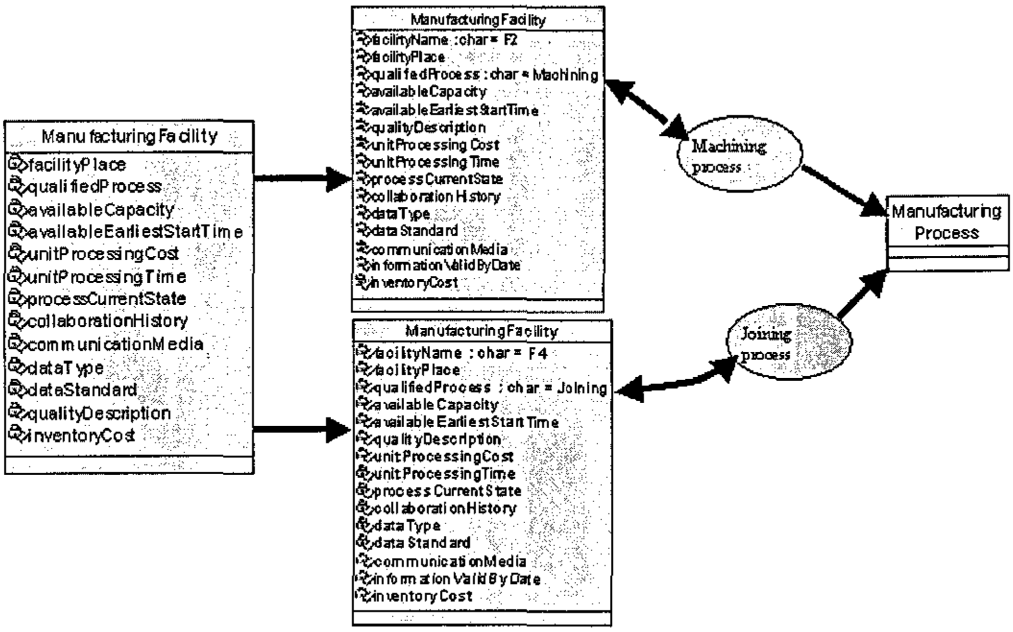


Figure 5-25 Class attribute values make link from manufacturing facility to manufacturing process

Another useful way to connect class objects is to specify correct attribute types. As shown in *figure 5-26*, *if the attribute type of fromFacility in TransportationProcess* class is specified as a customised pointer *ManufacturingFacility**, this attribute will automatically reference to the involved manufacturing facilities at any time.

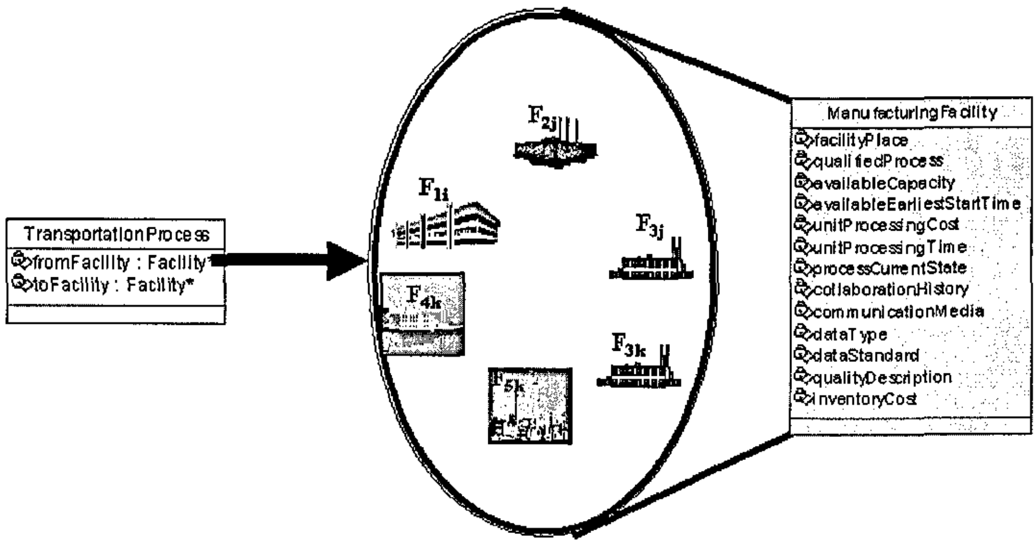


Figure 5-26 Customised pointer link transportation process to manufacturing facility

Considering all the relationships between classes and interactions between objects, an extended structure of the manufacturing model has been defined for global manufacturing co-ordination, shown as figure 5-27. In this structure, all the attributes and operations of classes have been supressed to simplify the details of each class and to get a whole picture of all the classes modelled in the manufacturing model.

In this picture, the relationships between four main classes and their sub-classes have been clearly represented. The interaction relationship between the objects across different main classes defined in the above three ways have been applied and highlighted: (1) by class inheritance, i.e. if an inheritance relationship has been defined, then the sub-classes will inherit the relationship from the super-classes. For example, an association relationship has been specified between *Process* class and *Knowledge* class, then classes of *CoordinationProcess* and *CoordinationKnowledge* will inherit the relationship. (2) by attribute value definition. For example, in *ManufacturingFacility* class, by specifying the value of attribute of *qualifiedProcess*, a link between specific manufacturing facility and specific process has been built. (3) by reference to specific attribute type. For

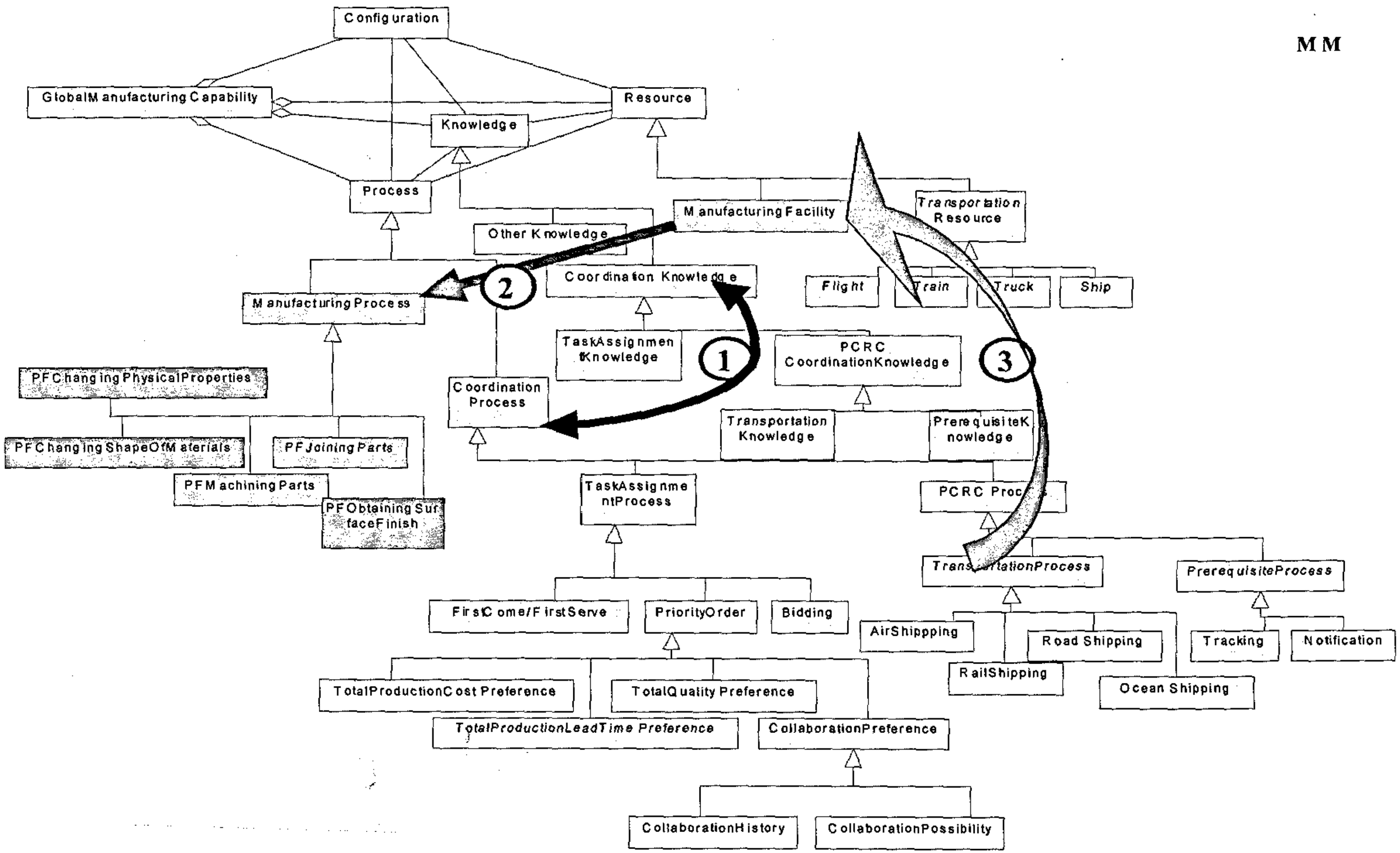


Figure 5-27 Relationships in Extended structure of the MM with UML

example, when the type of attributes of *TransportationProcess* class are defined as a *ManufacturingFacility**, the departure and destination attributes will point to those qualified manufacturing facilities. The extended structure of the manufacturing model provides the availability and guideline of information and knowledge navigation both under one main class and between different main classes in the manufacturing model.

5.4 Summary

A well-defined structure of a manufacturing model is the key to the successful provision of high quality manufacturing capability information and knowledge for global manufacturing co-ordination decisions. The manufacturing model structure defined in this research contains four main types of information and knowledge related to global manufacturing capability. They are *Process*, *Resource*, *Configuration*, and *Knowledge*. Each main class has its own information structure and a set of sub-classes to capture the detailed information required for global manufacturing co-ordination. The specified relationships between classes give the possibility for objects interaction and collaboration. The new manufacturing model structure defined in this chapter will be tested by experimental systems and applied to case study in chapter 7.

6 The Exploration of Product and Order Information Structures for Global Manufacturing Co-ordination

6.1 Introduction

This chapter explores the structures of product-related information and order-related information involved in global manufacturing co-ordination. Firstly, section 6.2 presents the understanding of product information structures and order information structures respectively. Then section 6.3 addresses the links from order model (OM) through product model (PM) to manufacturing model (MM). Finally, section 6.4 is a short summary of this chapter.

The information structures presented in this chapter have been built on the understanding of the global manufacturing co-ordination issue discussed in chapter 3 and based on the information requirements modelling in chapter 4. All information structure diagrams in this chapter are represented with UML.

6.2 Exploration of the Structures of Product and Order Models

6.2.1 Exploration the Information Structure of a Product Model

The product definition data model provides the generic representation of how a product can be defined by a set of definitions and be grouped by a set of versions (Peng and Trappey, 1998). The goal of the product information structure is the management of all relevant information of a product type (Streppel et al, 2000). In this context, the perception of relevant information can be outlined as anything that is a consideration or a result of a manufacturing decision. Such a decision can bear reference to any stage of a product's life cycle. Moreover, such a decision can be concerned with elements of different aspects of a product. It can address geometry, material, tolerance, surface finish, and product volume (McMahon and Browne, 1998). However, with respect to global manufacturing co-ordination, decisions are especially related to specific aspects of the product information: (1) product structure; (2) manufacturing view.

6.2.1.1 Understanding of Product Structure in a Product Model

A product is a thing or substance produced by a natural or artificial process (ISO 10303–1). Therefore, a product can be very simple with only one component or very complex with a multi-level decomposition hierarchy. Product structure defines a product in terms of its composition as a set of constituents or consumed products (ISO 10303–44). Taking its constituents point of view, it means that a product can be seen as a system. The system can be generally considered as a conglomeration of objects that perform a specific function (Ullman, 1997). A system can be decomposed in different sub-systems, further in smaller sub-systems and finally in components (figure 6-1). A component is a product that is not subject to decomposition

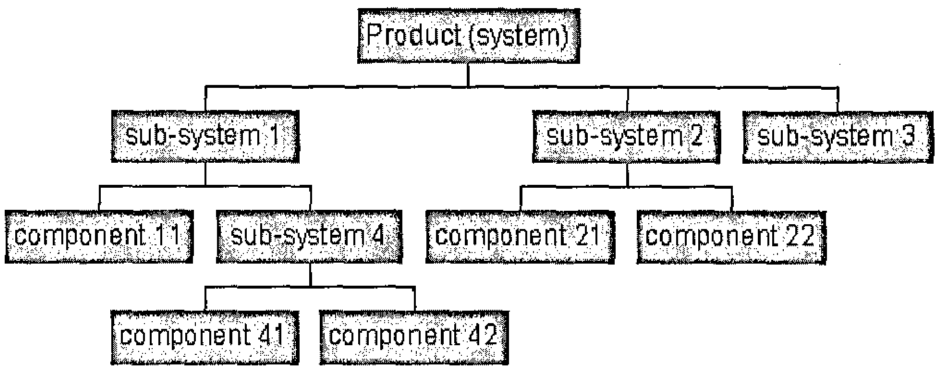


Figure 6-1 Exemplification of a product structure

from the perspective of a specific application (ISO 10303–1). As an example of a mechatronic product, consider a car and its engine assembly. The engine assembly is part of the power system, one of the many systems in a car. The car is an automotive system, its function is to transport on land from one place to another place. The engine is part of the power system providing power to propel a car, which also includes a fuel system, a cooling system, a lubrication system, and an exhaust system. Thus, we have decomposed the car into three system levels, while still referring to the function of objects.

According to the above description of the product structure, two important relationships should be understood in this part of the information structure of a product. Firstly, a system, a sub-system or a component is a product. The difference between them is the levels of decomposition. A system has the most levels of decomposition, and a component has no further decomposition. This relationship can be modelled by an inheritance relationship from the *Product* class (figure 6-2). The second important relationship should be captured is that a system can have several sub-systems and a sub-system can have further sub-systems or components. Therefore, a reflexive aggregation relationship has been specified for *Product* class to model this relationship between system, sub-system, and component. Reflexive relationship is a special kind of relation to represent that multiple objects (such as system, sub-system, and component) belonging to the same class may have to communicate with each other.

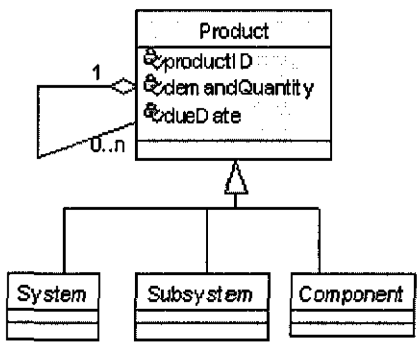


Figure 6-2 Information structure of product structure in the PM with UML

As a component cannot be decomposed any more, a restriction must be set to avoid misunderstanding. This problem can be solved by the specification of multiplicity indicators for the reflexive aggregation relationship. As seen from figure 6-2, multiplicity indicator 0..n has been specified for the Product class, it defines the number (zero or more) of objects that participate in the relationship. For example, when the reflexive aggregation relationship is applied to a *Component* class and the cardinality is zero, it means that a component has no further decomposition.

Figure 6-2 shows the UML representation of the information structure of a product in the product structure. Besides the relationship between the classes, three attributes have been designed for the *Product* class. *ProductID* indicates the identification of each product, *demandQuantity* captures the quantity of a product that will be demanded, and *dueDate* reflects the product delivery requirement. Any system, subsystem, or component will get these attributes from the super-class, i.e. *Product* class.

6.2.1.2 Understanding Manufacturing View in PM

As stated by IS0 10303-44, a product may be assembled from the constituents or produced by consuming other products, or both. Taking this point of view, i.e. from manufacturing point of view, a product can be seen as a final assembly that has a series of hierarchical sub-assemblies, further with components (figure 6-3). This interpretation is apparently quite different from the understanding discussed in section 6.2.1.1, which takes a design view of the product. To address these two different views, two kinds of bill of materials (BOM) have been referenced, which are commonly described as engineering bill of material (E_BOM) and manufacturing bill of material (M_BOM) (Chang, Lee and Li, 1997). E_BOM is used by a design engineer to represent designed product structure. Its structure is viewed as a series of hierarchical subsystems that functionally form the product. M_BOM is used by manufacturing engineers for process planning. It's formed by considering assembly sequence and constraints. Its structure is viewed as a series of hierarchical subassemblies, displaying how a product is assembled on the shop floor. However, there is a close link between these two views. An E_BOM can be transformed into the M_BOM by considering assembly sequence and constraints.

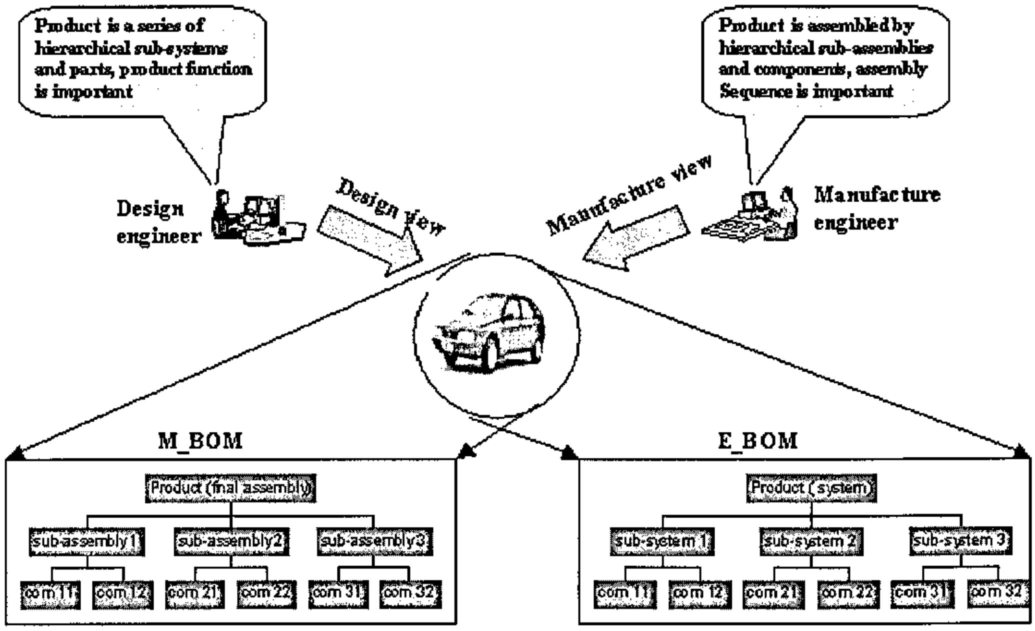


Figure 6-3 Manufacturing view and design view of a product structure

To capture this information in a PM, a *Views* class has been created to permit product seen from different perspectives (Zhao, Cheung, and Young, 2000). The necessity of having a multi-viewpoint distributed information infrastructure was further addressed by (Young, 2003). This thesis follows the idea that *Product* has *Views* and *Views* are classified into *design view* and *manufacturing view*. In terms of global manufacturing co-ordination scenario, manufacturing view further has three sub-classes of *ProcessPlan*, *M_BOM*, and *ManufacturingProcess*. From the understanding of manufacturing process planning, it is easy to understand that *ProcessPlan* class uses the constraints of *M_BOM* and consists of a set of manufacturing processes, as illustrated in figure 6-4.

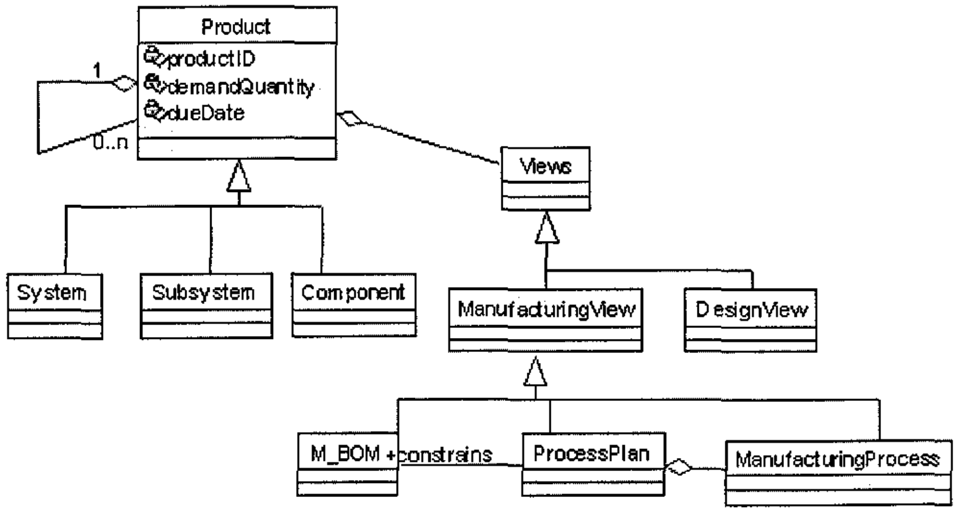


Figure 6-4 Manufacturing view in PM structure

6.2.1.3 Product Model Structure for Global Manufacturing Co-ordination

The product model structure for global manufacturing co-ordination has been defined based on the understanding of general product model concept and special requirements of global manufacturing co-ordination scenario. For most product model applications, characteristics of a product are important (Young et al, 2002), so too, for global manufacturing co-ordination. The characteristics (such as specification, geometry, material and tolerance) information has also been considered as a basic part in the product model in this work. Therefore, the complete product model structure for global manufacturing co-ordination includes all three important parts of information: product structure, product characteristics, and views (figure 6-5).

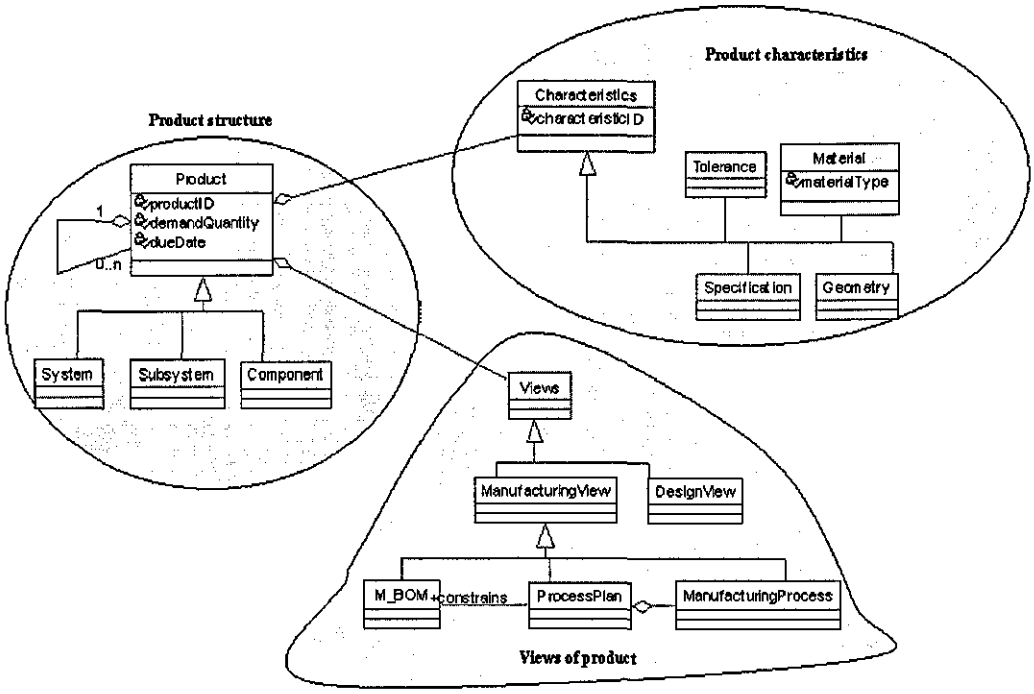


Figure 6-5 PM structure for global manufacturing co-ordination

6.2.2 Defining the Information Structure of the Order Model

The order information structure is defined to construct the information model that establishes the understanding of which product elements are to be produced, as well as when and where to deliver the products (Streppel, 2000). With respect to the global manufacturing co-ordination situation, the most important establishment in the order model is the relation between a customer order and a product variant that is to be delivered.

The understanding of relevant information of a product order can be based on the following four aspects: customer identity, order repetition, delivery time, and product type (figure 6-6).

The customer identity is an important property of a product order. When the order is not received from end customers but from the forecast of demand of the market, the possible customers should be still identified. Because customers from different classes and places might have an effect with product cost and delivery time, further with product design and manufacture strategies.

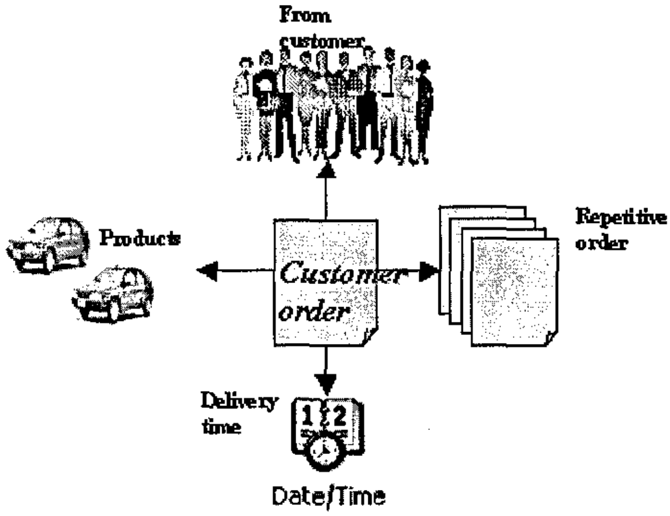


Figure 6-6 Information aspects of a product order

Order repetition is designed to record how many times an order has repeated. If the order repetition is zero, i.e. a new order, it means a company needs to think about more things before receiving the order, for example how difficult it would be to accomplish the order. If it is a repetitive order, that means the company has some existing experience to fulfil the order, so it should be confident to accept the order. Also maybe it can give the customer some discount of the price to enhance the collaboration relationship with the customers.

Delivery time is crucial for any product order. On the one hand, it specifies the demand from the customer when they will need the product. On the other hand, it provides the guideline of the production schedule for all participatory manufacturing facilities and transportation enterprises. Violation of delivery time may mean cost penalties or the danger of losing customers (Azevedo and Sousa, 2000).

One of the most important information views with respect to a product order is the product that an order consists of. It is not only concerned with product types but also the demand quantities of each type of product.

Based on the above understanding, the information structure of a product order should reflect the following properties:

- order ID;
- from customer;
- order repetition.

As a product order may contain different types of products, therefore the following properties should be captured in a *Product* class:

- product ID;
- demand quantity;
- due date.

As a result, the structure of order information has been defined and represented with UML as in figure 6-7. Relevant attributes have been created for both classes. In other cases, customers may require service of product orders. But this work focuses on producing products rather than providing service for customers.

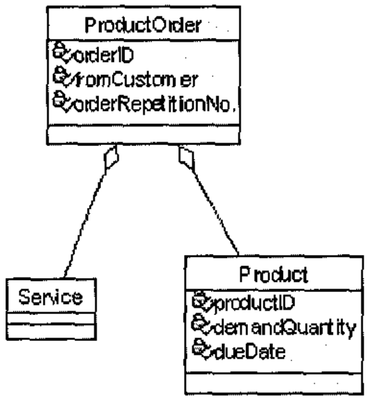


Figure 6-7 Relationship between order and product in OM

6.3 Relationships between the Information and Knowledge Models

In order to use the manufacturing model (MM), order model (OM), and product model (PM) together to support global manufacturing co-ordination decisions properly, there is a need to investigate the links between the three information and knowledge models. Among the three models, the product model plays the role of an intermediate bridge to connect with the order model and the manufacturing model.

The link between the product model and the order model is straightforward (figure 6-8). Because the *Product* class has been defined in both information structures, and the attribute of productID provides the unique identification for each product. Through the productIDs, a product order can always find the products included in it.

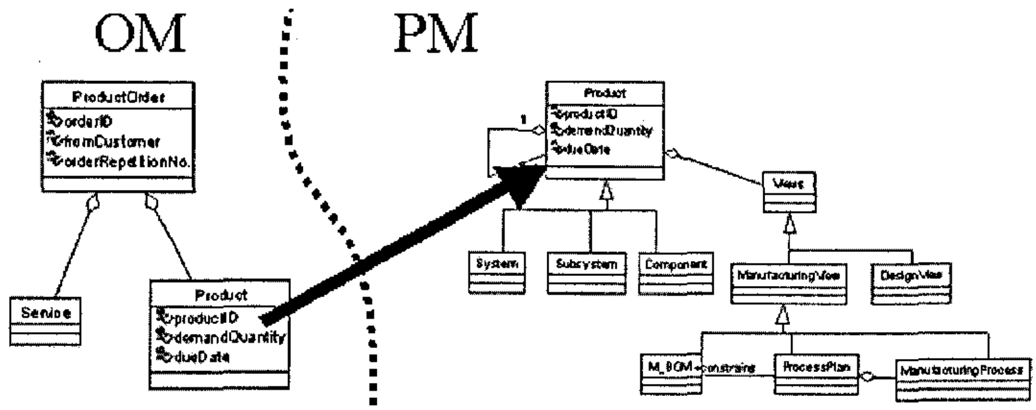


Figure 6-8 Link between the order model and the product model

The link between the product model and the manufacturing model is not as simple as that between product model and order model. However, its complex relationship has been established on the ManufacturingProcess class under the manufacturing view in the product model and the ManufacturingProcess class under the process class in the manufacturing model (figure 6-9). The information structures of the two ManufacturingProcess classes are the same, however the instances of objects are different. The manufacturing model holds all manufacturing processes and the product model only has specific instances of the manufacturing processes for that product realisation.

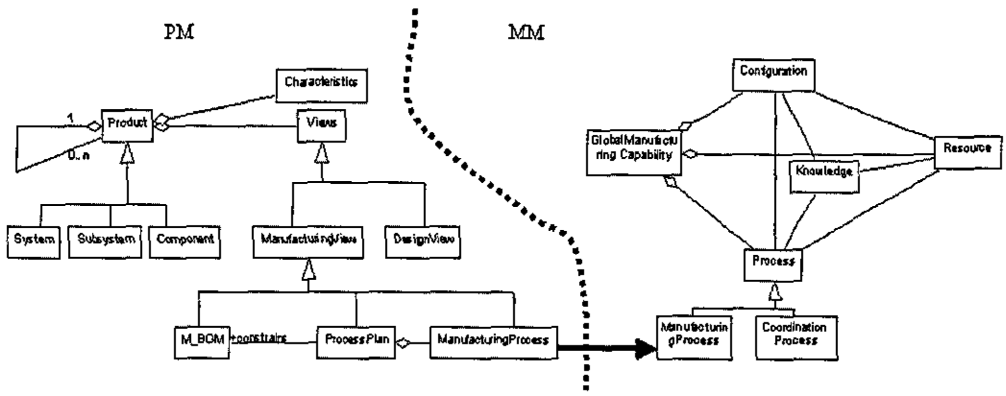


Figure 6-9 Manufacturing process as an interaction between information structures

In order to understand the relationship between product and manufacturing process through process planning, two levels of process planning have been referenced, macro process planning and micro process planning (Streppel et al, 2000). Firstly, the macro process planning is based on physical product properties (geometry and material etc.) and only focused on assigning candidates of manufacturing processes to designed parts of a product. It is time and company independent. Secondly, the micro process planning should be able to perform its traditional task of generating detailed process plans in the preparation of the actual production. In terms of global manufacturing co-ordination, at a global enterprise level, the focus is on macro process planning, i.e. to identify the specific types of manufacturing process, as classified in section 5.2.3.1, for the designed product under development while leaving the micro process planning to factory level. However, in the enterprise level process planning, the relationship between the manufacturing processes is important for the implementation of the co-ordination process, because we need to know what processes can be performed concurrently and what processes must be performed serially (Wu, Mao, and Qian, 1999).

Once the link between the product model and the manufacturing model has been built through manufacturing process, the required manufacturing resources can be accessed by the process evaluation of a manufacturing facility at the factory level (Minis et al, 1999). For example, the manufacturing model on a factory level describes the compatibility of manufacturing processes with materials, specific product features, production quantities, and other important product attributes provided by a product model. This interaction between the product model and the manufacturing model across both enterprise level and factory level is illustrated in figure 6-10. At factory level, according to the product features captured in the product model, the qualification of a manufacturing facility for specific processes can be recognised by process evaluation. If a facility has been identified for the specific processes, then it is transferred into an enterprise level manufacturing model as a potential facility. At the enterprise level, according to the E_BOM information in the product model, an M_BOM can be generated. As a point of manufacturing view, macro process planning based on the M_BOM needs to search for required manufacturing processes in the manufacturing model and the potential facilities qualified for the manufacturing processes. Therefore, the enterprise level manufacturing model needs the support from the factory level manufacturing model.

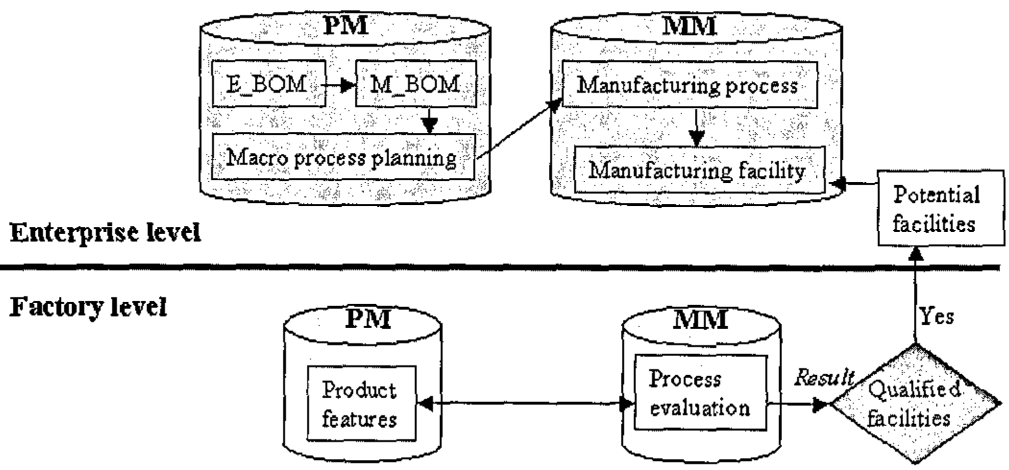


Figure 6-10 Interaction between PM and MM at both levels

6.4 Summary

This chapter discusses the structures of the product model and the order model as well as the links between the order model, product model and manufacturing model.

Two main parts of the product model structure have been addressed in this chapter. They are the information structure of the product structure and the manufacturing view. In the structure of the order model, the class structure of product order has been defined, and the relationship between product order and product has been specified.

The link between the order model and the product model is built on the *Product* class, while the link between the product model and the manufacturing model is based on the common structure of the *ManufacturingProcess* class under both *ManufacturingView* class in the product model and *Process* class in the manufacturing model.

The structures of the product model and the order model defined in this chapter will be tested by the experimental systems in chapter 7 and applied to a case study.

7 Development of the Experimental System

7.1 Introduction

This chapter explains the development of the experimental system to explore the three information and knowledge structures of the manufacturing model (MM), the product model (PM), and the order model (OM) presented in chapters 5 and 6, as well as the application of these models to support global manufacturing co-ordination decisions. Section 7.2 first presents the overview of the design of the global manufacturing co-ordination system. Then section 7.3 describes the implementation of the experimental system. Section 7.4 addresses the application of the information and knowledge models through a case study. Finally, section 7.5 is a short summary of the chapter.

The objectives of the design and development of the experimental system are:

- To explore the information and knowledge structure of the manufacturing model;
- To explore the information structure of the product model;
- To explore the information structure of the order model;
- To explore of the use of the these three information and knowledge models to support production task assignment decisions;
- To explore the use of the three information and knowledge models to support producer and consumer relation co-ordination decisions.

7.2 Overview of the Design of Global Manufacturing Co-ordination System

7.2.1 System Development Environment

The global manufacturing co-ordination system development environment includes three important aspects, i.e. the software tools, the programming language, and the software development process that have been used in this work.

