

COMPUTER INTEGRATED MANUFACTURING

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1. INTRODUCTION

CIM stands for Computer Integrated Manufacturing. In 1973, Joseph Harrington published the initial concepts of CIM in his book called *Computer Integrated Manufacturing* (Harrington, 1979). It was not until about 1984 that people began to realized the potential benefits these concepts promised. Since 1984, thousands of articles have been published on this subject. Thanks to the contribution of researchers and practitioners from industries, CIM has become a very challenging and fruitful research area. Different people with different disciplines proposed their understanding about CIM. They use their knowledge to solve different problems in industry practice and contribute to the development of CIM methodologies and theories.

This chapter is organized as follows. In the second section, manufacturing environments, CIM definitions, concepts, and integration issues are discussed. In section 3, CIMS (CIM System) components and their functions are introduced. In section 4, flexible manufacturing system is discussed. In section 5, CIM system architecture and enterprise modeling methods are presented. In section 6, general implementation methods for CIM system are presented. In section 7, the application of CIM in process industry is introduced. In section 8, the benefits gained from CIM implementations are presented. In the last section, some of the development trends for CIM are discussed.

2. CIM DEFINITIONS AND CONCEPTS

2.1 MANUFACTURING ENVIRONMENT

Before the definitions and concepts of CIM are discussed. It is beneficial to give a general description for the environment that CIM concepts are applied. From the acronym C(Computer) I(Integrated) M (Manufacturing), it can be seen that the application area of CIM is manufacturing, or manufacturing company. The

manufacturing companies today have faced intensive market competition, major changes are being experienced with respect to resources, markets, manufacturing processes, and product strategies. Manufacturing companies must respond to the rapidly changing market and to the new technologies being implemented by their competitors. Furthermore, manufacturing, which has been treated as an outcast by corporate planning and strategy, must become directly involved in these critical long-range decisions. Manufacturing can indeed be a “formidable competitive weapon”, but only if we plan for it and provide the necessary tools and technologies (Buffa, 1984).

Besides the traditional competition requirements for low cost and high quality, the competition pressure for today’s manufacturing companies are more complex products, shorter product life cycle, shorter delivery time, more customized products and fewer skilled workers. The importance of these elements varies among industries. Even among different companies in the same industry their impact varies from each company’s strategy.

Today’s products are becoming much more complex and difficult to design and manufacture. One example is the automobile that is becoming more complex with computer-controlled ignition, braking, and maintenance systems. To avoid long design time for the more complex products, companies should develop tools and use new technologies, such as concurrent engineering, and at the same time it should also improve their design and manufacturing processes.

Higher quality is the basic demand of the customers who want their money be worth for the products they buy. This applies to both consumers and industrial customer. The improved quality can be achieved through better design and better quality control in the manufacturing operation. Besides the higher quality demand, customers are not satisfied with the basic products with no options. There is a competitive advantage in having a broad product line with many versions, or with a few basic models that can be customized. A brand new concept in manufacturing is to involve users in the product design, with the aid of design tools or modeling box, the company will allow the users to design the products with their own favor.

In the past, once a product was designed, it had a long life over which to recover its development costs. Today many products, especially high-technology products, have a relative short life cycle. This change has two implications. First, companies must design products and get them to the market faster. Second, a shorter product life provides less time over which we can to recover the development costs. So, the companies should use new technologies to reduce both the time and cost in product design. The concurrent engineering is one of the methods in improving product design efficiency and reducing product costs. Another method is to distribute the cost and risks of new product development to partners, and to share benefits among the partners, this new manufacturing paradigm is called agile manufacturing. This paradigm requires the change or reengineering of traditional organization structures.

Several demographic trends are serious affecting manufacturing employment.. The education level and expectations of people are changing. Fewer new workers are interested in manufacturing jobs, especially the unskilled and semiskilled ones. The lack of new employees for the skilled jobs that are essential for a factory even more critical. On the other hand, many people may not have sufficient education background so that they are not qualified for these jobs (Bray, 1988).

In order to win in the global market, manufacturing companies should improve their competition ability. Some key elements include creative new products, higher quality, better service, great agility and low pollution to the environment. Creative new product is of vital importance to companies in the current “knowledge economy” era.

Figure 2.1 presents a market change graph. From this Figure, it can be seen that the numbers for lot size, and repetitive order is decreasing, the product life cycle is shortening, and the product variety is increasing rapidly.

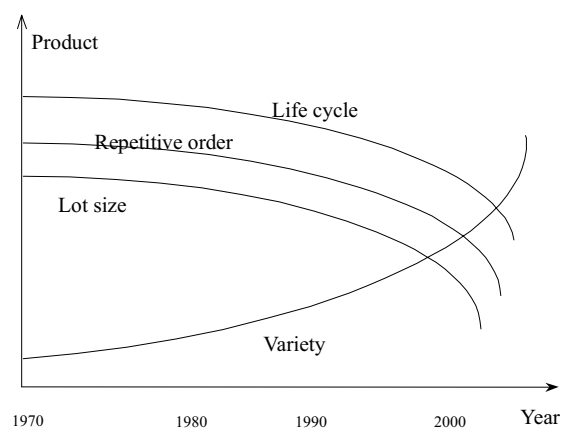


Figure 2.1 Market change

The end user or customers always need new products with advancements in function, operation, energy consumption. The company can get higher benefit through new products. To some extent, we believe that a manufacturing company without new products has no chance to survive in the future market. Better services are needed for any kind of companies. However, for manufacturing companies, better service means fast delivery of products, easy use of the products and satisfying customer need with low price, and rapid response to customer maintenance request.

