5. CIM ARCHITECTURE AND ENTERPRISE MODELING

An enterprise is a complicated social, economical, and physical system. The implementation of CIMS in an enterprise is a even more complicated system engineering. In order to implement CIMS successfully, besides engineers with substantial analytical background, excellent technology and abundant experiences are required, the guidance of advanced CIM system architecture, and implementation methodology and powerful support tool are also needed. CIM system architecture studies the components and their relationship of CIM. It is used as the basis and guidelines for the design and implementation of CIMS in a company. A good system architecture can not only act as a basis in describing the system components, but also provide a good way to communicate among users, designers, and other parties. There are a number of CIM system architectures, such as SME wheel structure (Figure 2.3), CIM open system architecture (CIMOSA), Purdue enterprise reference architecture (PERA)(Williams, 1992), Architecture for information system (ARIS) (Scheer, 1992), GRAI (Graphs with results and activities interrelated) integrated methodology (GIM) (Doumeingts, Vallespir, Zanettin, and Chen, 1992), etc.

With the development of CIM reference architecture, a number of enterprise modeling methods have been put forward to describe the enterprise. Because the enterprise is a very complex system, it is difficult to describe it using a simple and unified model. A typical method used by almost all enterprise modeling methods is to describe the enterprise using several view models. Each view defines one aspect from a specific point of view, then the integration method between the different view models is defined. The general view models now used in describing enterprise are function view, information view, organization view, resource view, and process view. Some other views are also presented by researchers, they are control view defined in ARIS, decision view defined in GRAI/GIM, economic view proposed by Chen（Chen, Dong, Zhang, and Xie, 1994).

5.1 VIEWS OF THE ENTERPRISE MODEL

As discussed in the above section, the enterprise model consists of several interrelated view models. Each view describes a specific aspect of the enterprise. Each view has its own modeling method. In this section, we give a brief description about the aims of each view and the currently used method in building the view model.

5.1.1 Process View

Process view model takes major roles in defining, establishing, analyzing and extracting of the business processes of a company. It fulfills the requirements of transforming business process, manufacturing process and product development process into a process view model. Process model is the basis for business process simulation, optimization, and reengineering.

- **Modeling Method for Process View**

Process view modeling mainly focuses on how to organize internal activities into a proper business processes according to the enterprise goals and system restrictions. Traditional function-decomposing-orientated modeling method, whose characteristics is to set up process based on activities (functions), such as SADT, can be used in business process modeling. IDEF0 is another example of function-decomposing-oriented modeling method.

The business description languages of WFMC (Workflow Management Coalition, 1994), IDEF3, and CIMOSA are process-orientated modeling methods. Another modeling method is using object-orientated technology, in which a business process can be comprehended as a set of coordinated request/service operations between a group of objects. Jacobson (1995) presents a method about how to use object-orientated technology, Use the Case method, to re-engineer business process. Using object-orientated method to model business process has its intrinsic benefits, it can improve systemic extendibility and adaptability greatly, its services based on object-operated mode can assign systemic responsibility easily, existing business processes can be reused easily, distribution and autonomy properties can be described easily.

The main objective of process view modeling method is to provide a set of modeling language that can depict business process completely and effectively. To depict a business process, it should be able to depict the consequent structure of the processes, such as sequence, embranchment, join, condition, and circle, thus to establish a formal description of the business process. At present, generally accepted modeling languages are IDEF3, CIMOSA business process description language, and WFMC workflow description language.

Some business process description methods coming from the concepts and models of some traditional project management tool, such as PERT chart and other kinds of network chart, are generally adopted in practical application systems, because they can be easily extended from existing project management tool software. If the business process is relatively complex, for example, existing concurrent or collision activities, some super formal descriptions, such as Petri net, should be used.

Figure 5.1 is a workflow model of machine tool handle manufacturing process. The process model is designed using CIMFlow tool (Luo and Fan, 1999). In Figure 5.1 (a), the main sequential process is described and the icon  stands for a subprocess activity. Figure 5.1(b) is the decomposition of the subprocess activity "Rough Machining" in Figure 5.1 (a). After "Turing" activity is executed, two conditional arcs are defined which split the activity route into two branches. Activity "Checking" is a decision making task which is in charge of the product quality or the progress of the whole process.

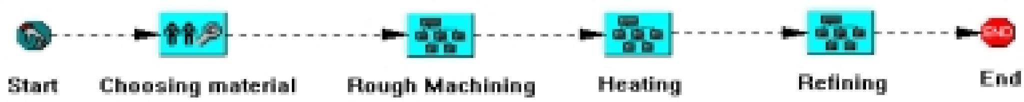


Figure 5.1 (a)

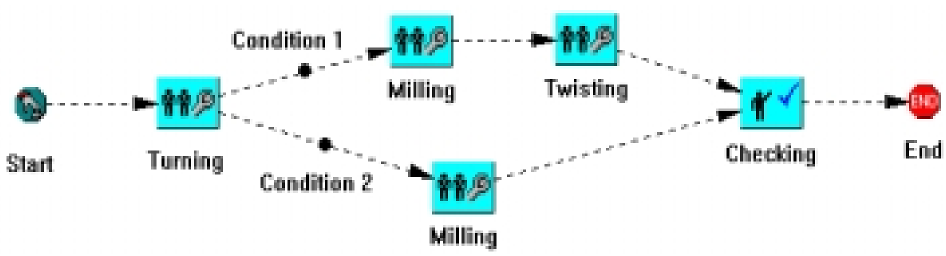


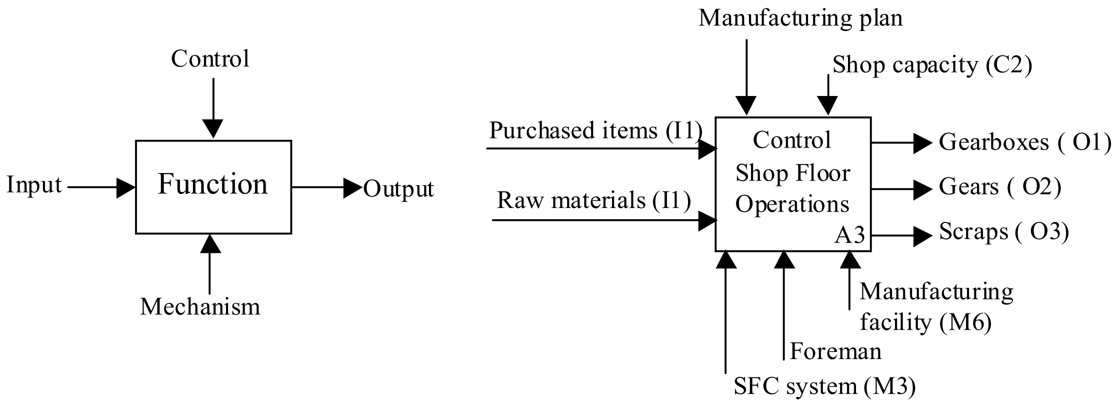
Figure 5.1 (b) Process model for tool handle manufacturing

5.1.2 Function View

Function view is used to describe the functions and their relationships of a company. These functions fulfil the objectives of the company, such as sales, order planning, product design, part manufacturing, human resource management, etc. The efficient and effective operations of these functions contribute to the success of a company's competition in the market.

- **Modeling Method for Function View**

Function view modeling normally uses top-down structural decomposition method. Function tree is the simplest modeling method, but it lacks the links between different functions, especially the data flow and control flow between different functions, so it is generally used to depict simple function belonging relationships. In order to reflect data and control flow relationships between different functions, SADT and IDEF0 (Colquhoun and Baines, 1991) methods are used to model function view. The IDEF0 formalism is based on the SADT developed by Ross (Ross, 1985).



(a) General symbol (b) Practical model

Figure 5.2 General symbol and a practical model of IDEF0

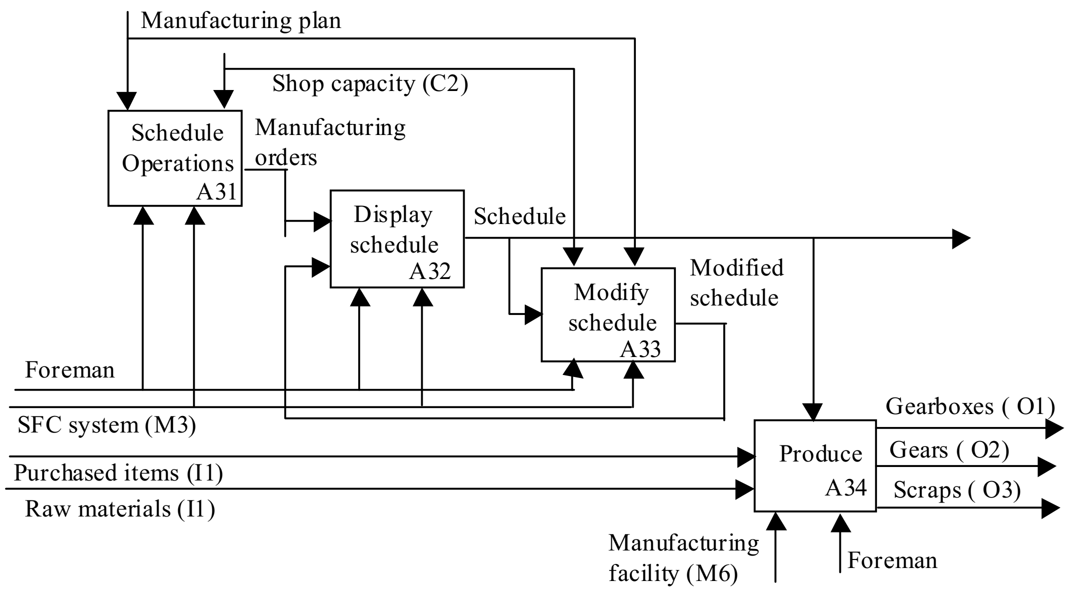


Figure 5.3 IDEF0 model of the control shop floor operation function

The IDEF0 model has two basic elements: activity and arrow. Figure 5.2 gives the basic graphic symbol used in IDEF0 method. IDEF0 supports hierarchical modeling, so every activity can be further decomposed into a network of activities. In order to organize the whole model clearly, it is advised that the number of the child activities decomposed from the parent activity is less than 7 and great than 2. Figure 5.3 gives a demonstration IDEF0 model (A0 model) of the control shop floor operation function.

In the CIMOSA model, the overall enterprise functions are represented as an event driven network of Domain Processes (DP). Individual Domain Process is represented as a network of activities. The Domain Process is composed of a set of Business Processes (BP) and Enterprise Activities (EA). The BP is composed of a set of EAs or other BPs. An EA is composed of a set of Functional Operations (FO). BP has behavior property that defines the evolution of the enterprise states over time in reaction to enterprise event generation or conditions external or internal to the enterprise. It is defined by means of a set of rules (called Procedure Rules). The structure property of BP describes the functional decomposition of the enterprise functions of enterprise. This can be achieved by means of a pair of pointers attached to each enterprise function. EA has an activity behavior which defines the internal behavior (or flow of control) of Enterprise Activities. It specifies how to perform the functionality of an EA in terms of an algorithm making use of FO.

It can be seen that the process view and function view is closely related in CIMOSA modeling method. It is very hard to separate it from the CIMOSA modeling method, hence any tool that support CIMOSA modeling methodology should be process oriented as well as including function decomposition in it.