During the course of the development of the experimental software, the following software tools and language have been applied as they were readily available:

(1) ObjectStore Rapid Database Development (RDD) to build an ObjectStore application from database design to code generation (Object Design, 2003). This includes RDD tools, the Database Designer and the Component Wizard. The Database Designer has been used to design the ObjectSotre databases – their classes, data members, methods, and relationships. The Component Wizard has been used to generate Microsoft Foundation Class applications.

(2) Visual C++ 6.0 programming language to implement an application using the code created by the Component Wizard (Gosselin, 2001).

(3) Object-Oriented Database Management System ObjectStore SP8.0 to manage the data. It allows us to:
   - Manipulate information in the database transparently by creating and modifying persistent objects;
   - Store and access data in the same format as it exists in the application;
   - Describe, store, and query complex data used in complex software applications.

(4) ObjectStore Inspector (Object Design, 2003). ObjectStore Inspector is a graphical tool that lets us browse, edit, query, and report on the data in an ObjectStore database.

The software development process provides the rules and discipline to ensure the quality of the software system under development. This research employs the Rational Unified Process (Quatrani, 2000). The Rational Unified Process is structured along two dimensions: time and process components. Structuring a software development project along the time dimension involves the adoption of four time-based phases: inception, elaboration, construction, and transition. Within each phase the work may be broken down further into iterations. Structuring the project along the process component dimension includes six activities: business model, requirements, analysis and design, implementation, test, and deployment, taken place during each iteration. Figure 7-1 shows how the process components are applied to each time-based phase.

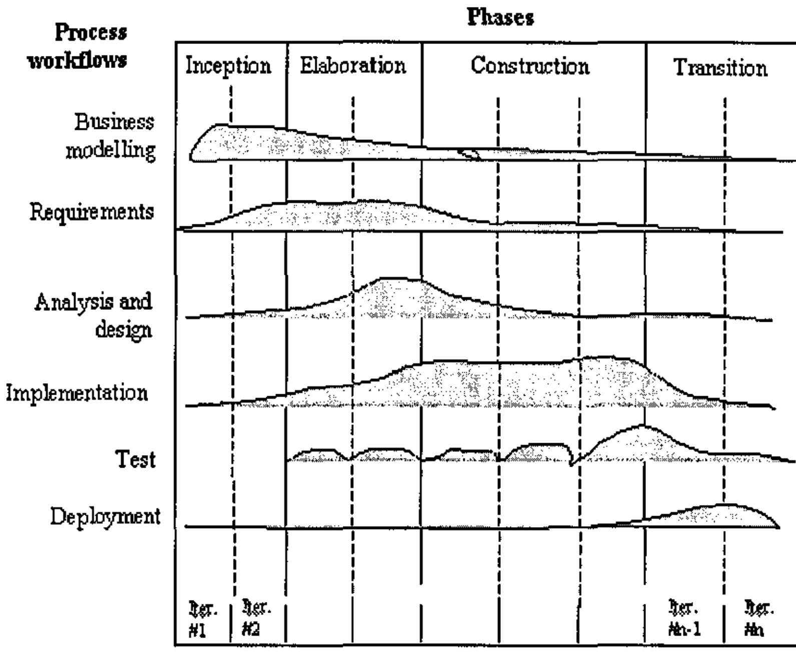


Figure 7-1 The GMC system development process (Quatrani, 2000)

The reason to choose the above development environment is to provide a consistent set of object-oriented tools and process for readily implementing the complicated application such as global manufacturing co-ordination.

7.2.2 Use Case Model of Global Manufacturing Co-ordination System with UML

A use case model is one of communication that illustrates a system's intended functions (use cases), its surroundings (actors), and relationships between the use cases and actors (use case diagrams). It provides a vehicle used by users and developers to communicate the system's functionality and behaviour.

The actors of the global manufacturing co-ordination system have been identified as global decision makers. They can be enterprise production engineers, or co-ordination agents if there are any involved. Actors are not part of the system, but need to interact with the system (Quatrani, 2000).

Use cases model a dialogue between the actors and the system. They represent the functionality provided by the system, i.e. what capabilities will be provided to an actor by the system. A series of use cases have been identified in this global manufacturing co-ordination system as shown in figure 7-2.

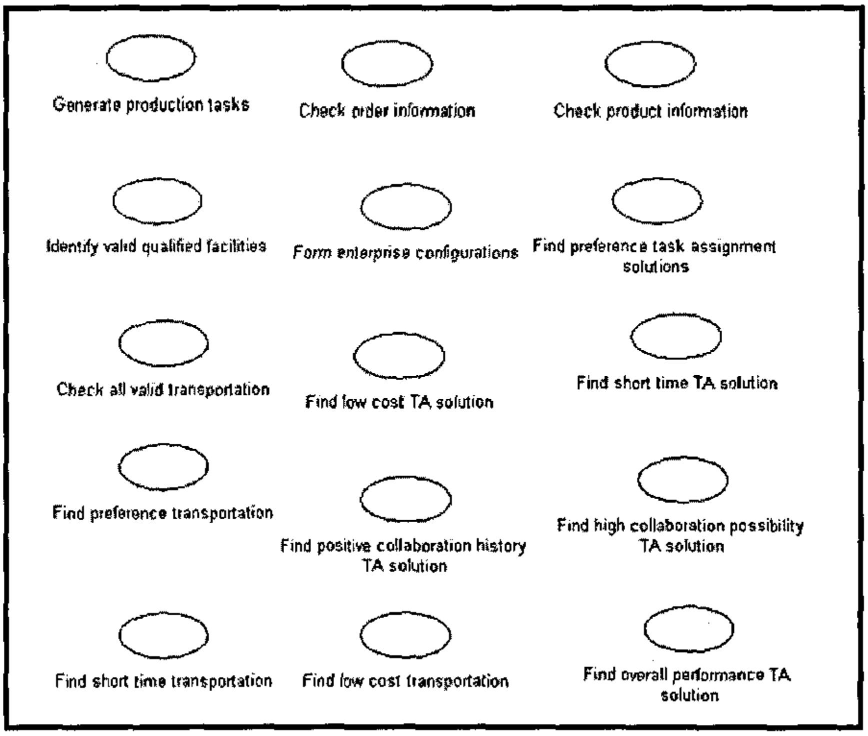


Figure 7-2 Use cases identified for the global manufacturing co-ordination system

The identified actors and use cases have been organised in a use case diagram that is a graphical view of the actors, use cases, and their interactions for a system, as shown in figure 7-3. In the figure, two popular types of use case relationships have been used: <<include>> and <<extend>> relationships. The <<include>> relationship is created between one use case and any other use case that "uses" its functionality. For example, use case of *Generate production tasks* uses use cases

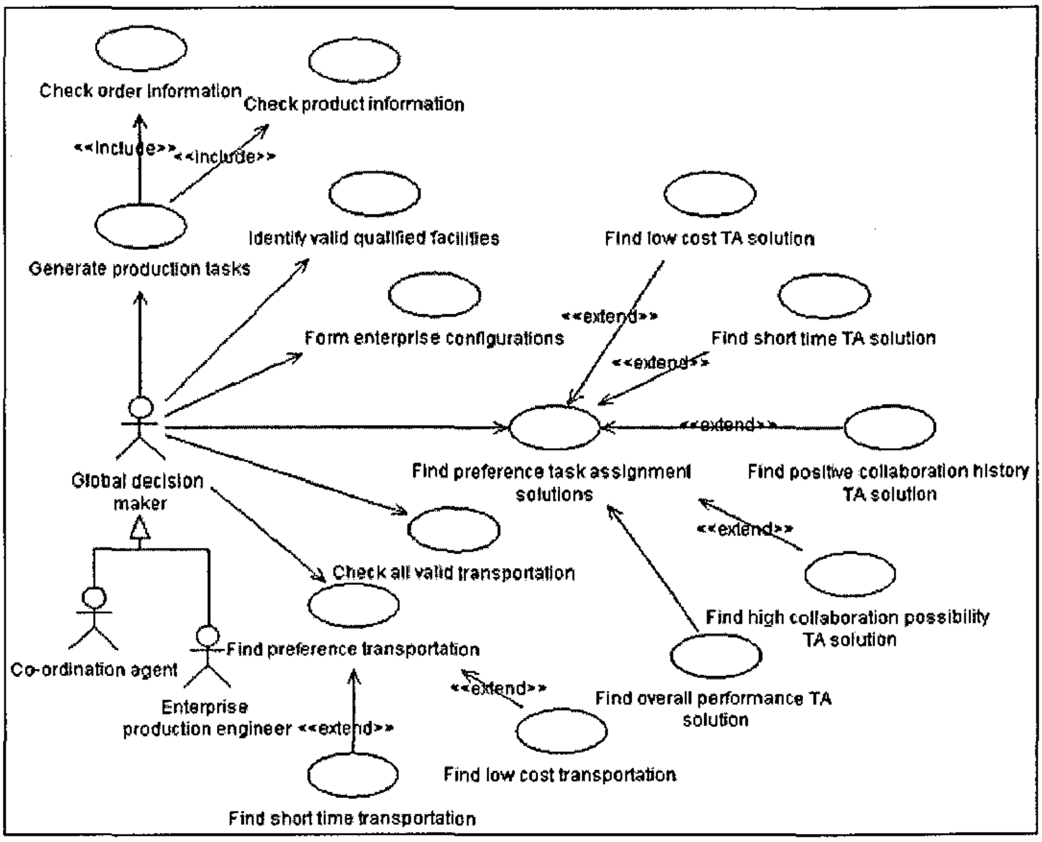


Figure 7-3 Use case diagram of global manufacturing co-ordination system modelled with UML

of *Check order information* and *Check product information*. The <<extend>> relationship depicts the optional behaviour of a use case provided by the system based on *Actors* selection. For example, the use case of *Find preference task assignment (TA) solutions* can provide either low cost task assignment solution, short time task assignment solution, or good collaboration task assignment solution, according to actor's choice.

From the figure 7-3, we can see that the system users, i.e. global decision makers, communicate with the six first-level use cases:

- To generate production tasks;
- To identify valid qualified facilities;
- To form enterprise configurations;
- To find preference task assignment solutions;
- To check all valid transportation;
- To find preference transportation.

The above first-level use cases further use or extend second-level use cases to provide the required functions to the system users. The second-level use cases include:

- Check order information;
- Check product information;
- Find low cost task assignment solution;
- Find short time task assignment solution;
- Find positive collaboration history task assignment solution;
- Find high collaboration possibility task assignment solution;
- Find overall performance task assignment solution;
- Find short time transportation;
- Find low cost transportation.

7.3 Implementation of the Experimental System

This section discusses the implementation of the experimental system that tests the information and knowledge structures of the global manufacturing capability, product, and customer order.

The information used to populate the database in this section to validate the information and knowledge structures was initially based on information drawn from the literature and from information from ALSTOM Electrical Machines Ltd.

7.3.1 *Implementation of the Manufacturing Model Structure*

The manufacturing model structure has been defined in chapter 5 and shown in appendix C. In order to capture the main classes and relationships in the *manufacturing model structure to generate* C ++ programming code, the initial UML Manufacturing model structure has been re-designed by ObjectStore Database Designer as shown in figure 7-4.

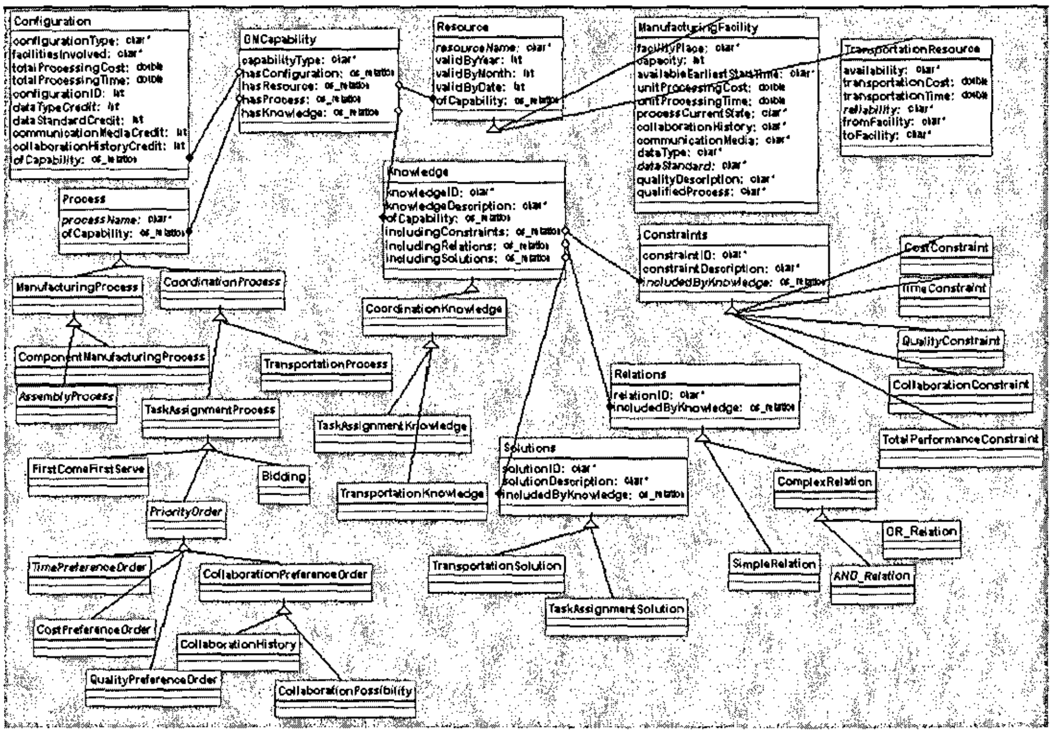


Figure 7-4 MM structure implemented in the experimental system

Comparing the *implemented manufacturing model structure* with the initial *manufacturing model structure presented* in chapter 5, we can see two main differences between them. Firstly, in the implemented manufacturing model structure, all attributes must be specified data types (e.g. integer, double, or character) as well as inheritance mode constrained by key word public (+), private (-), or protected ( ) to clearly tell the program the access purview for the objects and member functions of each class. Secondly, all bi-directional relationships must be instantiated by two data members with "os_relation" types ready for programming. For example, the one-to-many relationship between the *Knowledge* class and the *Constraints* class has been translated into two data members: *includingConstraints* in the *Knowledge* class and *includedByKnowledge* in the *Constraints* class. Above manufacturing model structure with Database Designer can be taken in by ComponentWizard to directly generate programming code and integrated in Visual C++ program realisation.

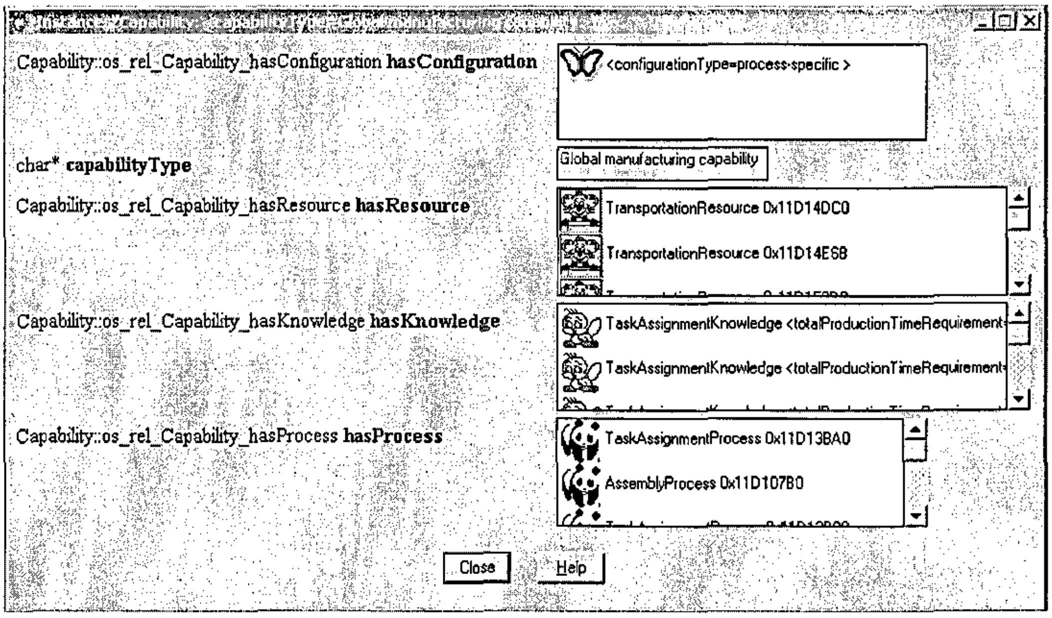


Figure 7-5 Main classes of information and knowledge captured in a manufacturing model

The following several figures are selected from the experimental results to show the information and knowledge captured in the manufacturing model.

Figure 7-5 shows the main classes of global manufacturing capability that have been captured in a manufacturing model and viewed from ObjectStore Inspector instance pane. Clearly, the instance of the GlobalManufacturingCapability has successfully captured four main classes of information: configuration information with a butterfly icon, resource information with a cat icon, knowledge with a bird icon, and process information with a panda icon.

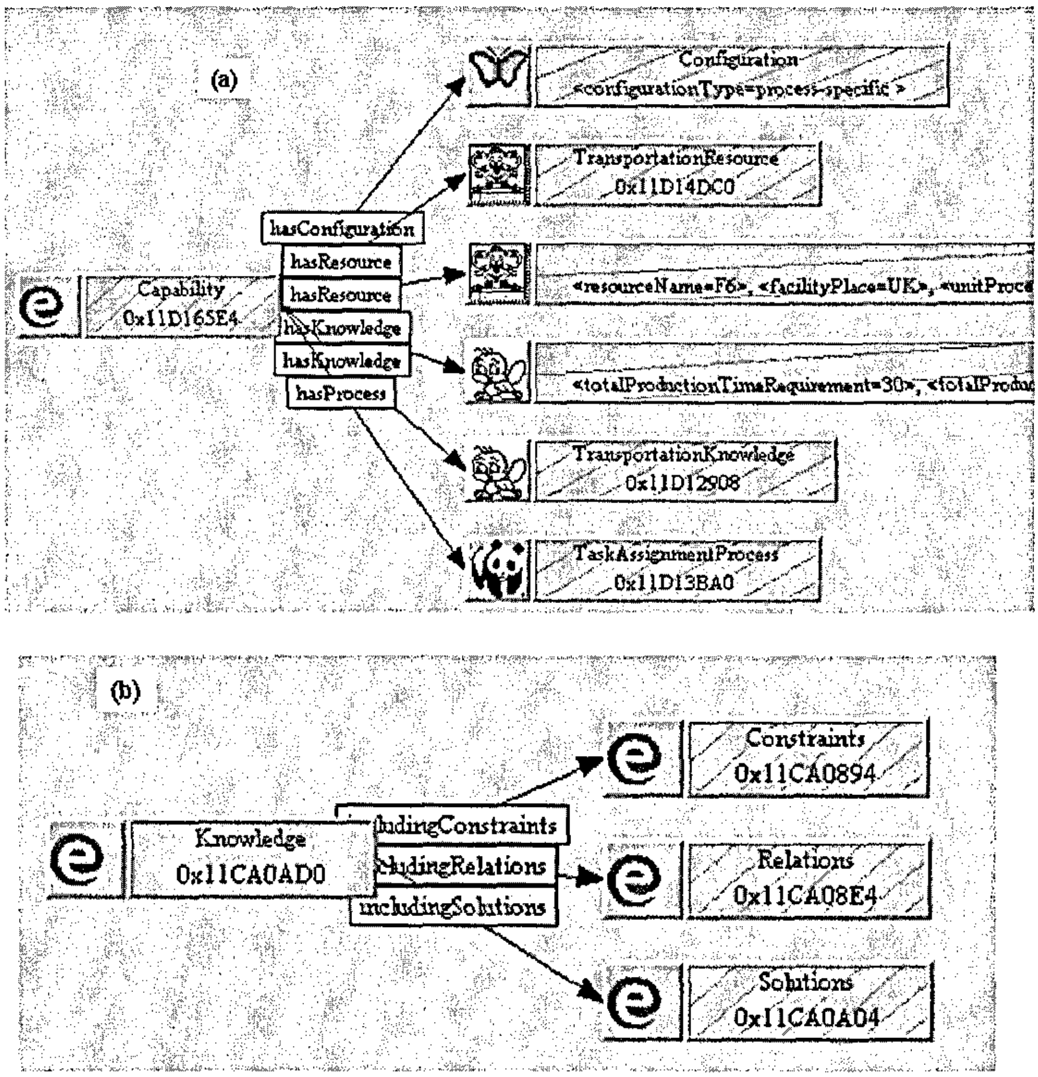


Figure 7-6 Information navigation trees in a manufacturing model

The implemented relationship between information classes can be viewed by ObjectStore Inspector navigation tree. Navigation is the process of following relationships from one instance to another. The experimental results in figure 7-6(a) shows that the information navigation can start from the capability to any of the four main classes of information: configuration, resource, process or knowledge.

Figure 7-6(b) is the example of information navigation from the *Knowledge* to the *Constraints*, *Relations* and *Solutions*. The realisation of the above information navigation means that the relationship between the information classes designed in the manufacturing model structure has been implemented successfully and tested to be correct.

Experimental results in figure 7-5 and figure 7-6 indicate that the manufacturing model structure defined in chapter 5 is able to capture the required information and knowledge of global manufacturing capability elements as well as the relationship between the information and knowledge classes.

The detail information of specific classes captured in the manufacturing model has been presented by class instance views and customised dialogues. Figure 7-7 is an example to show the detailed information of a manufacturing facility. In figure 7-7(a), a database view window has three different panes: a database root pane, a schema pane, and an instance pane. The database root pane displays all the roots that have been defined for the current database. The schema pane displays the database schema using UML notation. The instance pane displays the extent of instances for a specific class – manufacturing facilities in this case.

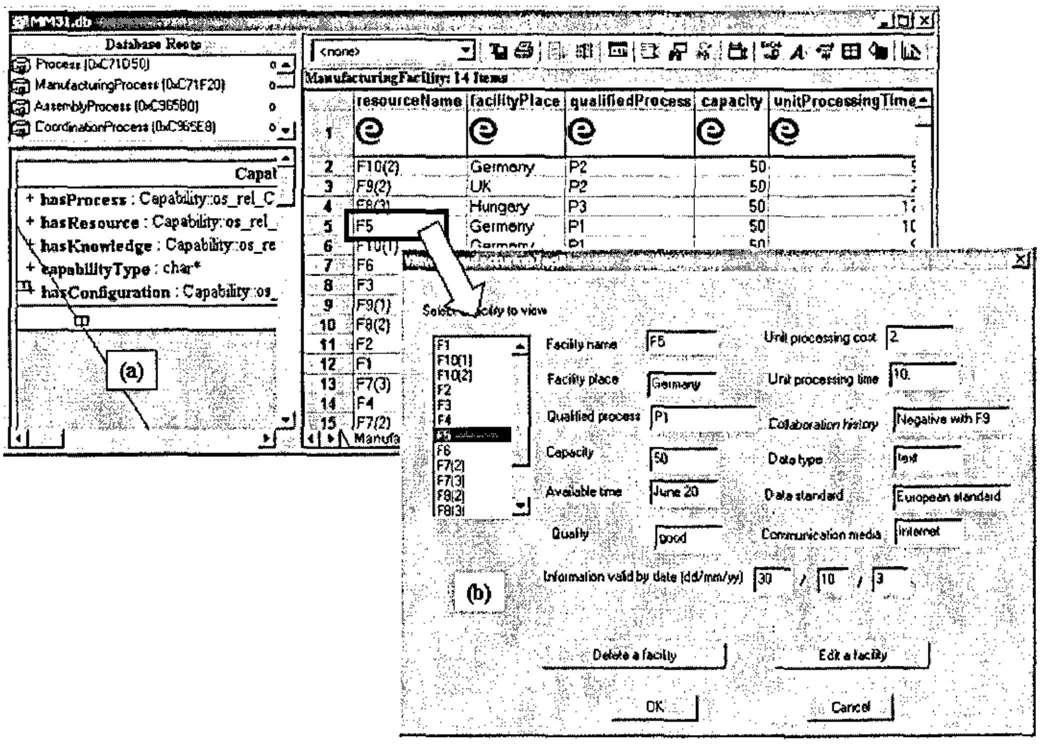


Figure 7-7 Information of manufacturing facilities captured in a manufacturing model

In this example, ten manufacturing facilities (Facility F1 to F10) are considered. Figure 7-7(b) is a dialogue which shows all the facilities captured in the database and the detailed information of facility F5. From the figure, we know the information captured about facility F5:

- *Facility place: German;*
- Qualified process: P1;
- Capacity: 50;
- Available time: 20 June;
- Quality: good;
- Unit process cost: £2.0k;
- Unit processing time: ten days;
- *Collaboration history: Negative with facility F9;*
- Data type: text;
- Data standard: European standard;
- Communication media: Internet;
- Information valid by date: 30^{th} October 2003.

Also, the button of "Delete a facility" allows us to get rid of the out-of-date facilities, and the button of "Edit a facility" allows us to change any of the information about the facilities and keep the information up-to-date.

For some facilities such as F7, F8, and F10, as they are qualified for more than one manufacturing process, a number has been attached with the facility name to show the manufacturing process in action. The reason to do this is that the same facilities could form different configurations. For example, both configuration F7 (3) + F8 (2) + F5 and F8 (3) + F7 (2) + F5, as shown in figure 7-8 (a) and (b), are actually formed by the same facilities: F7, F8, and F5. The difference between the two configurations is that F7 and F8 perform different processes in the two configurations. In configuration F7 (3) + F8 (2) + F5, facility F7 performs process 3 and facility F8 performs process 2. While In configuration F8 (3) + F7 (2) + F5, facility F8 performs process 3 and facility F7 performs process 2. The relevant information about two configurations is also different.

More information and knowledge stored in a manufacturing model can be found in **appendix D** of this thesis.

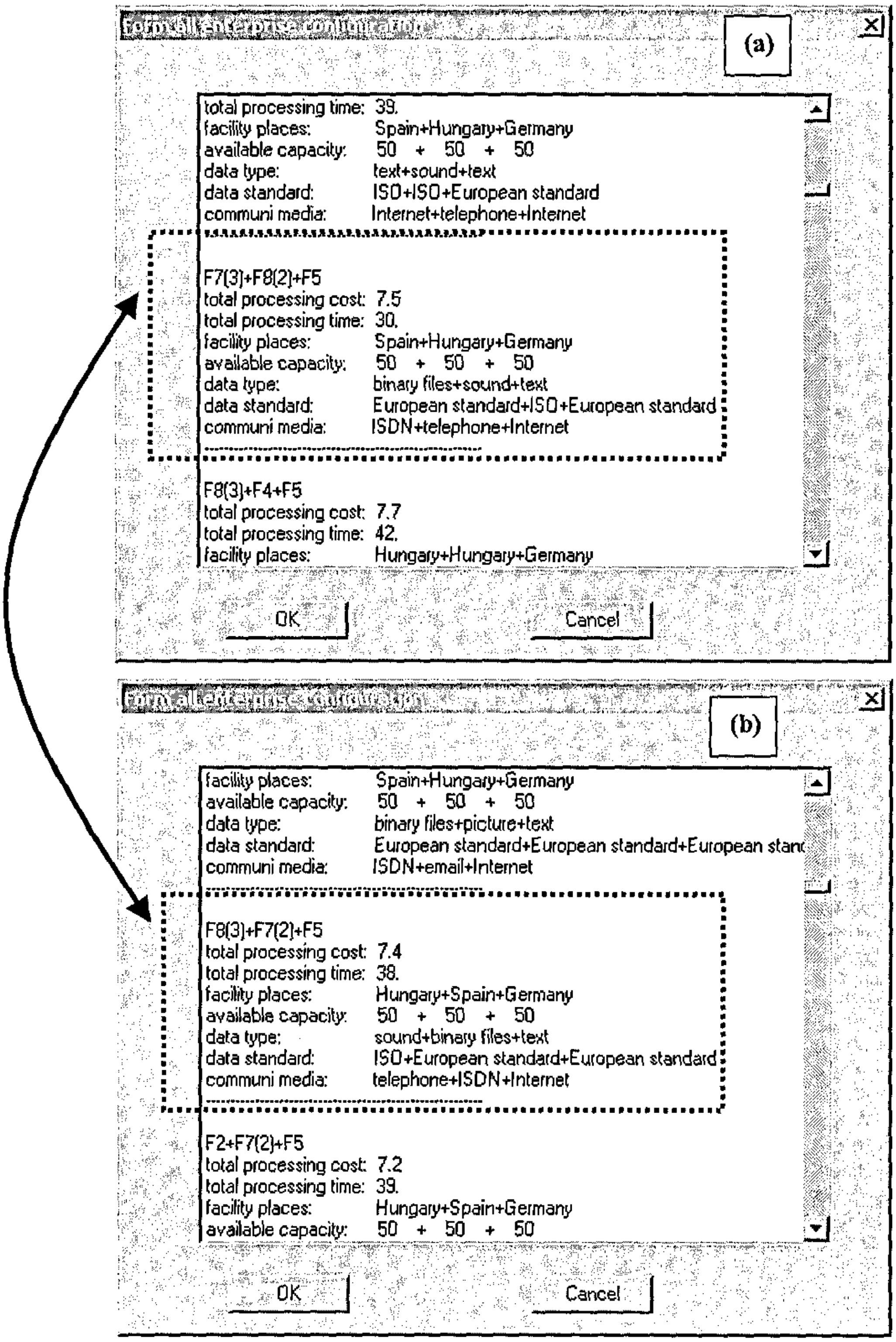


Figure 7-8 Same facilities perform different processes in different configurations

7.3.2 The Implementation of the Structures for the Order and Product Model

The implementation of the order model structure (defined in chapter 6) is to capture the information of *ProductOrder* class, and the relationship between *ProductOrder* class and *Product_OM* class in an order model. The re-designed order model structure with Database Designer to be implemented in the experimental system is shown as figure 7-9.

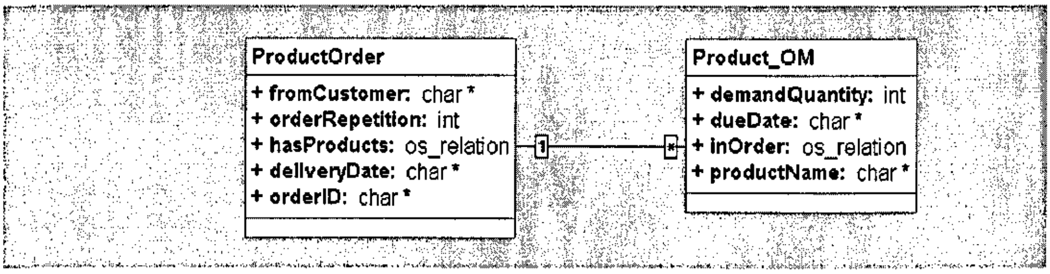


Figure 7-9 Order model structure implemented in the experimental system

Similar to the manufacturing model structure implementation procedure, the re-designed order model structure has been used by the Component Wizard to generate code and integrated with Visual C++ programming. The experimental results can be viewed by ObjectStore Inspector. Figure 7-10(a) illustrates the information of a product order captured in an order model:

- Order ID: order 01;
- Order repetition: 1;
- From customer: a;
- Delivery date: 1 August.

Figure 7-10(b) is the information navigation tree from product order to product. From this figure we can see that there are three products in the order 01, which means the aggregation relationship between *ProductOrder* and *Product* classes has been properly captured and implemented.

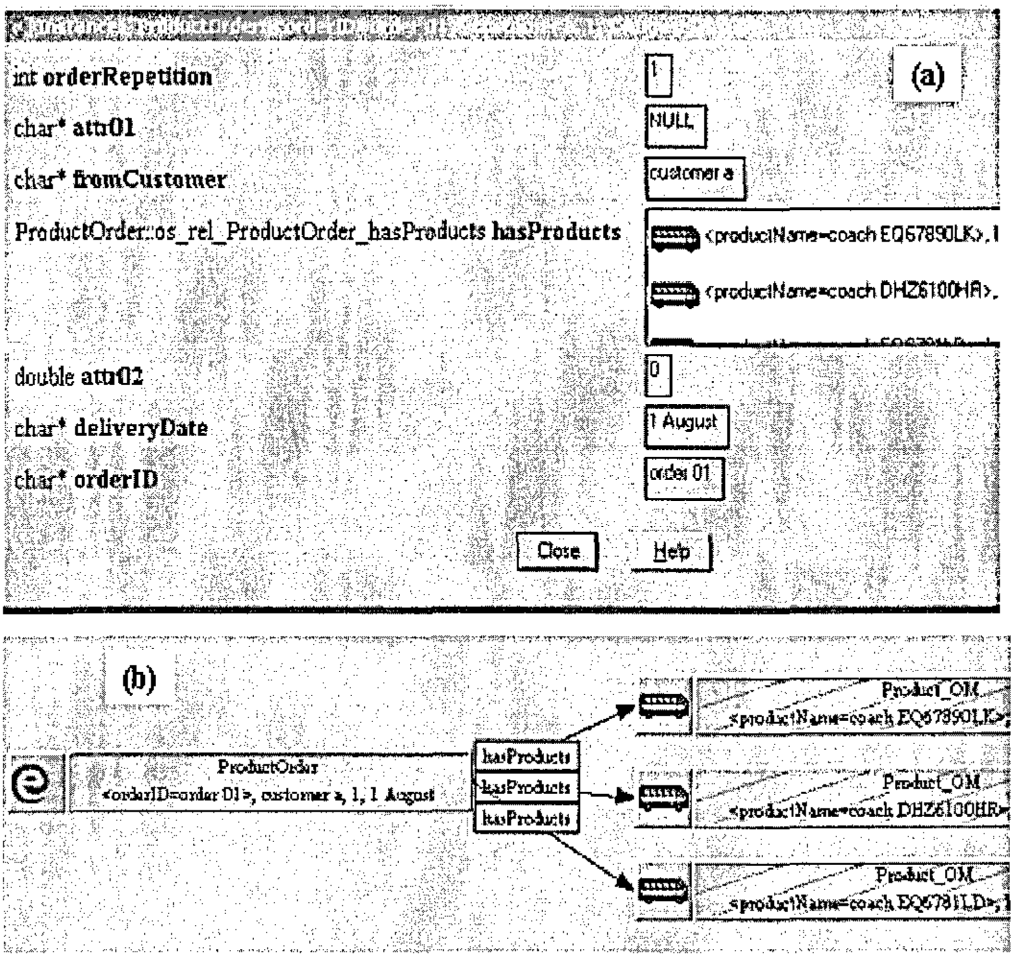


Figure 7-10 Product order information and its relation to product in a OM

In order to capture detail information of a product, there is a need to implement the product model structure. In this experimental system, implementation of the product model structure focuses on the product structure tree and product specification. The following product model structure in figure 7-11 re-designed with Database Designer has been used.

After the re-designed product model structure has been implemented, the experimental results are obtained. Firstly, the result of product structure tree is shown in figure 7-12. The information navigation tree shows that the navigation from sub-system can be performed upstream to system and downstream to components, which means that in the product structure tree navigation from one instance to another instance is accessible. Specification of a specific product can also be viewed with the object instance window (figure 7-13).