2.2 FEATURES OF A GENERAL MANUFACTURING SYSTEM

The manufacturing company in itself is a quite complex system. It is a complex, dynamic, and stochastic entity consisting of a number of semi-independent subsystems interacting and intercommunicating in an attempt to make the overall system function profitably. The complexity comes from the heterogeneous environment (both hardware and software), huge quantity of data, and the uncertainty external environment. The complex structure of the system and the complex relationships between the interacting semi-autonomous subsystems are also the affecting factors to make the system more complicated.

A simple model of a manufacturing system can be a black box that takes input materials, energy, and information and gives output products. The internal details of the manufacturing system depend on the particular industry involved, but the key features common to all manufacturing organizations are that the system processes both materials and information. The general manufacturing systems can be decomposed into seven levels of decision hierarchies (Rogers, Upton, and Williams, 1992) (Figure 2.2). Decisions at the upper levels are made at less frequent intervals (but have implications for longer periods into the future) and are made on the basis of more abstract (and slower to change) information on the state of the system. Decisions at the lower levels are made more frequently using much more detailed information on the state of the system.

Three kinds of decisions should be made for any manufacturing company: (1) what kinds of products will be made, (2) what resource is needed to make the products,

and (3) how to control the manufacturing systems. It should be pointed out that these decisions can not be made separately. If the company want to make a decision at a certain level, for example, at business level, it should also get access to the information at other levels. In the whole processes of decision making, the core concept is integration. This is the fundamental requirements for the research and development of Computer Integrated Manufacturing.

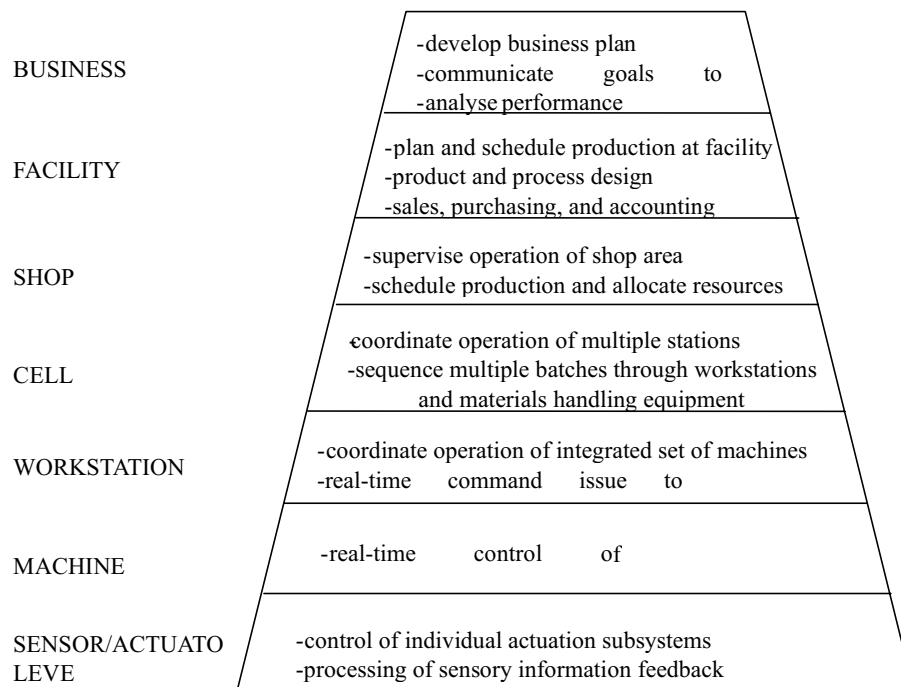


Figure 2.2 A seven-level manufacturing hierarchy

2.3 CIM DEFINITIONS

There are many definitions for CIM emphasizing different aspects of it as a philosophy, a strategic tool, a process, an organizational structure, a network of computer systems, or as a stepwise integration of subsystems. These different definitions are given by peoples working at different areas and at different times from different viewpoints. Since the concept of CIM was put forward in 1973, it has been enriched due to the contributions of many researchers and practitioners. One earlier definition of CIM given by Kochan and Cowan (1986) is: *the concept of a totally automated factory in which all manufacturing processes are integrated and controlled by a CAD/CAM system. CIM enables production planners and schedules, shop floor foremen, and accountants to use the same database as product designers and*

engineers. This definition does not put much emphasis on the role of information.

Another definition given by Digital Equipment Corporation (DEC) (Ayres, 1991) has put much emphasis on the role of information. The definition is: *CIM is the application of computer science technology to the enterprise of manufacturing in order to provide the right information to the right place at the right time, which enables the achievement of its product, process and business goals*. This definition points out the importance of information in manufacturing enterprise, but unfortunately it does not give much emphasis to the very important concept of integration.