5.1.3 Information View

Information view organizes the information necessary to support the enterprise function and process using an information model. Data or information of a company is an important resource, so it is necessary to provide a method to describe or model the data, such as data structures, repository types, and locations, especially the relationship among different data. It is very important for the company to consistently maintain the data resource, eliminate possible data redundancy, and finally enable the data integration.

The information view modeling method provides different model for different phases of a company's information system, from requirement analysis, design specification, to implementation. The most commonly used model to express data today is relational data model, which is the basis for the relational database management system. Currently used IDEF1X method is extended from entity-relationship model proposed by Chen (1976). Three phases of modeling process from conceptual model, logical model, and physical model are used in design and implementation of an information system. Vernadat (1996) gives a good introduction on information modeling in the context of enterprise modeling.

5.1.4 Organization View

Organization view is used to define and represent the organization model of a company. The defined model includes the organization tree, team, faculty, role and authority. It also creates an organization matrix. In the organization view, the relationships between different organization entities are defined. It provides a support for execution of the company's functions and processes.

The hierarchical relationship between the organization unit forms the organization tree. It describes the static organization structure. The team describes the dynamic structure of the company. It is formed according to requirements of business processes. Personnel and organization units are the constituents of the team.

Figure 5.4 gives the organization view structure. The basic elements of the organization view are organization unit, team, and personnel.

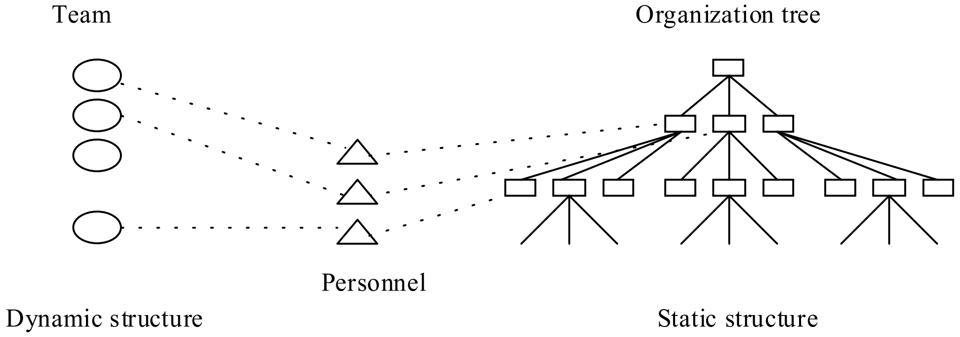


Figure 5.4 Organization view structure

The attributes of the organization unit include organization unit name, position, description, role list, leader, its associated activities and resources. The leader and subordinate relationships between different units are also defined in the organization unit. In defining team, the following attributes are needed: team name, description, project or process ID, associated personnel, and resources.

5.1.5 Resource View

The resource view is similar to the organization view. It describes resources used by the processes to fulfil the company's business functions. Three main objects are defined in the resource view model. They are resource type object, resource pool object, and resource entity object. Resource type object describes the company's resource according to the resource classification. The resource type object inherits the attributes from its parent object. A resource classification tree is created to describe the company's resource. The resource pool object describes resources at a certain area. All the resources located at this area form a resource pool. Resource entity object defines the atomic resources. The atomic resource is some kind of resource that can not be decomposed further, i.e., the smallest resource entity.

Figure 5.5 gives the resource classification tree structure. In this tree, the parent node resource consists of all its child node resources. It depicts the static structure of the company's resources.

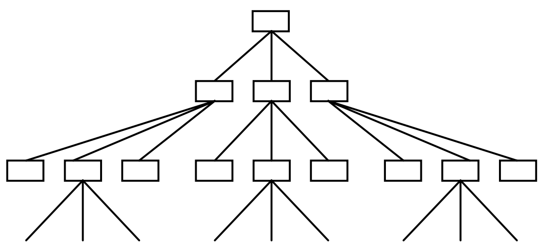


Figure 5.5 Resource classification tree structure

The resource-activity matrix (Table 5.1) defines the relationships between resources and process activities, every cross × means the resource is used by this activity. The resource-activity matrix presents the dynamic structure of the resources.

Table5.1 Resource-activity matrix

	Activity 1	Activity 2	....	Activity n
Resource 1	×			
Resource 2	×	×		
.....			×	
Resource m		×		×

5.2 ENTERPRISE MODELING METHODS

As pointed in the above section, there are many enterprise modeling methods. Here we only give a brief introduction about CIMOSA, ARIS, and GIM method.

5.2.1 CIMOSA

CIMOSA supports all phases of a CIM system life-cycle from requirements specification, through system design, implementation, operation and maintenance, to even a system migration towards CIMOSA solution. CIMOSA provides modeling, analysis, and design concepts in a set of languages and methodologies adapted to enterprise users at different levels and according to different user's viewpoints.

The CIMOSA reference architecture, developed by AMICE consortium in the frame of the European ESPRIT project, is a set of semi-formal structures and semantics that is intended to be used as a modeling language environment for any business enterprise. The basic constructs and fundamental control structures of the architecture are collected in volumes called the Formal Reference Base II (FRB) and the Formal Reference Base III. The FRB consists of two parts: one is the modeling framework; the other is the integrating infrastructure (IIS).

The CIMOSA modeling framework, known as the "CIMOSA cube", is shown in Figure 5.6. The modeling framework provides a reference architecture and a particular architecture. It contains three modeling levels (Requirements Definition, Design Specification, Implementation Description) and four views (Function, Information, Resource, Organization). The CIMOSA reference architecture (two left slices of the CIMOSA cube) provides a set of generic building blocks, partial models and user guidelines for each of the three modeling levels. The particular architecture (right slice of the CIMOSA cube) is the part of the framework that is provided for the modeling of a particular enterprise, i.e. it exhibits a given CIM solution.

Generic building blocks or basic constructs are modeling elements with which the requirements and solutions for a particular enterprise can be described. Partial models, which are partially instantiated CIMOSA solutions applicable to one or more industrial sectors, are also provided in the reference architecture. The user can customize partial models to a part of the model of his/her particular enterprise. CIMOSA modeling framework ensures that partial models from different sources can be used to build a model of one particular enterprise.

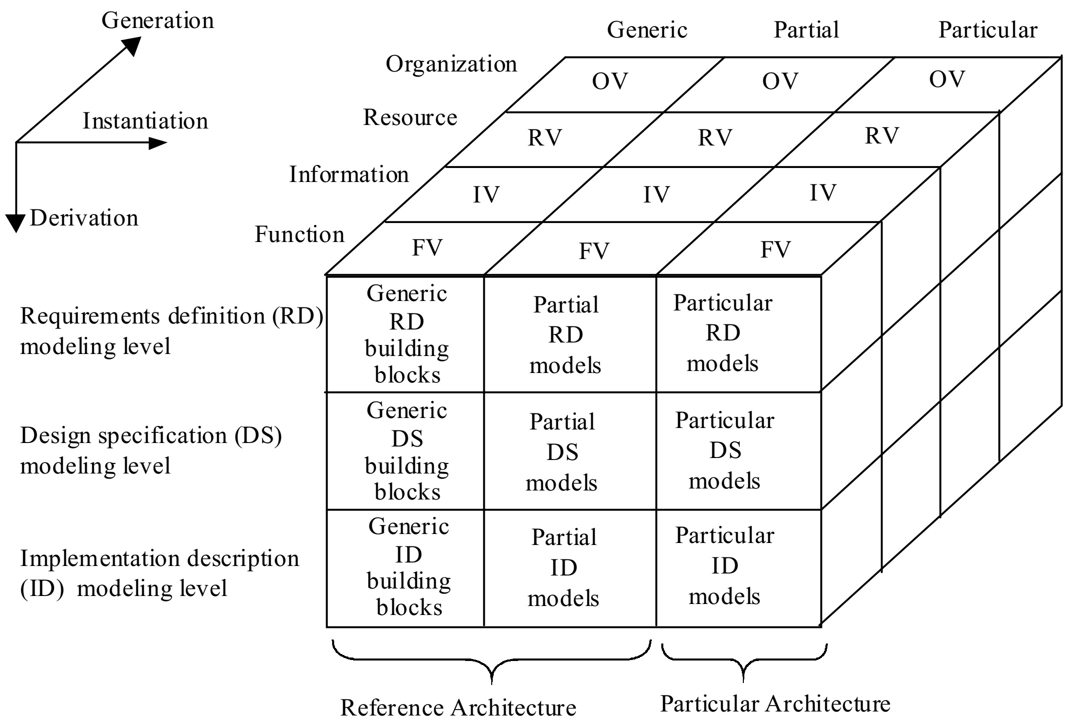


Figure 5.6 CIMOSA modeling framework

CIMOSA integrating infrastructure (IIS) provides services to integrate all specific application processes of the enterprise into one co-operating system. IIS consists of the following services:

- **Information Services**: administrating all information required by the various application processes.
- **Business Process Services**: scheduling the provision of resources and dispatching the execution of enterprise activities.

- **Presentation Services:** representing the various types of manufacturing resources to the Business Process Services in a homogeneous fashion.
- **Communication Service**: being responsible for system-wide homogeneous and reliable data communication.

CIMOSA model creation processes, namely instantiation, derivation and generation, define how generic building blocks and partial models are used to create particular enterprise models.

The instantiation process is a design principle which suggests: **(1)** to go from a generic type to particular type(types are refined into subtypes down to particular instances); and **(2)** to reuse previous solutions (i.e. use particular models or previously defined models) as much as possible. It applies to all four views. It advocates to go from left to right of the CIMOSA cube.

The derivation process is a design principle which forces analysis to adopt a structured approach to system design and implementation, going from Requirements Specification, through Design specification and finally to full Implementation Description. It applies to all four views. It advocates going from the top to the bottom of the CIMOSA cube.

The generation process is a design principle which encourages users to think about the entire enterprise in terms of Function, Information, Resource and Organization Views in that order. However, the complete definition of the four views at all modeling levels usually requires one to go back and forth on this axis of the CIMOSA cube.

5.2.2 ARIS

ARIS (Architecture of Integrated Information Systems) approach proposed by Prof. Scheer in 1990 describes an information system for supporting the business process. The ARIS architecture consists of the data view, function view, organization view, and the control view. The data view, function view, and organization view are constructed by extracting the information from the process chain model in a relatively independent way. The relationships between the components are recorded in the control view. Control view is the essential and distinguishable component of ARIS.

The information technology components such as computer and database are described in resource view. But the lifecycle model replaces the resource view as the independent descriptive object. The lifecycle model of ARIS is divided into three levels. The Requirement Definition level describes the business application using the formalized language. The Design Specification level transfers the conceptual environment of requirement definition to the data process. And the Implement Description level establishes the physical link to the information technology. The ARIS architecture is shown in Figure 5.7.

ARIS approach is supported by a set of standard software, such as application system ARIS Easy Design, ARIS toolset, and ARIS for R/3, which help the implementation of ARIS greatly.