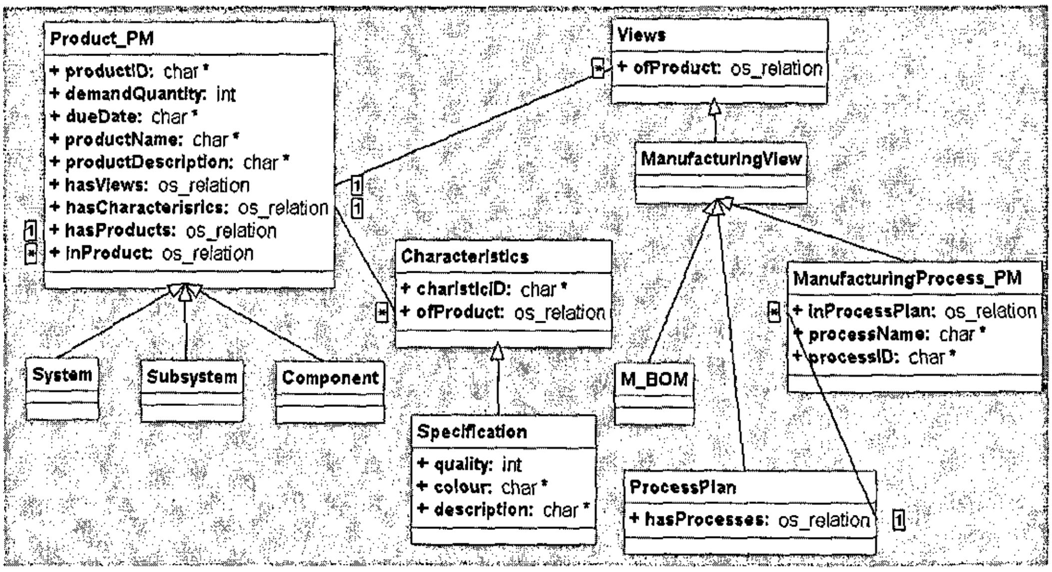


Figure 7-11 Product model structure implemented in the experimental system

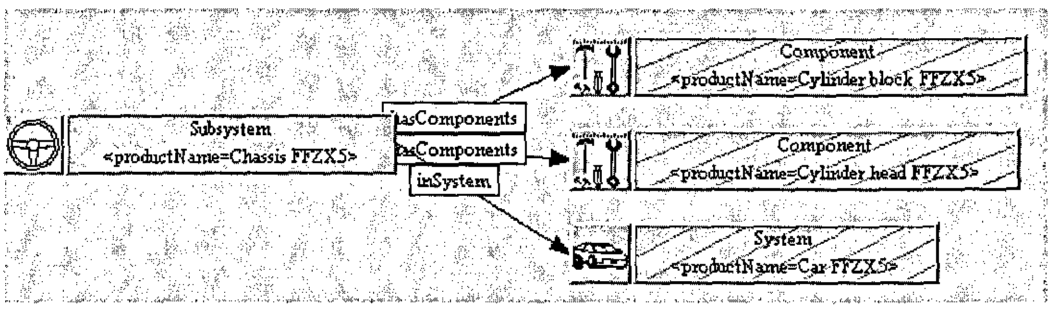


Figure 7-12 Information navigation in the product structure in a PM

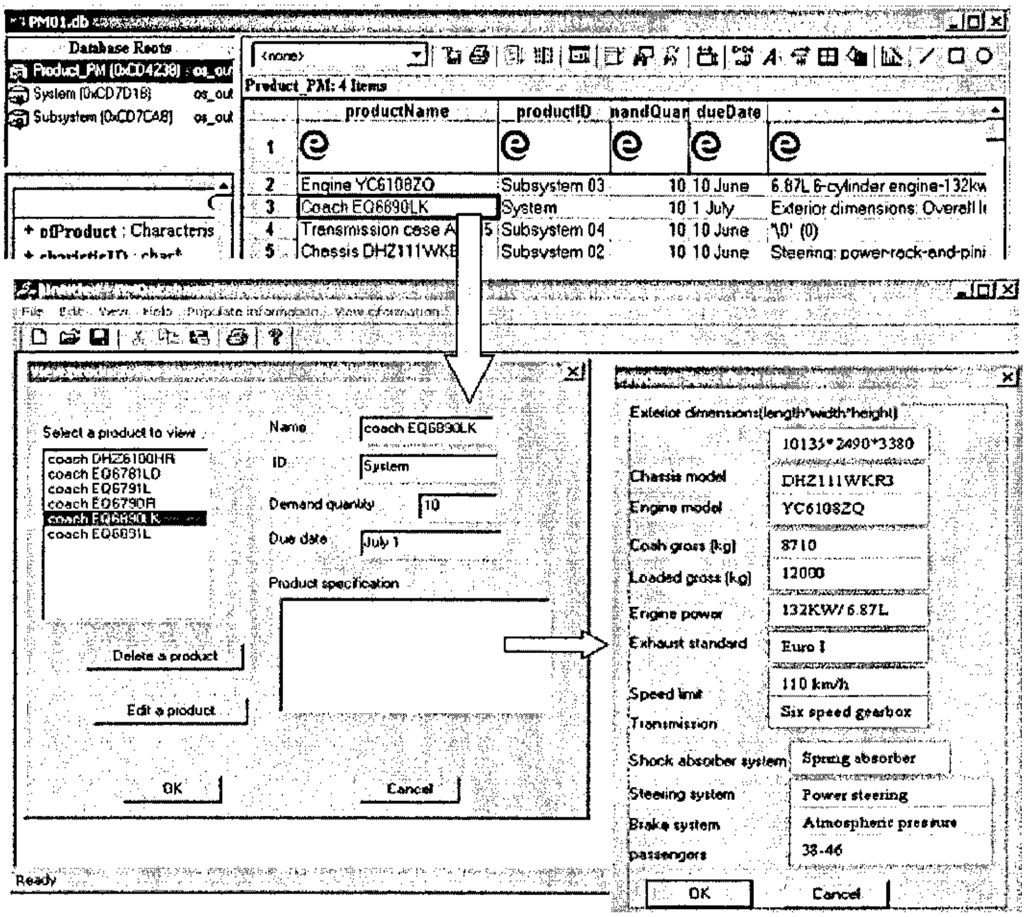


Figure 7-13 Product instances in product model

These experimental results show that the product model structure defined in this work is able to capture the required product information classes and their relationships.

7.3.3 Implementation of the functions in the Global Manufacturing Co-ordination System

This section explains the implementation of the functions in the global manufacturing co-ordination system.

Six functions have been implemented in the experimental system. The four functions related to task assignment (TA) are:

- (1) Generate production tasks (according to order information and product structure, generate *all* *bill-of-materials* and product specification);
- (2) Check potential manufacturing facilities that are qualified for the processes;
- (3) Form all configurations that can perform the processes;
- (4) Find preference task *assignment* solutions.

The two functions concerning producer and consumer relation co-ordination (PCRC) are emphasised on transportation:

- (5) Check all valid transportation between producer and consumer facility pairs;
- (6) Find preference *transportation solutions according* to the actual manufacturing process state and enterprise production objectives.

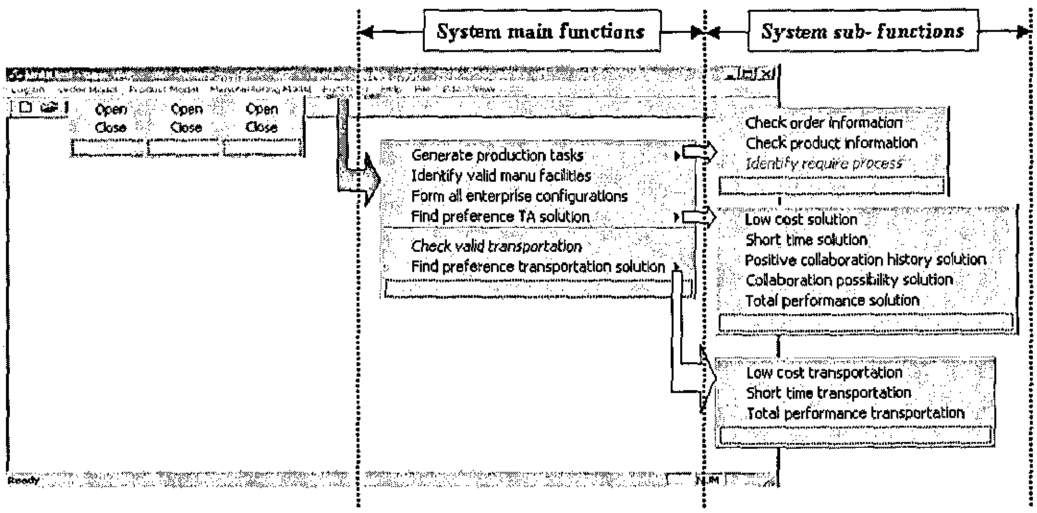


Figure 7-14 Interface of functions performed by the experimental system

The functions in the experimental system have been implemented through window menus to provide the visual user interface, as presented in figure 7-14. Some main functions such as function (1), (4), and (6) have been embodied by more sub- functions.

As stated earlier, the roles of the three information and knowledge models in this experimental system are different. The order model supplies general order information and product types. The product model provides the information about product structure and product specification. According to the order information and product information, the specific manufacturing processes required to manufacture the product will be identified based on the process plan requirement under the manufacturing view in the product model. The manufacturing model then provides the information about resources that are qualified for the manufacturing processes and perform the transferring processes, configuration of the manufacturing facilities, co-ordination processes to manage the dependency between manufacturing processes, and co-ordination knowledge. Figure 7-15 illustrates the process of how the global decision makers use three information and knowledge models to support global manufacturing co-ordination applications. The solid arrows indicate that the decision makers get the required information and knowledge from three models, the dashed arrows indicate the functions supported by the information and knowledge models. The numbers attached with the arrows indicate the information and knowledge used to support decisions related to the same numbered functions designed in the experimental system (section 7.2.1).

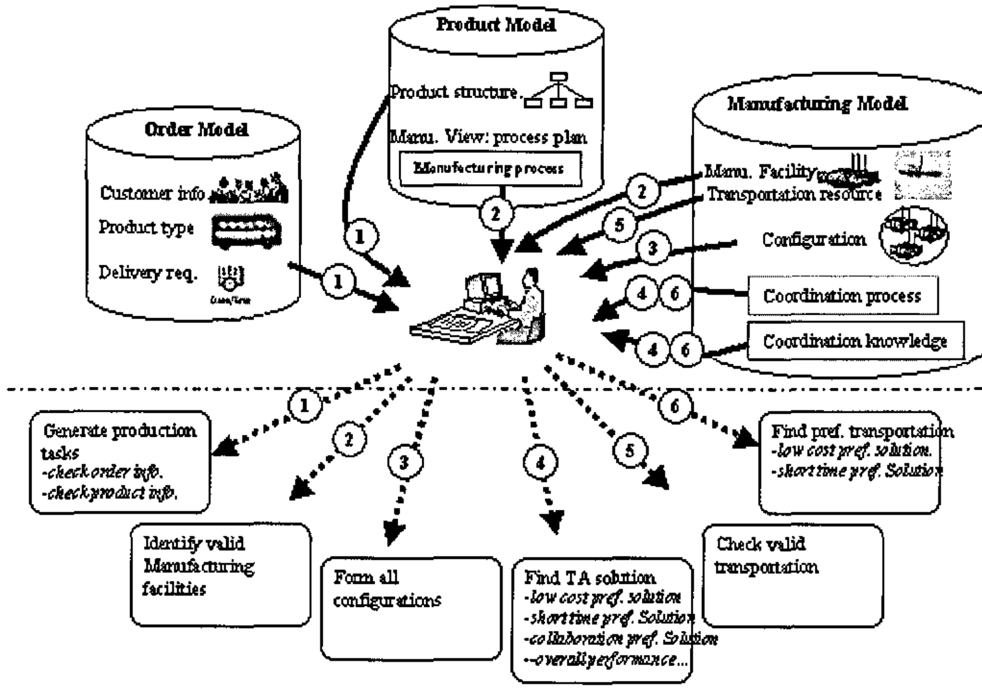


Figure 7-15 Information and knowledge flows in the experimental system

7.4 Case Study

In order to explore the application of the manufacturing model, the product model, and the order model constructed on the basis of the information and knowledge structures tested in last section, a case study has been pursued and the results have been presented in this section. The objective is to apply the global manufacturing co-ordination system to a real industry environment. The case study is based on the information collected from an automotive company – Aeolus Automotive Corporation.

7.4.1 Background to the Aeolus Automotive Corporation (AAC)

Aeolus Automotive Corporation (AAC) is one of the biggest automotive corporations in China which has close collaboration with French Citroen, American General Motor, Japanese Nissan, South Korean Qiya, and Taiwan Yulong. Its products cover different ranges of final products, components and subassemblies for trucks, cars and coaches, having different types of customers from China and other Asia countries.

7.4.2 The Issue and Solution Approach

In AAC, one problem of management is how to provide the information of customer orders, products, and manufacturing capabilities of the company partners as well as subsidiaries to manage the activity interdependence within the whole organisation. Three information and knowledge models, i.e. the manufacturing model, the product model, and order model, can be used to solve this problem. On the one hand, considering the complexity of the customer requirement, product range, and organisation hierarchy in AAC; on the other hand, considering the demonstration role of the three information and knowledge models, specific assumptions have been made to apply the global manufacturing co-ordination system to AAC situations.

7.4.3 Assumptions

The experiments performed in this section are based on the following two assumptions as shown in figure 7-16.

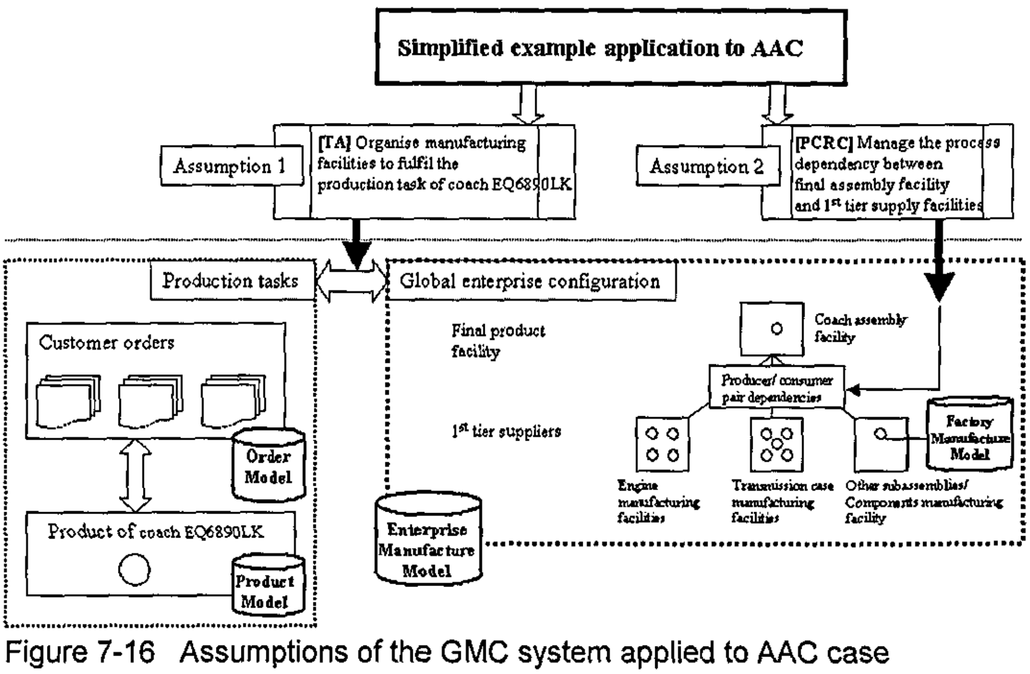


Figure 7-16 Assumptions of the GMC system applied to AAC case

Assumption 1: The production task is concerned with only one final product, i.e. *coach* EQ6890LK;

Assumption 2: The supply chain only contains coach final assembly facility and the first material (components or subassemblies) supply tier. In this case, eight manufacturing facilities are considered. Among which four facilities (facility CC, facility NN, facility DF, facility YC) are qualified for process of "engine manufacturing", five facilities (facility ZC, facility TM, facility DF, facility AN, facility GM) for process of "transmission case manufacturing", one facility, i.e. facility DF is qualified for process of "coach assembly" and providing other components and subassemblies. The distribution of these facilities is described in table 7-1.

Facility		Qualified process			
Name	Location	Engine manufacturing	Transmission case manu.	Others	Coach assembly
Facility CC	America	☆			
Facility NN	Japan	☆			
Facility DF	Central China	☆		☆	☆
Facility YC	Northern China	☆			
Facility ZC	Southern China		☆		
Facility TM	Western China		☆		
Facility AN	Eastern China		☆		
Facility GM	America		☆		

Table 7-1 Facilities and processes for production of coach EQ6890LK

7.4.4 Models to Support Global Manufacturing Co-ordination Decisions

7.4.4.1 Models to Support the Generation of Production Tasks

This experiment is to test if the information models can support the generation of production tasks including two sub-functions: (1) check order information; (2) check product information.

The first sub-function of the global manufacturing co-ordination system allows the users to check detailed information about each order. As shown in figure 7-19, detailed information about order 01, order 02, or any other order can be viewed, edited (if necessary), or deleted (if applicable).

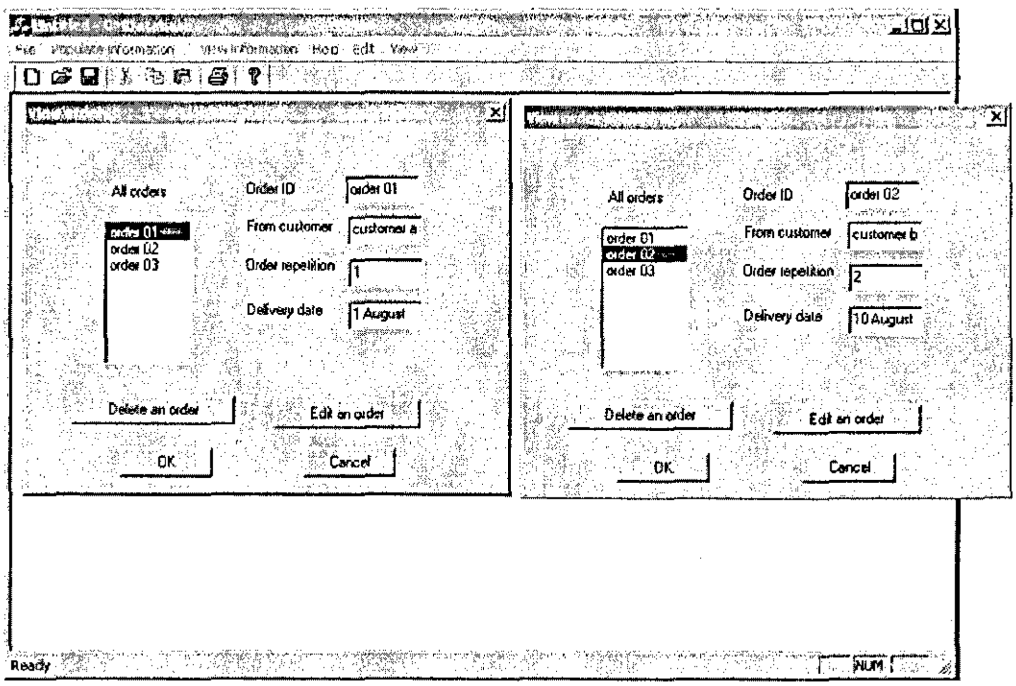


Figure 7-17 Check order information using GMC system

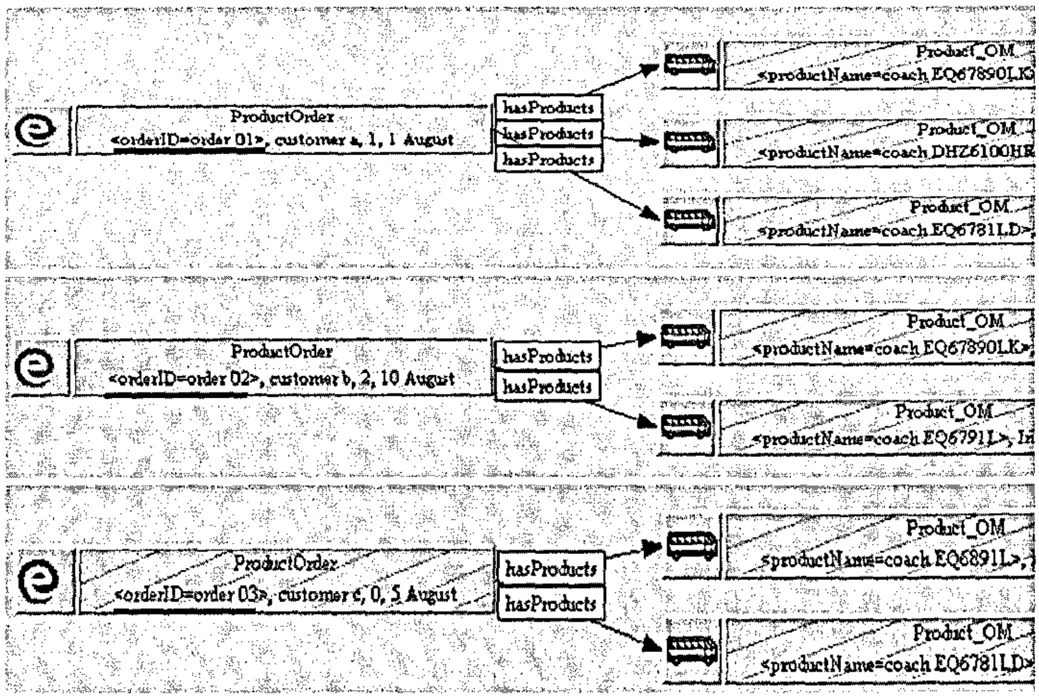


Figure 7-18 Product types included in each order

As the information of types of products included in each order has already been captured in the order model, this makes the sub-function 2 possible. Figure 7-18 shows clearly the product types included in each order. For example, order 01 has three different product types, order 02 and order 03 each has two product types.

Sub-function 2 of the global manufacturing co-ordination system allows users to check detail information about each product and its bill of materials, as shown in figure 7-19. For example, the specification of the coach EQ66890LK includes "Exterior dimensions: Overall length 10135; Overall width 2490; Overall height 3380;Occupant protection; accident avoidance; Anti-theft security".

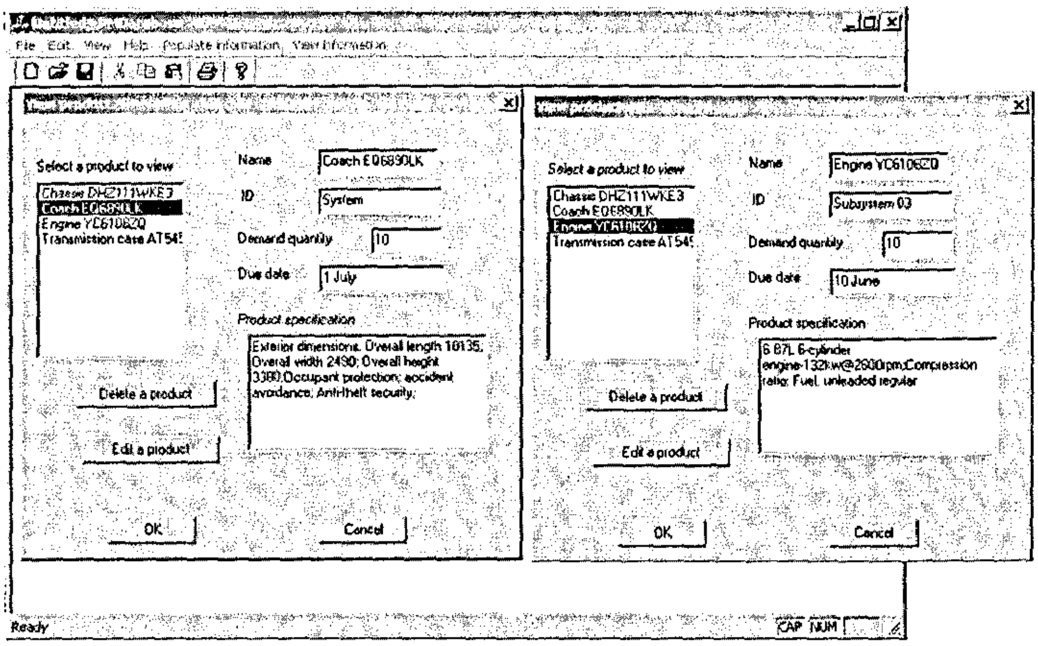


Figure 7-19 Check detail information of products

7.4.4.2 Models to Support the Identify Valid Manufacturing Facilities Function

This experiment is to demonstrate how to use information and knowledge models to identify valid manufacturing facilities for the required manufacturing processes. According to the production tasks generated by system function 1, the required manufacturing processes to perform the production tasks will be identified by manufacturing engineers based on process planning. The global manufacturing co-ordination system then interrogates the manufacturing model for the information about manufacturing facilities for each manufacturing process and identifies the valid manufacturing facilities. This process is performed based on two criteria. The first criterion is that the attribute of "qualified process" of the potential facilities has to match the required manufacturing process. The second criterion is that the attribute of "information valid by date" of the potential facilities must not be earlier than the actual information transaction time. Expected system input and results have been presented as in figure 7-20. This function is based on the support of the enterprise manufacturing model and under condition of the factory manufacturing model, which plays the role of process evaluation and recommends the potential manufacturing facilities to the enterprise manufacturing model.

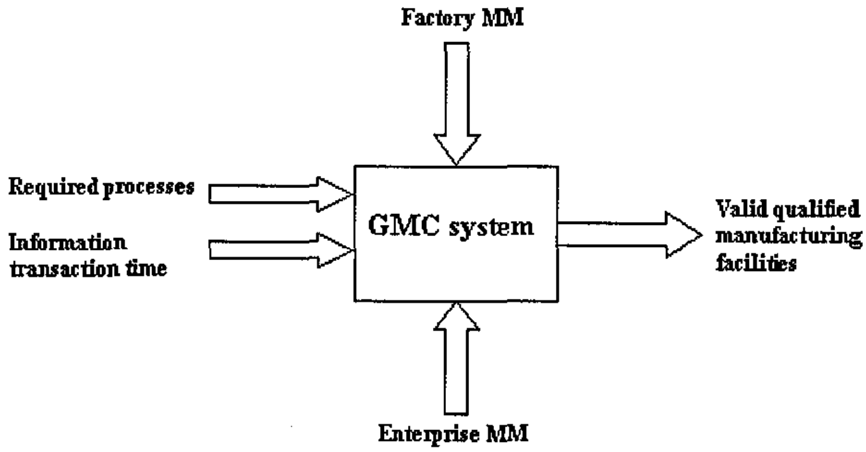


Figure 7-20 Expected GMC system performance of function 2

For example, if the demanded processes are process 1 - " coach assembly", process 2 – "transmission case manufacturing", and process 3 – "engine manufacturing", the system should be able to identify the valid manufacturing facilities qualified for the above processes. Figure 7-21 shows the real results of the experiment. As seen from the figure, the GMC system found one valid qualified facility for the process of "coach assembly" (Facility DF), five facilities qualified for the process of "transmission case manufacturing" (Facility DF, Facility AN, Facility TM, Facility GM, Facility ZC), and four facilities qualified for the process of "engine manufacturing" (Facility CC, Facility YC, Facility NN, Facility DF). The information valid by date of these facilities is 30 October 2003 when is later than the information transaction date – 10th October 2003.

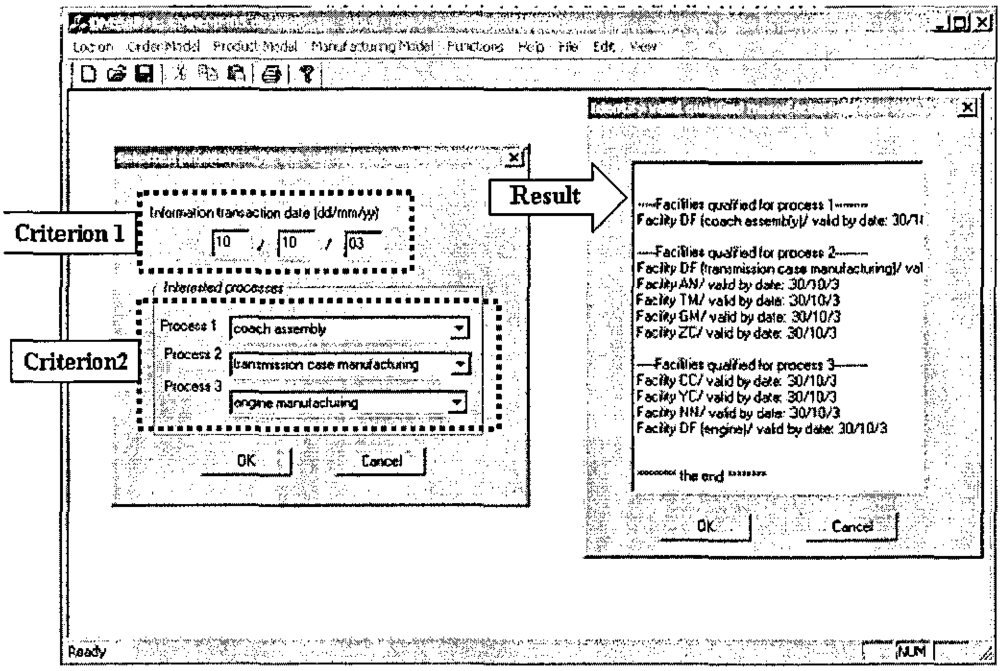


Figure 7-21 Valid qualified manufacturing facilities identified by the GMC system

7.4.4.3 Models to Support the Form all Enterprise Configurations Function

This experiment is to demonstrate how to use the information and knowledge models to form enterprise configurations. The facilities identified in function 2 should be organised to perform all the required processes so that the final product in the order can be finished as demanded. In this step, the global manufacturing co-ordination system first retrieves all valid manufacturing facilities from the manufacturing model, and then arranges the facilities according to the configuration type. For example, if the configuration type has been designed as "process-specific", i.e. the configuration should include the facilities qualified for all the required manufacturing processes. Following the experimental results in function 2 (one, five, and four facilities qualified for the three manufacturing processes respectively), twenty (1*5*4) configurations have been formed, as shown in figure 7-22. Relevant information about each configuration has also been available. For instance, one of the configurations is configuration Facility

CC + Facility AN +Facility DF. The total processing cost of this configuration would be £12.7k, and the total processing time would be nineteen days, etc.

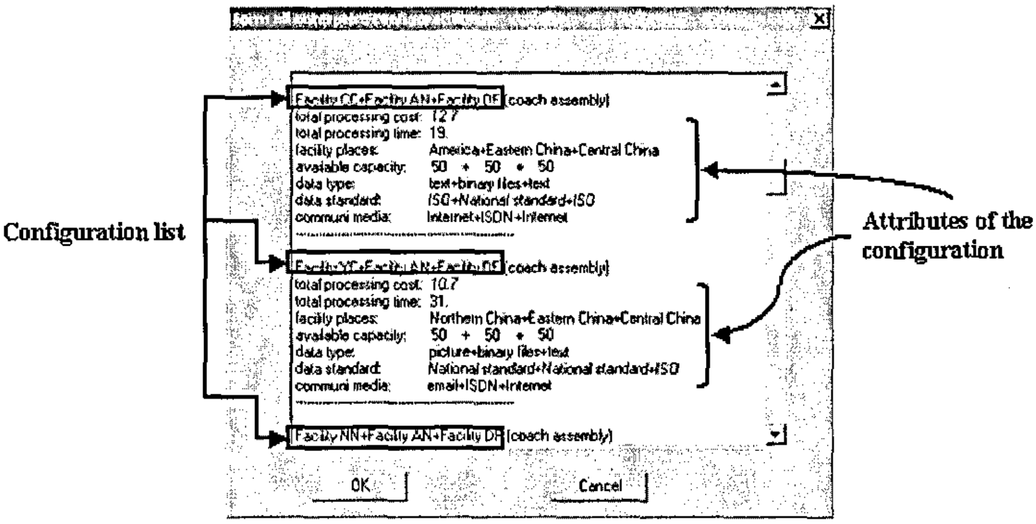


Figure 7-22 Experimental result of forming configurations

7.4.4.4 Models to Support the Find Preferable Task Assignment Solutions Function

This experiment is to show how to use information and knowledge models to make task assignment decisions. The production tasks have been generated in system function 1 with the support of order model and product model, and all possible enterprise configurations have been formed in system function 3. In this step, production tasks will be assigned to most preferable configuration according to the task assignment knowledge provided by the manufacturing model. For knowledge retrieval to be effective, the discovered patterns have been represented in multiple forms, such as rules, tables, and decisions trees. Based on the understanding of the task assignment process modelled in manufacturing model, patterns can be total production cost, total production time, facility collaboration or overall performance. According to different pattern, the global manufacturing co-ordination system will first decide the class of task assignment knowledge and then retrieve the most appropriate task assignment solution according to the value of parameter constraint. Figure 7-23 shows the decision tree for the classification of task assignment knowledge. Five classes, class A to E, of task assignment knowledge are grouped according to five patterns, i.e. *overall performance, total production cost, total production time, collaboration history, and collaboration possibility*. The five classes of task assignment knowledge should be able to help the global manufacturing co-ordination system to retrieve *corresponding task assignment solutions such as overall* performance task assignment solution and low cost solution.

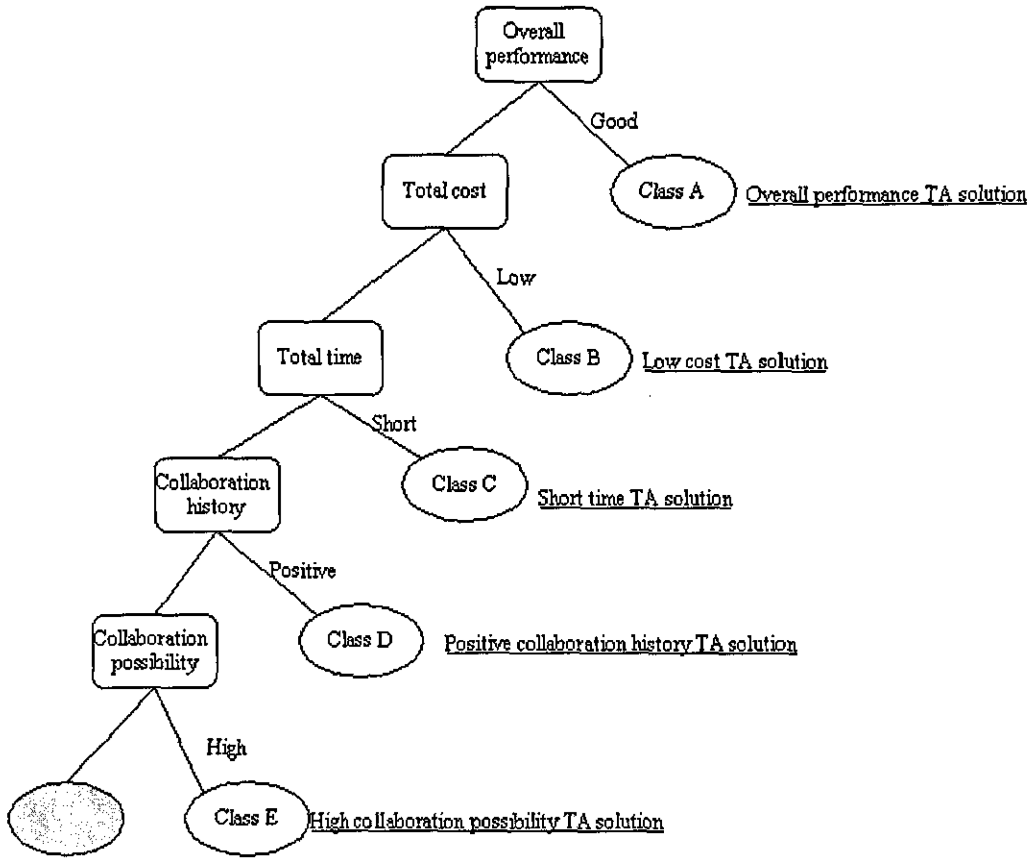


Figure 7-23 Decision tree of classification of task assignment knowledge

To implement the above idea in the global manufacturing co-ordination experimental system, five sub-functions have been designed under system *function 4 – find preferred task assignment solutions*, as shown in figure 7-24.