Some other definitions have pointed out that CIM is a philosophy in operating a manufacturing company. One definition given by Greenwood (1988) is: *CIM is an operating philosophy aiming at greater efficiency across the whole cycle of product design, manufacturing, and marketing, thereby improving quality, productivity, and competitiveness*.

In order to stress the importance of integration, the Computer and Automation Systems Association of the Society of Manufacturing Engineers has given the following CIM definition (Singh, 1996). *CIM is the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personnel efficiency*.

It should be pointed that CIM does not mean to replace man by machine or computer, so as to create a totally automatic business and manufacturing processes. It is not necessary to build a fully automatic factory in order to implement a CIM system. Especially, it is not wise to put a huge amount of investment in purchasing highly automation flexible manufacturing systems to improve manufacturing standards, if the bottleneck for the company's competition is not in this area. In current situation, the design standards for creative and customized products are more important than production ability in winning the market competition.

The importance of human factors should be much emphasized. Human plays a very important role in CIM design, implementation, and operation. Although

computer applications and artificial intelligence technologies have gained much progress, even in the future, computer can not replace people. In order to stress the importance, someone has presented the idea of human centered CIM.

From the above definitions, two views can be drawn from CIM concepts. They are the system view and information view. In CIM concepts, the whole activities of a company form a system. The different functions and activities can not be analyzed and improved separately. The whole company can operate in an efficient and profitable way only if these different functions and activities are running in an integrated and coordinated environment, and these activities are optimized in a global system range. The SME CIM wheel provides a clear portrayal of relationships among all parts of an enterprise. It illustrates a three-layered integration structure of an enterprise as shown in Figure 2.3.

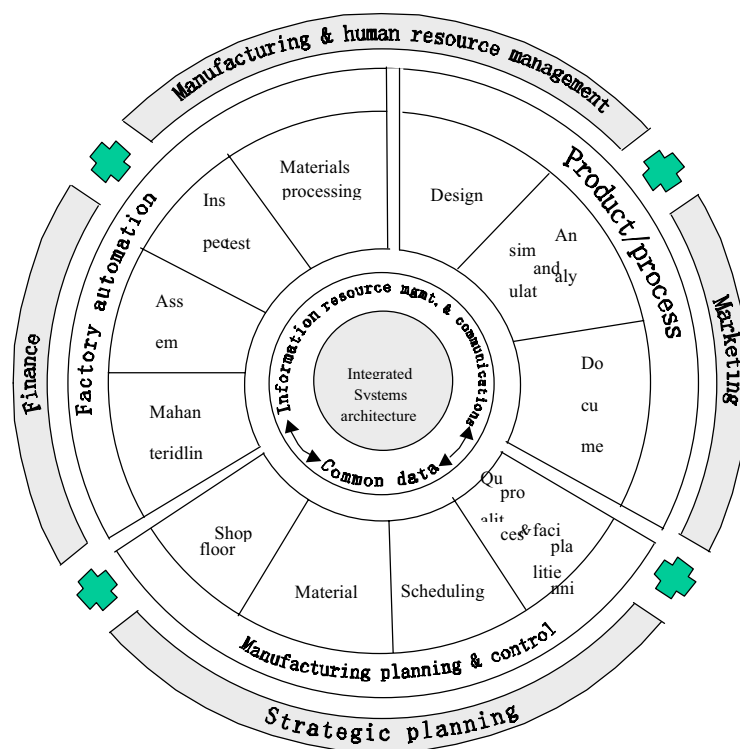


Figure 2.3 The SME CIM wheel

The outer layer represents general management, and human resources management. The middle layer has three process segments: product and process definition, manufacturing planning and control, and factory automation. These process segments represent all the activities in the design and manufacturing phases of

a product life cycle making the product from a concept to its assembly. The center of the wheel represents the third layer, which includes information resources management and the common database.

Another important view of CIM concepts is the information view. As stated in the definition given by Digital Equipment Corporation, the objective of CIM implementation is to enable the right information to be sent to the right person at the right time. The information system plays a vitally important role in the operation of CIM. Although there are many kinds of activities in managing a manufacturing company, each activity has different function in business management and production control, the associated function unit for the information system of CIM normally can be classified into three kinds of tasks: information collection, information processing, and information transfer. Information collection task is the basic function of an information system, the collected information forms the basis of decision making at different levels from business management to device control. There are many methods of information collection depending on the information sources and technologies used. Device sensors may provide data regarding device status, barcode scanner may provide data about the production status of the on line products, form scanner and database table view interfaces may provide data about order, raw material purchasing, and user requirements. Some data may also come from e-mail systems. The data collected can be stored in different data formats and in different repositories.

The second task of information systems is information processing, which is closely related with the business functions of a company. The business functions vary from strategy planning, process planning, product design, warehouse management, material supply, to production management and control. The upper-stream process data is processed by algorithms or human interference, the produced instructions are used for the down-stream process. In the data processing process, different decisions will be made. The decisions made can be used in optimizing the production processes or satisfying some user requirements, such as delivery time and quality requirements. The third task of information system is data transfer between different function units. It has three main functions, i.e., data output from application software in certain data

format to one kind of data repository, data format transformation, and data transfer from one application to another application within the same computer or in a network environment.