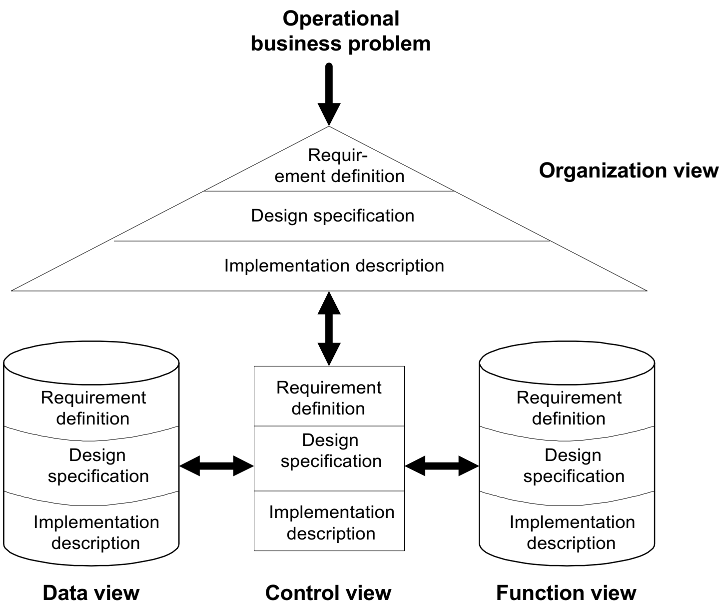


Figure 5.7 ARIS-Architecture

5.2.3 GIM

GIM stands for GRAI integrated methodology. It is rooted from GRAI conceptual model shown in Figure 5.8. In this method, an enterprise is modeled by four systems, i.e., a physical system, an operating system, an information system, and a decision system.

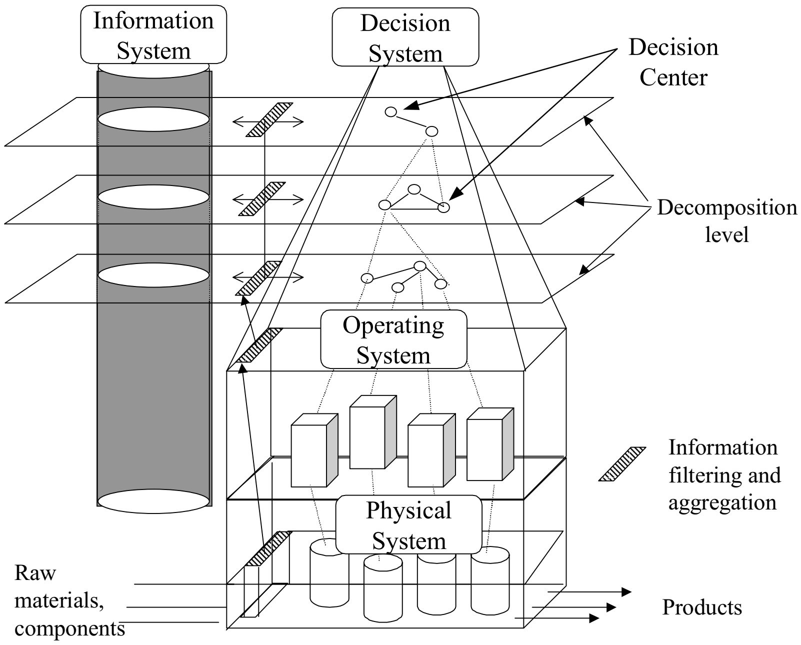


Figure 5.8 The GRAI Conceptual Model

GRAI method makes use of two basic modeling tools that are GRAI grid and GRAI net. GRAI grid is used to perform a top-down analysis of the domain of the enterprise to be analyzed. It is made of a two-dimensional matrix in which columns represent functions, and lines represent decision levels. The decision level is defined by a horizon H and a period P. Long-term planning horizons are at the top, and short-term levels are at the bottom of the grid. Each cell in the matrix defines a decision center. The grid is then used to analyze relationships among decision centers in terms of flows of information and flows of decisions.

GRAI nets are used to further analyze decision centers in terms of their activities, resources, and input/output objects. By this method, a bottom-up analysis of the manufacturing systems studied can be made to validate the top-down analysis. In practice, several paths in both ways are necessary to converge to a final model accepted by all concerned business.

GRAI and GIM are supported by a structured methodology. The goal is to provide specifications for building a new manufacturing system in terms of organization, information technology, and manufacturing technology viewpoints. The methodology includes four phases. The phases are initialization, analysis, design, and implementation.

6. CIM IMPLEMENTATION

CIM implementation is a very important but also a very complex process. It needs the participation of many people with different disciplines. The benefits can be gained from the successful implementation, the loss in investment can also be caused from inadequate implementation. So much attention should be imposed on CIM implementation.

6.1 GENERAL STEPS FOR CIM IMPLEMENTATION

The general life-cycle model discussed in CIM architecture and modeling methodology is the overall theoretical background for CIM implementation. In a practical application, due to the complexity of CIM implementation, several phases are generally followed in order to get best effect and economical benefits from CIM implementation. The phases are feasibility study, overall system design, detailed system design, implementation, operation, and maintenance. Each phase has its own goals and can be divided into several steps.

6.1.1 Feasibility Study

Understanding the strategy objectives, figuring out the internal and external environment, defining the overall goals and major functions of a CIM system, analyzing the feasibility for the CIM implementation from technical, economical, and social factors are the major tasks of feasibility study. The result of this phase is to produce a feasibility study report. In this report, besides the above mentioned contents, the investment plan, development plan, cost and benefits analysis will be given. The organization adjustment proposal should also be suggested. A supervisory committee will evaluate the feasibility study report. When it is approved, it will lay the foundation for following up phases for CIM implementation. Figure 6.1 presents the working steps for feasibility study.

6.1.2 Overall System Design

Based on the results of the feasibility study, the overall system design phase further details the objectives and plans regarding proposed CIM system implementation. The tasks for overall system design are to define the CIM system requirements, set up system function and information model, put forward an overall system design plan, design the system architecture, draft the implementation plan, present the investment plan, carry out cost-benefit analysis, and finally form the overall system design report. The key technologies and their problem solving methods should also been given in the overall system design report. Data coding are important work to be done in the overall system design phase.

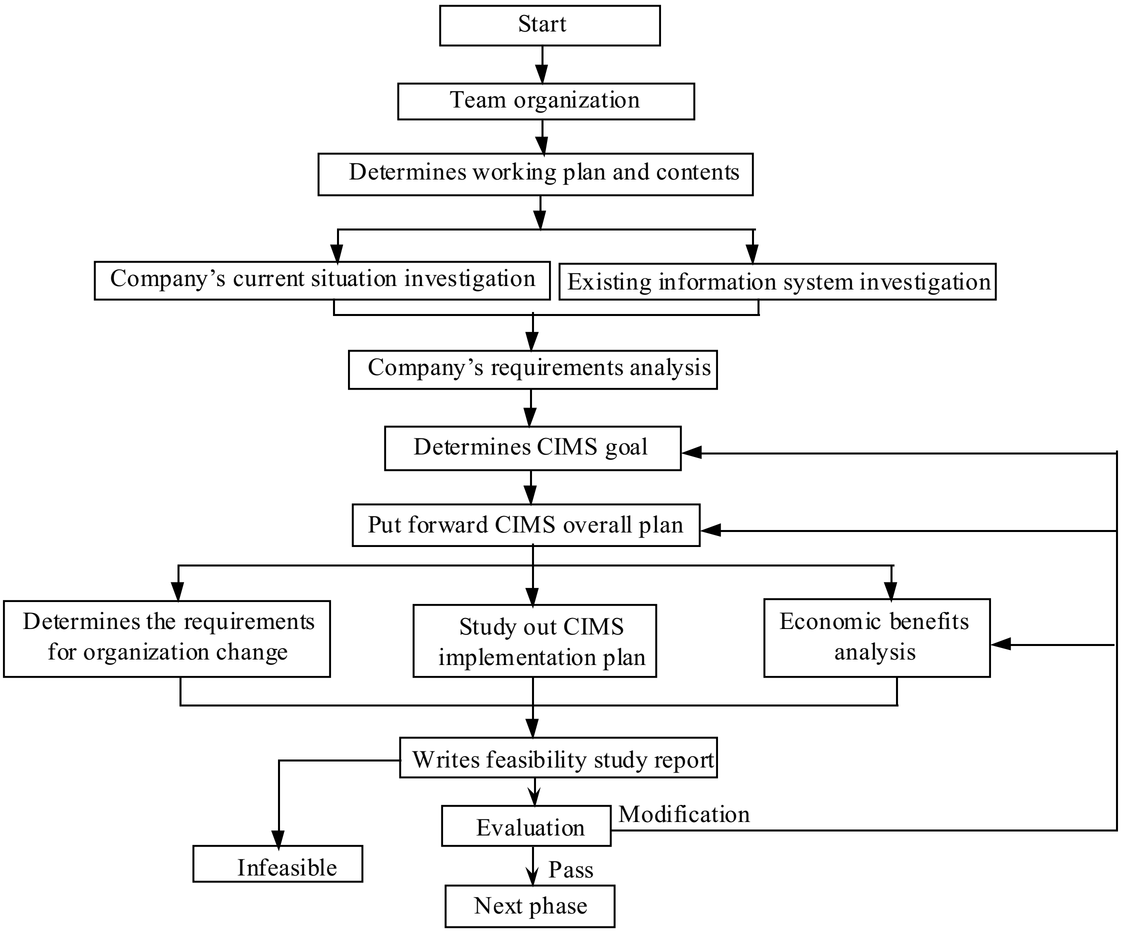


Figure 6.1 Steps of feasibility study

In order to keep the whole CIM system to be an integrated one, in the functional and logical model design, the overall system design follows the top-down decomposition principle. The top level and general functions should be first considered, then they are decomposed to low level and detailed operations.

The general procedures and contents of overall system design are as follows:

(1). **System requirement analysis:** determines the system requirements of functional, performance, information, resource, and organization. This phase's work focus on managerial and tactical view of point;

(2). **System architecture design:** determines the overall system architecture of the CIM system;

(3). **System function and technical performance design:** determines the functions needed to meet the system requirements and the system performance;

(4). **Information model design:** determines the logical data model of the information system;

(5). **Internal and external interface design:** determines these interfaces for the purpose of system integration, including the functional interfaces between different sub-systems and data interfaces between different applications;

(6). **Key technology:** lists all key technologies that has important influence on CIM system implementation, gives their solution methods;

(7). **System configuration specification:** determines the hardware and software configurations;

(8). **Implementation schedule definition:** defines the implementation schedule for the CIM system in network plan or other forms;

(9). **CIM system organization definition:** defines the suitable organization structure for CIM environment;

(10). **Budget making and cost-benefit analysis**;

(11). **Overall system design report generation**.

6.1.3 Detailed System Design

The detailed system design phase solves the problem of system specification definition, the associated hardware and software configuration assignment, the functional and data interface definition, the implementation plan and steps making, the associated implementation team forming, and the responsibility assignment and benchmarking setting.

In this phase, an important work is to define the interfaces between different sub-systems. The shared data physical model for the CIM system needs to be specified. The number, type, and configuration for hardware system should be defined. The detailed software products should also be specified which should meet the requirements defined in overall system design. The network scheduling for the implementation plan should be generated and evaluated. A leadership group is formed who will manage the whole CIM implementation. A number of implementation teams with personnel from different disciplines and different business sectors are formed. Every implementation team will be engaged in the implementation of a specific part of the CIM system.

After the detailed system design phase is finished, the CIM system is ready to go into practical implementation.