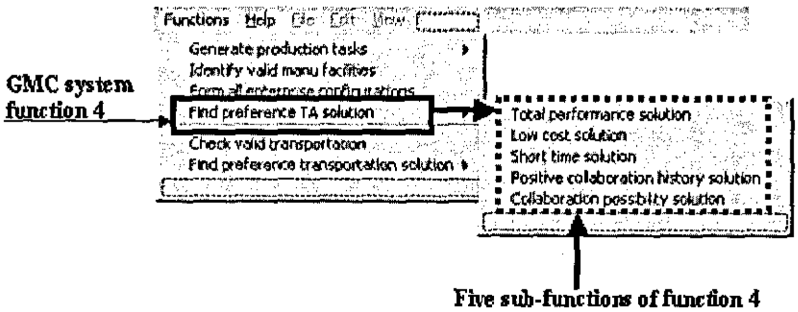


Figure 7-24 Sub-functions under the GMC system function 4

The first experiment is to find the overall performance task assignment solution. The overall performance is constrained by all of the parameters including total processing cost, total processing time, collaboration history credit, data type credit, data standard credit, and communication media credit. In the course of the system implementation, all the parameter constraints have been selected at the same time, as shown in figure 7-25 (a).

Figure 7-25(b) and (c) are the experimental results using the overall performance pattern at different values of the parameter constraints. On the occasion of (b) and (c), the value of the parameter constraints is different, the global manufacturing co-ordination system retrieves different task assignment solutions to meet the specific requirements, i.e. production tasks should be preferably assigned to the configuration of Facility YC + Facility ZC + Facility DF on the occasion of (b) and to the configuration of Facility CC + Facility TM + Facility DF. Subsequently, the actual processing cost and processing time on the two occasions are different.

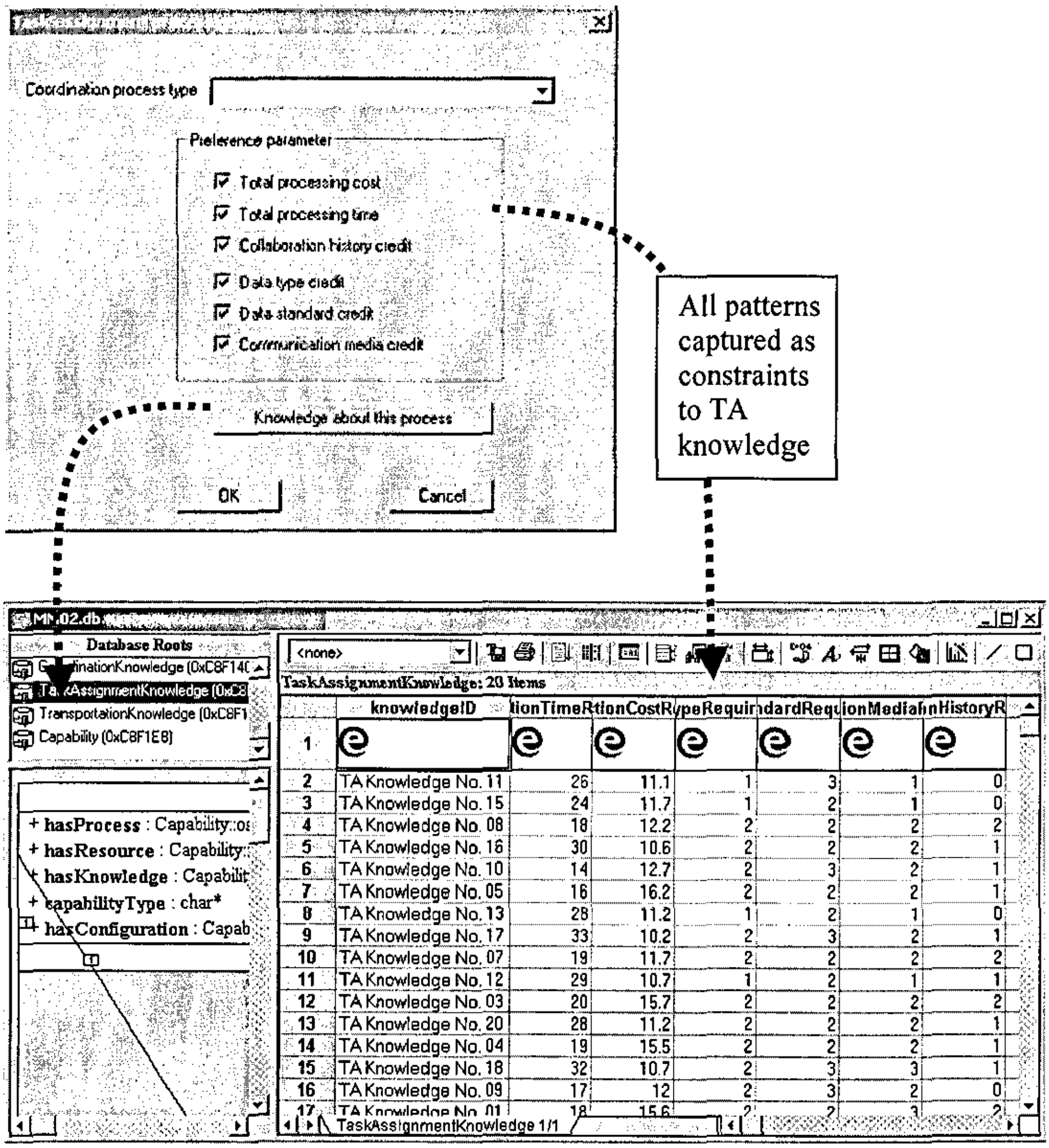


Figure 7-25(a) Overall performance pattern and TA knowledge captured in the MM

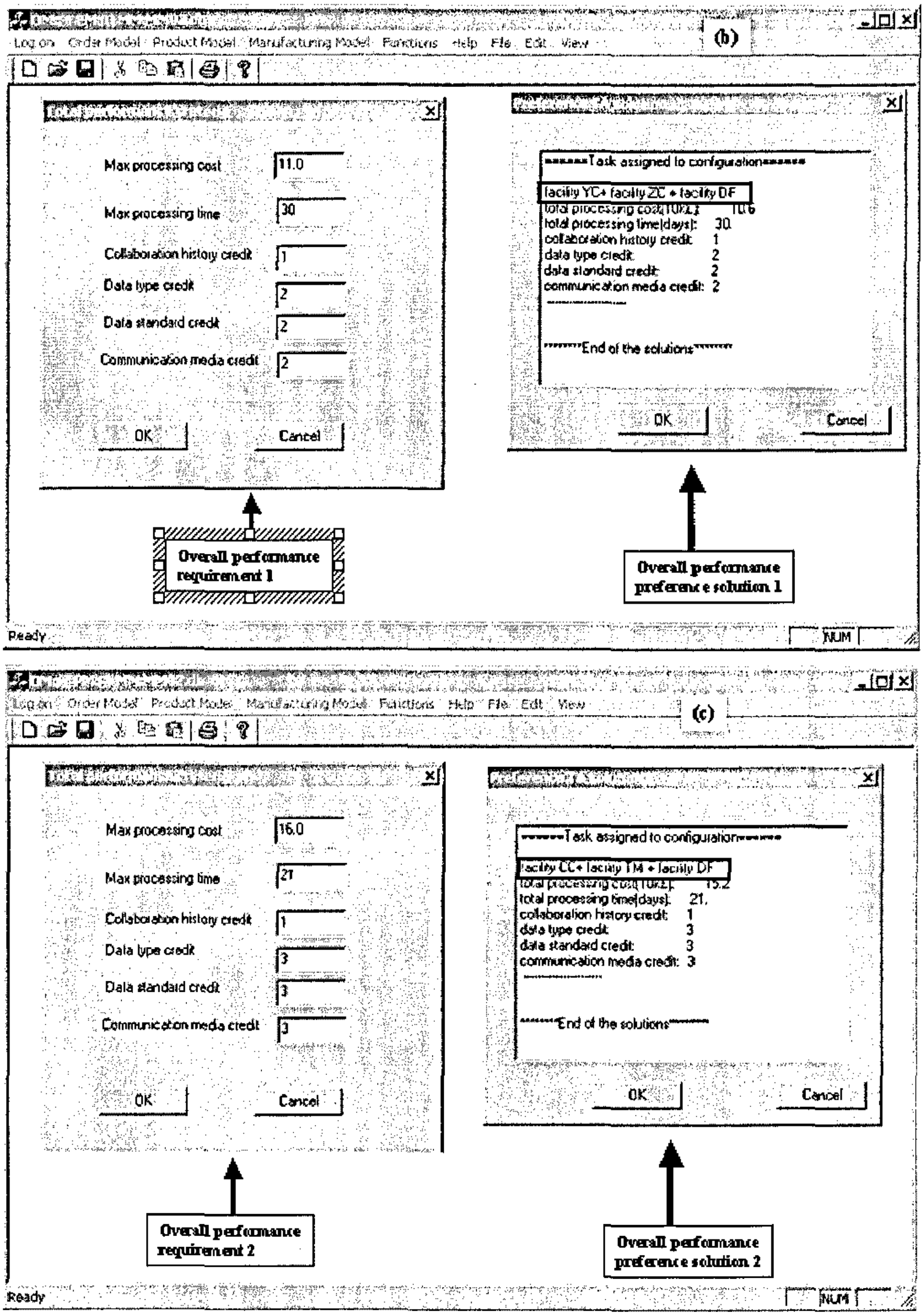


Figure 7-25 (b) and (c) TA solution under overall performance constraints

Total cost pattern is commonly used, as shown in figure 7-26 (a). Figure 7-26(b) and (c) show the results under this pattern with different values of the total cost requirement.

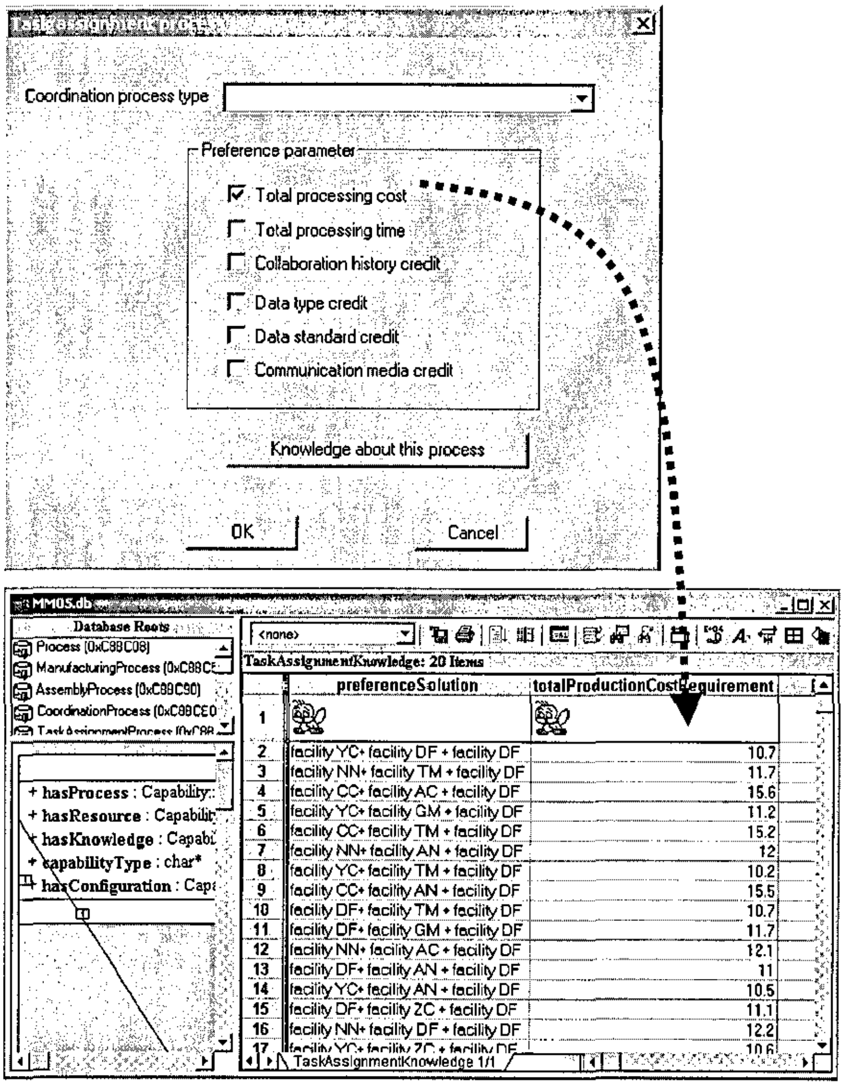


Figure 7-26 (a) Total processing cost pattern and TA knowledge captured in MM

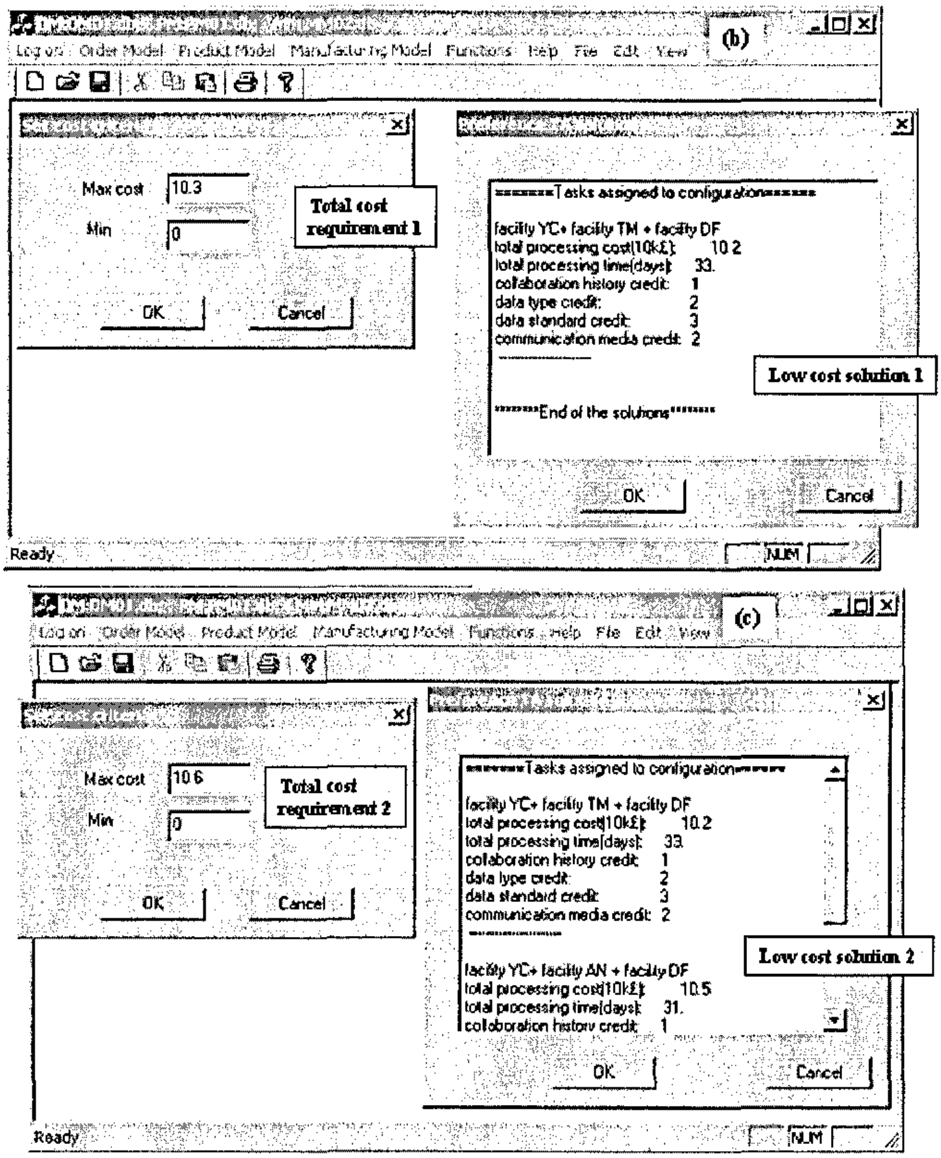


Figure 7-26 (b) and (c) TA solution under low processing cost constraint

As in figure 7-26 (b), if the requirement of the total processing cost is less than £10.3k, the solution is that the production tasks should be preferably assigned to configuration Facility YC + Facility TM + Facility DF. While in figure 7-26 (c), if the cost requirement is less than £10.6k, then there are two choices, i.e. the production tasks can be either assigned to configuration of Facility YC + Facility TM + Facility DF or to configuration of Facility YC + Facility AN + Facility DF.

When the product delivery is urgent or a new product is to be introduced to a new market, the production time pattern is important. On this occasion, the total processing time constraint is used to task assignment. Figure 7-27 (a) shows the total processing time pattern and the corresponding task assignment knowledge captured in the manufacturing model.

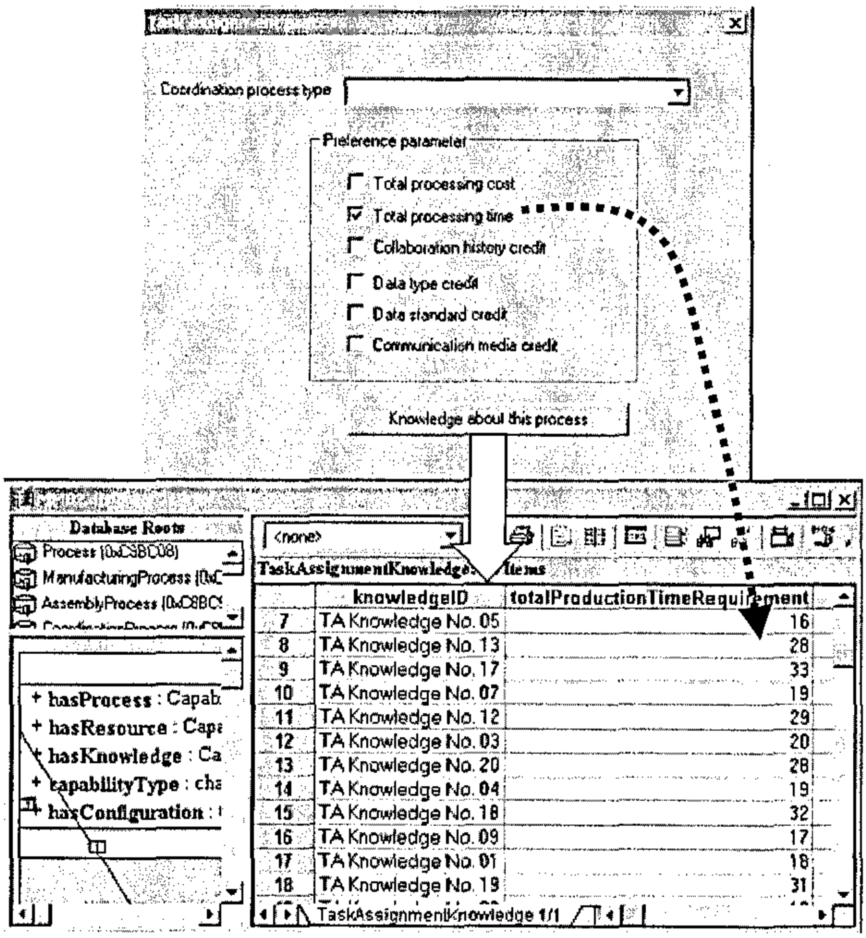


Figure 7-27(a) Total processing time pattern and TA knowledge captured in MM

An example of the experimental result for this sub-function is shown in figure 7-27(b). For example, as shown in the figure, if the requirement of total processing time is less than 15 days, then the solution is that the production tasks should be preferably assigned to configuration Facility NN + Facility GM + Facility DF.

Comparing this result with the experimental result in figure 7-26(b), we can see that when the production tasks are assigned to configuration Facility NN + Facility GM + Facility DF, the short product time requirement has been achieved, which is only fourteen days. Much less than the thirty-three days of configuration Facility YC + Facility TM + Facility DF as in figure 7-26(b). However, other parameters might get worse. For instance, the total processing cost is £12.7k more than solution in figure 7-26(b), which is only £10.2k.

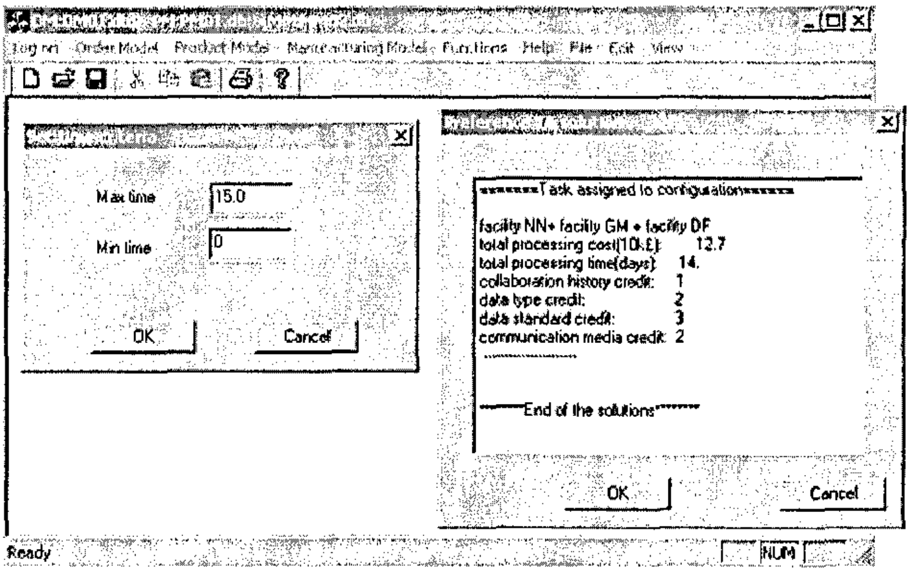


Figure 7-27(b) Example of TA solution under short processing time constraint

If the collaboration history between facilities is important, the requirement of collaboration history credit should be set as shown in figure 7-28.

Alternatively, the highlighted patterns can be information flow collaboration possibilities between facilities pairs. In this case the requirements of data type, data standard, and communication media will be constrained. For example, as shown in figure 7-29, if the requirement of data type credit is

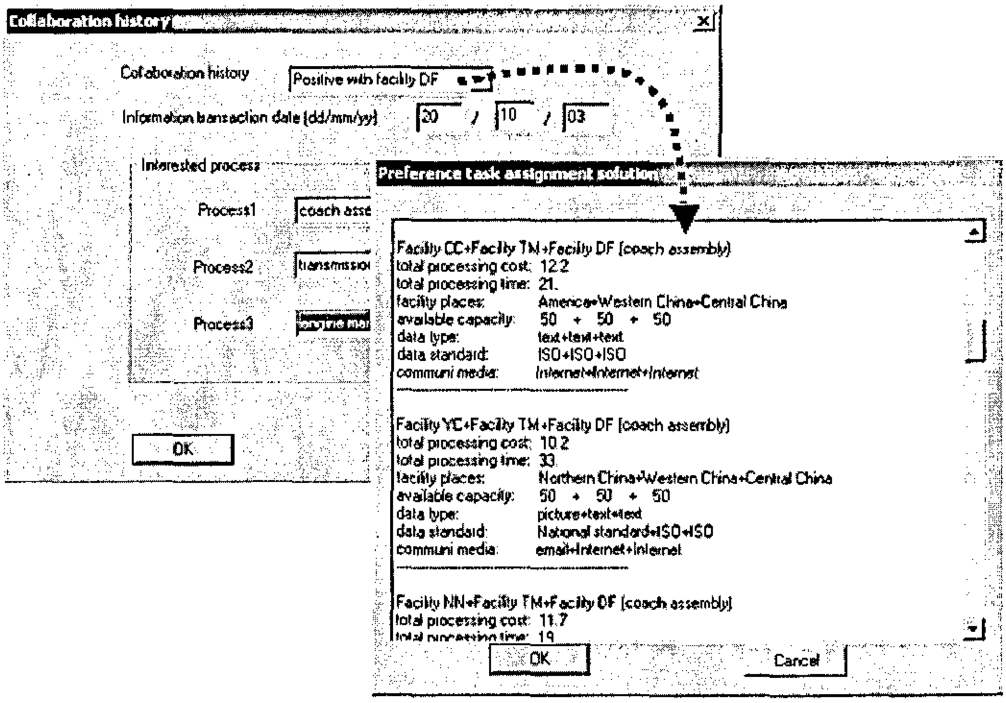


Figure 7-28 Example of TA solution under collaboration history constraint

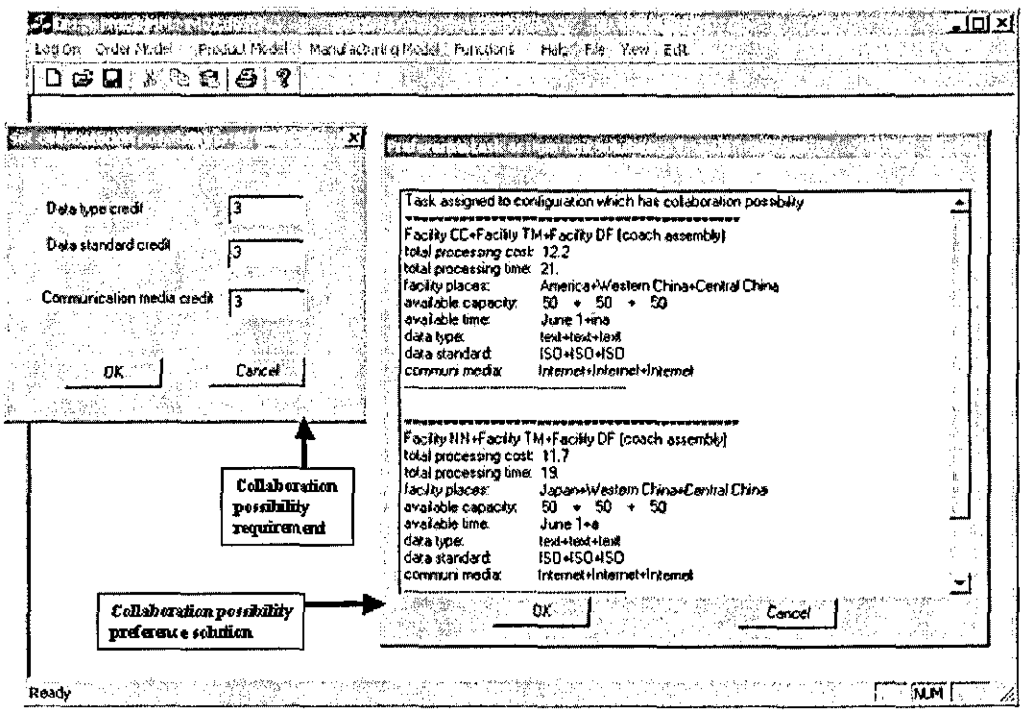


Figure 7-29 Example of TA solution under collaboration possibility constraint

three, data standard also three, and communication media is three, which means the information flow between all three manufacturing facilities are one hundred percent collaborative, then the solution is that production tasks should be preferably assigned to configuration Facility CC + Facility TM + Facility DF or Facility NN + Facility TM + Facility DF.

7.4.4.5 Models to Support the Check Valid Transportation Choice Function

This experiment demonstrates how to use the manufacturing model to check all valid transportation between participating manufacturing facilities. When users choose the transportation rout, the system will first inquiry all the transportation resource information from the manufacturing model and the information timing constraint. If the information transaction data is earlier than the information valid by date, the transportation will be picked out and listed with relevant information of transportation cost and transportation time for users' reference. Figure 7-30 shows the experimental result of the valid transportation between facility CC and facility DF on 20th October 2003.

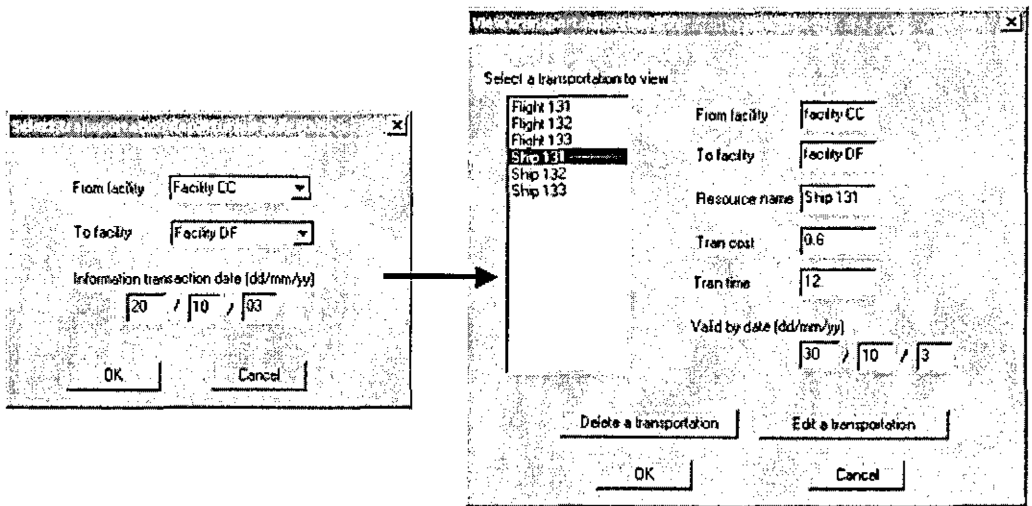


Figure 7-30 Example of checking valid transportation

7.4.4.6 Models to Support the Find Preferable Transportation Solutions Function

This experiment demonstrates how the global manufacturing co-ordination system uses the manufacturing model to find the most appropriate transportation under specific parameter constraint requirements. The parameter constraints can be transportation cost or transportation time.

Figure 7-31 shows the result of preferred transportation solution under transportation cost constraint. For example, if the transportation cost is required at less than £0.5k, the global manufacturing co-ordination system recommends using transportation of ship 133.

Similarly, figure 7-32 shows the result of the preferred transportation solution under the transportation time constraint. For example, if a transportation cost is required at less than £0.5k, the global manufacturing co-ordination system recommends using transportation of flight 131 or flight 132.

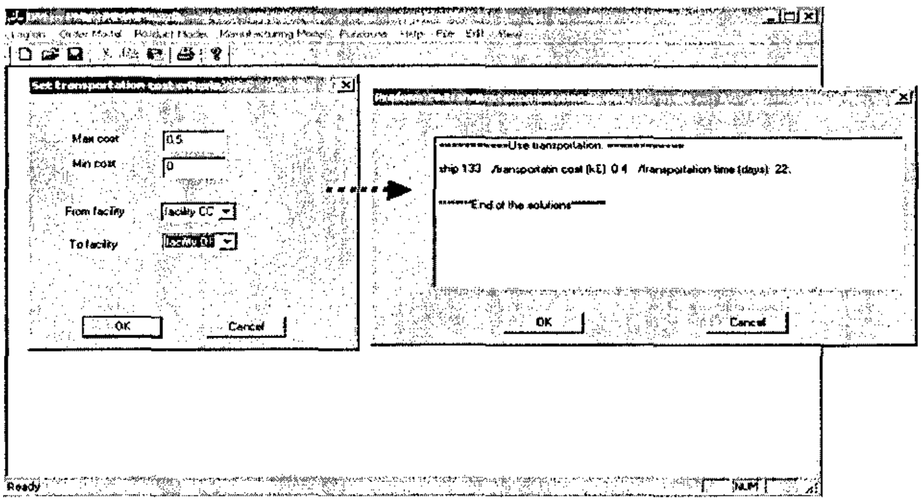


Figure 7-31 Low cost preferred transportation solution

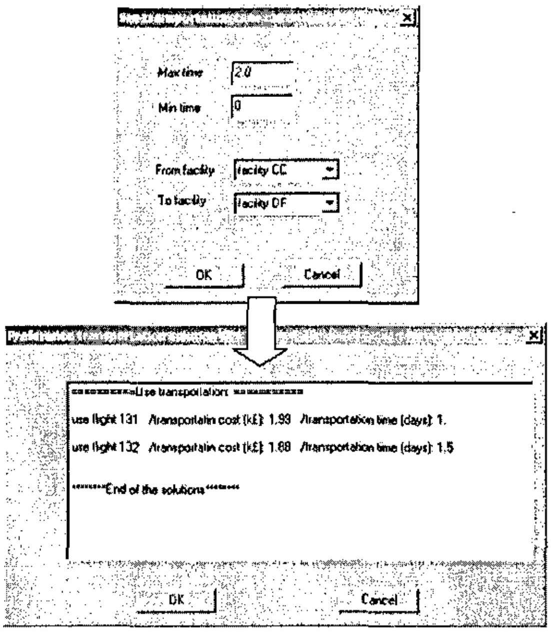


Figure 7-32 Short time transportation solution

7.5 Summary

This chapter explains the development and implementation of the experimental system, and demonstrates the result of the experiments.

The results show that the information and knowledge structure of global manufacturing capability explored in this work can capture the required classes of information and knowledge as well as the relationships between the classes. The information and knowledge models have been shown to work in the context of the global manufacturing co-ordination system application to Aeolus Automotive Corporation. However, the global manufacturing co-ordination system is not restricted to specific product ranges or manufacturing processes, and therefore has much wider applicability. More importantly, the manufacturing information and knowledge structures explored in this work provide the capability to construct information and knowledge models which do not have to be restricted to particular industry areas. With some simple changes of the interface design and programming of the global manufacturing co-ordination system, the manufacturing information and knowledge models can be applied to situations involving with more products and global enterprise configuration with more supply tiers.

8 Discussion, Conclusions, and Further Research Recommendations

8.1 Introduction

The research reported in this thesis has explored the structure of manufacturing information and knowledge models as well as the necessary interaction mechanisms between the models. The use of the information and knowledge models to support global manufacturing co-ordination decisions has been investigated through an experimental system and an industrial case study.

This chapter summarises the research that has been undertaken. First section 8.2 discusses the important issues that have arisen in the research process. Then section 8.3 presents the conclusions that have been reached in the research. Finally, section 8.4 gives some recommendations for further work.

8.2 Discussion

This research proposed the concept of a manufacturing information and knowledge model to support global manufacturing co-ordination as described in chapter 3, and illustrated in figure 3-6. This approach is based on the idea that separates information and knowledge models from applications (Young, Canciglieri-Jnr et al, 2002).

(1) Methodology of Capturing Manufacturing Information and Knowledge

This research used a multi-perspective-modelling (MPM) approach to explore the information and knowledge requirements for global manufacturing co-ordination, which was discussed in chapter 4, in line with (Dorador and Young 2000; Abdullah et al, 2002; Kim and Weston, 2003).

The multi-perspective modelling approach including IDEF0 activity modelling, IDEF3 process modelling, and UML, has been found useful in the exploration of global manufacturing co-ordination. Because each method taken in this research models a specific aspect of information and knowledge, the three methods complement each other and represent more complete information and knowledge required for global manufacturing co-ordination. The author believes that multi-perspective modelling approach has obvious advantages in modelling complex domains such as global manufacturing co-ordination. The combined use of IDEF0, IDEF3, and UML may be not the only way to model the global manufacturing co-ordination scenario. However, a problem of using a multi-perspective modelling approach lies in which modelling methods should be selected to work together. If the modelling methods chosen are not compatible with each other, the purpose of use the multi-perspective modelling approach to produce different models of the same artefact to support different viewpoints cannot be achieved. The compatibility between IDEF0, IDEF3, and UML has been discussed in section 4.5.

(2) Structure of the Manufacturing Model

The manufacturing model explored in this research provides all global manufacturing capability information rather than specific aspect(s) of the manufacturing capability (Maropoulos et al, 2001). This makes it possible to conveniently model the strict relationships between different aspects of global manufacturing capability including process, resource, configuration and knowledge, as discussed in chapter 5, section 5.3.1. Modelling the four aspects of global manufacturing capabilities in one manufacturing model, complex information and knowledge links between models can be reduced, which improves the efficiency of information access and retrieval.

In the structure of the manufacturing model explored in this research, configuration class is a new class, compared with previous work in this area (Molina, 1995; Zhao, Cheung and Young, 1999; Giachetti, 1999). The definition of the configuration class in the manufacturing model provides the capability of a manufacturing facility to access network-based resources and flexible manufacturing capability in response to rapidly changing global market requirements. The exploration of the configuration information structure is focused on process-specific type, which applies to the situation of global partnership using outsourcing strategies to survive global competition. The definition of the attributes for the configuration class provides a way to evaluate the performance of each configuration such as the collaboration possibilities between the facilities. The exploration of the configuration information structure is based on the not very detailed understanding of the collaboration in terms of information communication between facilities.