2.4 INTEGRATION-CORE OF CIM

Nowadays most people believe the core is integration. In our opinion, computer technology is the basis of CIM, manufacturing is the aim of CIM, integration is the key technology. Why should integration be considered as the core of CIM? This can be seen from different aspects. As we stated above, a system view is an important view in CIM concepts. By system we mean the whole company, including man, business, and technology. In order to form a coordinated system, the man, business, and technology in a company must be integrated. So the first aims of the integration is the integration of three basic elements (man, business, and technology) of the company. Another aim of the integration is the integration of material flow, information flow, and capital flow. Although the aims of an integration seem to be clear, the technology for realizing the integration is far from mature. We still have a long way to go in the route of integration.

CIMOSA (AMICE, 1993) identifies that enterprise integration has to be an ongoing process. Enterprise will evolve over time according to both internal needs and external challenges and opportunities. The level of integration should remain a managerial decision and should be open to change over a period of time. Hence, one could find in some parts of a CIM enterprise, a set of tightly coupled systems and elsewhere, a set of loosely coupled systems according to choices made by this particular enterprise. The need to implement multi-vendor systems both in terms of hardware, software and an easy re-configuration requires the provision of standard interfaces. To solve the many problems of the industry, integration has to recognize and proceed on more than one operational aspect. The AMICE (European Computer Integrated Manufacturing Architecture) project identifies three levels of integration covering physical systems, application and business integration (See Figure 2.4).

Business integration is concerned with the integration of those functions that

manage, control and monitor business processes. It provides supervisory control of the operational processes and coordinates the day-to-day execution of activities at the application level.

Application integration is concerned with the control and integration of applications. Integration at this level means providing a sufficient information technology infrastructure to permit the system wide access to all relevant information regardless of where the data reside.

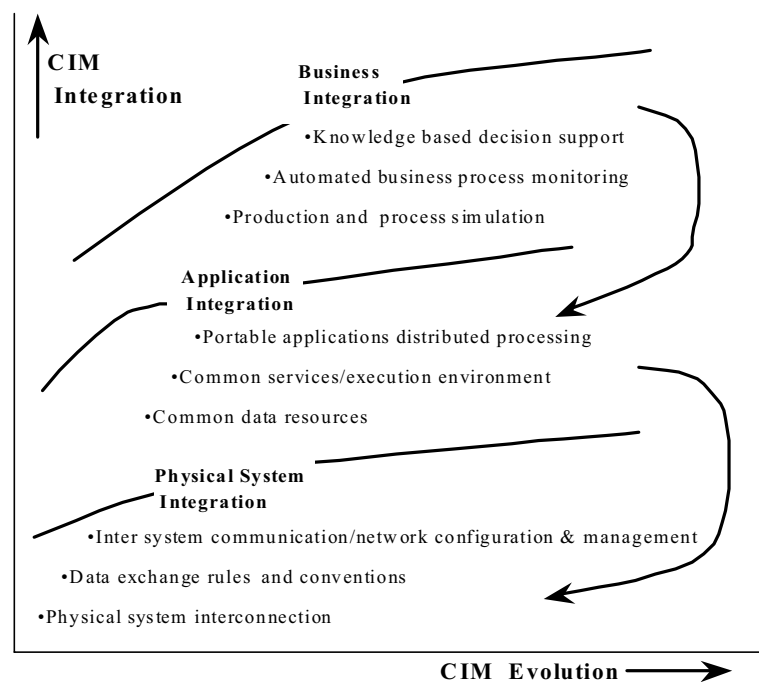


Figure 2.4 Three Levels of Integration

The physical system integration is concerned with the interconnection of manufacturing automation and data processing facilities to permit interchange of information between the so called 'islands of automation' (inter system communications). The interconnection of physical systems was the first integration requirement to be recognized and fulfilled.

Even when business integration has been achieved at one point in time, business opportunities, new technologies, modified legislation will make integration a vision rather than an achievable goal. However, this vision will drive the management of the required changes in the enterprise operation.

The classification of integration can also be given in another method that is different from that given by CIMOSA. Regarding integration objectives and methods,

integration can be classified as information integration, process integration, and enterprise-wide integration.

Information integration enables data to be shared between different applications. The transparent data access and data consistency maintenance under heterogeneous computing environment is the aim of information integration. The information integration needs the support of communication system, data represent standards, and data transfer interfaces. Communication system provides data transfer mechanism and channel between applications located at different computer nodes. Data represent standards are severd as common structures for data used by different applications. Data transfer interfaces are used to transfer data from one application to another. They fulfill two kinds of functions, one function is the data format transfer (from application specified data structure to common structure and vice versa), another function is the data transfer from application to interface module and vice versa. The traditional information integration methods include database data integration, file integration, and compound data integration. The most efficient support tool for information integration is the integration platform (Fan and Wu, 1997).