6.1.4 Implementation and operation

The implementation phase follows a bottom-up approach. According to the implementation scheduling, the sub-system will be first implemented. When the sub-system implementation is finished, integration interfaces between these sub-systems are developed, and several higher-level sub-systems are formed through integration of some low-level sub-systems. Finally, the whole CIM system is implemented through an integration.

After the system is built and tested, it is turned to an experimental operation. The experimental operation will last for three to six months. During that period, errors occurred in the operation are recorded and system modification are carried. Then the CIM system is turned to a practical use. In the implementation and operation phase, the following steps are generally followed:

① **Building computer supporting environment:** including computer network, computer room, network and database server, UPS, air-conditioner, and fire-proof system;

② **Building manufacturing environment:** including whole system layout setup, new manufacturing devices installment, and old manufacturing configuration;

③ **Application system development:** including new commercial software installment, new application system development, old software system modification;

④ **Sub-system integration:** including interface development, sub-system integration, and system operation test;

⑤ **CIM system integration:** including integration and test of whole CIM system;

⑥ **Software documentation:** including user manual writing, operation rule definition, system security and data backup strategies set up;

⑦ **Organization adjustment:** including business process operation mode, organization structure, and operation responsibility adjustment;

⑧ **Training:** including personal training at different levels, from top managers to machine operators;

⑨ **System operations and maintenance:** including daily operations of CIM system, recording errors occurred in the operation, application system modification, and new system requirements recording for future development.

6.2 INTEGRATION PLATFORM TECHNOLOGY

6.2.1 Requirements for Integration Platform

The complexity of manufacturing systems and the lack of effective integration mechanism are the main difficulties for CIMS implementation. Some of these problems are lack of openness and flexibility, inconvenient and inefficient interaction between applications, difficult in integration of a legacy information system, long time for CIMS implementation, and inconsistency of user interfaces.

To meet the requirements enumerated above, the Integration Platform (IP) concept has been proposed. IP is a complete set of support tools for rapid application system development and application integration in order to reduce the complexity of CIMS implementation and to improve integration efficiency. By providing common services for application interaction and data access, IP fills the gaps between the different kinds of hardware platforms, operating systems, and data storage mechanisms; it also provides a unified integration interface, which enables quick and efficient integration of different applications in various computing environments.

6.2.2 The evolution of Integration Platform Technology

The Integration Platform has evolved through a number of stages. The early concept about IP was considered as an application programming support platform, which provided a common set of services for application integration through API. A typical structure of the early IPs is the System Enabler/Application Enabler architecture proposed by IBM, shown in Figure 6.2. Under such a structure, the IP provides a common and low level set of services for the communication and data transfer (the System Enabler), and also provides application domain specific enabling services (the Application Enabler) for the development of application systems. Thus application developer need not start from coding with the operating system primitive services. One of the disadvantages of the early IP products is that they only provide support for one or a limited number of hardware and operating systems, and the problem of heterogeneous and distributed computation was not addressed. Also the released products often covered a specific domain in the enterprises, such as the shopfloor control. These early IPs focused mainly on the support for the development of application software, and their support for application integration was rather weak.

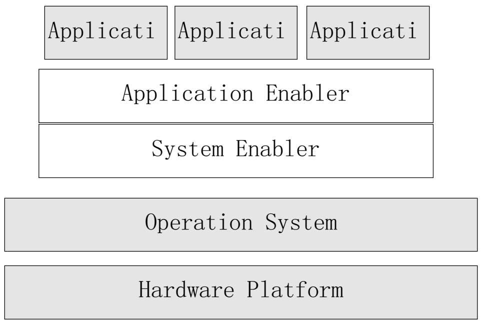


Figure 6.2 IBM System Enabler/Application Enabler

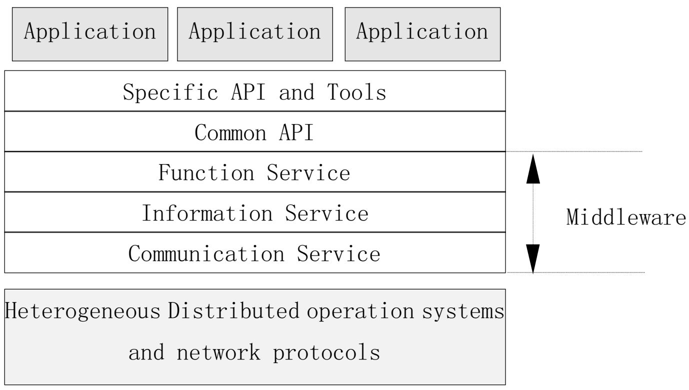


Figure 6.3 A multi-layer IP structure

Since 1990's, IP is developed to be used in a heterogeneous and distributed environment. An example is shown in Figure 6.3, where the architecture is divided into several layers, communication layer, information management service layer and function service layer providing commonly used system-level services. These services form the middleware layer of IP, and the higher layers of IP are classified as general-purpose API, domain-specific API, and application development integration tools. The integration supporting area is extended from a specific domain to the whole enterprise, including management, planning and manufacturing execution.

6.2.3 MACIP System Architecture

MACIP stands for CIMS Application Integration Platform for Manufacturing Enterprises. MACIP is a national high technology R&D key technology research project of China. The MACIP project is designed to develop a research prototype of an application platform oriented to the new IP technology described above.

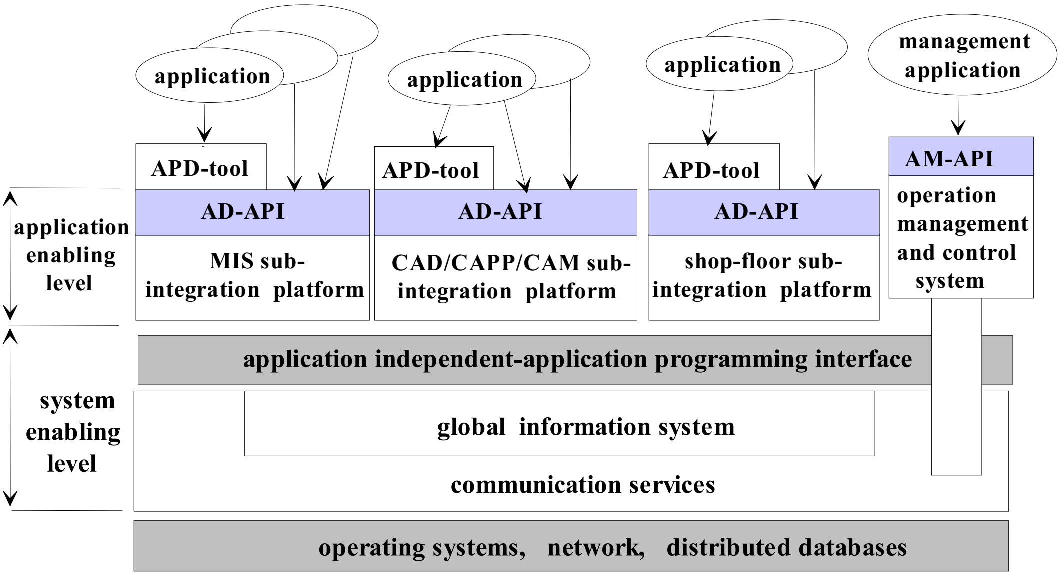


Figure 6.4 System architecture of MACIP

The MACIP system architecture is presented in Figure 6.4. It is a Client/Server structured, Object-Oriented platform with high degree of flexibility. MACIP consists of two layers that are system enabling level and application enabling level. The system enabling level is itself composed of two functions; communication system and Global Information System (GIS). The primary function of these components is to allow for the integration of applications in a heterogeneous and distributed computing environment. The communication system provides a set of services that allow for the transparent communication between applications. The global information system allows for applications to have a common means for accessing data sources in a variety of databases and file systems. These functions are implemented in the form of

Application-Independent-API (AI-API). Application independence means that these functions are not designed for specific applications, but are general services for communication, data access and file management. Hence the system enabling level provides the basic integration mechanisms for information and application integration.

The application enabling level, which utilizes the functions contained within the system enabling level is composed of three domain Sub-Integration Platforms (SIP); MIS SIP, CAD/CAM/CAPP SIP and shop-floor control SIP. Each SIP is designed according to the requirements of a domain application and provides functions for applications in the form of Application Dependent-API (AD-API). The AD-API functions are designed specifically to enable the quick and easy development of domain specific applications. These functions enable the complete integration of the application. Application Development Tools (APD-tools) are developed using the AD-API. Users can also develop applications using the functions provided by AD-API. Existing applications are integrated by modifying its data exchange interface using AD-API functions. An Internet interface is also included in the application enabling level interfaces, and provides the access to MACIP through appropriate Internet technologies.

An operation management system was also designed which uses AI-API functions to provide an Application Management-API (AM-API) for the users., Users use AM-API to develop management applications which manage the IP resources and coordinate the operation of different applications.

MACIP has finished its development in early 1999. It has been used in several companies to support the rapid implementation of CIMS since then.

7. CIMS IN PROCESS INDUSTRY

7.1 INTRODUCTION

Process industry, by which we refer to continuous or semi-continuous production industry processes, mainly includes petroleum industry, electric power industry, metallurgical industry, chemical industry, paper industry, ceramic industry, glass industry, pharmaceutical industry etc. Process industry is a kind of highly complicated industrial system, which not only goes with biochemical reactions, physical and chemical reactions, but also goes with either transmission or transition of matter and energy. Most process industries are subjected to the locked relations of enterprise decision-making, business marketing, schedule planning, material supplying, repertory transportation, product research and development, in addition to the characteristics of continuity in wide scope, uncertainty, high non-linearity and strong coupling. All these factors bring the unusual difficulty for comprehensive management, scheduling, optimization and control in process industry enterprise. So people can not solve these problems relying on either control and optimization theory which are based on the accurate mathematical models and exact analytical mathematical methods, or some techniques of automation alone (Ashayberi *et al.*,1996). CIMS technique is one of possible solutions to complex comprehensive automation of process industry.

7.1.1 Definitions

- **Process Industry** It is a general appellation of those industries in which the values of raw materials are increased by the means of mixing and separating, molding or chemical reaction. Its production could be continuous or batch process. The characteristics of process industry must be considered, when CIMS is applied to those industries.
- **Architecture Structure** It is the aggregation of models which reflect these characteristics of production and business in process industry, and those models represent all the aspects of CIMS in the multi-view and multi-layer way.
- **Models** They are the structural presentations of object concepts. Models include rules, data and formal logical methods which are used to depict states, behaviors and the interactive and inferential relations of objects or events.
- **Reference Model** It is the model definition filled in the architecture structure.
- **Modeling Method** According to the architecture descriptions, designers obtain the descriptions of all the states in an enterprise by the way of abstracting the business function, business data and business period.
- **Information Integration** Those activities in the production process or

enterprise or even group could be considered as a process obtaining information, manipulating information and processing information, then the accurate information in the appropriate form could be sent to the right men so they can make some decisions properly.

7.1.2 Key Technologies

Because CIMS in process industry is at a developing stage, some key technologies still need to be solved. These key technologies mostly include the following four items.

(1) Total technology:

① architecture structure and reference model of CIMS in process industry,

② business reengineering model and managerial modes of enterprise,

③ control modes of material and cost streams,

④ modeling methods for CIMS in process industry,

⑤ structural design methods for CIMS in process industry,

⑥ design specifications for CIMS in process industry.