The knowledge class is another new class which was upgraded from the strategy class in the existing manufacturing model structures (Molina, 1995; Zhao, Cheung and Young, 1999). The definition of the knowledge class in the structure provides the potential to retrieve standard and consistent solutions for global manufacturing co-ordination decisions under specific conditions. As discussed in section 5.2.4, the creation of the constraint class, relation class, and solution class in the knowledge structure makes it possible to capture required co-ordination knowledge such as task assignment knowledge and transportation knowledge. More types of co-ordination knowledge need to capture to expand the use of the manufacturing model to more situations.

Time has a crucial importance in real world applications where entities change continuously. For instance, In the case of global manufacturing co-ordination, both manufacturing resources and transportation resources available for specific manufacturing processes change from time to time. Hence, this research imposes time constraints to support the storage and querying of information that varies over time, in line with (Rodriguez, Ogata and Yano, 1999; Ozsoyoglu and Snodgrass, 1995). The time constraints definition has been based on a point of time (ISO 15531-42). However, time constraints can also be based on a time interval, which has not been tried in this research.

Two levels of manufacturing model are involved in global manufacturing co-ordination, i.e. enterprise level manufacturing model and factory level manufacturing model. This research has been focused on an enterprise level manufacturing model, but there is a further need to consider its interaction with a factory level manufacturing model. This has been discussed in chapter 6 and illustrated in figure 6-10. The integration of the two levels of manufacturing model is still a challenge. As shown in the figure 8-1, the first step would focus on investigating the bi-directional relationship between the manufacturing model at enterprise level and the manufacturing model at factory level, then it would be possible to explore how the changes of global decisions will affect local decisions, and vice versa.

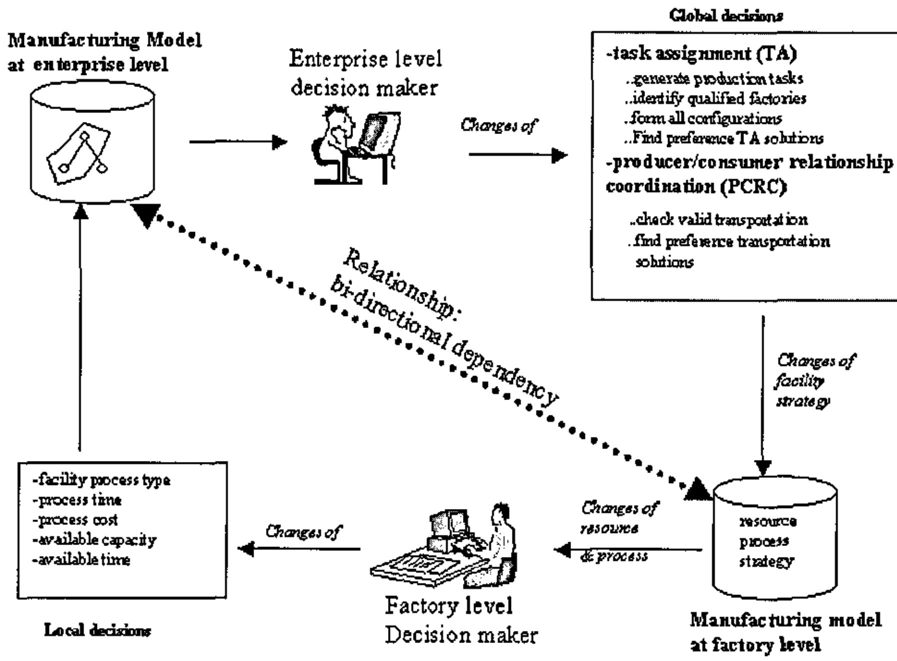


Figure 8-1 Relationship between enterprise level MM and factory level MM

(3) The Structure of the Product Model and the Order Model

Most structures of product model address the product properties such as geometry, material, tolerance, surface finish, and product volume. However, for global manufacturing co-ordination other properties of a product such as product structure and manufacturing views are important and therefore need to be captured in a product model.

The product structure has been modelled with reference to the standard ISO 10303 part 44. There are two important aspects with respect to the product structure. One is the definition of different levels of the decomposition of a product. The other is the specification of proper relationships between different levels of the decomposition of a product. This has been explored in chapter 6 section 6.2.1.1.

The manufacturing view provides a viewpoint for manufacturing engineers to look at the product. Different from the design view of product structure, which are called as Engineering Bill of Material (E_BOM) (Chang, Lee and Li, 1997), the manufacturing view of the product structure leads to a Manufacturing Bill of Material (M_BOM), which forms the constraints to enterprise level process planning. The definition of the manufacturing view class in the product model structure provides the potential of the interaction between the product model and the manufacturing model.

The information about product characteristics such as geometry and material has not been discussed in detail in the product model structure in this work, which does not means these product characteristics are less important. In fact, at a factory level or any other lower levels, the product features are very important and have to be captured by the product model structure, as illustrated in figure 6-10.

Order related information has been modelled in the structure of order model. Order information is an important bridge which links customer requirements and the products that a global enterprise aims to provide. In this research, the information structure of the order model is quite simple and focuses on the ProductOrder class and its relationship with Product class. If more aspects of a customer order such as product service are required, more information should be added to the order model structure. But in this research the customer requirement of an order is limited to products.

(4) Interaction between Information and Knowledge Models

The three information and knowledge models, i.e. a manufacturing model, a product model, and an order model, explored in this research need to work together and collaboratively to support global manufacturing co-ordination. Therefore, appropriate interaction mechanisms between models have been explored for the effective access and retrieval of required information and knowledge throughout the manufacturing model, the product model, and the order model.

The link from the order model to the product model is realised by recognising the unique identification of products and the "part of" relationship between a product and an order, which has been facilitated to implement in the object-oriented environment taken in this work. The link from product model to manufacturing model has been built by the creation of a bridge between product properties and manufacturing capabilities, i.e. the creation of a ManufacturingView class in the product model that provides the possibility to look at the product from manufacturing engineer's point of view, thus building the connection to the manufacturing model. This mechanism allows bi-directional interaction between the order model and the product model, but a one-way interaction from the product model to the manufacturing model. This means that if order information is known its product information can always be obtained, and vice versa. But the communication between the product properties and manufacturing capabilities can only be initialised by product information, i.e. according to the product property information, appropriate manufacturing process information, resource information, configuration information and knowledge can be retrieved, while the manufacturing model cannot start the communication with the product model. This adapts the situations that manufacturing enterprises are driven by global markets (customer orders and products), but market requirements are not decided by global manufacturing capabilities of enterprises.

(5) The Application of Information and Knowledge Models

The experimental system developed has been shown to be adequate for exploring the research ideas discussed in this thesis. It has demonstrated how the manufacturing model can capture the required information of process, resource, configuration, and knowledge of global manufacturing capability. The use of UML notation alongside use case models has provided effective support for the design and representation of the experimental system developed.

The application of the information and knowledge models within the global manufacturing co-ordination scenario can be significantly dependent on the number of product types and the complexity of the global enterprise supply chains. A case study has been performed in automotive industry based on specific assumptions. However, it is not necessarily constrained to specific product types or specific tiers of global supply chain, therefore, there is the potential for the information and knowledge models to be applied to support other global manufacturing occasions such as electronic industry.

8.3 Conclusions

(1) A new information and knowledge structure for a manufacturing model has been defined for global manufacturing co-ordination applications. Four main information and knowledge classes have been created. These are process class, resource class, configuration class, and knowledge class.

(2) The creation of the configuration class in the structure of the manufacturing model reflected the flexible capability of a global enterprise to access dynamic and unlimited resource through network.

(3) The consideration of the knowledge class in the structure of the manufacturing model provided consistent co-ordination solutions under a global manufacturing environment, and improved the intelligence of the manufacturing model.

(4) It has been shown that all types of global manufacturing capabilities are structured in one manufacturing model have the advantage of detecting the contradiction between information and knowledge types. The specification of relationship between the four main classes of information and knowledge makes it convenient to impose strict constraints between the information and knowledge classes, and avoid information and knowledge discrepancies.

(5) A product model and an order model have also been identified besides the manufacturing model. The structure of the product model addresses product hierarchy and manufacturing view at enterprise level as well as parameter, material, tolerance, surface finish and product volume. The customer and order delivery information has been modelled in the structure of order model.

(6) The link between the information and knowledge models has been built on the common structures of particular information classes in different information and knowledge models, i.e. the Product class for the bridge of order and product model, and ManufacturingProcess class for product and manufacturing model.

(7) An experimental system has been developed using the object-oriented database management system ObjectStore, Visual C++ programming language, and Rational Unified Process environment. The system has been explored using a real case from automotive industry to successfully demonstrate the feasibility of the manufacturing information and knowledge model concept to support global manufacturing co-ordination decisions.

8.4 Recommendations for Further Research

(1) This research has defined an information and knowledge structure to represent global manufacturing capability, and has explored how a manufacturing model together with a product model and an order model to support global manufacturing co-ordination. The implementation of the manufacturing model at global enterprise level has also been demonstrated. However, there is a need to further investigate the interdependency of a manufacturing model at the global enterprise level and at the local facility level.

(2) The definition of the structure of the manufacturing model in this research is based on the information and knowledge requirements of two specific cases of global manufacturing co-ordination: task assignment and producer and consumer relation co-ordination. Further work should identify more cases of global manufacturing co-ordination and expand the applications of the manufacturing model.

(3) The definition of a configuration class in the structure of the manufacturing model is an important aspect of this research. It provides the flexibility of the manufacturing model so that it adapts to the global enterprise rather than a single facility. The author believes that further work on configuration information would make the manufacturing model more valuable:

- The discussion of the information structure of the configuration class is restricted to process-specific configuration type. Further investigation in other configuration types such as product-specific configuration would be useful;
- The discussion of the performance of a configuration has been built on the understanding of product and manufacturing data type, data standard referred, and communication media used in involved facilities. What other factors could be important to affect the collaboration between facilities is still to be identified.

(4) The introduction of a knowledge class in the manufacturing model is another important aspect of this research. The following may be worth further exploring: identify and define more patterns to retrieve co-ordination knowledge. For instance, how to use total quality pattern to retrieve preferable task assignment knowledge as well as the use of patterns of cost, time, collaboration possibilities (see section 7.4.4.4).

(5) The manufacturing information and knowledge models have been explored to the application of automotive industry, and shows the potential for application to wider areas, which can only be tested by further work.

Papers

The papers to which this work has contributed:

(1) **S. Liu** and **R.I. Young**, Utilising Information and Knowledge Models to Support Global Manufacturing Co-ordination Decisions, International Journal of Computer Integrated Manufacturing (IJCIM), (Accepted to be published in 2004).

(2) **R.I. Young**, A. Espinosa, G. Gunendran, D. Guerra and **S. Liu**, 2003, Information and knowledge sharing in design decision support, Concurrent Engineering: Advanced Design, Production and Management Systems, 147-153.

(3) **S. Liu** and **R.I. Young**, 2003, Exploration of the information and knowledge structure for global manufacturing capability, 9^{th} CACSUK, Luton, 20 September.

(4) **S. Liu** and **R.I. Young**, 2001, Information models for the global manufacturing enterprise, Advances in Manufacturing Technology - XV, 307-312.

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Zhao, J., Cheung, W. M. and Young, R.I.M., 2000, The influence of manufacturing information models on product development systems, Engineering Design Conference, Brunel University, UK, 27^{th}-29^{th}.

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Appendix A IDEF0 Representation of Global Manufacturing Co-ordination

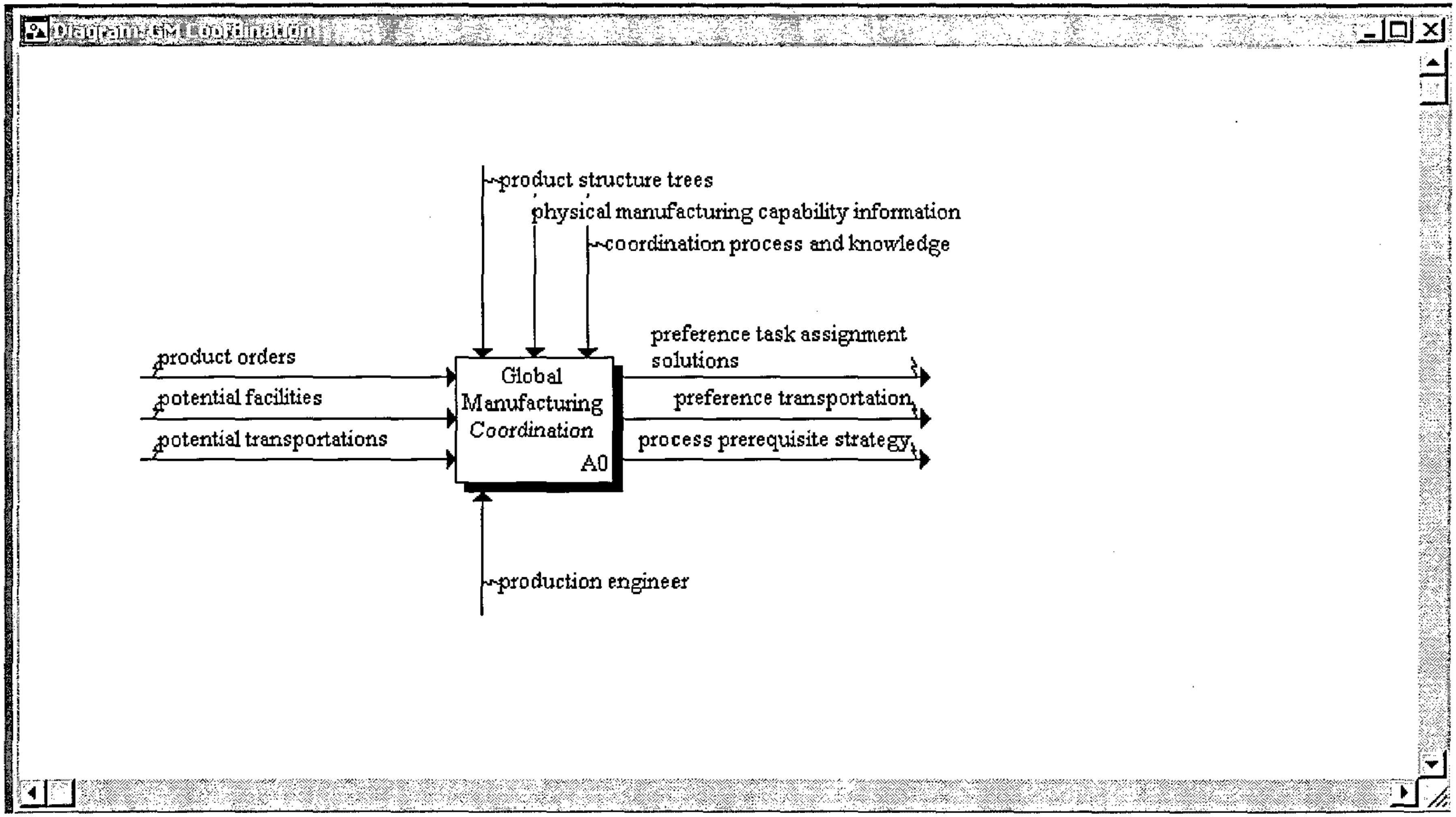
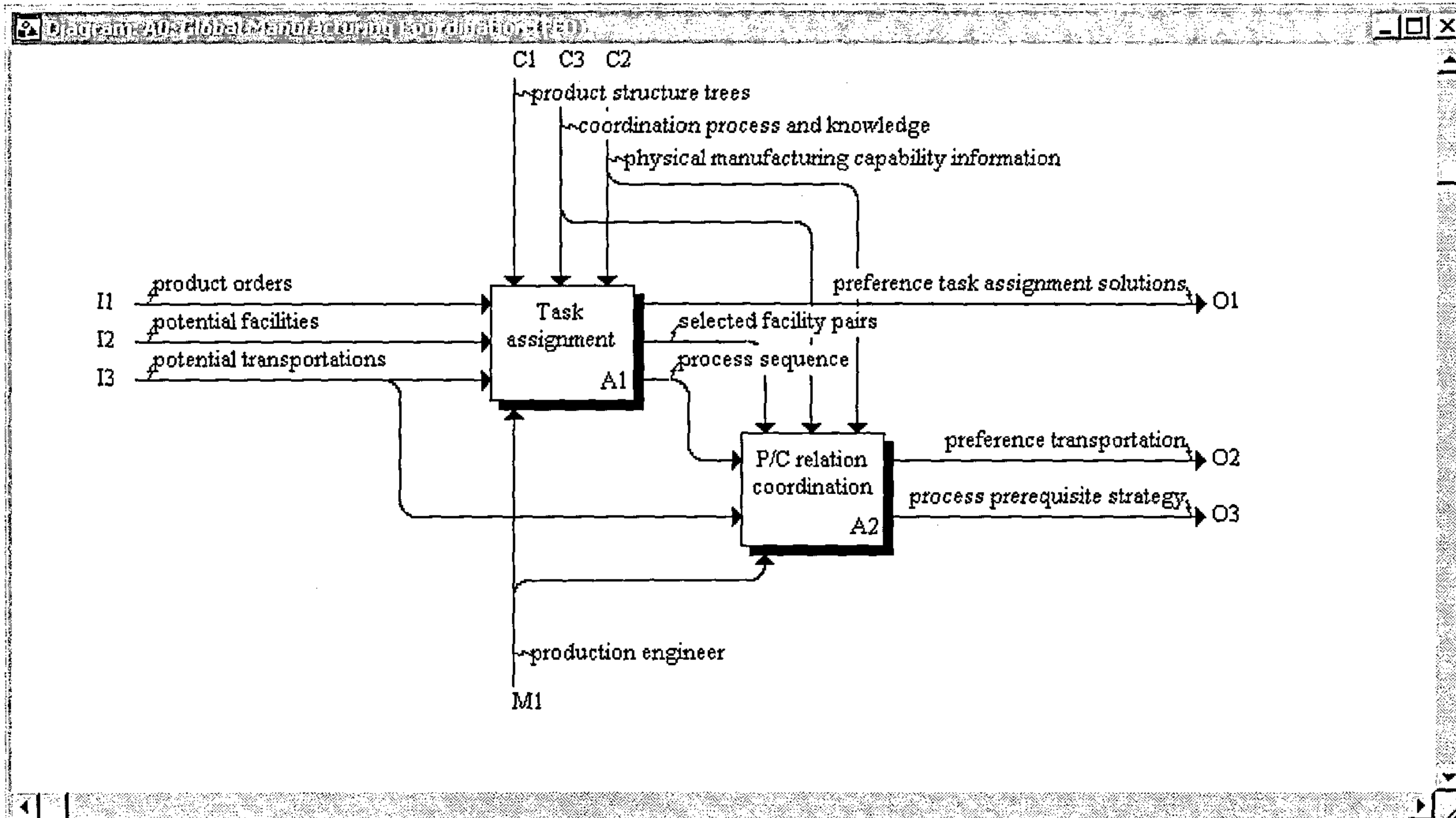
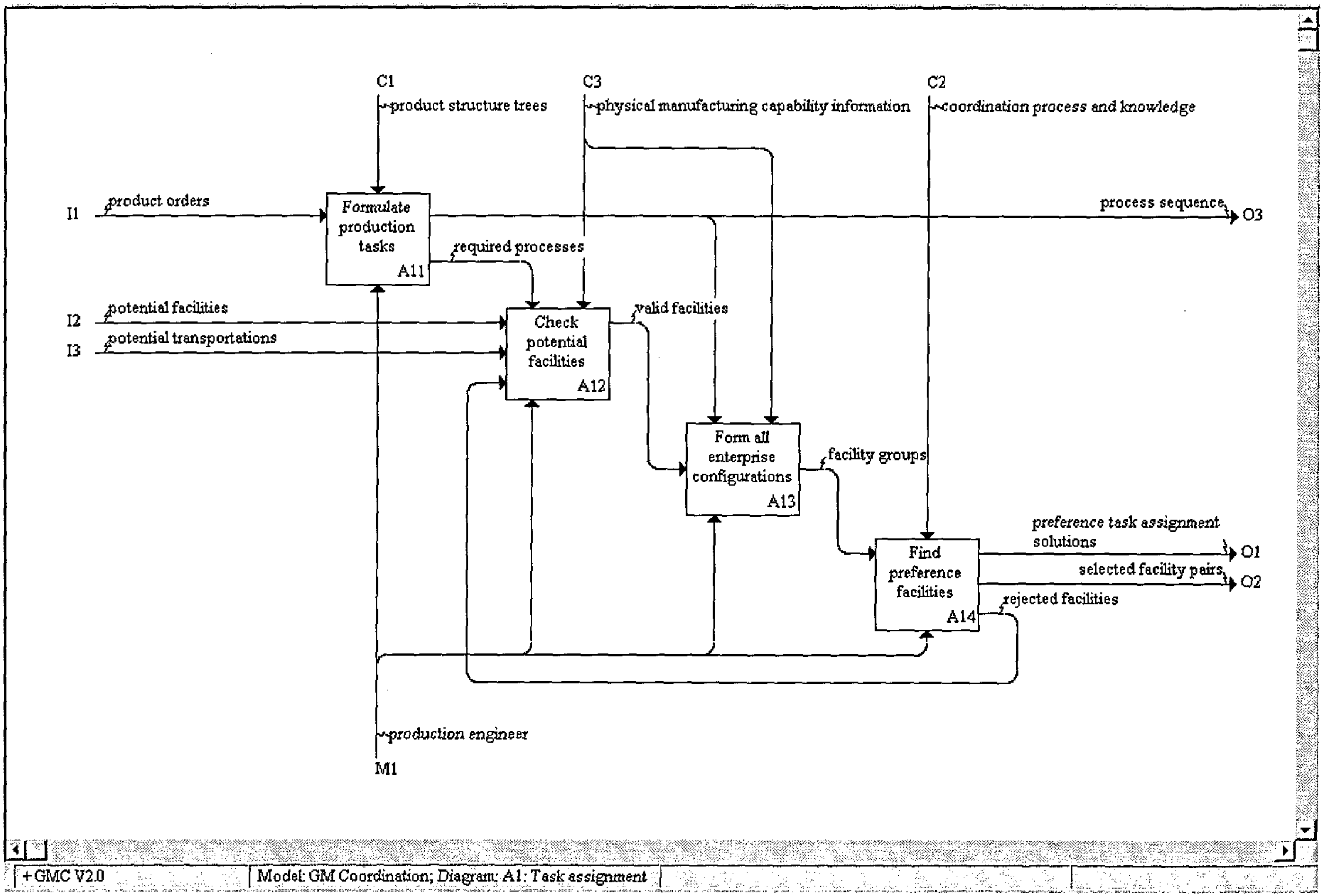


Diagram: GM Coordination
product structure trees
physical manufacturing capability information
coordination process and knowledge
product orders
potential facilities
potential transportations
Global Manufacturing Coordination
A0
preference task assignment solutions
preference transportation
process prerequisite strategy
production engineer


C1
C3
C2
product structure trees
coordination process and knowledge
physical manufacturing capability information
I1
I2
I3
product orders
potential facilities
potential transportations
Task assignment
A1
preference task assignment solutions
O1
selected facility pairs
process sequence
P/C relation coordination
A2
preference transportation
O2
process prerequisite strategy
O3
production engineer
M1



C1
product structure trees
C3
physical manufacturing capability information
C2
coordination process and knowledge
I1
product orders
Formulate production tasks
A11
process sequence
O3
required processes
I2
potential facilities
I3
potential transportations
Check potential facilities
A12
valid facilities
Form all enterprise configurations
A13
facility groups
Find preference facilities
A14
preference task assignment solutions
O1
selected facility pairs
O2
rejected facilities
production engineer
M1
+GMC V2.0
Model: GM Coordination; Diagram: A1: Task assignment

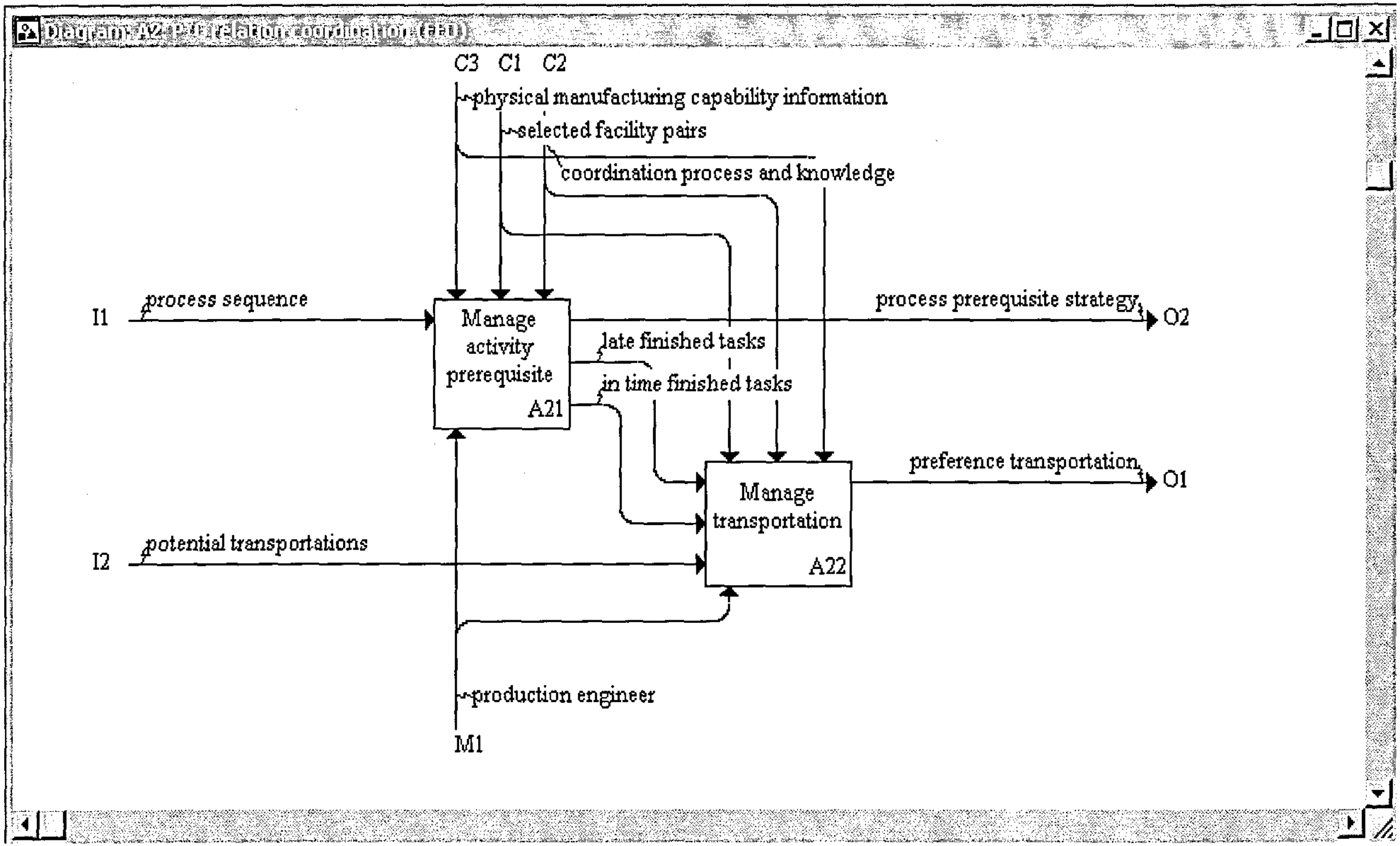
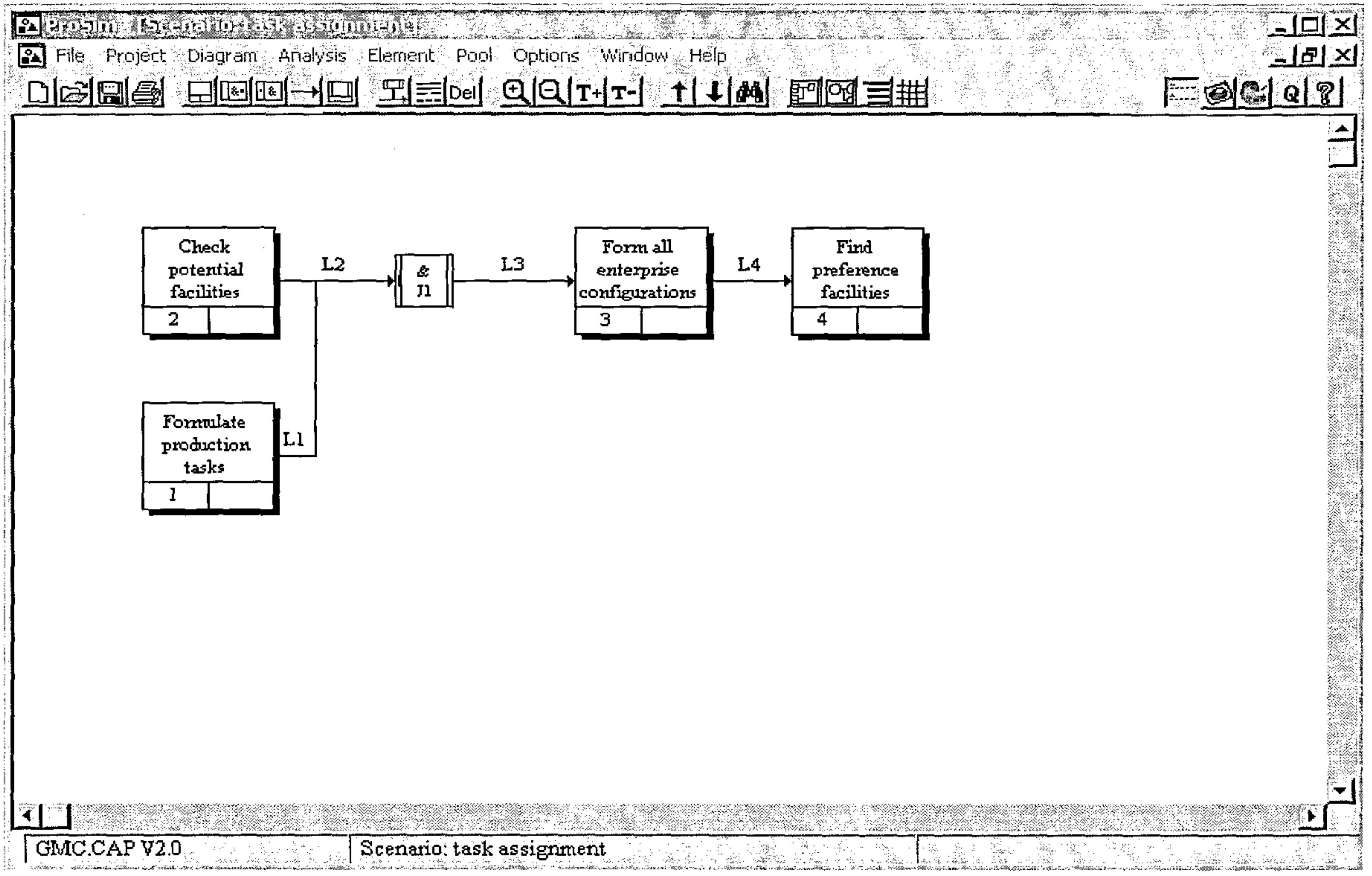
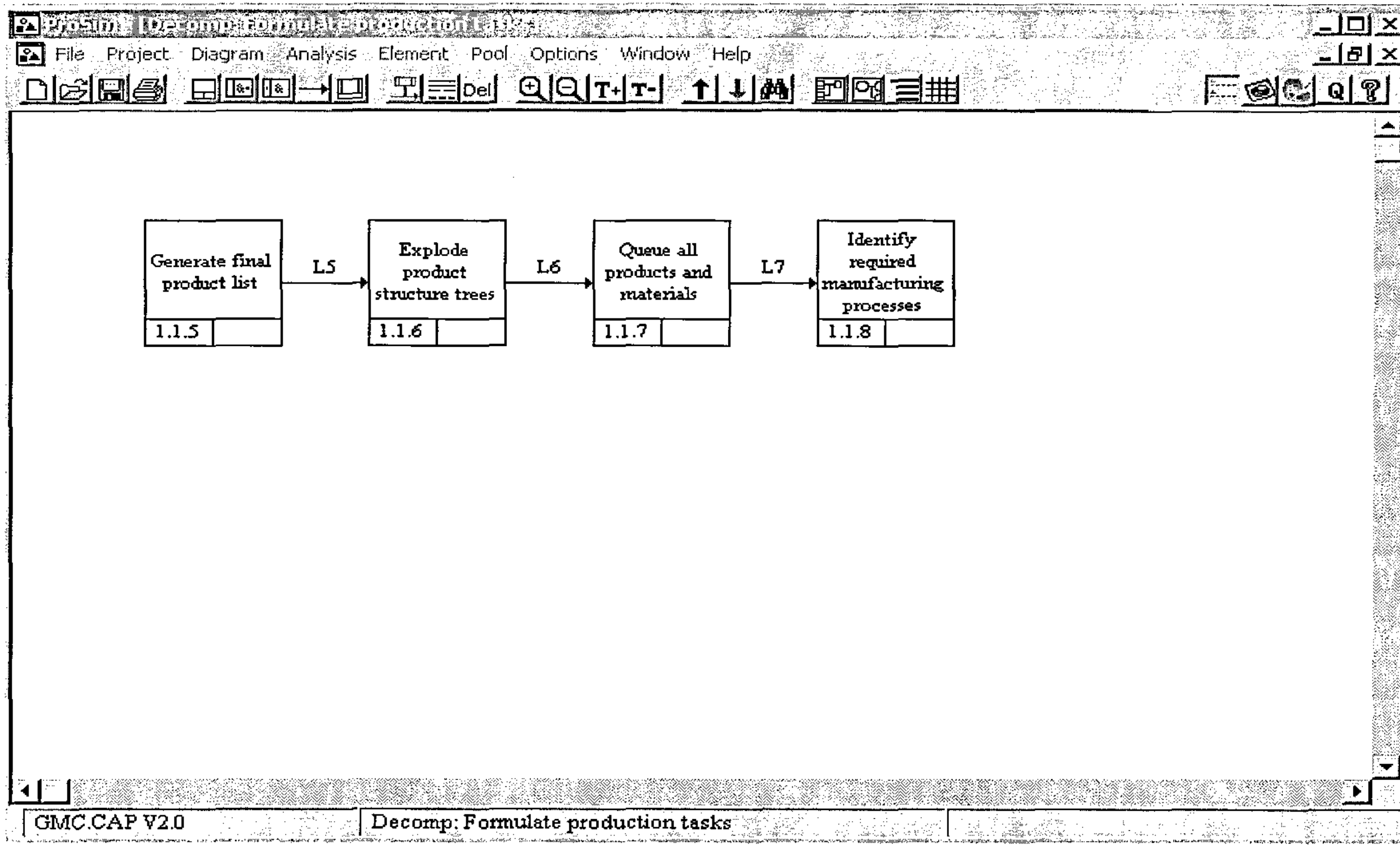