Process integration is concerned with the collaboration between different applications in order to fulfill some business functions, such as the product design or process control. The need for implementing process integration comes from the pursuit of the company for shorter product design time, higher product quality, shorter delivery time, and high business process efficiency. Business Process Reengineering (BPR) (Jacobson, 1995) and Concurrent Engineering (CE) (Prased, 1996) have promoted the research and application of process integration. Business process modeling, business process simulation, and business process execution are three main research topics related to process integration.

There are a number of methods that can be used in modeling business processes. They are CIMOSA business process modeling, IDEF3 (Mayer, Cullinane, et al. 1992), Petri nets (Zhou, 1995), event driven process chain (Keller, 1995), and workflow (Georgakopoulos, Hornick, and Sheth, 1995) modeling methods. The modeling objective is to define the activities within a business process and the relationships

between these activities. The activity is a basic function unit within a business process. The control and data flow between these activities form the business process which fulfils the business task of a company. The optimization of the flow path and shortening the flow time can help the company in increasing their working efficiency and reducing cost.

The third integration is called enterprise-wide integration. Following the concept of agile manufacturing, the need of virtual organization is ever more important than before. In agile manufacturing mode, a number of companies collaborate in a virtual company form to obtain a new chance in the market. The enterprise-wide integration is required to enhance the information change between the companies. Success of virtual organizations is predicated on empowerment of people within the enterprise with the aid of computer technology including communication networks, database management systems, and groupware. These facilitate team members of the virtual organization to make effective and faster group decisions. Such interaction lays the foundation for enterprise-wide integration, encompassing various plants and offices of an enterprise, possibly located in different counties and cities, as well as customers and suppliers worldwide. Therefore, enterprise-wide integration is much broader than factory automation integration. It is the integration of people, technology, and the business processes throughout the enterprise.

Enterprise-wide integration is required to ensure that all the technical and administrative units can work in unison. This, however, requires a great deal of information about a large number of activities, from product conception through manufacturing, customer delivery, and in-field support. All these life-cycle steps require a large volume of data. The transformation process from one stage to another yields volumes of new data. Furthermore, many of these design, manufacturing, distribution, and service activities, responsible for generating and using volumes of data, are scattered across a wide spectrum of physical locations. The information is generated by a diverse set of highly specialized software tools on heterogeneous computing hardware systems. Often, incompatible storage media with divergent data structures and formats are used for a data storage. This is due to the peculiarities of

the tools and systems that generate data without any regard to the needs of the tools or systems that would eventually use the data.

The main idea of enterprise-wide integration is the integration of all the processes necessary for meeting the enterprise goals. Three major tools for integration, required for overcoming the local and structural peculiarities of an enterprise's data processing applications, are network communications, database management systems, and groupware. A number of methods regarding enterprise-wide integration have been much proposed. They are supply chain management, global manufacturing, and virtual information system supporting dynamic collaboration of companies. The Internet, Web, and CORBA (Otte, Patrick, and Roy, 1996) technologies are playing important roles in the realization of enterprise-wide integration.

3. CIMS STRUCTURE AND FUNCTIONS

3.1 CIMS STRUCTURE

The components of CIMS include both hardware and software. The hardware includes computer hardware, network, manufacturing devices, and peripherals. The software includes operating systems, communication software, database management systems, manufacturing planning and control software, management information software, design software, office automation software, decision support software, and so on. These different hardware and software systems have different functions. They work together to fulfill the company's business goals. In order to understand such a complex CIM system, people normally decomposes CIMS into a number of subsystems interacting with each other. Unfortunately, there does not exist a unique and standard decomposition method for CIMS. Every company can define system decomposition method according to its specific situation and requirements. In our opinion, one decomposition method of CIMS may be as shown in Figure 3.1.

From Figure 3.1, it can be seen that CIMS consists of four functional subsystems and two support sub-systems. Four functional subsystems are Management Information Subsystem, CAD/CAPP/CAM Subsystem, Manufacturing Automation Subsystem, and Computer Aided Quality Management Subsystem. These functional

subsystems cover the business processes of a company. Two support subsystems are Computer Network Subsystem and Database Management Subsystem, they are the basis for the functional subsystems to fulfill their tasks. The arcs denote the interfaces between different subsystems. Through these interfaces, shared data are exchanged between different subsystems.

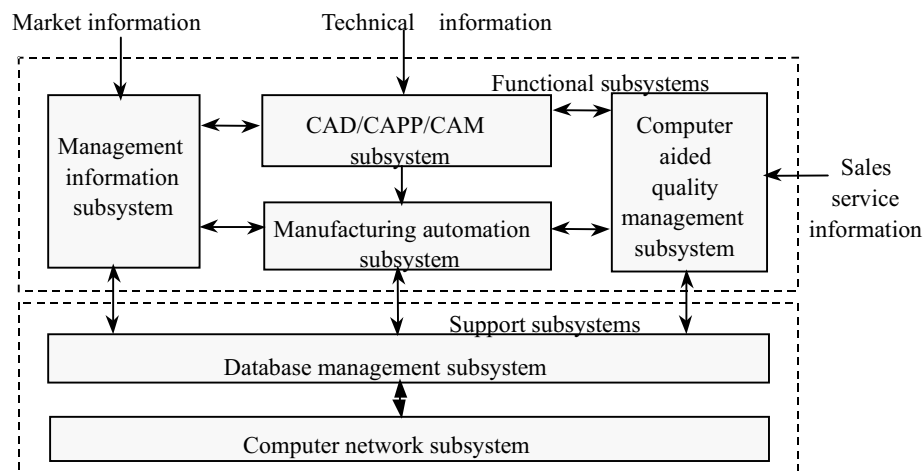


Figure 3.1 Decomposition of CIMS

3.2 COMPONENTS OF CIMS

In this section, we give a brief description about the components of CIMS.