(2) Integration technologies:

① information integration in enterprise and those between enterprises,

② integration of relation database and real time database systems,

③ core data model, data booting, data compression and data mining,

④ integration and utilization of development tools and applications,

⑤ information integration based Internet, data navigation and browser technology.

(3) Network technologies:

① architecture structure of computer network system,

② open, reliability, safety, expandability, monitoring and management of networks,

③ speed, collisions resolution, concurrency control of networks.

(4) Supervisor control technologies:

① distributed intelligent decision-making support system based intelligent agent,

② optimization model establishment of large scale systems,

③ description and analysis of hybrid system, ④ multi-mode grouping modeling and production operation optimization,

⑤ advanced process control strategy and intelligent coordination control,

⑥ production safety monitoring, fault diagnosis and isolation, failure forecast,

⑦ “soft” measurement, intelligent data synthesis and coordination.

7.2 REFEREBCE ARCHITECTURE OF CIMS IN PROCESS INDUSTRY

The CIMS in process industry is a complex systematic engineering. Since it started, some advanced management theories, such as BPR (Business Process Reengineering), CE (Concurrent Engineering), and TQM (Total Quality Management), have been introduced. Using these theories, the managers could reorganize their departments that are overlap in functions so as to facilitate the development of the enterprise. The realization of CIMS in these enterprises must build a clear reference architecture that can depict all functions in various phases and levels. Under guidance of the reference architecture, the designers can simulate all potential solutions in an appropriate workbench and determine the total integration solution. The reference architecture of CIMS in process industry can refer the frame of CIMS-OSA and PERA. CIMS-OSA frame has considerable definitions and modeling approaches, of which the concepts are very clear. PERA frame is perfect in definition of every phase in CIMS life cycle, which considers every factor of human that will effect the enterprise integration.

7.2.1 Architecture Structure Model

The architecture structure model of CIMS in process industry comprises of four phases (Aguiar,1995): strategic planning, requirement analysis and definition phase, conceptual designs phase, detailed design and implementation phase, and operation and maintenance phase, as shown in Figure 7.1. They reflected all the aspects of building process of CIMS. Strategic planning and requirement definition phase is related to senior management. The models in this phase manipulate information with reference to enterprise models and external factors to assess enterprise's behavior, objective and strategy in multi-view and multi-domain, so as to support decision-making. The conceptual design phase is the domain of system analysis. According to the scope defined in previous phase, these models in this phase depict the detailed description of system in formalized system modeling technology. The solution will be found, which satisfies the demands for performance, and includes what and how to integrate. In general, the solution is given with a form of functions. Detailed design and implementation phase is the scope of system design. In the phase, the physical solutions should be specified, which include all subsystem and components. The models given in this phase are the most detailed. The models in operation and maintenance phase embody the characteristics of the system in operation. These models, which define all active entities and their interaction, encapsulate a lot of activities in enterprise operation.

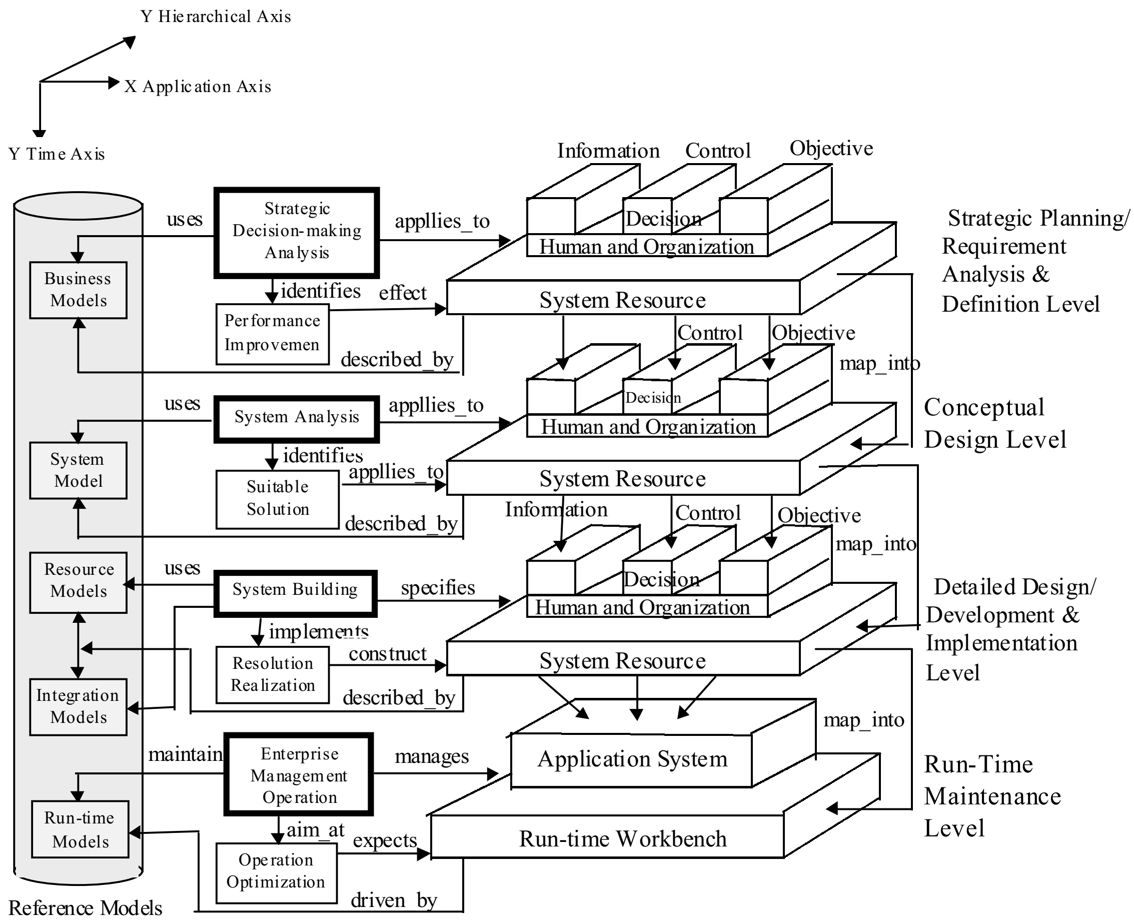


Figure 7.1 Architecture structure model

The reference models depicted in Figure 7.1 consist of run-time models, resource models, integration models, system models and business models, which correspond to the descriptions of AS-IS system and TO-BE system in the process of designing CIMS in process industry. Their relationships are abstracted step by step from down to up, opposing to the process of building CIMS.

- **Run-time Models** They encapsulate the information related to system operation such as dynamic math models of production, input-output models and orders' management models etc.
- **Resource Models** They comprise the information related to relationships between the resource and the satisfaction of demands. In these models, the resource information that designers will add for some special functions is still included.
- **Integration Models** They present the way in which various component elements of AS-IS system and TO-BE system could be integrated to complete an integrated system.
- **System Models** They capture the structure and knowledge of the department in related domains which are currently organized or should be organized to improve the performance of the system. They encapsulate the experiences of system analyst and the descriptions of prototype.
- **Business Models** They collectively comprise the business knowledge required to accomplish strategic analysis and requirement definition, including business rules and accumulated experience of analyzing enterprise performance.

Instructed by these reference models, CIMS in process industry could be built from up to down. Every phase is dynamic in nature, and may be related to each other too, that is the implementation in every phase may be modified to adapt to the changes of environment and demands.

7.2.2 Hierarchic Structure Model

The hierarchical structure model is a structured description of CIMS engineering. It is an aggregation of models and their relationships in the whole CIMS of an enterprise. It is the fundation of the design and realization of CIMS. A hierarchical structure model used in CIMS in process industry is shown in Figure 7.2, which comprises of five levels and two supporting systems. The five levels refer to the direct control system, the supervising control system, the production scheduling system, the management information system and the enterprise decision-making system respectively, and two supporting systems are the database system and the computer network system.

The main function of the hierarchical structure model is:

- **Direct Control System Level** It is the lowest level of automated system in production process, including the distributed control system used in production devices and the fundamental automated equipment used in offsite. The parameters of production process are measured and controlled by the systems. They also receive the instruction from the supervising control system level, and accomplish the process operation and control.
- **Supervising Control System Level** The system in this level fulfills supervising control on main production links in the whole production process. According to the instructions from the scheduling system level, it forms process tactics, and conducts the actions at the direct control system level, including operation optimization, advanced control, fault diagnosis and process simulation.
- **Production Scheduling System Level** In the level the production, load is determined, and the production planning is decomposed into five days rolling work planning month by month, according to the information from the decision-making system and the data of material stream and energy stream. By optimizing scheduling, allocating energy, and coordinating operations in every workshop, the production becomes balanced, stable and high efficient.
- **Management Information System Level** This system accomplishes MIS function in the whole enterprise, and makes integrated management of production and business information. According to the instruction from the decision-making system, it makes logical decisions. It is in charge of day-to-day management including business management and production management.
- **Enterprise Decision-making System Level** This system comes up with decisions supporting enterprise business, product strategy, long-term objective and developing planning, and determines the strategy of production and business. Within the across-board of enterprise, it aims at the integration optimization in the whole enterprise so as to obtain the maximum benefit.

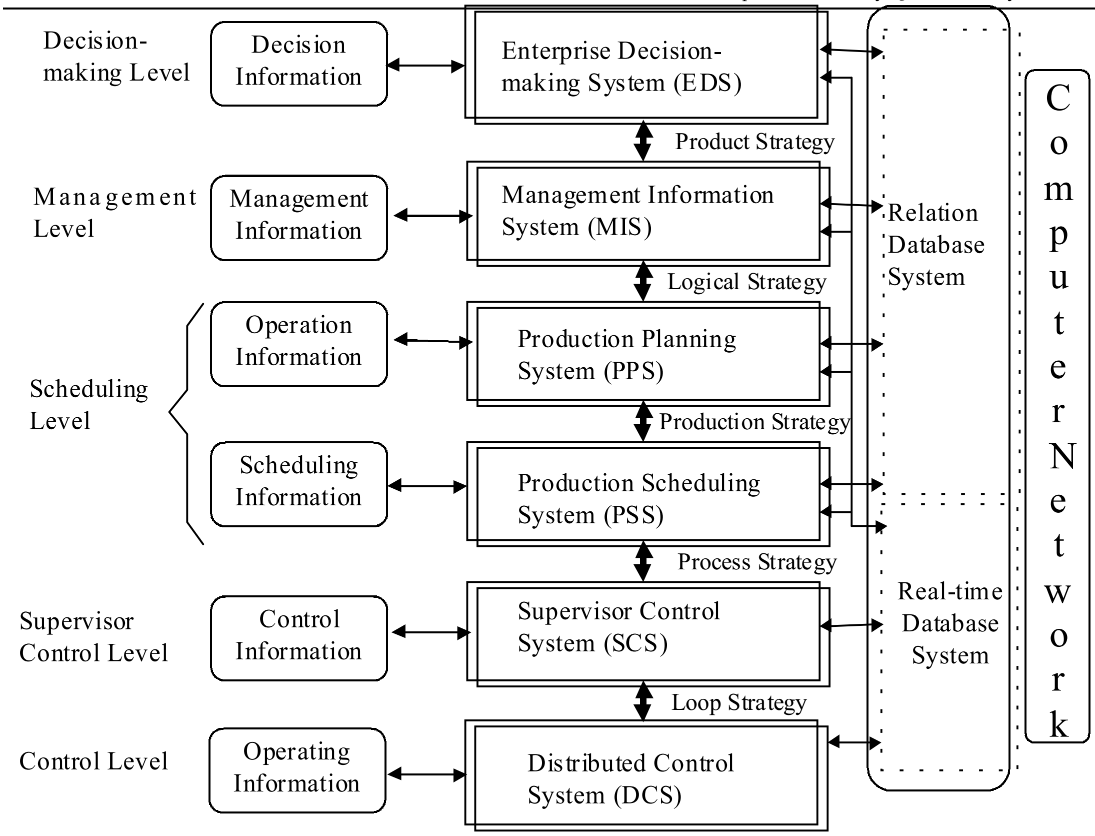


Figure 7.2 Hierarchic structure model

7.3 APPROACH TO INFORMATION INTEGRATION FOR CIMS IN PROCESS INDUSTRY

The core of CIMS in process industry is the integration and utilization of information. The so-called information integration can be presented precisely as follows: The production process or an enterprise could be regarded as a process of obtaining, processing and handling of information. CIMS should ensure the correct information could be transmitted to appropriate person in punctual time with accurate form so as to make correct decision.