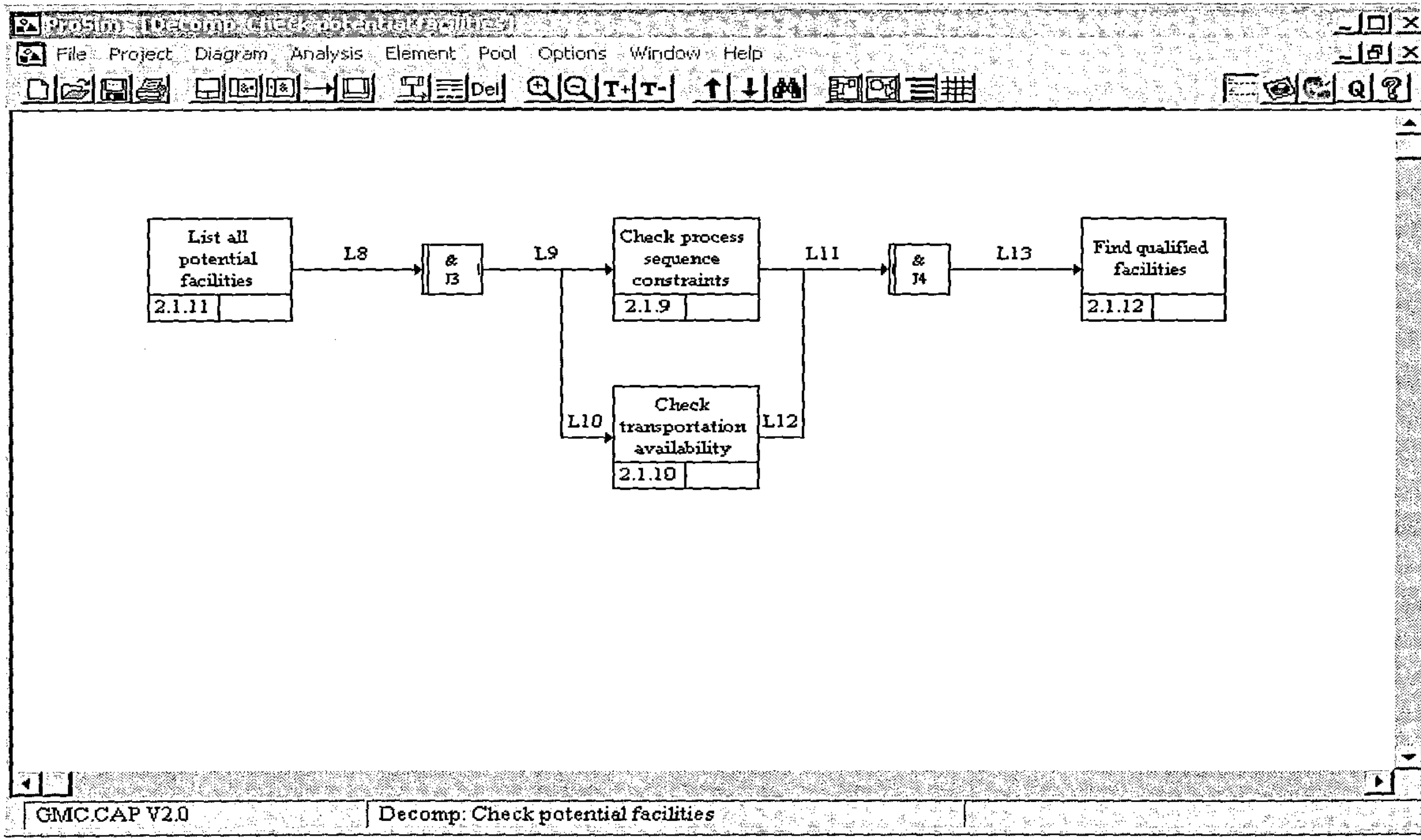
Diagram: A2 P10 relation coordination (FEO)
C3 C1 C2
physical manufacturing capability information
selected facility pairs
coordination process and knowledge
I1
process sequence
Manage activity prerequisite
A21
process prerequisite strategy
O2
late finished tasks
in time finished tasks
Manage transportation
A22
preference transportation
O1
I2
potential transportations
production engineer
M1

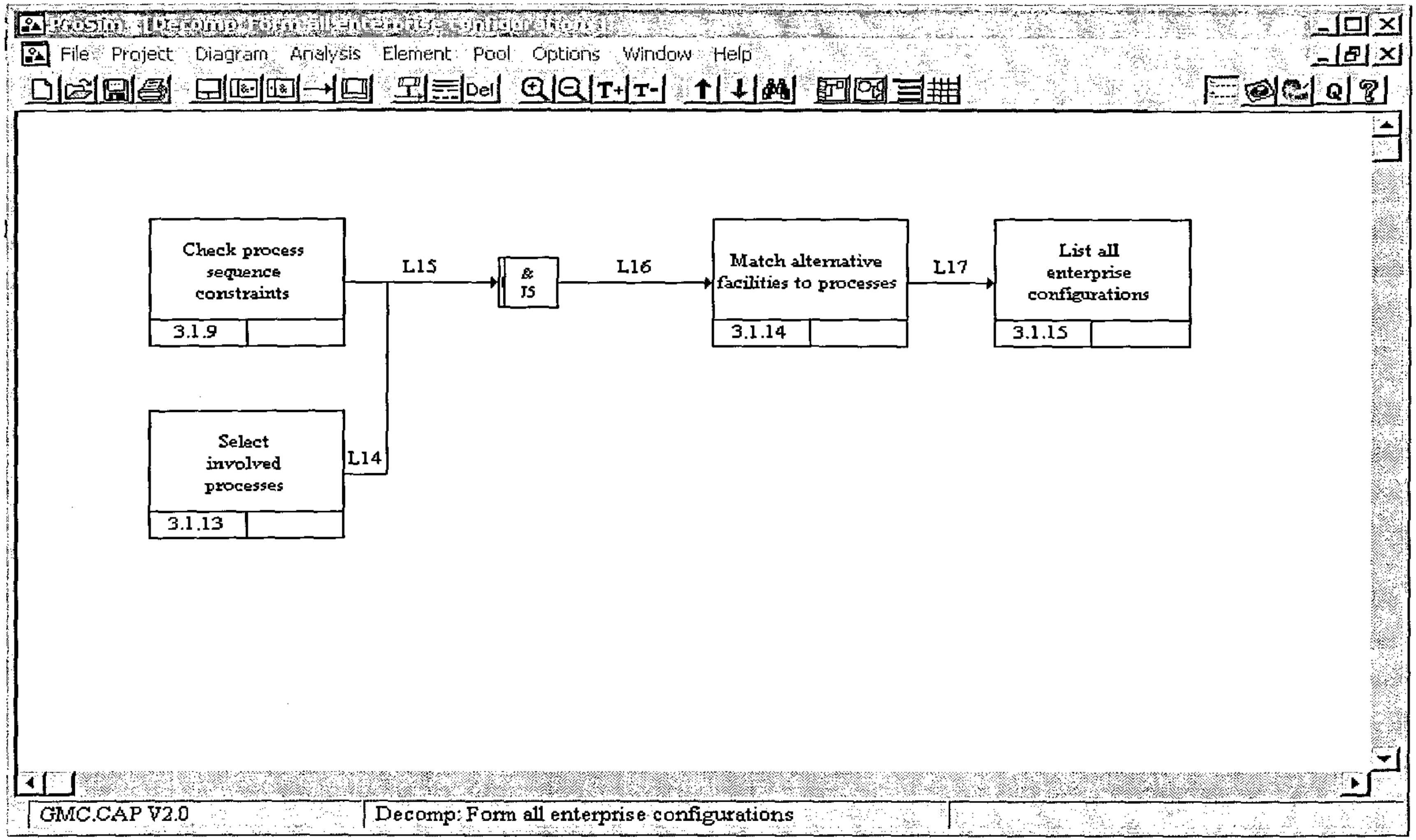
Appendix B IDEF3 Representation of Global Manufacturing Co-ordination

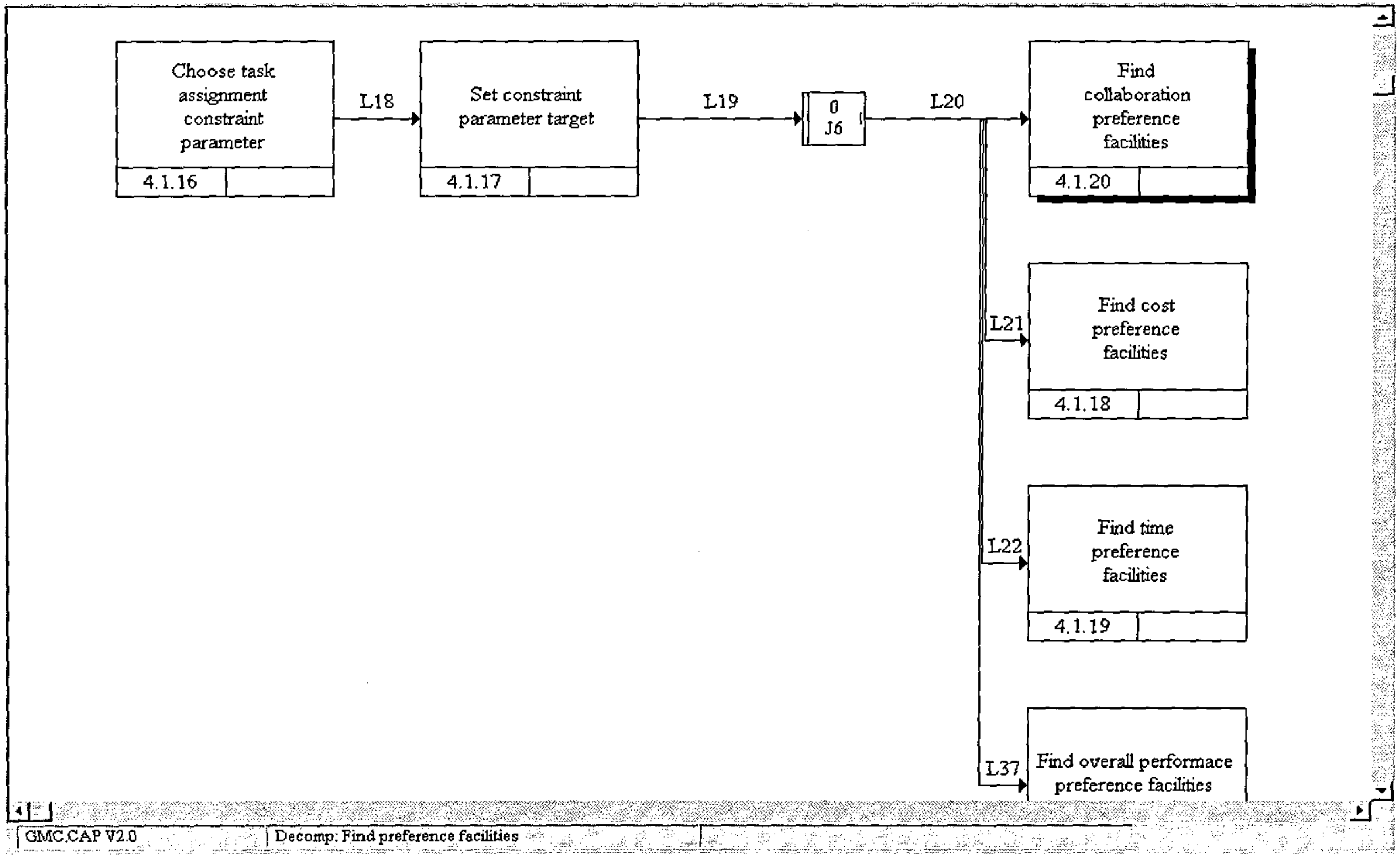
Appendix B-1 IDEF3 Process Diagrams of Global Manufacturing Co-ordination


ProSim - [Scenario: task assignment]
File Project Diagram Analysis Element Pool Options Window Help
Check potential facilities
2
L2
&
J1
L3
Form all enterprise configurations
3
L4
Find preference facilities
4
Formulate production tasks
1
L1
GMC.CAP V2.0
Scenario: task assignment

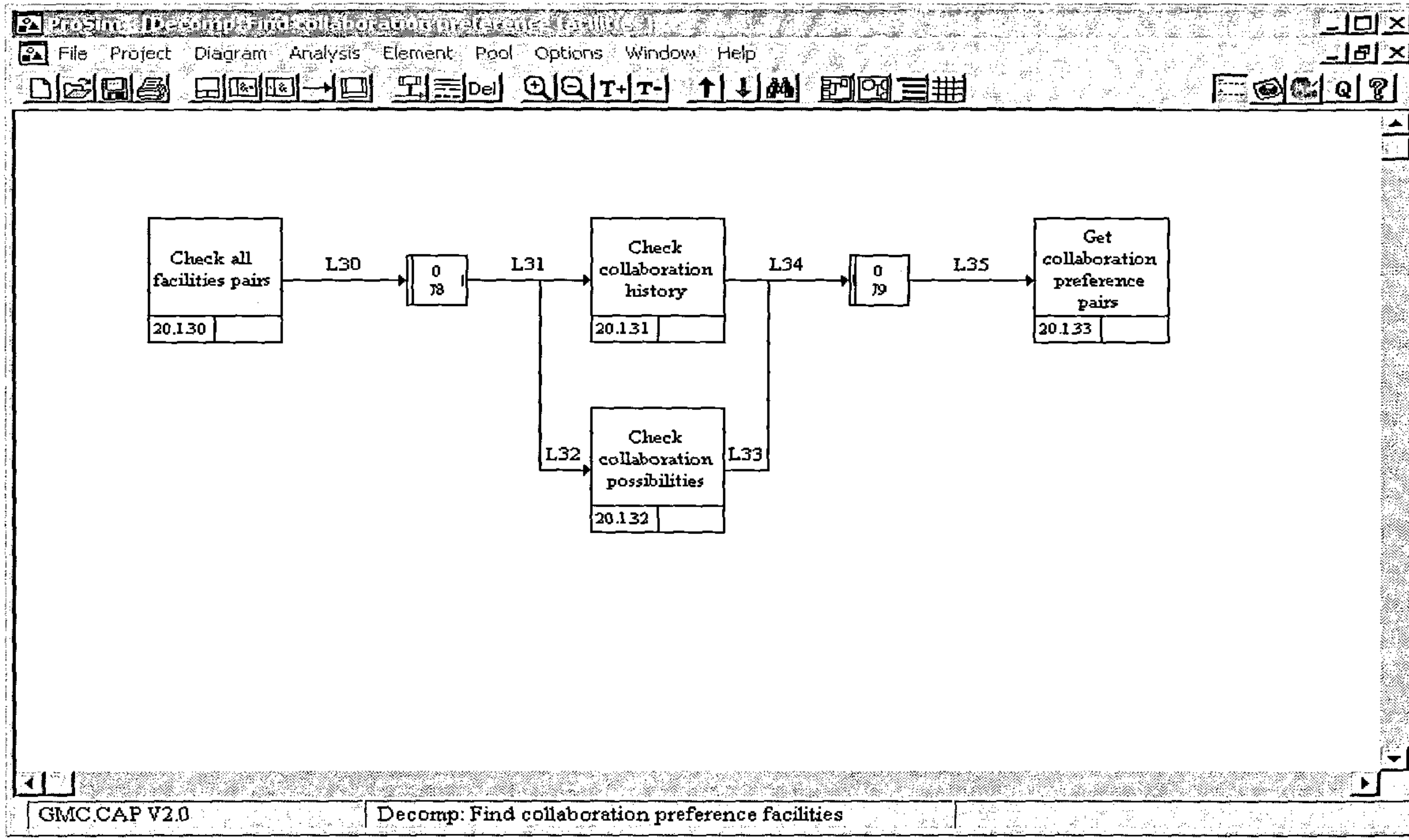

File Project Diagram Analysis Element Pool Options Window Help
Generate final product list
L5
Explode product structure trees
L6
Queue all products and materials
L7
Identify required manufacturing processes
1.1.5
1.1.6
1.1.7
1.1.8
GMC.CAP V2.0
Decomp: Formulate production tasks

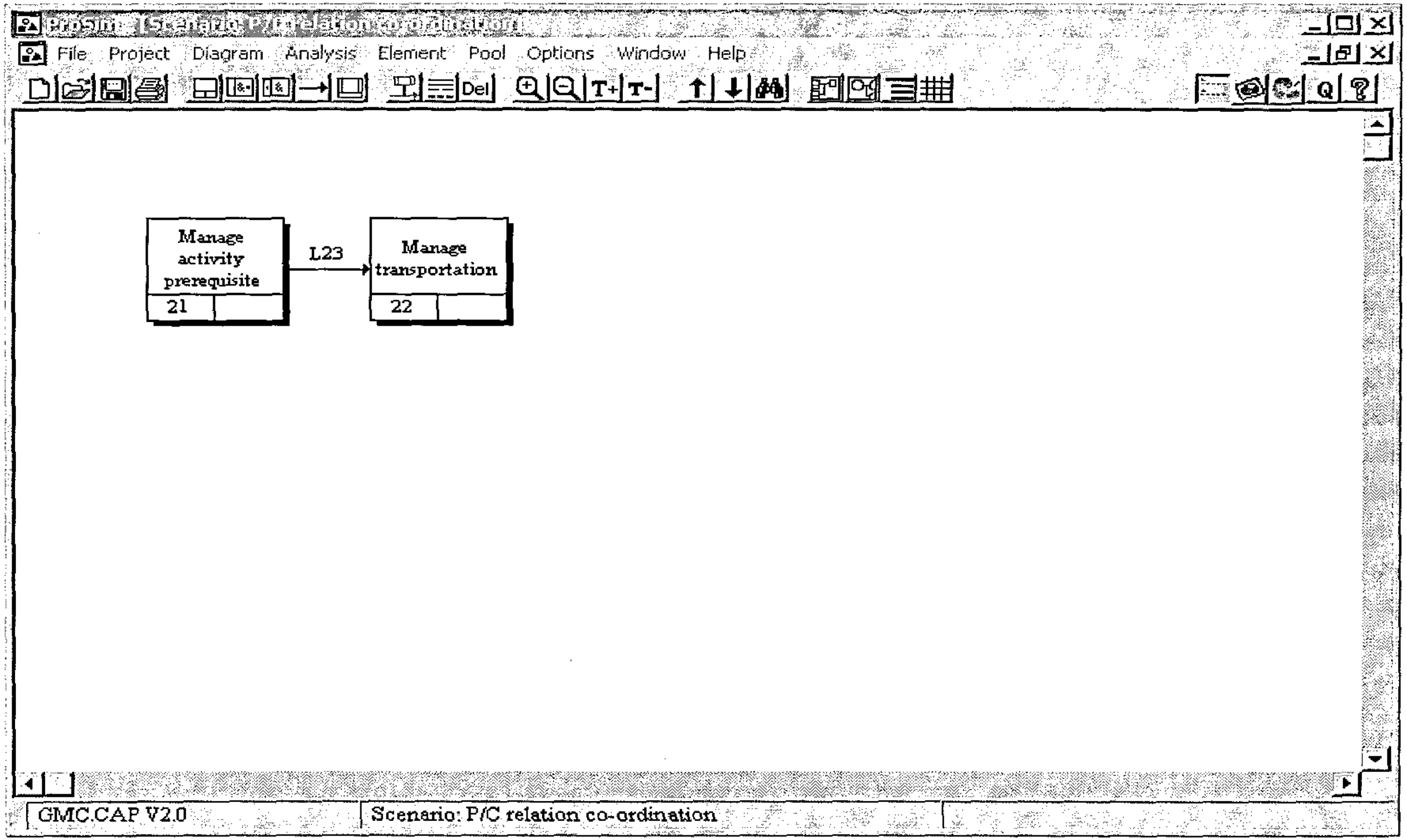

ProSim - [Decomp: Check potential facilities]
File Project Diagram Analysis Element Pool Options Window Help
List all potential facilities
2.1.11
L8
&
J3
L9
Check process sequence constraints
2.1.9
L10
Check transportation availability
2.1.10
L12
L11
&
J4
L13
Find qualified facilities
2.1.12
GMC.CAP V2.0
Decomp: Check potential facilities

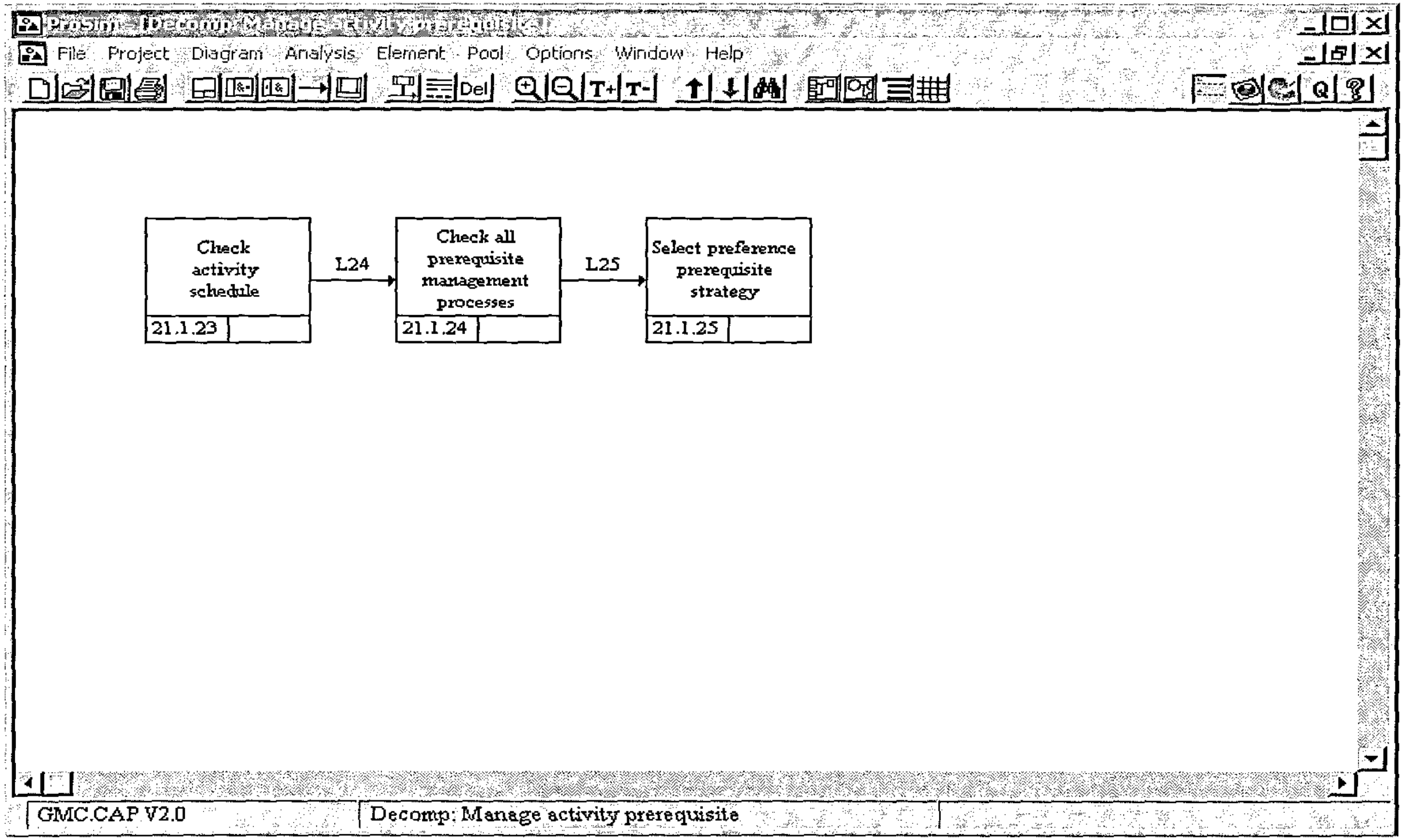

ProSim - [Decomp: Form all enterprise configurations]
File Project Diagram Analysis Element Pool Options Window Help
Check process sequence constraints
3.1.9
Select involved processes
3.1.13
L14
L15
&
J5
L16
Match alternative facilities to processes
3.1.14
L17
List all enterprise configurations
3.1.15
GMC.CAP V2.0
Decomp: Form all enterprise configurations



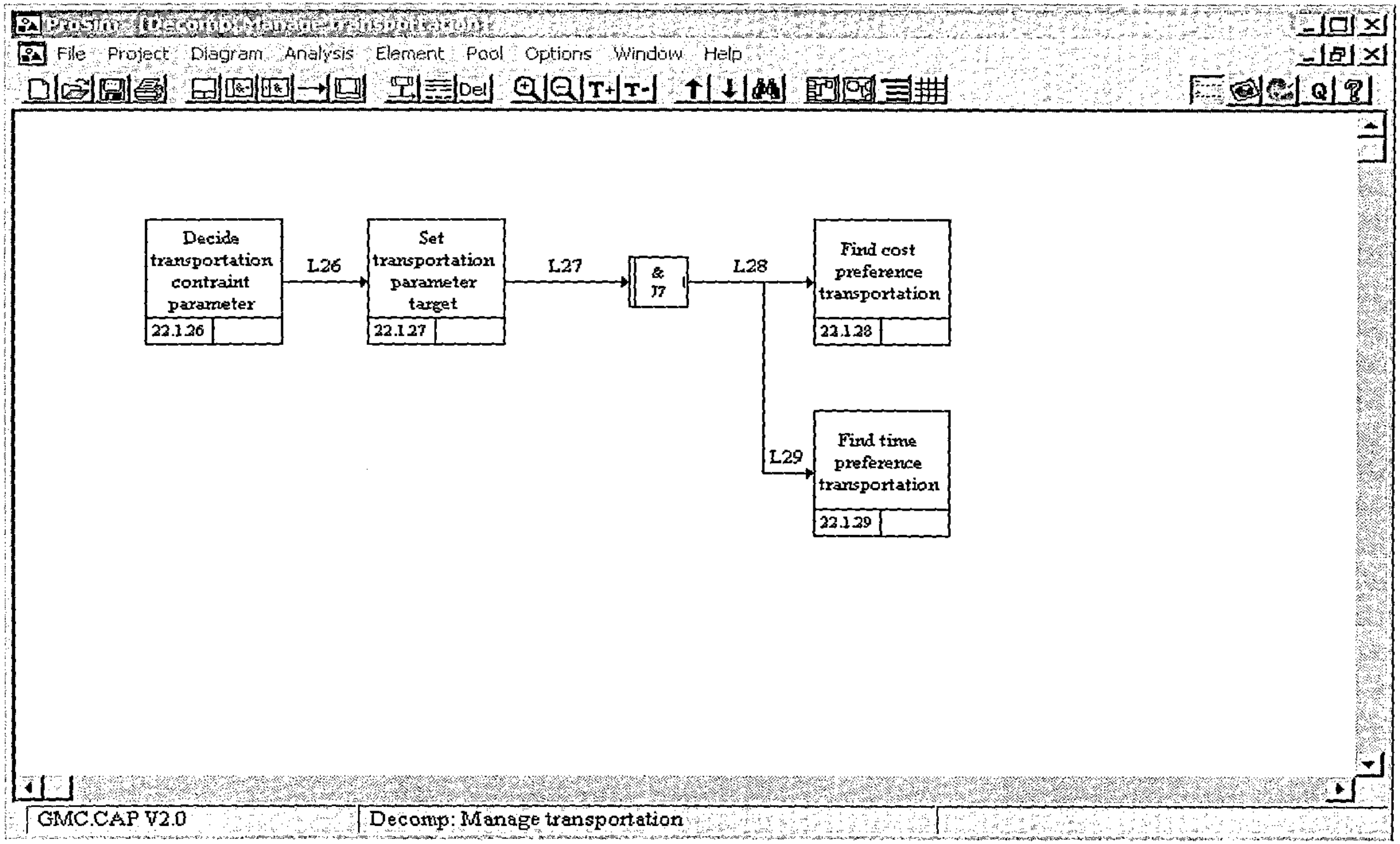
Choose task assignment constraint parameter
4.1.16
L18
Set constraint parameter target
4.1.17
L19
0
J6
L20
Find collaboration preference facilities
4.1.20
L21
Find cost preference facilities
4.1.18
L22
Find time preference facilities
4.1.19
L37
Find overall performace preference facilities
GMC.CAP V2.0
Decomp: Find preference facilities


File Project Diagram Analysis Element Pool Options Window Help
Check all facilities pairs
20.1.30
L30
0
J8
L31
Check collaboration history
20.1.31
L34
0
J9
L35
Get collaboration preference pairs
20.1.33
L32
Check collaboration possibilities
20.1.32
L33
GMC.CAP V2.0
Decomp: Find collaboration preference facilities

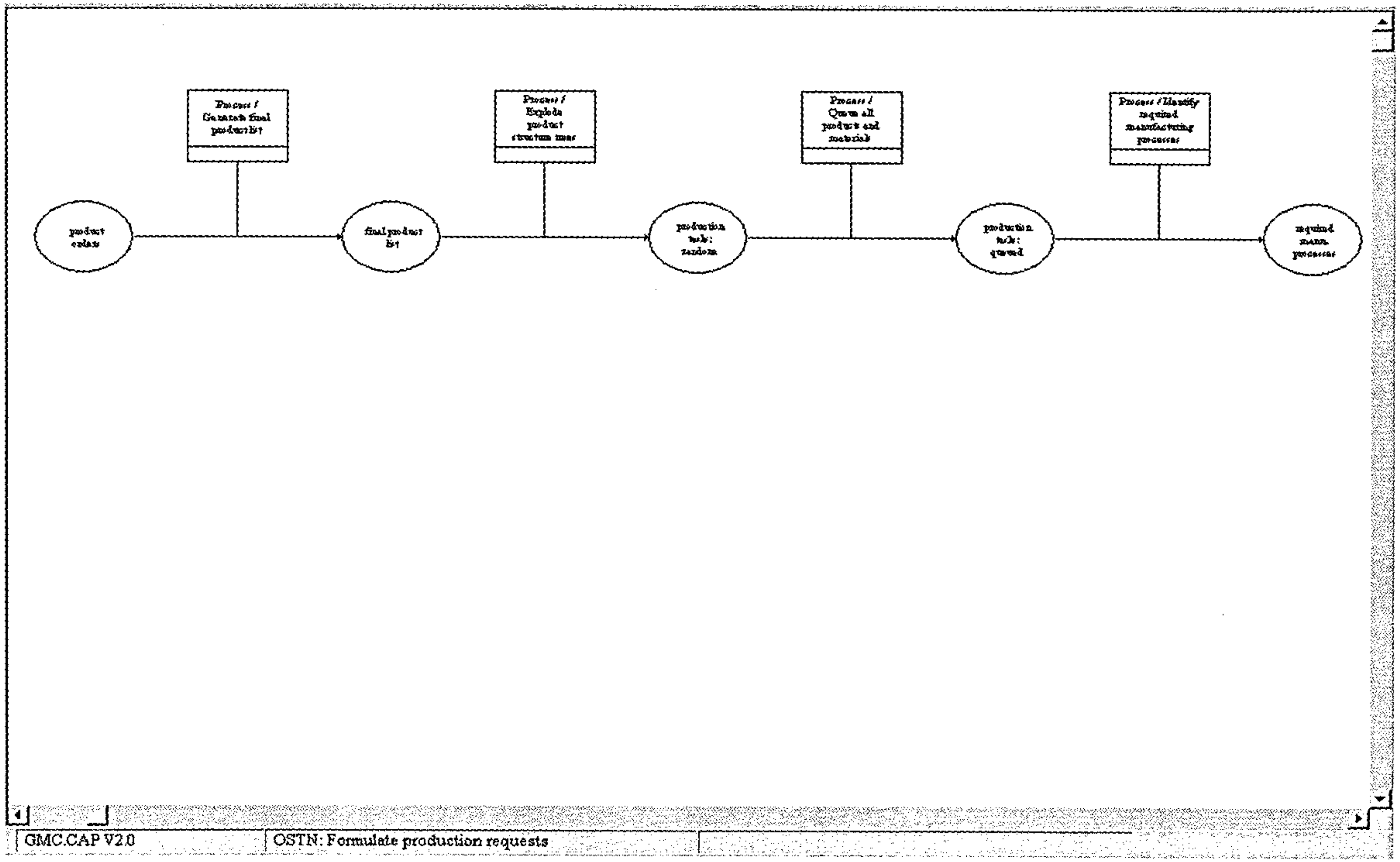

ProSim - [Scenario: P/C relation co-ordination]
File Project Diagram Analysis Element Pool Options Window Help
Manage activity prerequisite
21
L23
Manage transportation
22
GMC.CAP V2.0
Scenario: P/C relation co-ordination



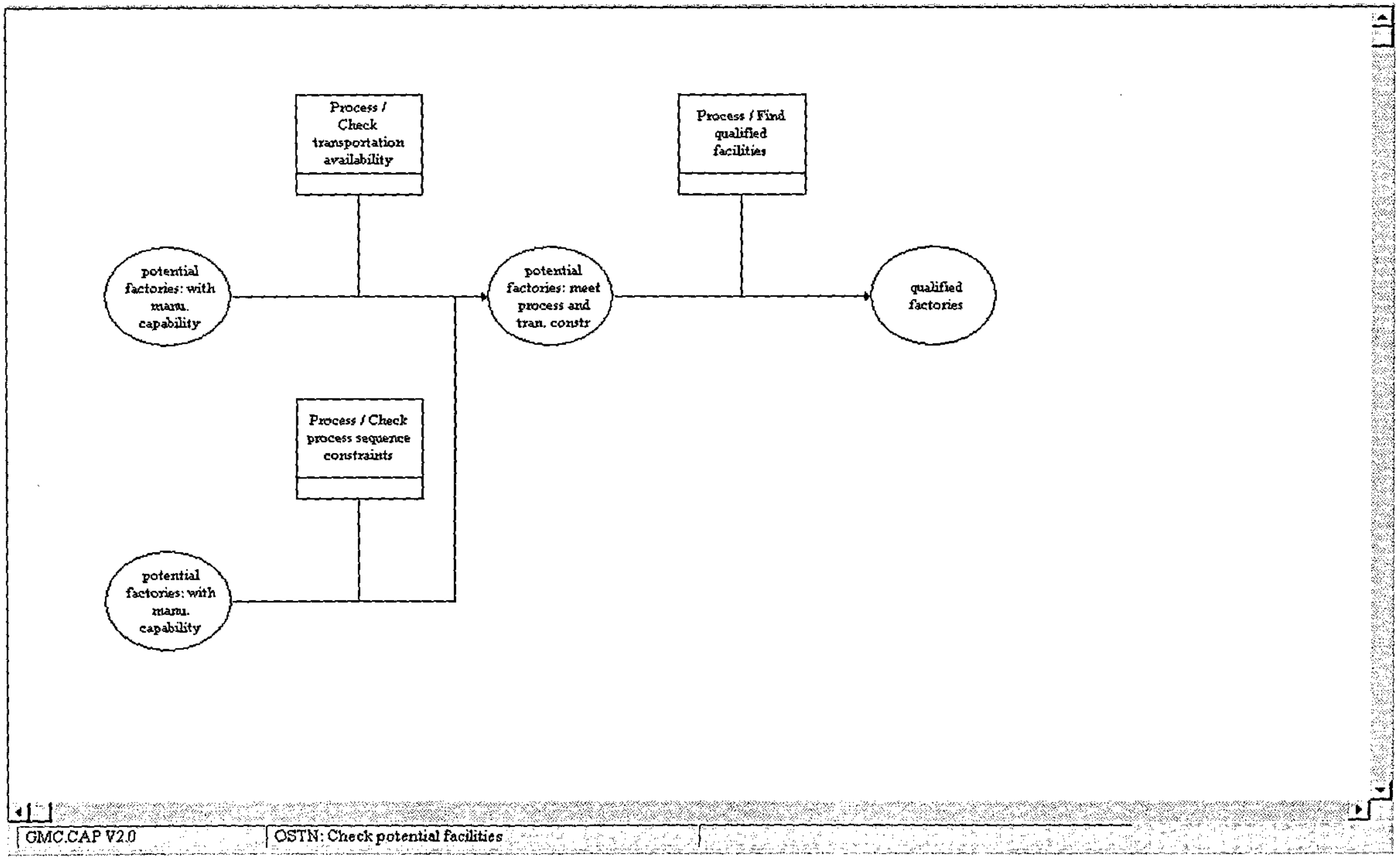
ProSim - [Decomp: Manage activity prerequisite]
File Project Diagram Analysis Element Pool Options Window Help
Del
T+
T-
Check activity schedule
21.1.23
L24
Check all prerequisite management processes
21.1.24
L25
Select preference prerequisite strategy
21.1.25
GMC.CAP V2.0
Decomp: Manage activity prerequisite