3.2.1 Management Information System

Management Information System (MIS) plays an important role in the company's information system. It manages business processes and information based on market strategy, sales prediction, business decision, order processing, material supply, finance management, inventory management, human resource management, company production plan, and etc. The aims of MIS are to shorten delivery time, reduce cost, and help the company to make rapid decision to react to market change.

Currently, ERP (Enterprise Resource Planning) software is normally used as the key application software in MIS. There are many commercial ERP software products in the market, such as SAP R/3 developed by SAP company and BaanERP developed by Baan Company.

- **Basic Concept of ERP**

In balancing manufacturing, distribution, financial and other business functions to optimize company productivity, ERP systems are considered to be the backbone of

corporate infrastructure. ERP concept is derived from MRPII (Wright, 1992) (Manufacturing Resources Planning) system. It extends the MRPII functions. Besides the traditional functions of MRPII in manufacturing management, material supply management, production planning, finance, and sales management, ERP introduces new functions, such as transportation management, supply chain management, corporate strategy planning, workflow management, and electronic data exchange, into the system. So the ERP system provides more flexibility and ability to the company in business process reengineering, integration with customers, and integration with material suppliers as well as product dispatchers.

- **Manufacturing Resource Planning**

The basis of MRPII is MRP (Material Requirements Planning) which comes out in 1940's. MRPII uses computer-enhanced materials ordering and inventory control methods, it has the advantages in enhancing the speed and accuracy of issuing raw materials to factory work station. It immediately becomes apparent that linking materials with production demand schedules could optimize the flow of the product as it is being constructed in the factory. This could be done in such a manner that material queue times could be minimized (e.g., have the material show up only when needed), and the amount of material needed throughout the factory at any one time could be reduced ultimately. This is an optimization technique that allocates identified sets of materials (sometimes called kits) to specific jobs as they go through the manufacturing processes.

Since it is possible for a computer to keep track of large numbers of kits, it is reserves or mortgages materials for specific jobs in time-order sequences. Linking these sequences with a production plan based on customer need dates allows management to release and track orders through the shop accurately. Prior to releasing orders by means of the kiting process based on the production schedule, it was necessary to obtain supplies. The supplies are based on a gross basis depending on the number of orders expected to be shipped to customers over the selected time period and by having the gross amount of inventory on hand at the start of the period to support production. Obviously, the kit will result in less extra materials on hand at any

point in the production period. This results in large raw material reductions and reductions in material needs for work in process and, hence, lower operation costs.

Figure 3.2 gives the flow diagram of MRPII system (Waldner, 1992).