7.3.1 Production Process Information Integration

Production is the main line of design guidance of CIMS for a process industry. Driven by the hierarchical structure model discussed in the section 7.2.2, these information models of every subsystem at all levels are built. In these models, the modeling of production process information integration is the crux of matter. This model embodies the design guidance centered on production in three aspects:

① Decision → Comprehensive planning → Planning decomposition →

Scheduling →Process optimization → Advanced control,

② Purchase → Material management → Maintenance,

③ Decision → Comprehensive planning → Planning decomposition → Scheduling → Product storage and shipment control.

Using this model, the computation of material equilibrium, heat equilibrium and the analysis/ evaluation of equipment, material and energy can be done, so as to realize the optimization manipulations in overall technological process.

7.3.2 Model-Driven Approach to Information Integration

The Figure 7.3 depicts the mapping relationship of the models in the building process of CIMS in process industry. It demonstrates that the designed function related to every phase of building CIMS could be depicted from the design view using the structural and model-driven way (Aguiar, 1995).

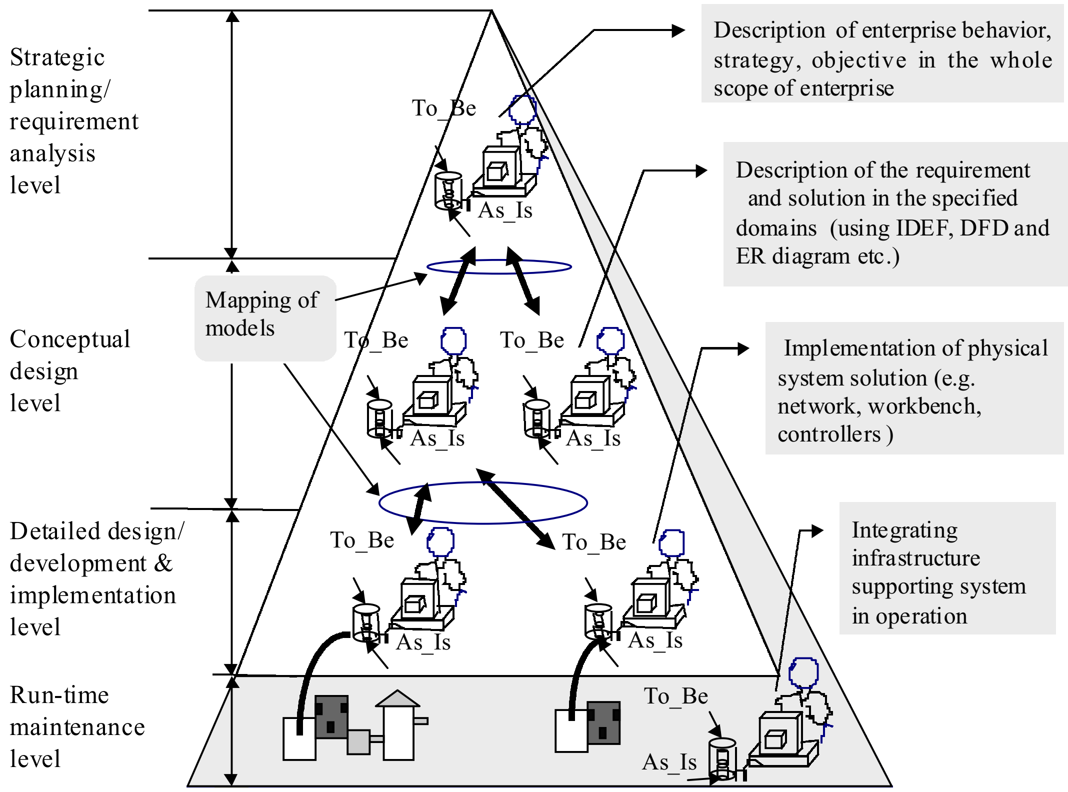


Figure 7.3 Integrating map of models based on model-driven way

The realizations of models mapping rely on the building of software tools supporting every phase in a hierarchical way. The so-called model mapping means the evolutionary relationships of models between the phases in building CIMS. As the enterprise hierarchy is developed downwards, the description in models becomes more detailed. As opposed to it, with the increasingly widening of modeling scope, the granularity of descriptions in models will reduce so as to form more abstract models. For example, in detailed design and implementation level various dynamic math models depicted system should be used, and detailed IDEF0 and static math models should be used in conceptual design phase. We can conclude that the models of various phases in the building CIMS can be evolved step by step in the model-driven way from up to down.

In the previous analysis, it could be noticed that the realization of the model-driven information integration method requires a workbench. It consists of a series of tools, such as modeling tools from entity to model, simulating tools supporting the simulations in various levels from higher level-strategic planning to the lower level detailed design and assessing tools appraising the performance of solution's simulation in various levels.

7.4 AN APPLICATION EXAMPLE

Here we introduce an application example of CIMS in a giant refinery enterprise. The technological process of the refinery is continuous, material stream cannot be interrupted, and strict real time demands of production manipulation are need. The enterprise aims at the following objective: material equilibrium, energy equilibrium, safety and high efficient, low cost and good quality, and optimized operation of technological process. The realization of CIMS in this type enterprise not only needs the consideration of problems such as production management, production scheduling, operation optimization and process control, but also needs to consider the following activities: business, marketing, material supply, oil product transport and storage, developing new product, capital investment etc (Fujii *et al*, 1992). According to the changes of crude oil, requirements of product in market, feasible flexibility of production process and different management modes, the computer integrated production system of the enterprise is constructed, and the integration of business decision-making, production scheduling, workshop management and process optimization is realized in the giant refinery.

7.4.1 Refinery Planning Process

The refinery enterprise consists of many production activities (Kemper,1997). If the blend operation day is called the original day denotes, then the production activities in the day, 90 days before the original day, include the crude oil evaluation, the production strategy-making and the crude oil purchase etc. In the same way, the production activities in the day, 10-30 days after the original day, include the stock transportation and the performance adjustment of oil products etc. Every activity in the production process is relevant to each other. For example, in the activity of the crude oil evaluation, ones need to analyse the factors in the activities following the production strategy-making. In another example, ones in the activity of the crude oil evaluation need to analyse those production activities following the refinery balance in detail. The deep analysis of those activities in the refinery enterprise is the basis of design of CIMS in it. The Figure 7.4 depicts the refinery planning process.

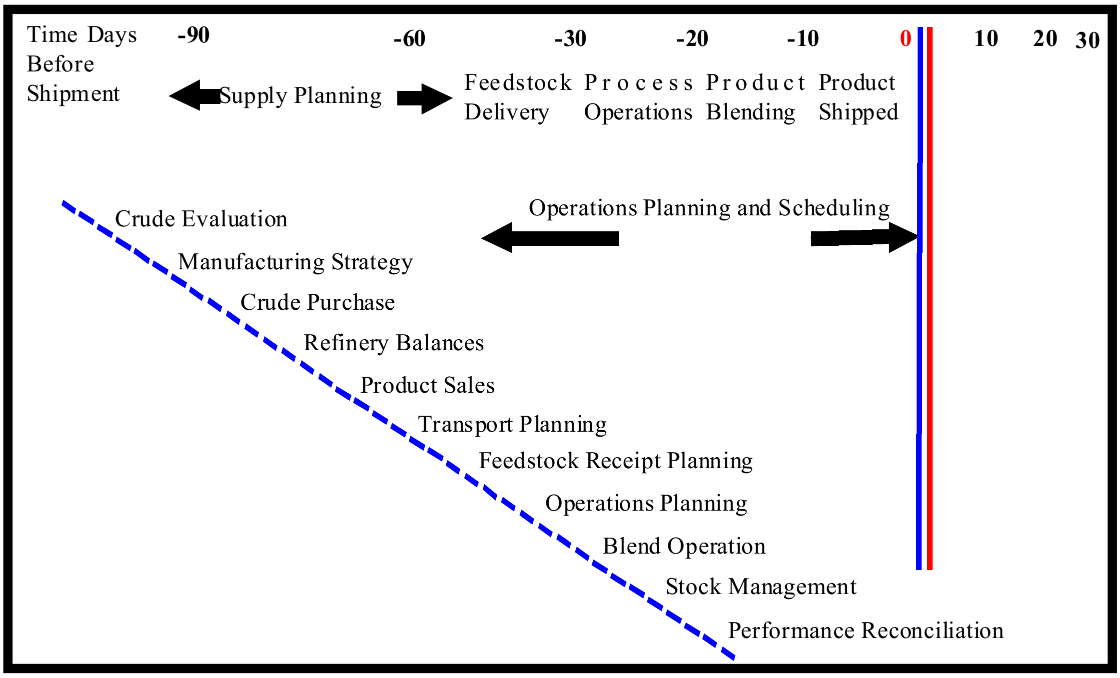


Figure 7.4 Refinery planning process

7.4.2 Integrated Information Architecture

By analysis of the refinery planning process, we can construct the integration frame depicted in Figure 7.5.

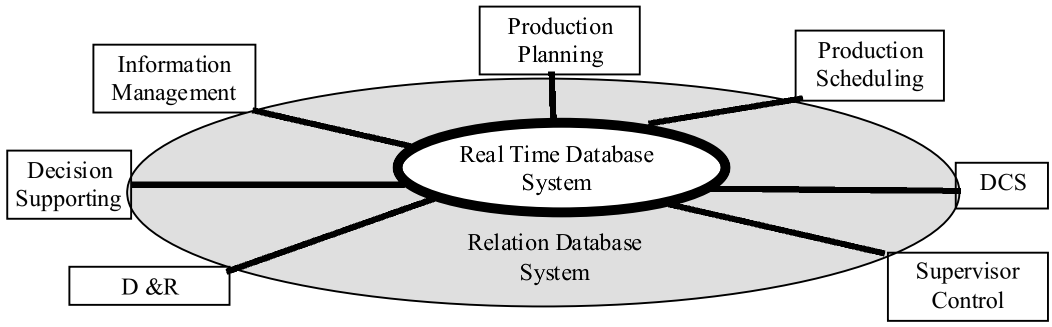


Figure 7.5 Integration frame

Using the model-driven approach to the modeling of all subsystems, the information integration model in this refinery enterprise could be built as shown in Figure 7.6 (Mo and Xiao,1999). The model comprises the business decision-making level, the planning scheduling level and the process supervisor control level. Their integration is supported by two database systems.