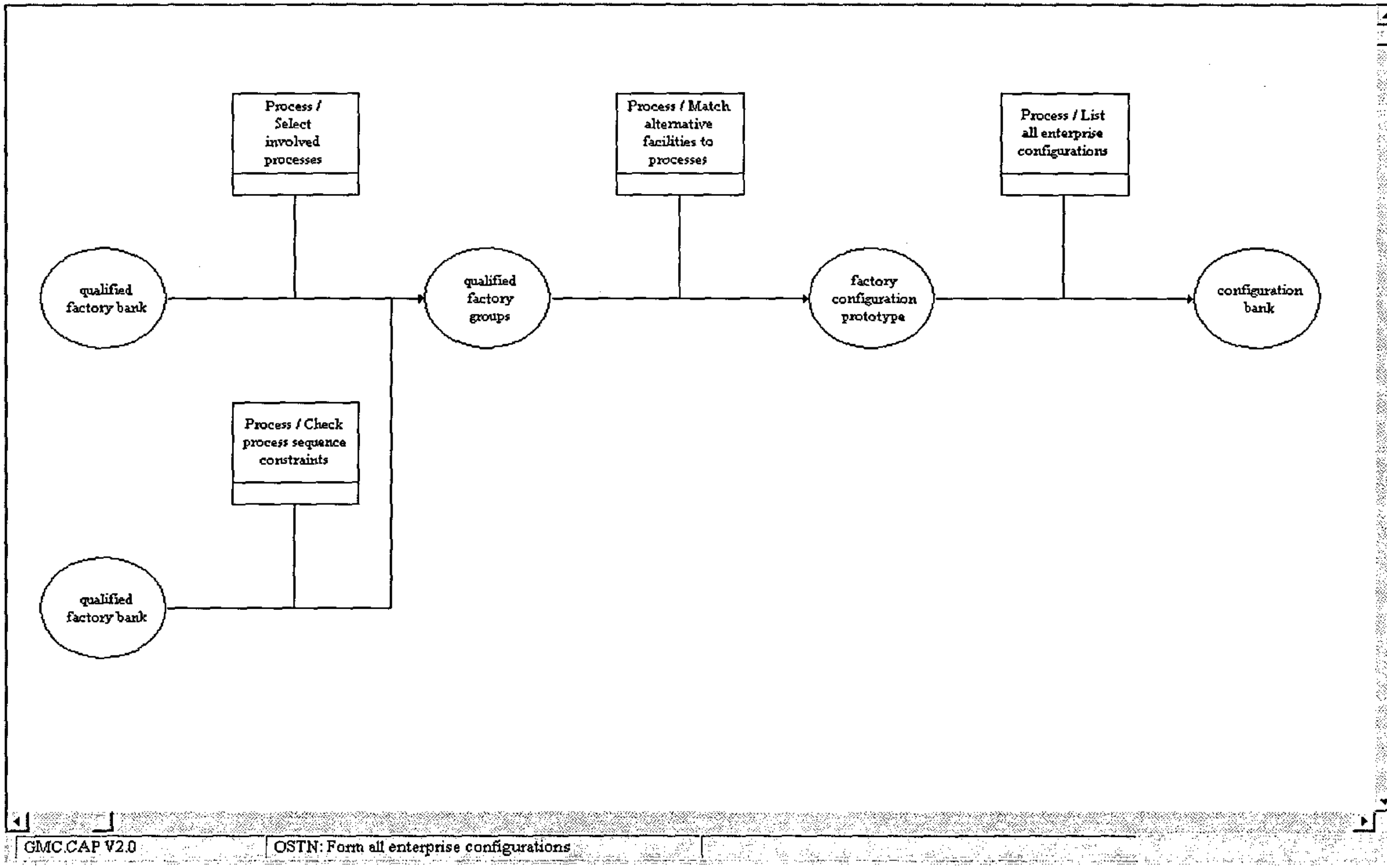

ProSim - [Decomp: Manage transportation]
File Project Diagram Analysis Element Pool Options Window Help
Decide transportation contraint parameter
22.1.26
L26
Set transportation parameter target
22.1.27
L27
&
J7
L28
Find cost preference transportation
22.1.28
L29
Find time preference transportation
22.1.29
GMC.CAP V2.0
Decomp: Manage transportation

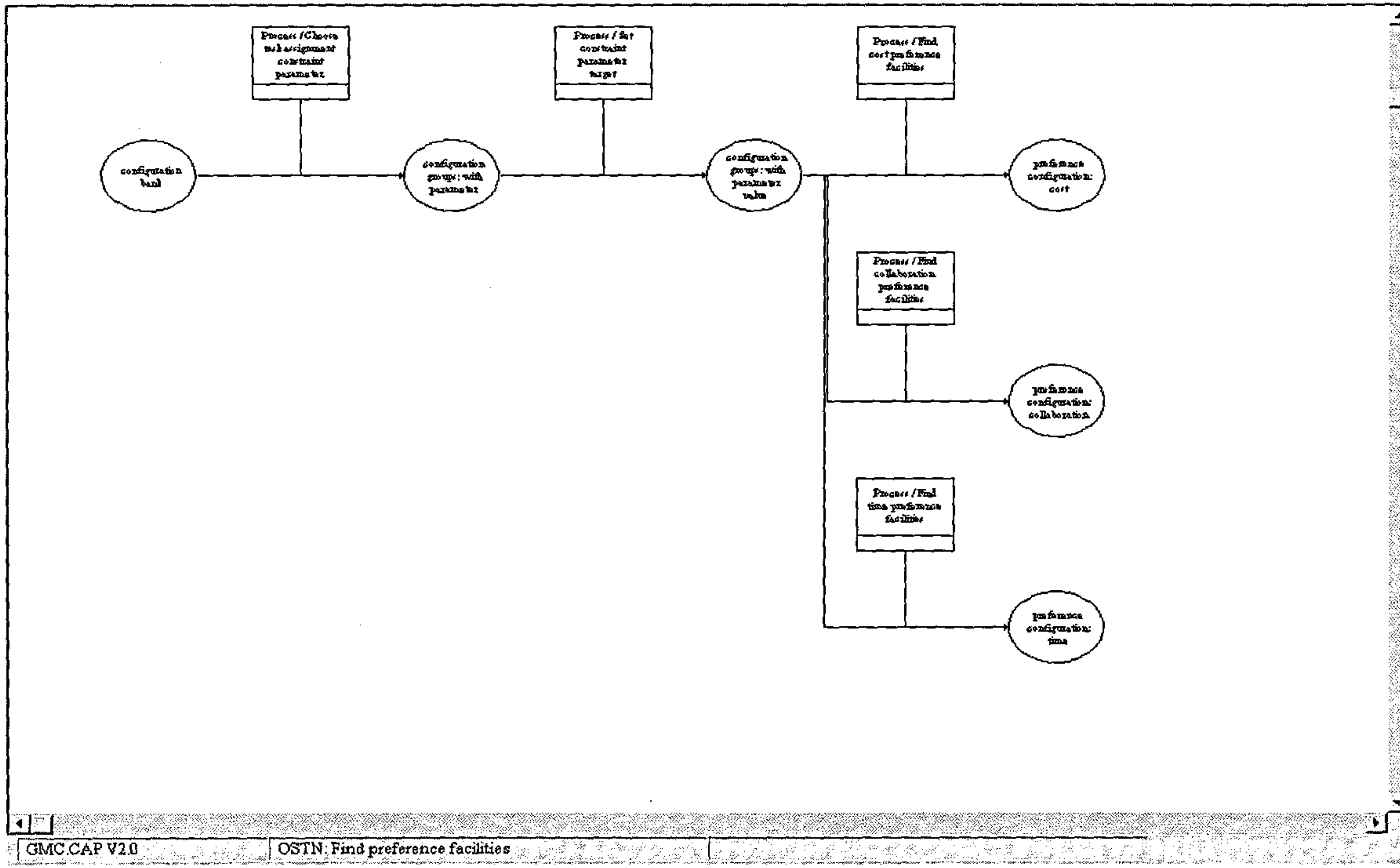
Appendix B-2 IDEF3 OSTN Diagrams of Global Manufacturing Co-ordination

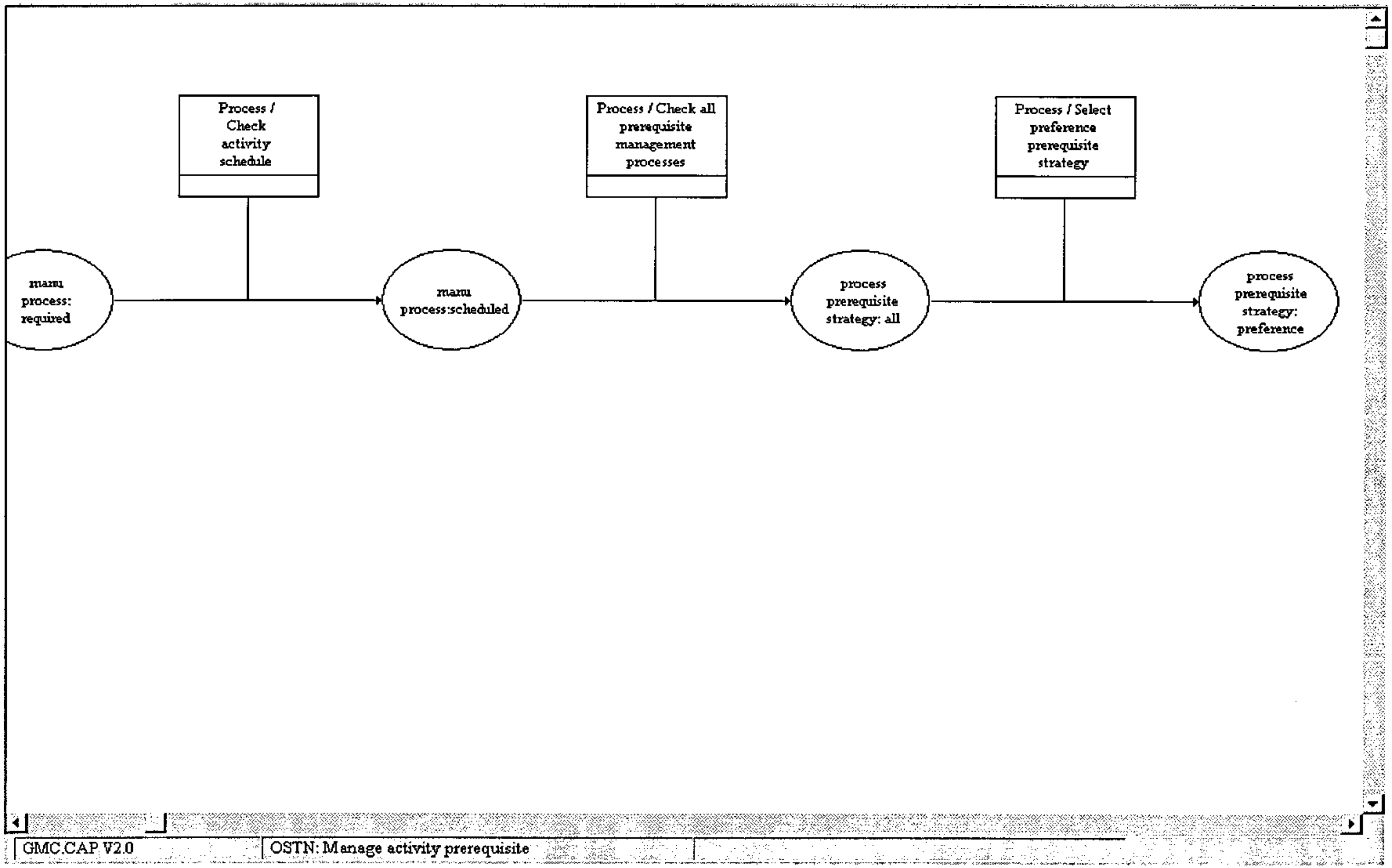


Process / Generate final product list
Process / Explode product structure tree
Process / Queue all products and materials
Process / Identify required manufacturing processes
product orders
final product list
production tasks: random
production tasks: queued
required manu. processes
GMC.CAP V2.0
OSTN: Formulate production requests

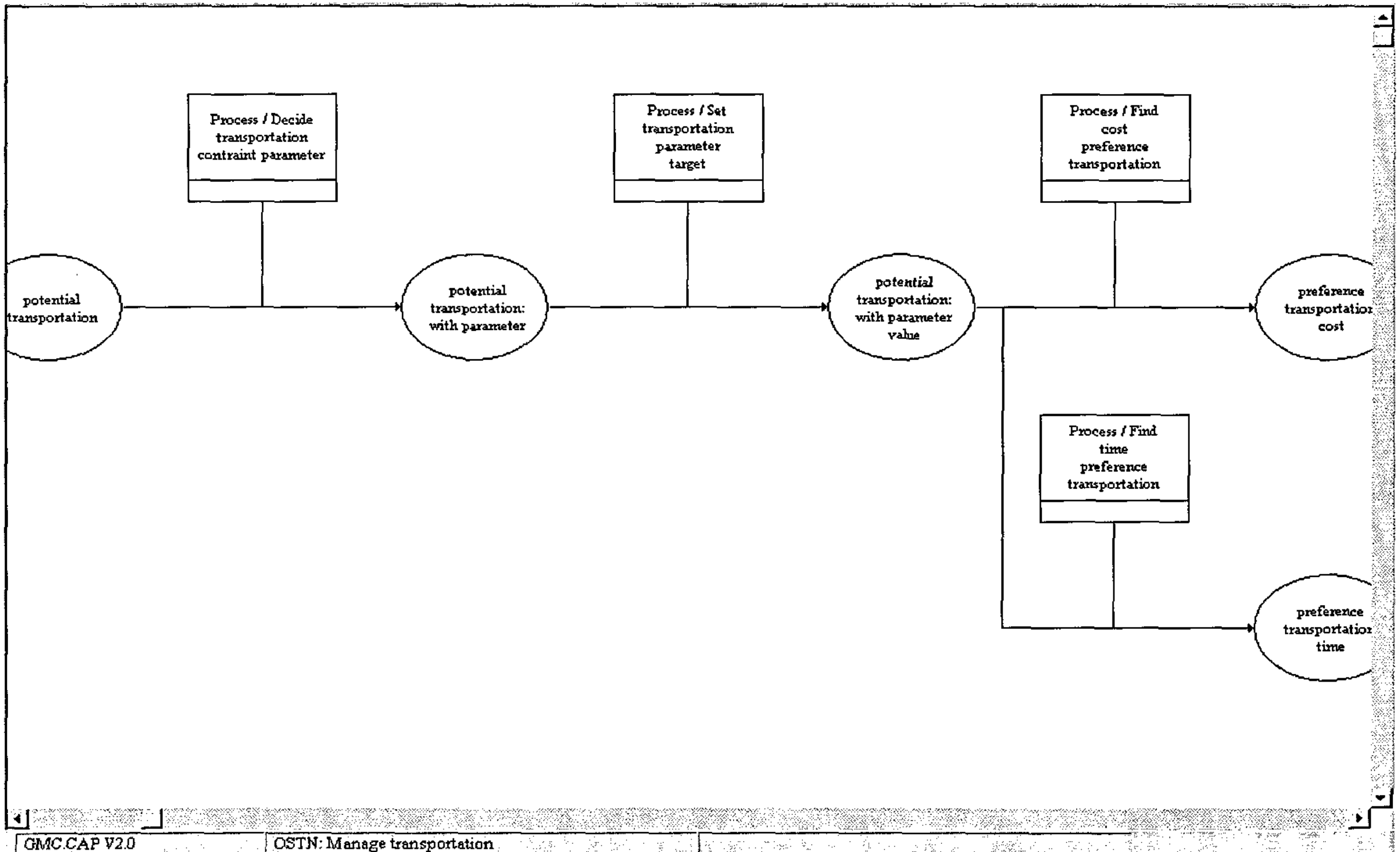

Process / Check transportation availability
Process / Find qualified facilities
potential factories: with manu. capability
potential factories: meet process and tran. constr
qualified factories
Process / Check process sequence constraints
potential factories: with manu. capability
GMC.CAP V2.0
OSTN: Check potential facilities


Process / Select involved processes
Process / Match alternative facilities to processes
Process / List all enterprise configurations
qualified factory bank
qualified factory groups
factory configuration prototype
configuration bank
Process / Check process sequence constraints
qualified factory bank
GMC.CAP V2.0
OSTN: Form all enterprise configurations


GMC.CAP V2.0
OSTN: Find preference facilities



Process / Check activity schedule
Process / Check all prerequisite management processes
Process / Select preference prerequisite strategy
manu process: required
manu process:scheduled
process prerequisite strategy: all
process prerequisite strategy: preference
GMC.CAP V2.0
OSTN: Manage activity prerequisite



Process / Decide transportation contraint parameter
Process / Set transportation parameter target
Process / Find cost preference transportation
potential transportation
potential transportation: with parameter
potential transportation: with parameter value
preference transportation cost
Process / Find time preference transportation
preference transportation time
GMC.CAP V2.0
OSTN: Manage transportation