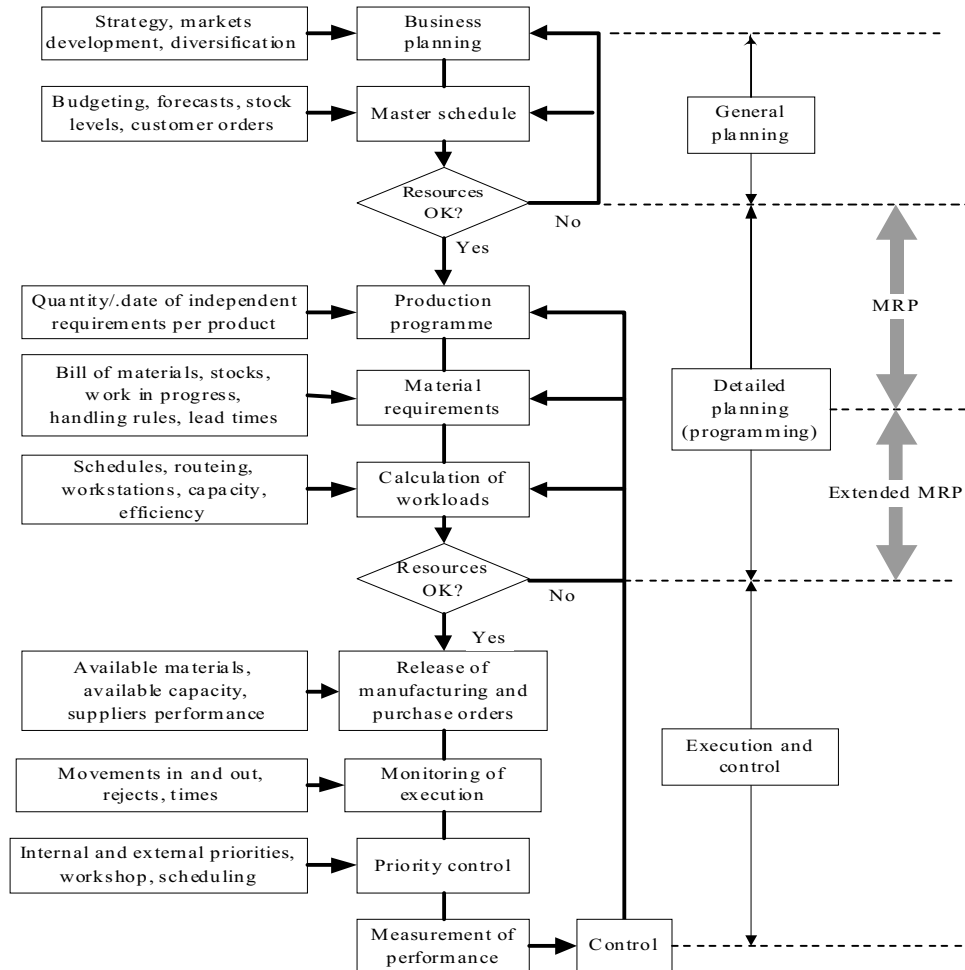


Figure 3.2 Flow diagram of MRPII system

- **Just-in-Time**

Another method that received much attention for production planning and control is Just-in-Time theory. In contrast to MRPII which can be referred to as a "push" oriented, the JIT philosophy of management is totally "pull" oriented, i.e., to manufacture something only when there is a firm order for it. JIT is a productivity enhancer based on a simple proposition that all waste in the manufacturing process must be eliminated.

JIT theory states that wastes can only begin to be eliminated if the push production control system is replaced with a pull production control system. It can be seen that a very large volume of wastes are bloated at inventory levels. Therefore, we

must find a way to minimize inventory levels. If you do this without the analytical capability of the computer, then it is logical to assume you would conceive a system that will not let material move or be used until it is necessary. This is what Toyota did. They instituted a backward scheduling technique that started with the desired ship date. They had to know when the product needed to be at final assembly and before that when it needed to be at the subassembly levels and so forth, back through component part manufacturing. Ultimately, it means determining precisely when the raw materials should show up at the receiving dock. This, in itself, is not unusual or unique.

Although JIT proposed ways to reduce wastes in greatest extent, it can not be implemented without the help of CIM and MRPII systems. For example, the means for producing products only at the rate the customer wants them can be best realized using the feedback control system production schedule of MRPII. By using the MRPII system, we can monitor progress of all workstations carrying out the dictates of the strategic plan and thus speed up or slow down the preceding operation to optimize the usage of materials and labor. In his book, Koenig (1990) explained in detail about the relationship of JIT with MRPII and CIM systems.

Since JIT and MRPII have their advantages as well as limitations in applications, it is proposed that the combination of JIT and MRPII systems in the common framework of CIM may produce excellent results in production scheduling and control.

3.2.2 CAD/CAPP/CAM System

CAD/CAPP/CAM stands for Computer Aided Design/Computer Aided Process Planning/Computer Aided Manufacturing. CAD/CAPP/CAM system is sometimes called design automation system. It means that CAD/CAPP/CAM is used to promote the design automation standard and provide means to design high quality products faster.

- **Computer Aided Design**

CAD is a process that uses computers to assist in the creation, modification, analysis, or optimization of a product design. It refers to the integration of computers

into design activities by providing a close coupling between the designer and the computer. Typical design activities involving a CAD system are preliminary design, drafting, modeling, and simulation. Such activities may be viewed as CAD application modules interfaced into a controlled network operation under the supervision of a computer.

General CAD system consists of three basic components: hardware, which includes computer and input-output devices, application software, and the operating system software (Figure 3.3). The operating system software acts as the interface between the hardware and the application software system.

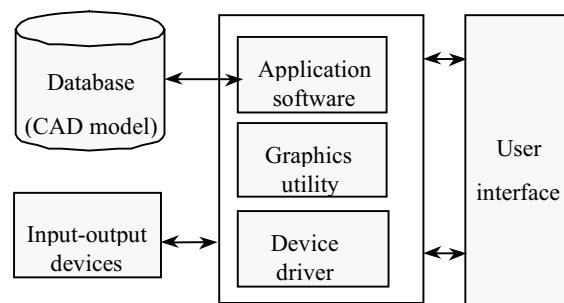


Figure 3.3 Basic components of CAD

The CAD system function can be grouped into three categories. They are geometric modeling, engineering analysis, and automated drafting.

Geometric modeling constructs the graphic images of a part using basic geometric elements, such as points, lines, and circles under the support of CAD software. Wireframe is one of the first geometric modeling methods. It uses points, curves, and other basic elements to define objects. Then the surface modeling, solid modeling, and parametric modeling methods are presented in the area of geometric modeling area. A detailed discussion about the development of geometric modeling methods is presented in the paper by Saxena and Irani (1994).