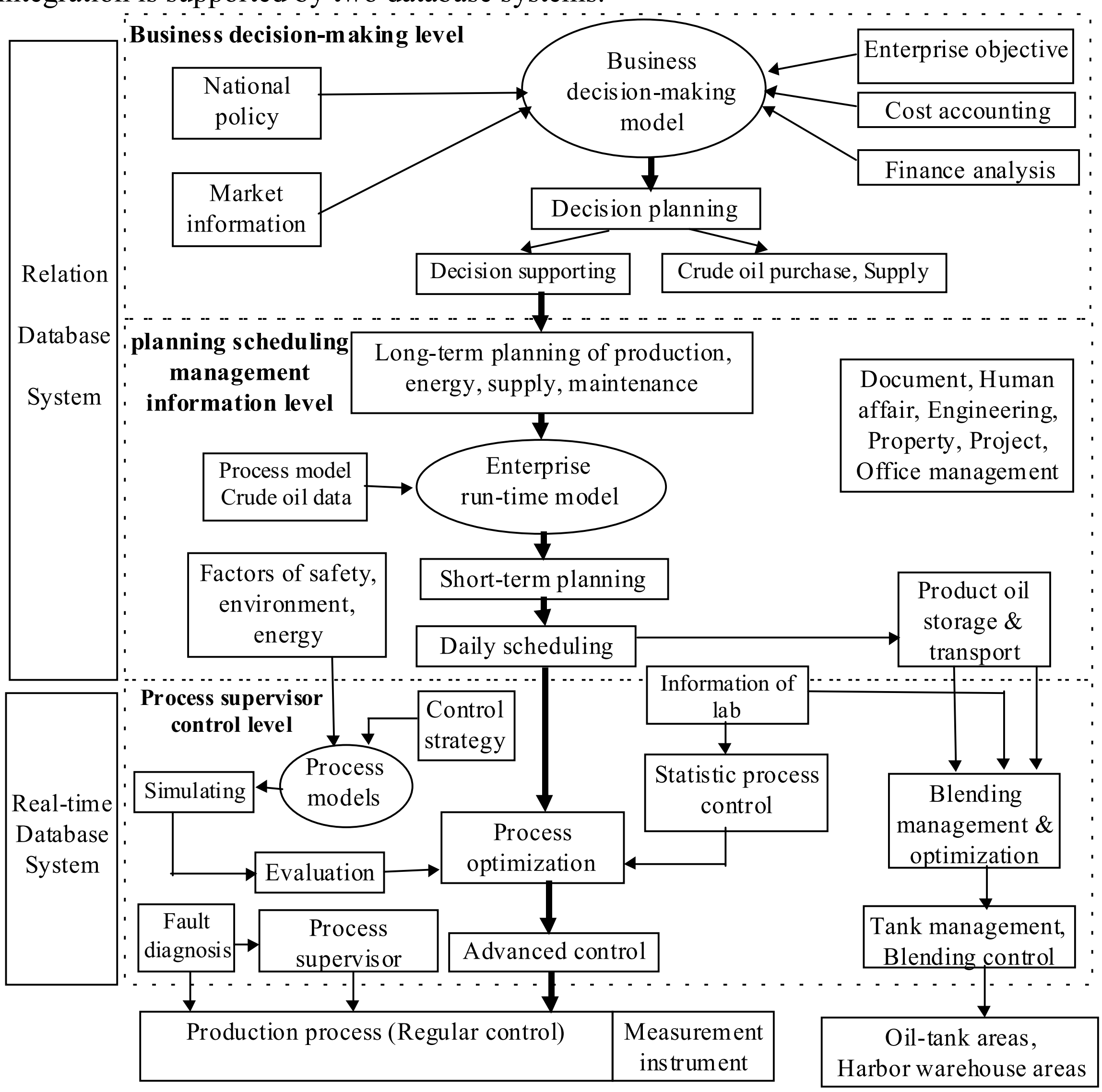


Figure 7.6 Information integration model

The relevant information, such as market, costing, financial affair, and production situation, is synthesized to make business decisions of the enterprise, and is formed crude oil supply and oil product sale planning both at the business decision making level.

The planning/scheduling level synthesizes management information, decomposed the production planning to short-term planning and executes the daily scheduling, and assigns instructions to process supervising control level directly. In the meantime, it accomplishes the management and control of oil product storage and transport, including the management and optimized scheduling control of harbor area and oil tank area.

The process supervising control accomplishes process optimization, advanced control, fault diagnosis and oil product optimized blending.

7.4.3 Advanced Computing Environment

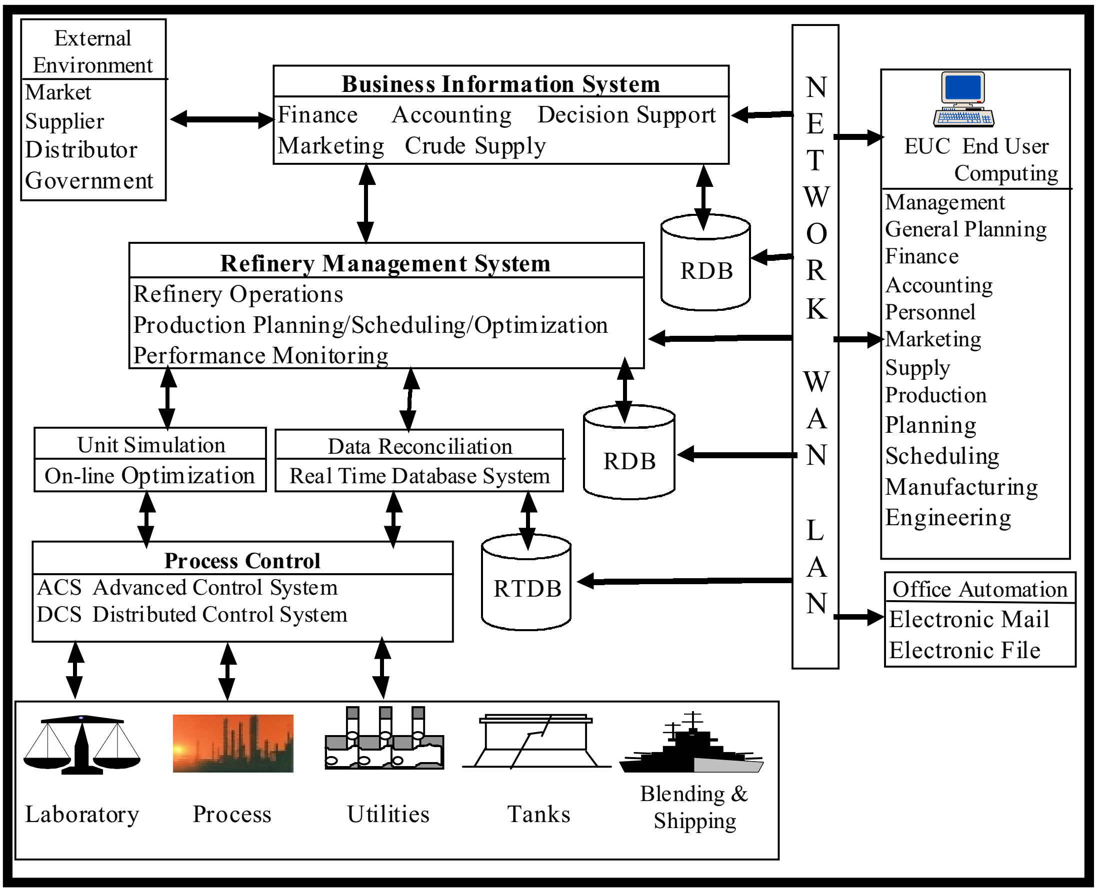


Figure 7.7 Advanced computing environment

The information integration model of the giant refinery depicted in Figure 7.6 is built by the model-driven method. The model is the design guidance of the realization of CIMS in the enterprise. The Figure 7.7 depicts computing environment for the realization of the information integration model, in which the client/server computing mode is used (Kemper,1997).

7.5 CONCLUSIONS

The reference architecture of CIMS in process industry can instruct the designers to optimize solutions by repeatedly optimizing and simulating so as to obtain the final physical system realization in an enterprise. The practical experiences indicate that CIMS in process industry is not a "handing in key" engineering. With the progressive development of technology and the changes of external environment, CIMS in process industry needs to keep doing adjustment so as to obtain the maximum economic and social benefit.

8. BENEFIS OF CIMS

Many benefits can be obtained from the successful implementation and operation CIM system in a manufacturing company. The benefits can be classified to three kinds of benefits that are technical, management, and human resources quality.

8.1 TECHNICAL BENEFITS

Technical benefits obtained from implementation CIM system are:

1) Reducing inventory and work in progress: the inventory and work in progress can be reduced through the utilization of MRPII or ERP system. The careful and reliable material purchasing planning and production planning can in a great extent eliminate high inventory and work in progress level, hence reducing capital overstock and even waste by long time material store.
2) Improving production efficiency: through the integration of production system, planning system, and material supply system, the production processes will be operated in a well organized way, hence the production can be carried with smallest waiting time, the machine utilization can be greatly increased. Through

the integration of CAD, CAPP, and CAM systems, the setup time for NC machines can be reduced significantly. The improvement of production efficiency will bring economic return from investment in CIM system.

3) Improving product quality: the integration of the company's business processes, design processes, and production processes will help in improving product quality. The total quality management can be put into effect in the CIM integrated environment.
4) Reducing cost: this is the direct effect obtained from the above three benefits.
5) Improving product design ability: through the integration of CAD, CAPP, and CAM systems, by using the current engineering method, the product design ability of the company can be significantly improved. New and improved products can be designed and developed in shorter time, the company can win the market competition with these new products.

8.2 MANAGEMENT BENEFITS

From the CIM system implementation, management benefits can be obtained. They are:

1) Standardizing processes: the business processes, design processes, and production processes can be standardized. This can help to streamline company's processes and reduce errors caused by uncontrolled and random operations.
2) Optimizing processes: the business processes, design processes, and production processes can be optimized. This can help to find bottlenecks in the processes. It can also help to find the cost-intensive activities, thus to provide methods to reduce the cost.
3) Improving market response ability: the implementation of CIM system will change the traditional pyramid organization structure to flat structure that can greatly improve the response speed to market change and user requirements.

8.3 HUMAN RESOURCE QUALITY

Almost all people will be involved in the implementation of CIM system. Through different courses of train, from CIM philosophy to computer operation, almost all employees will be trained, so the total quality of the employee can be improved. The improvement of human resource quality includes all levels from management staff to production operator. The more important factor is the employee will get to know better of the company's objectives, situation, technical standard, and manufacturing paradigm. This will inspire the employee to devote their energy to improve the company's operation efficiency.

9. FUTURE TRENDS OF CIM

As a manufacturing paradigm, CIM concepts and practice has developed for more than 20 years. It is still in active development and received much attention of researchers and companies. Some of the development trends for CIM are:

9.1 Agile Manufacturing

In the currently continuous, rapidly, and unforeseeable changing market environment, an effective way to keep the company's competition is to use agile manufacturing strategy. The agile manufacturing is called 21^{st} century manufacturing enterprise strategy (Goldman, et al, 1991, 1995). By agile, we mean the company can quickly respond to the market change by quickly reengineering its business processes, reconfiguring its manufacturing systems, and innovating its products.