Appendix C UML Representation of the Structures of the Models

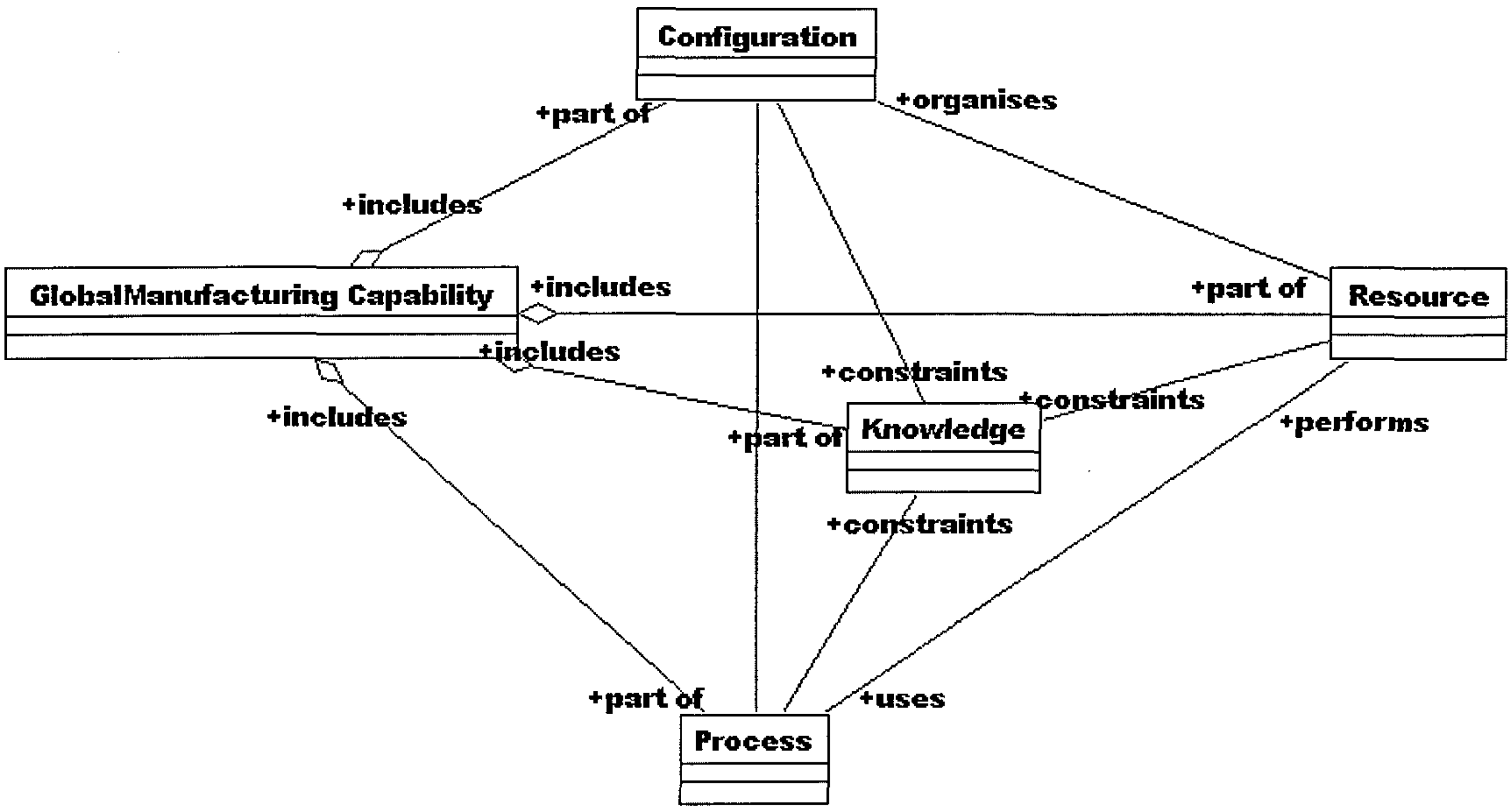


Figure C-1 Top-level structure of the MM

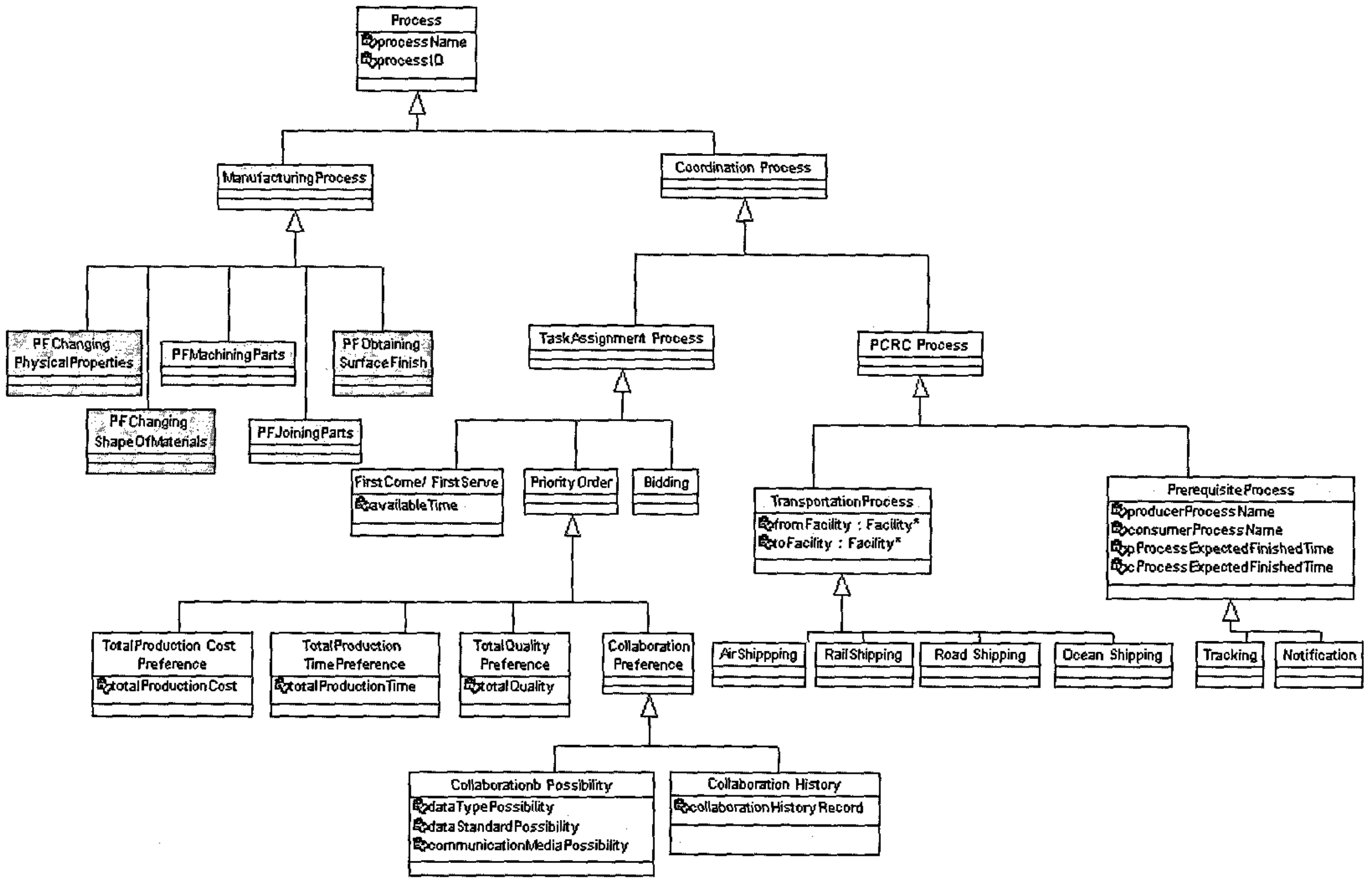


Figure C-2 Process information structure in the MM

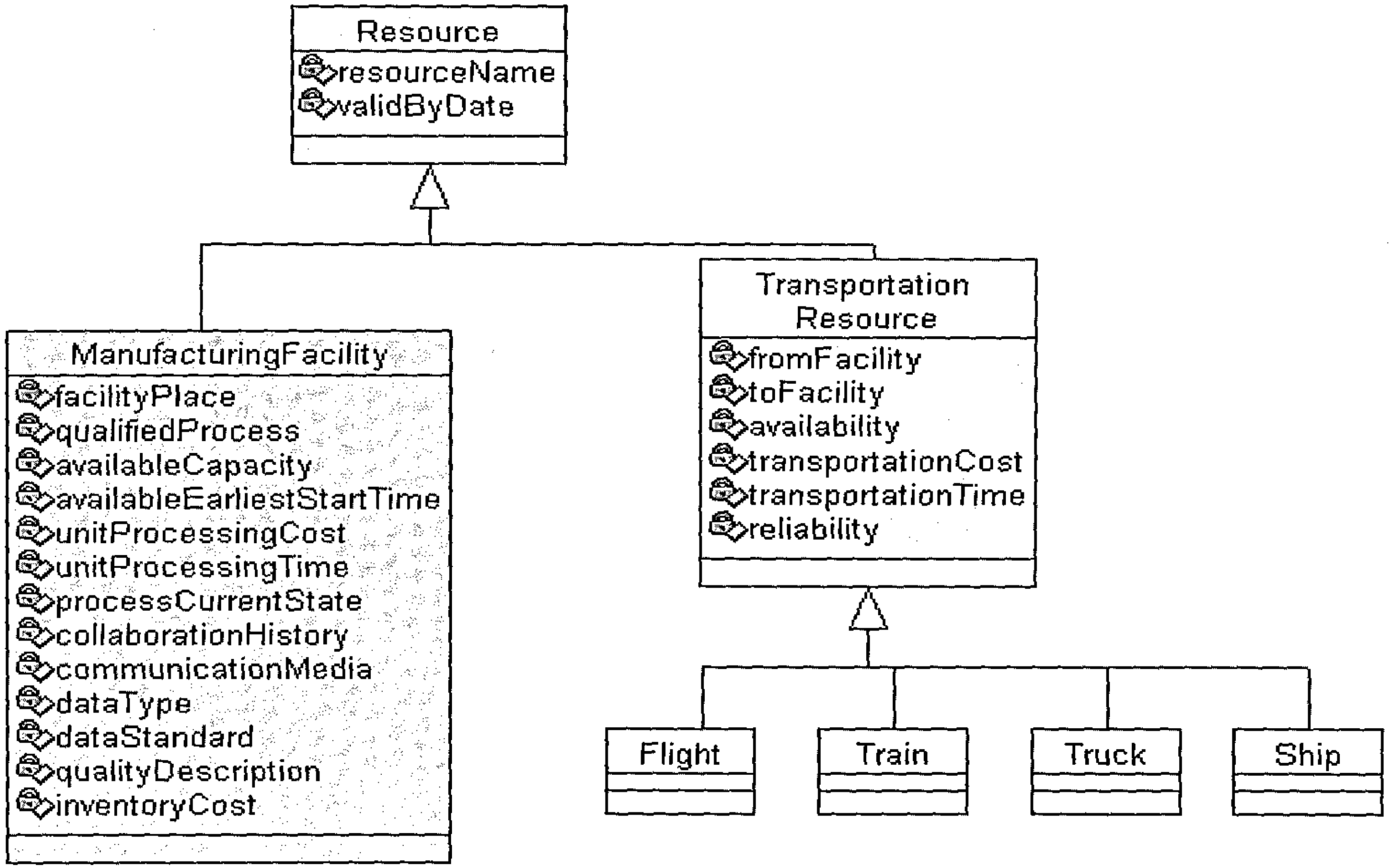


Figure C-3 Resource information structure in the MM

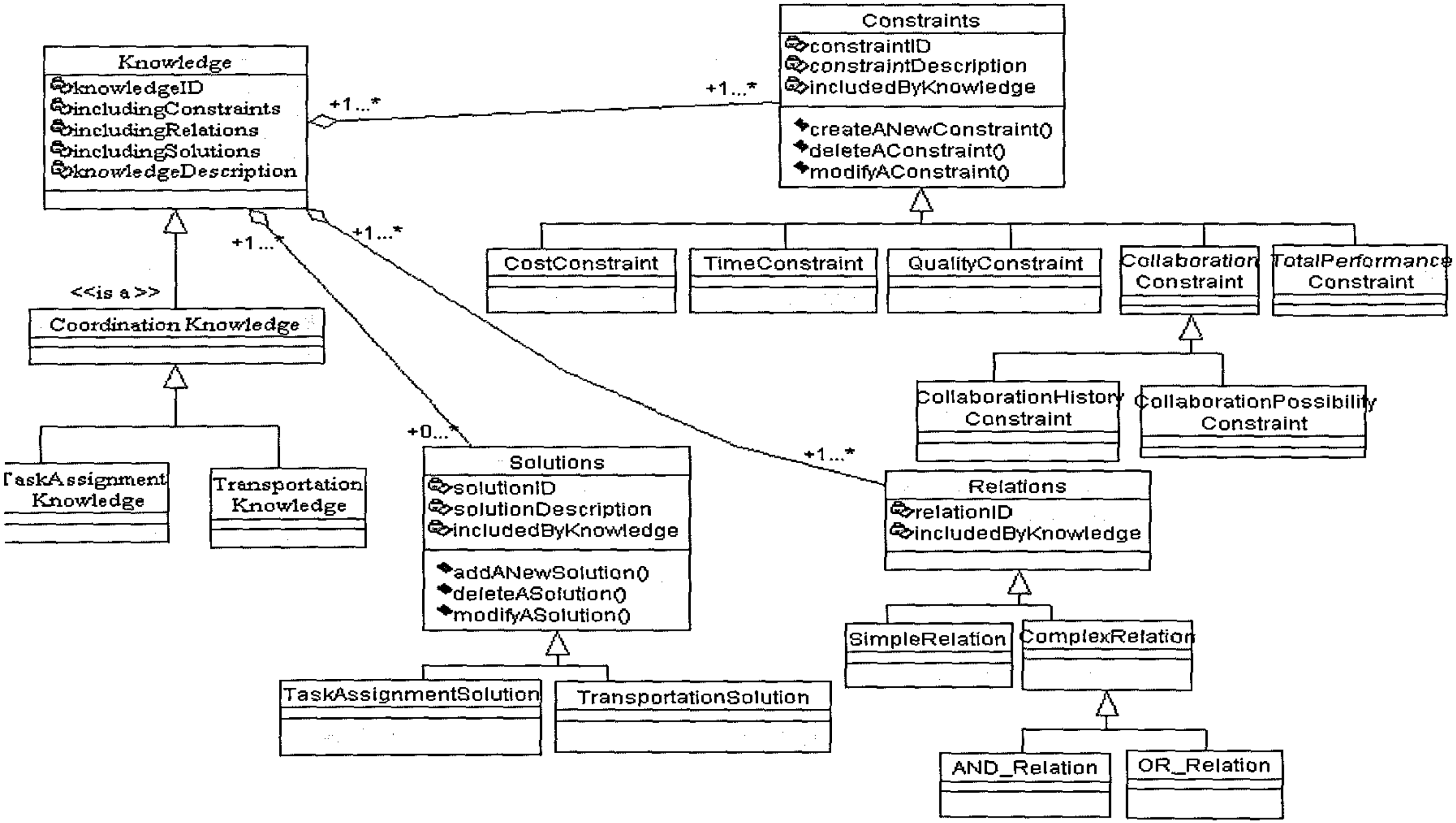


Figure C-4 Knowledge structure in the MM

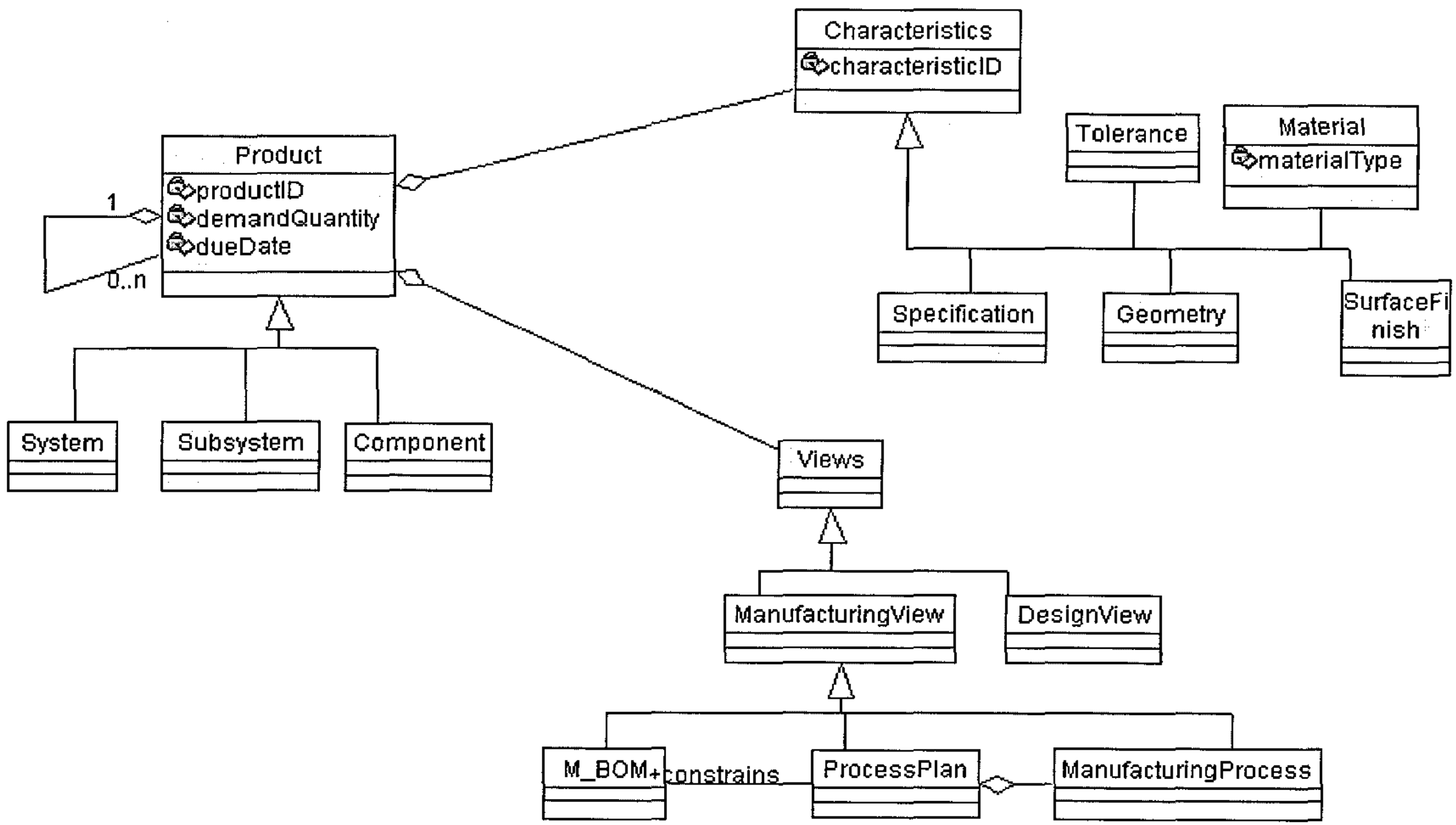


Figure C-5 Information structure of the PM

Appendix D Information and Knowledge Stored in a Manufacturing Model

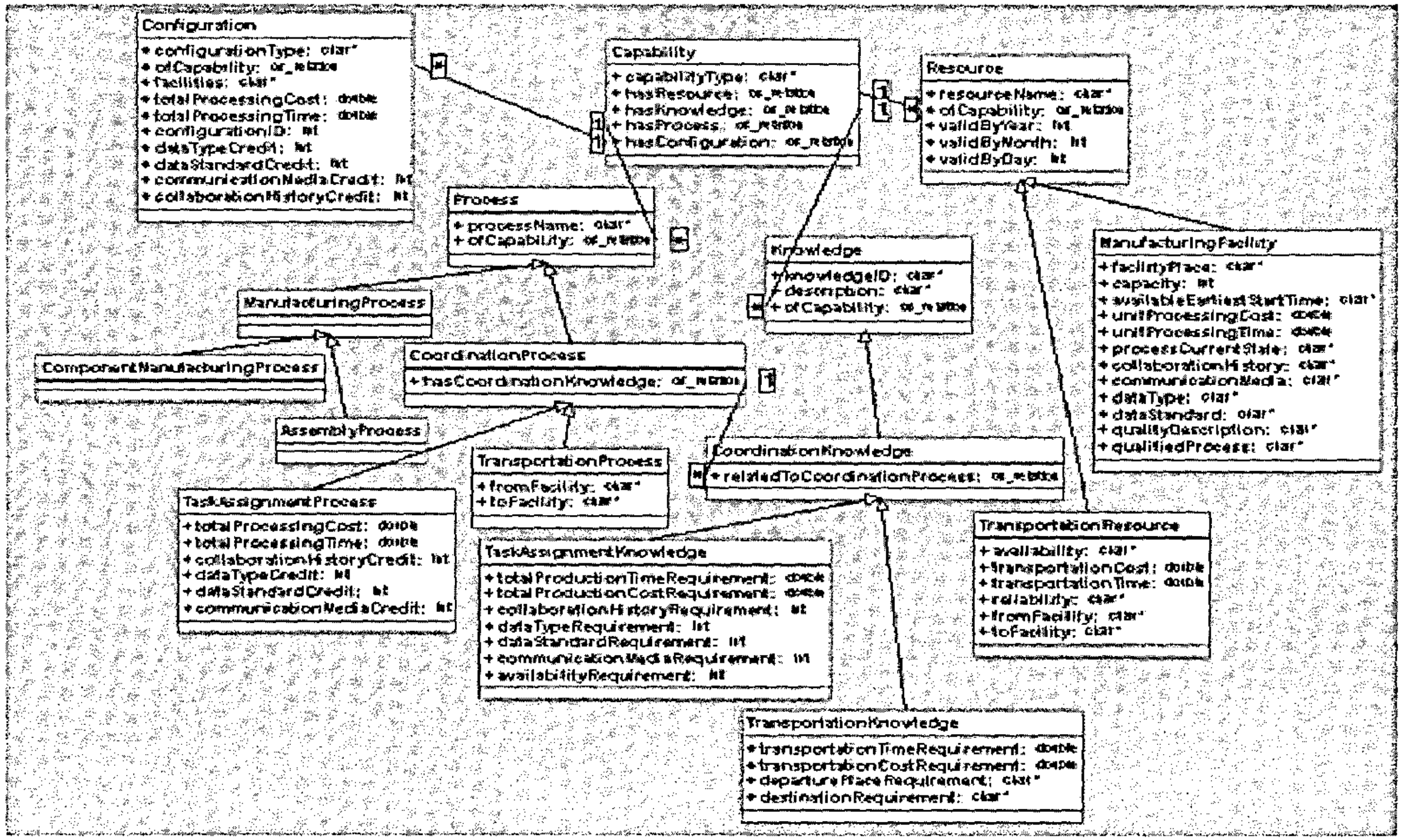


Figure D-1 Implemented MM structure

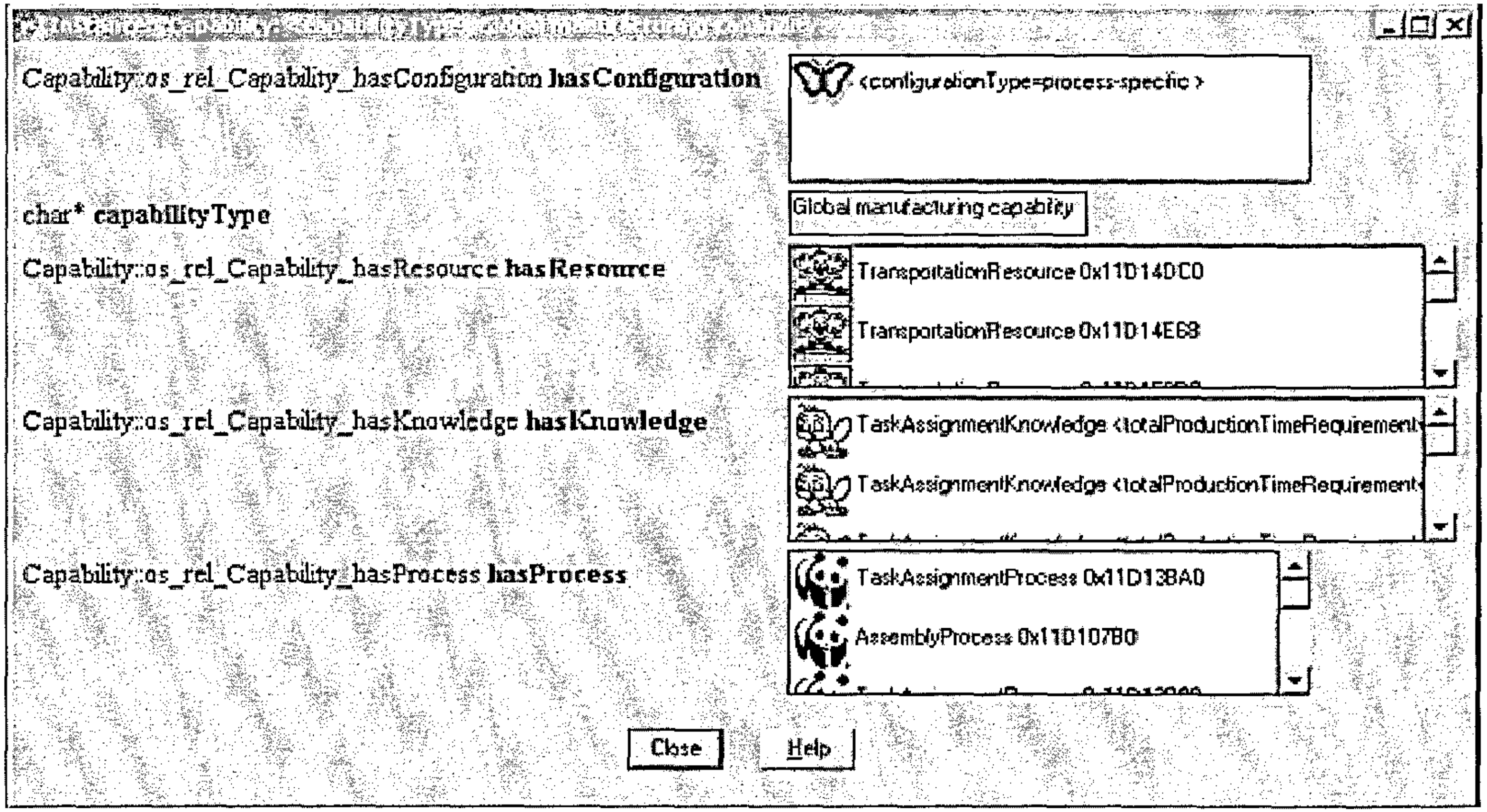


Figure D-2 Global manufacturing capability elements

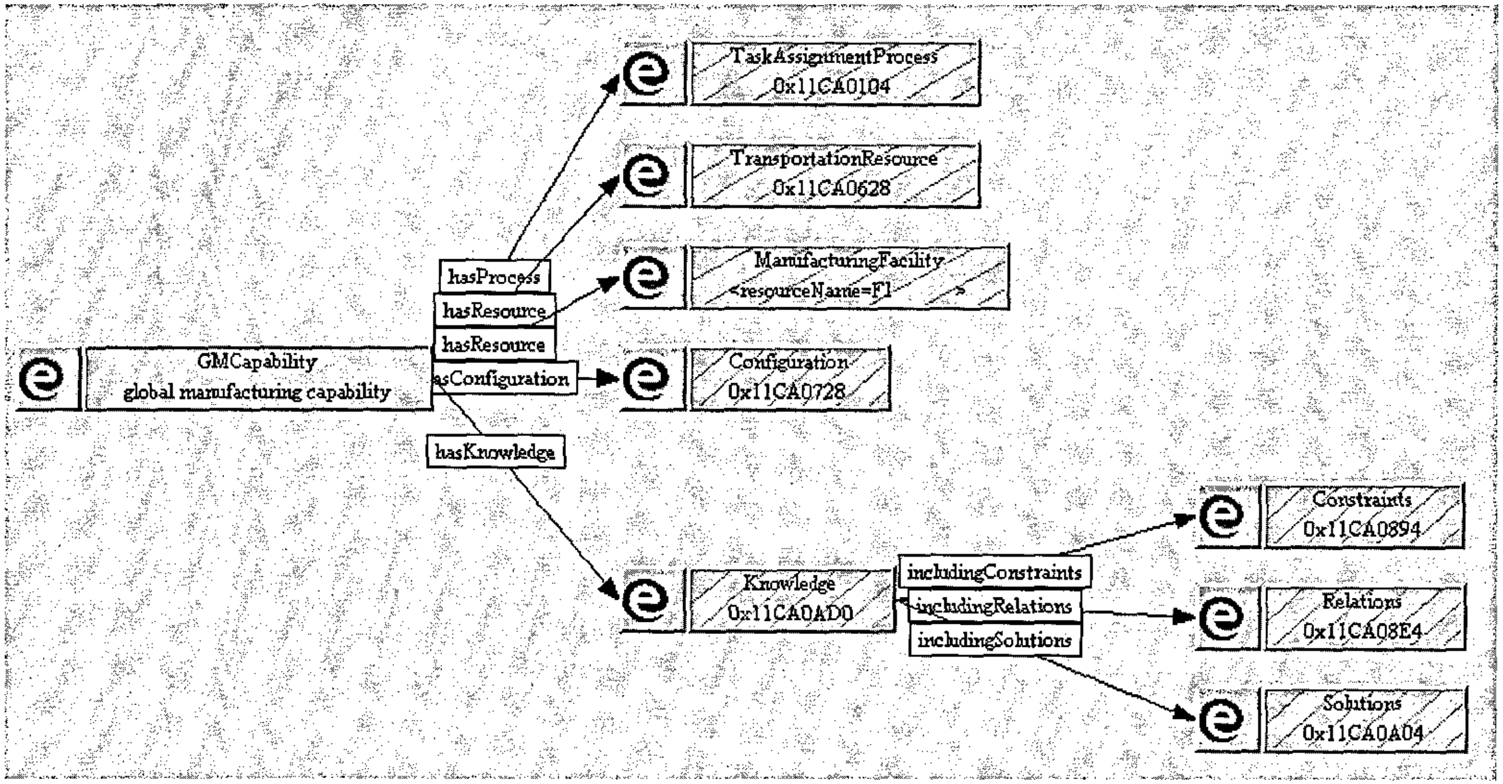
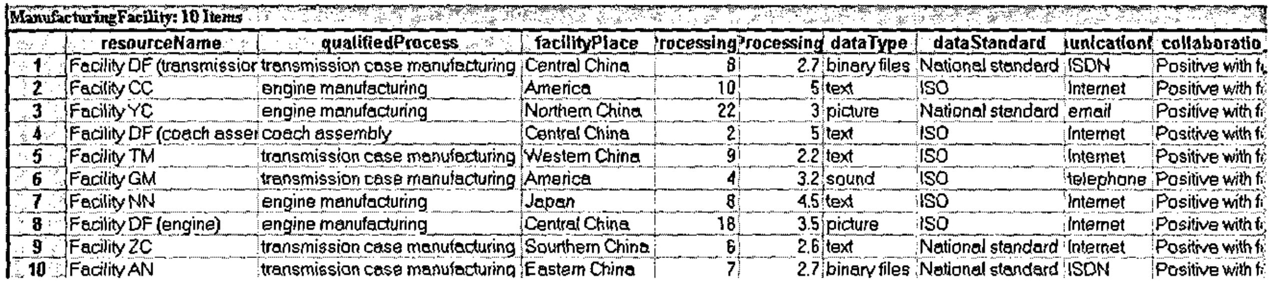


Figure D-3 MM information navigation trees

TransportationResource: 12 Items

	resourceName	fromFacility	toFacility	transportationTime	transportationCost	validByDay	validByMonth	alidByYea
1	Flight 232	facility NN	facility DF	1.5	0.88	30	10	3
2	Ship 231	facility NN	facility DF	7	0.3	30	10	3
3	Flight 231	facility NN	facility DF	1	0.9	30	10	3
4	Ship 131	facility CC	facility DF	12	0.6	30	10	3
5	Flight 131	facility CC	facility DF	1	1.9	30	10	3
6	Ship 133	facility CC	facility DF	22	0.4	30	10	3
7	Ship 232	facility NN	facility DF	8	0.29	30	10	3
8	Ship 132	facility CC	facility DF	18	0.5	30	10	3
9	Flight 132	facility CC	facility DF	1.5	1.88	30	10	3
10	Flight 233	facility NN	facility DF	2	0.85	30	10	3
11	Ship 233	facility NN	facility DF	9	0.28	30	10	3
12	Flight 133	facility CC	facility DF	2	1.85	30	10	3

Figure D-4 Transportation resources



ManufacturingFacility: 10 Items

	resourceName	qualifiedProcess	facilityPlace	rocessing	rocessing	dataType	dataStandard	unication	collaboratio
1	Facility DF (transmissior	transmission case manufacturing	Central China	8	2.7	binary files	National standard	ISDN	Positive with f
2	Facility CC	engine manufacturing	America	10	5	text	ISO	Internet	Positive with f
3	Facility YC	engine manufacturing	Northem China	22	3	picture	National standard	email	Positive with f
4	Facility DF (coach asser	coach assembly	Central China	2	5	text	ISO	Internet	Positive with f
5	Facility TM	transmission case manufacturing	Western China	9	2.2	text	ISO	Internet	Positive with f
6	Facility GM	transmission case manufacturing	America	4	3.2	sound	ISO	telephone	Positive with f
7	Facility NN	engine manufacturing	Japan	8	4.5	text	ISO	Internet	Positive with f
8	Facility DF (engine)	engine manufacturing	Central China	18	3.5	picture	ISO	Internet	Positive with f
9	Facility ZC	transmission case manufacturing	Southern China	6	2.6	text	National standard	Internet	Positive with f
10	Facility AN	transmission case manufacturing	Eastern China	7	2.7	binary files	National standard	ISDN	Positive with f

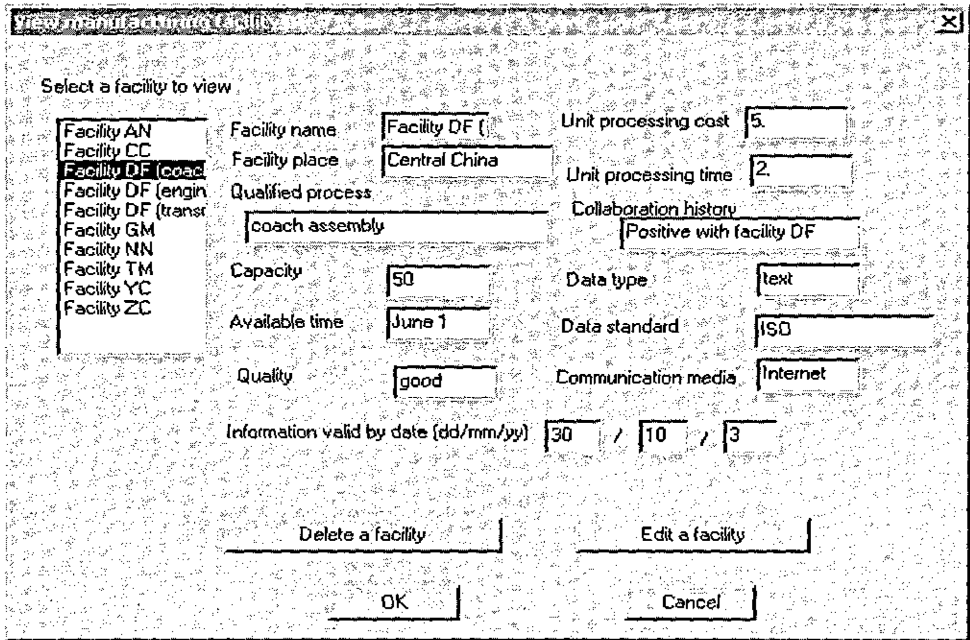


Figure D-5 Manufacturing facilities

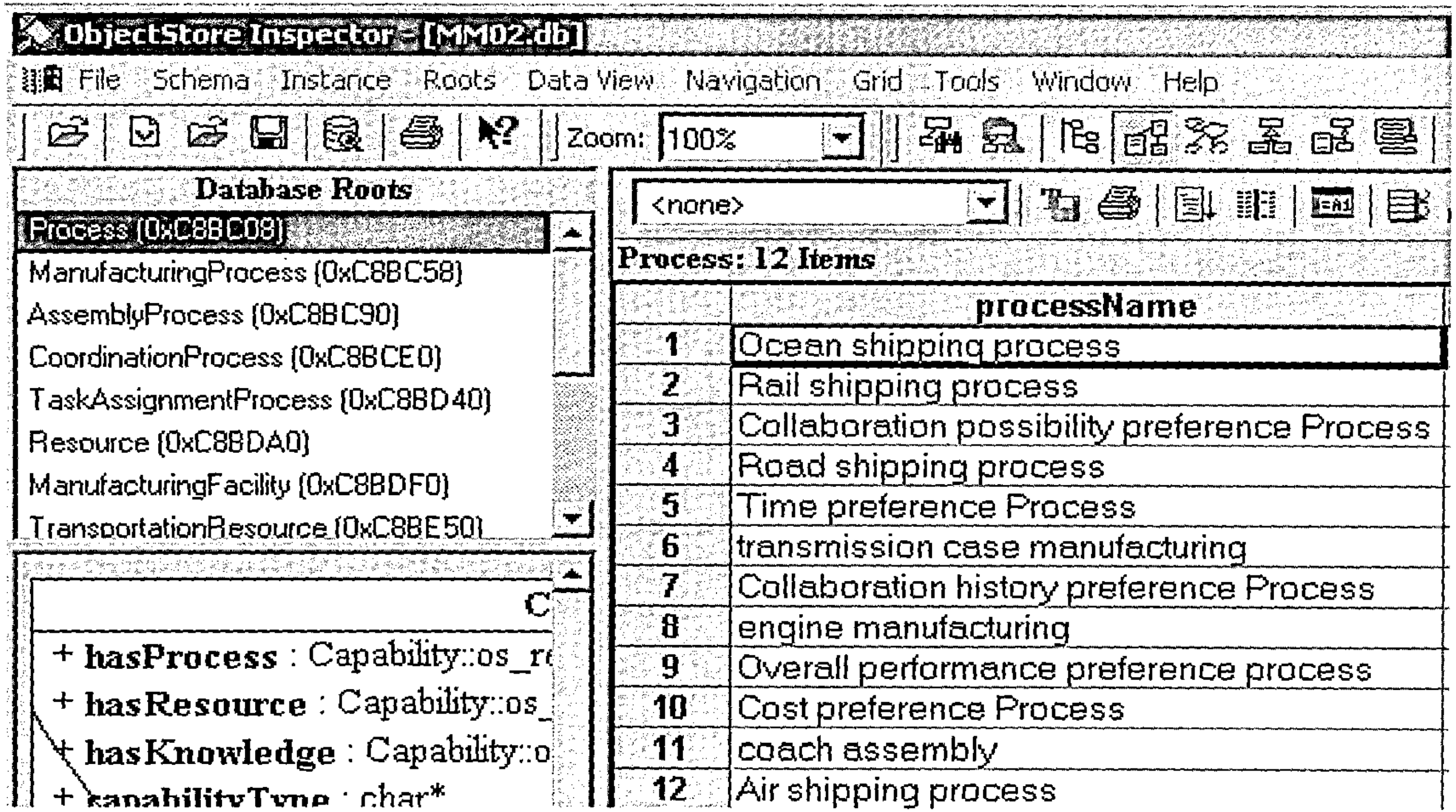
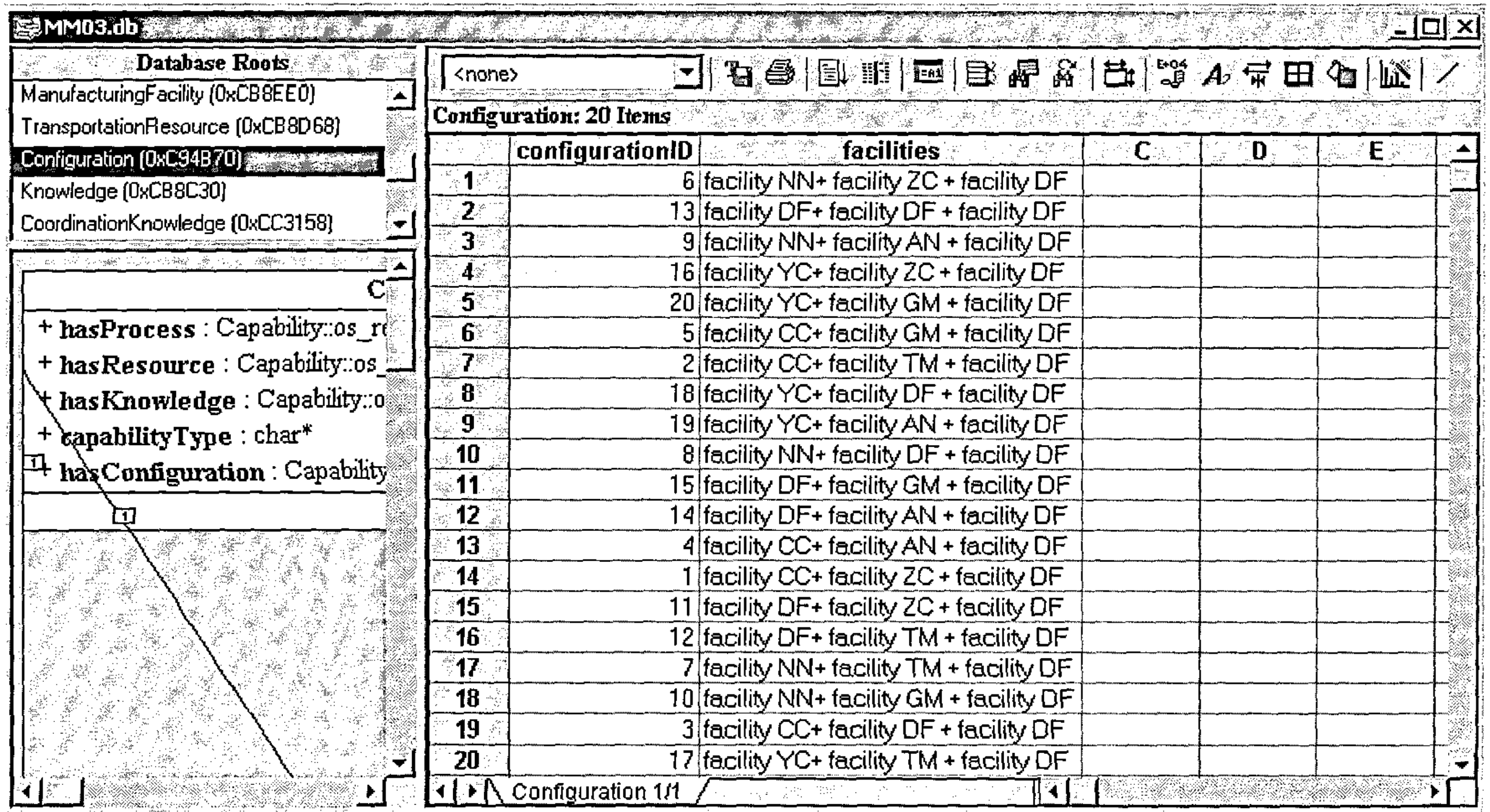
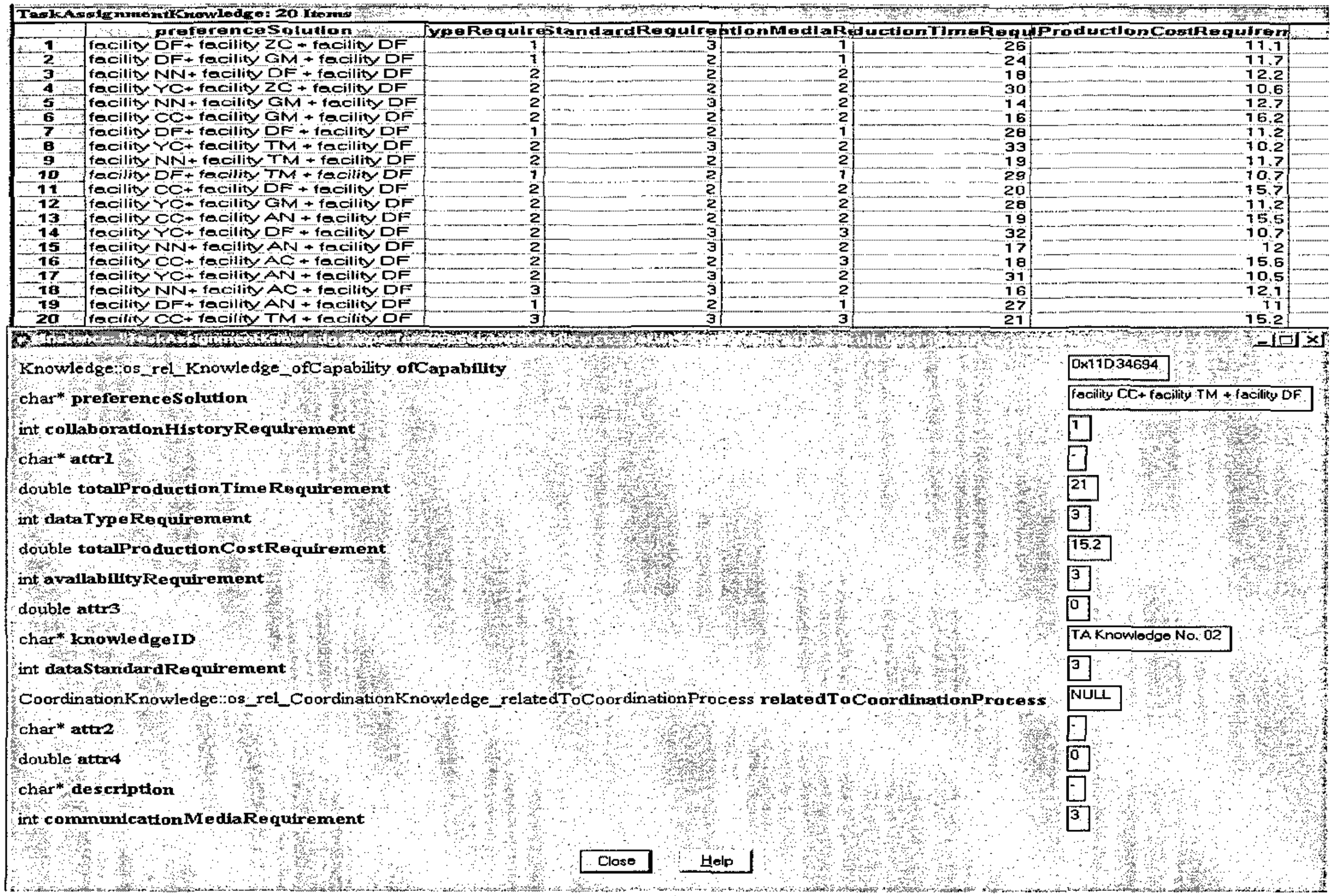


Figure D-6 Processes



	configurationID	facilities	C	D	E
1	6	facility NN+ facility ZC + facility DF			
2	13	facility DF+ facility DF + facility DF			
3	9	facility NN+ facility AN + facility DF			
4	16	facility YC+ facility ZC + facility DF			
5	20	facility YC+ facility GM + facility DF			
6	5	facility CC+ facility GM + facility DF			
7	2	facility CC+ facility TM + facility DF			
8	18	facility YC+ facility DF + facility DF			
9	19	facility YC+ facility AN + facility DF			
10	8	facility NN+ facility DF + facility DF			
11	15	facility DF+ facility GM + facility DF			
12	14	facility DF+ facility AN + facility DF			
13	4	facility CC+ facility AN + facility DF			
14	1	facility CC+ facility ZC + facility DF			
15	11	facility DF+ facility ZC + facility DF			
16	12	facility DF+ facility TM + facility DF			
17	7	facility NN+ facility TM + facility DF			
18	10	facility NN+ facility GM + facility DF			
19	3	facility CC+ facility DF + facility DF			
20	17	facility YC+ facility TM + facility DF			

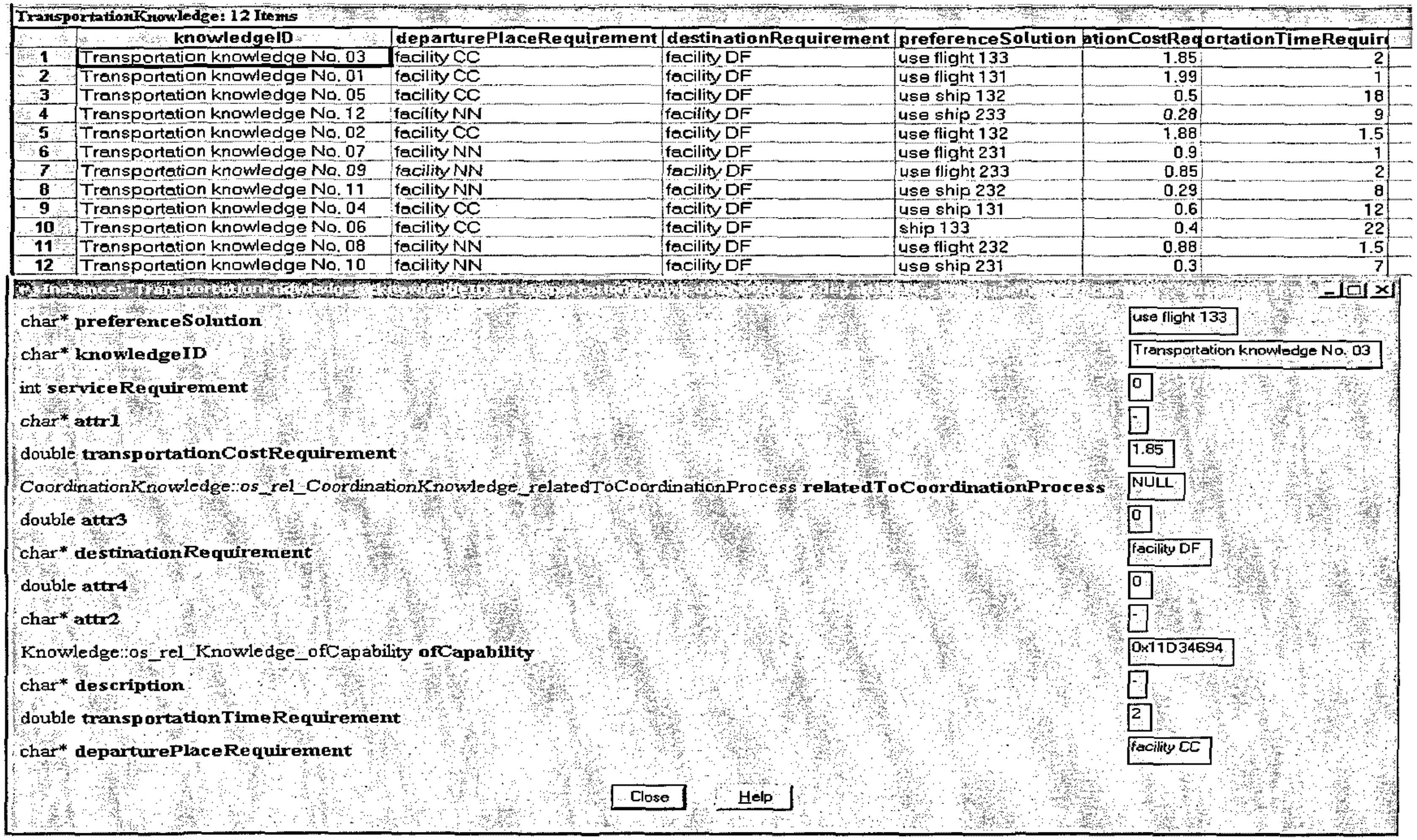
Figure D-7 Configurations



TaskAssignmentKnowledge: 20 Items

	preferenceSolution	ypeRequire	StandardRequire	tionMediaR	ductionTimeRequ	ProductionCostRequirem
1	facility DF+ facility ZC + facility DF	1	3	1	26	11.1
2	facility DF+ facility GM + facility DF	1	2	1	24	11.7
3	facility NN+ facility DF + facility DF	2	2	2	18	12.2
4	facility YC+ facility ZC + facility DF	2	2	2	30	10.6
5	facility NN+ facility GM + facility DF	2	3	2	14	12.7
6	facility CC+ facility GM + facility DF	2	2	2	16	16.2
7	facility DF+ facility DF + facility DF	1	2	1	28	11.2
8	facility YC+ facility TM + facility DF	2	3	2	33	10.2
9	facility NN+ facility TM + facility DF	2	2	2	19	11.7
10	facility DF+ facility TM + facility DF	1	2	1	29	10.7
11	facility CC+ facility DF + facility DF	2	2	2	20	15.7
12	facility YC+ facility GM + facility DF	2	2	2	28	11.2
13	facility CC+ facility AN + facility DF	2	2	2	19	15.5
14	facility YC+ facility DF + facility DF	2	3	3	32	10.7
15	facility NN+ facility AN + facility DF	2	3	2	17	12
16	facility CC+ facility AC + facility DF	2	2	3	18	15.6
17	facility YC+ facility AN + facility DF	2	3	2	31	10.5
18	facility NN+ facility AC + facility DF	3	3	2	16	12.1
19	facility DF+ facility AN + facility DF	1	2	1	27	11
20	facility CC+ facility TM + facility DF	3	3	3	21	15.2

Figure D-8 Task assignment knowledge



TransportationKnowledge: 12 Items

	knowledgeID	departurePlaceRequirement	destinationRequirement	preferenceSolution	ationCostReq	ortationTimeRequir
1	Transportation knowledge No. 03	facility CC	facility DF	use flight 133	1.85	2
2	Transportation knowledge No. 01	facility CC	facility DF	use flight 131	1.99	1
3	Transportation knowledge No. 05	facility CC	facility DF	use ship 132	0.5	18
4	Transportation knowledge No. 12	facility NN	facility DF	use ship 233	0.28	9
5	Transportation knowledge No. 02	facility CC	facility DF	use flight 132	1.88	1.5
6	Transportation knowledge No. 07	facility NN	facility DF	use flight 231	0.9	1
7	Transportation knowledge No. 09	facility NN	facility DF	use flight 233	0.85	2
8	Transportation knowledge No. 11	facility NN	facility DF	use ship 232	0.29	8
9	Transportation knowledge No. 04	facility CC	facility DF	use ship 131	0.6	12
10	Transportation knowledge No. 06	facility CC	facility DF	ship 133	0.4	22
11	Transportation knowledge No. 08	facility NN	facility DF	use flight 232	0.88	1.5
12	Transportation knowledge No. 10	facility NN	facility DF	use ship 231	0.3	7

char* **preferenceSolution**	use flight 133
char* **knowledgeID**	Transportation knowledge No. 03
int **serviceRequirement**	0
char* **attr1**	-
double **transportationCostRequirement**	1.85
CoordinationKnowledge::os_rel_CoordinationKnowledge_relatedToCoordinationProcess **relatedToCoordinationProcess**	NULL
double **attr3**	0
char* **destinationRequirement**	facility DF
double **attr4**	0
char* **attr2**	-
Knowledge::os_rel_Knowledge_ofCapability **ofCapability**	0x11D34694
char* **description**	-
double **transportationTimeRequirement**	2
char* **departurePlaceRequirement**	facility CC

Close Help

Figure D-9 Transportation knowledge