There are a number of papers discussing about the agility and characteristics of a agile manufacturing company. Some of the characteristics are:

- Greater product customization
- Rapid introduction of new or modified products
- Increased emphasis on knowledgeable, highly trained, empowered workers
- Interactive customer relationship
- Dynamic reconfiguration of production processes
- Greater use of flexible production technologies
- Rapid prototyping
- An agile and open system information environment
- Innovative and flexible management structures
- Rapid collaboration with other company to form a virtual company.

9.2 Green Manufacturing

The more and more rapid deterioration of environment has caused many problems to the society. During the production of products, manufacturing company also produces pollution to the environment. One kind of pollution is produced during the manufacturing processes, such as noise, waste gas, waste water, and waste materials. Another kind of pollution is caused by waste parts when the product comes out its life, such as the battery, printed circuit board, plastic cover, etc. The green manufacturing aims at developing a manufacturing paradigm and a number of methods to reduce pollution for a manufacturing company to the environment. Green manufacturing paradigm coves the whole life-cycle of a product, from requirements specification, design, manufacturing, maintenance, discard as useless. The research topics regarding green manufacturing coves:

- Green design: considers the product infection to the environment during the design process, designing a product which has minimum pollution to the environment. This design paradigm is also called design for environment. Multi-life cycle design which considers multiple use of most parts, and recycle those one time use parts has caused much attention.
- Green materials: development of materials that can be easily recycled.
- Green production: developing methods to reduce pollution during the production process, such as noise, waste gas, waste water, and waste materials.
- Green dispose: developing new methods to recycle the disposed products.

9.3 Virtual Manufacturing and Other Trends

By using virtual reality and high performance simulation, virtual manufacturing focuses on building digital model of the product and studies the dynamic and kinetic performance of the product, hence to reduce product development cost and time.

There are also many development trends regarding CIM and its relating technology. The technology which will have great influence for CIM may be network (Internet and WEB) technology, distributed object technology, intelligent agent technology, knowledge integration technology, and CSCW technology. The CIM system with these advanced paradigm and technology will have a brilliant future. The future manufacturing company supported by advanced CIM system may be operated on a internet environment (WEB user interface), running on a virtual dynamic organization structure, using CSCW tool, to design and produce products in a cooperated and integrated way. It can fully satisfy the user requirements and produce the products in a fast and cheap way. The delivery of materials and products will be on time.

REFERENCE

[1] Agrawal, S. C. (1985). *Metamodeling : a study of approximations in queueing models*, The MIT Press, Massachusetts

[2] Aguiar, M.W.C., and Weston, R.H. (1995). "A Model-driven Approach to Enterprise Integration", *Int. J. Integration Manufacturing*, **8**(3)**,** pp.210-224

[3] Ashayberi, J., and Selen, W. (1996). "Computer Integrated manufacturing in the Chemical Industry", *Production and Inventory Management Journal*, **37**(1), pp.52-57

[4] Ayres, R. U. (1991). *Computer Integrated Manufacturing-Volume I: Revolution in Progress*, Chapman & Hall, New York

[5] Bray, O. H. (1988). *Computer Integrated Manufacturing-The Data Management Strategy,* Digital Press

[6] Buffa, E. S. (1984). *Meeting the Competitive Challenge: Manufacturing Strategies for U.S. Companies*, Homewood, I11., Dow Jones-Irwin

[7] Butterworths Harrington, J. (1979). *Computer Integrated Manufacturing*, Krieger Publishing, Malaber, Florida

[8] Carrie, C. (1988). *Simulation of Manufacturing*, John Wiley & Sons, New York

[9] Carter, M. F. (1986). "Designing flexibility into automated manufacturing systems", In: *Proc. of the 2nd ORSA/TIMS Conference on FMS: Operations Research Models and Applications* (K. E. Stecke and R. Suri, eds.), Elsevier Science Publisher B. V., New York, pp.107-118

[10] CCE-CNMA Consortium (1995). *CCE-CNMA: An Integration Platform for Distributed Manufacturing Applications*, Springer-Verlag, Berlin，Germany

[11] Chen, P. P. S. (1976). "The entity-relationship model: toward a unified view of data", *ACM Transactions on Database Systems*, **1**(1), pp.9-36

[12] Chen, Y., Dong, Y., Zhang, W., and Xie, B. (1994). "Proposed CIM reference architecture", In: *Proc. of 2nd IFAC/IFIP/IFORS Workshop on Intelligent Manufacturing Systems*, June, Vienna, Austria

[13] Colquhoun, G. J., and Baines, R. W. (1991). "A generic IDEF0 model of process planning", *International Journal of Production Research*, **29**(11), pp.239-257

[14] Doumeingts, G., Vallespir, B., Zanettin, M., and Chen, D. (1992). GIM, GRAI Integrated Methodology—A Methodology for Designing CIM Systems, Version 1.0, Research Report, LAP/GRAI, University of Bordeaux I, France

[15] Esprit Consortium AMICE (Eds.) (1993). *CIMOSA: Open System Architecture for CIM*, 2nd Edition, Springer-Verlag, Berlin，Germany

[16] Fan, Y., and Wu, C. (1997). "MACIP: solution for CIMS implementation in manufacturing enterprises", In Proc: *IEEE International Conference on Factory Automation & Emerging Technology*, Los Angles, USA, Sept., pp.1-6.

[17] Georgakopoulos, D., Hornick, M., and Sheth, A. (1995). "An overview of workflow management: from process modeling to workflow automation infrastructure", *Distributed and Parallel Databases,* **l3**(2), April, pp.119-153

[18] Goldman, G. L., and Preiss, K., Eds. (1991). *21st Century Manufacturing Enterprise Stratery: An Industry-Led View*, Harold S. Mohler Laboratory, Iacocca Institute, Lehigh University, Bethlehem, Pennsylvania.

[19] Goldman, G. L., Nagel, R. N., and Preiss, K. (1995). *Agile Competitors and Virtual Organization: Strategies for Enriching the Customer*, Van Nostrand Reinhold, New York.

[20] Greenwood, E. (1988). *Introduction Computer-Integrated manufacturing*, Harcourt Brace Jovanovich

[21] Gupta, Y. P., and Goyal, S. (1989). "Flexibility of manufacturing systems: concepts and measurements", *European Journal of Operational Research*, **43**, pp.119-135

[22] Fujii, M.,Iwasaki, R., and Yoshitake, A.(1992). "The Refinery Management

System Under the Concept of Computer Integrated Manufacturing", *National Petroleum Refiners Association Computer Conference*, Washington, DC.

[23] Hall, R. W. (1983). *Zero Inventory*, Dow Jones-Irwin, Homewood, III.

[24] Hammer, M., and Champy, J. (1993). *Reengineering the Corporation: A Manifesto for Business Revolution,* Breadly, London

[25] Jacobson, I. (1995). *The Object Advantage: Business Process Reengineering with Object Technology*，Addison Wesley, New York

[26] Jha, N. K. (ed.) (1991). *Handbook of Flexible Manufacturing Systems*, Academic Press, San Diego

[27] Keller, G. (1995). "Creation of business processes with event-driven process chains: a strategic challenge", in *SAPinfo-Business reengineering*, SAP AG, Walldorf, pp.8-13

[28] Kemper M.(1997). *IBM Refinery Management System for the Hungarian MOL Refinery*, Erdoel Erdgas Kohle, ISSN 0179-3187, **113**(6) (in German).

[29] Kochan, A., and Cowan, D. (1986). I*mplementing CIM: Computer Integrated Manufacturing*, IFS Publications Ltd., Bedford, UK

[30] Koenig, D. T. (1990). *Computer Integrated Manufacturing: Theory and Practice*, Hemisphere Publishing Corporation, New York

[31] Luo, H., and Fan, Y. (1999). "CIMFlow: a workflow management system based on integration platform environment", In: *Proc. of 7th IEEE Int. Conf. on Emerging Technologies and Factory Automation*, Barcelona, Spain, October

[32] Mayer, R. J., Cullinane, T. P., et al. (1992). *Information Integration for Current Engineering,* IDEF3 Process Description Capture Method Report. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433, AL-TR-1992-0057

[33] Mo, Y. W., and Xiao, D.Y. (1999). "A Model-driven Approach to Information Integration in Continuous Process Industries", *in Proceedings of the 14th World Congress of IFAC*, Beijing, P. R. China, Vol.**A**, pp.115-120.

[34] Otte, R., Patrick, P., and Roy, M. (1996). *Understanding CORBA- the Common Object Request Broker Architecture*, Prentice Hall, New York

[35] Pegden, C. (1982). *Introduction to SIMAN*, System Modeling Corp.

[36] Prased, B. (1996). *Concurrent Engineering Fundamentals: Integrated Product and Process Organization*, Prentice-Hall, New Jersey

[37] Pritsker, A. (1984). *Introduction to Simulation and SLAM*, Halsted Press

[38] Rogers, P., Upton, D. M., and Williams, D. J. (1992). *Chapter 22. Computer Integrated Manufacturing*, In: *Handbook of Industrial Engineering*, Gavriel Salvendy (Ed.), New York : Wiley, Second Edition, pp.647-673

[39] Ross, D. T. (1985). Applications and extensions of SADT, *Computer*, **18**(4), pp.16-24

[40] Saxena, M., and Irani, R. K. (1994). "A knowledge-based engineering environment for automated analysis of nozzles", *Concurrent Engineering: Research and Applications*, **2(1)**, pp.45-57

[41] Scheer, W. A. (1992). *Architecture for Integrated Information Systems*, Springer-Verlag, Berlin

[42] Singh, N. (1996). *Systems Approach to Computer-Integrated Design and Manufacturing*, John Wiley & Sons, Inc., New York

[43] Taguchi, G., Elsayed, A. E., and Hsiang, T. (1990). *Quality Engineering in Production Systems*, McGraw-Hill Book Company, New York

[44] Talavage, J., and Lenz, J. (1977). *General Computerized Manufacturing Systems (GCMS) Simulator*, NSF Report No.7, August

[45] Talavage, J., and Hannam, R. G. (1988). *Flexible Manufacturing Systems in Practice: Application, Design, and Simulation*, Marcel Dekker, Inc., New York

[46] Tetzlaff, U. A. W. (1990). *Optimal design of flexible manufacturing systems*, Springer, New York

[47] Vernadat, F. B. (1996). *Enterprise Modeling and Integration: Principles and Applications*, Chapman & Hall, London

[48] Waldner, J.B. (1992). *Principles of Computer-Integrated Manufacturing*, John Wiley & Sons, New York

[49] Williams, T. J. (1992). *The Purdue Enterprise Reference Architecture*, Instrument Society of American, Research Triangle Park, NC

[50] Workflow Management Coalition. (1994). *The Workflow Reference Model*, [WfMC1003]，WFMC TC00-1003

[51] Wright, W. O. (1992). *The Executive's Guide to Successful MRPII*, Second Edition. Essex Junction, VT: Oliver Wright Limited Publications, Inc.

[52] Zhou, M.C. (ed.) (1995). *Petri Nets in Flexible and Agile Automation, Kluwer Academic Publishers*, Boston