Engineering design completes the analysis and evaluation of product design. A number of computer-based techniques are used to calculate the product's operational, functional, and manufacturing parameters. The major analysis includes finite-element analysis, heat transfer analysis, static and dynamic analysis, motion analysis, tolerance analysis. In the analysis, finite-element analysis is the most important method, by dividing an object into a number of small building blocks, called finite elements, FEA

will fulfil the task of the functional performance analysis of an object. Various methods and packages are developed to analyze different performance of the product design. The introduction of the objectives and methods can be found in any comprehensive book discussion CAD techniques. After the analysis, the product design will be optimized according to the analysis results.

The last function of CAD system is the automated drafting. The automated drafting function includes the 2-dimension and 3-dimension product design drafting, converting of 3-dimension entity model into 2-dimension representation.

- **Computer Aided Process Planning**

Computer Aided Processing Planning is responsible for detailed plans for the production of a part or an assembly. It acts as a bridge between design and manufacturing by translating design specifications into manufacturing process details. This operation includes a sequence of steps to be executed according to the instructions in each step and is consistent with the controls indicated in the instructions. Closely related to the process planning function are the functions that determine the cutting conditions and set the time standards. The foundation of CAPP is group technology (GT), which is the means of coding parts on the basis of similarities in their design and manufacturing attributes. A well-developed CAPP system can reduce clerical work in manufacturing engineering and provide assistance in production.

One of the first tasks of CAPP system is to complete the selection of raw workpiece. According to the functional requirements of the designed part, it determines the attributes of the raw workpiece, such as shape, size (dimension and weight), and materials. Other jobs for the CAPP system are determining manufacturing operations and their sequences, selecting machine tools, selecting tools, fixture and inspection equipment. Manufacturing conditions and manufacturing times determination are also part of the work of CAPP, these conditions will be used in optimizing manufacturing cost.

CAPP system consists of computer programs that allow planning personnel interactively to create, store, edit, and print fabrication and assembly planning

instructions. Such a system offers the potential for reducing the routine clerical work of manufacturing engineers. Figure 3.4 presents the classification of various CAPP systems.

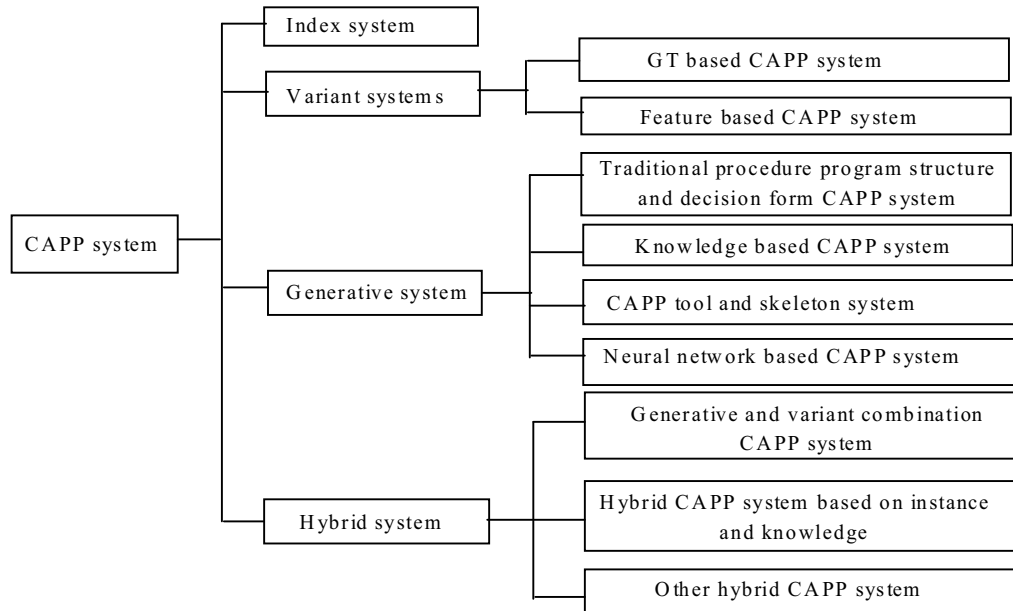


Figure 3.4 Classification of CAPP system

● Computer Aided Manufacturing

In this section, we refer Computer Aided Manufacturing to a very restricted area which do not include general production control functions. The production control functions will be introduced in the Manufacturing Automation Subsystem (MAS) section. Here, CAM is referred to preparing data for MAS, including producing NC code for NC machine, generating tool position, planning tool motion route, and simulating tool movement. Automatic NC code generation is a very important work in increasing work efficiency. Before the NC code for numerical control machine centers can be generated, a number of parameters regarding machine tool specification, performance, computer numerical control system behavior, and coding format should be determined first. According to these parameters, geometric dimensions, solid forms, and designed part specifications, the manufacturing method and operations will be selected. The CAM system will calculate the tool position data. Then the data regarding the part dimension, the tool motion track, cutting parameters, and numerical control instructions are generated in a program file. This file is called NC program that is used by the machine tool to process part automatically.

● **CAD/CAPP/CAM Integration**

Besides the utilization of CAD, CAPP, and CAM technology alone, the integration of CAD, CAPP, and CAM is an important way in enhancing the company’s product design standards. There are three methods that can be used in the integration of CAD/CAPP/CAM: exchange product data through specific defined data format; exchange product data through standard data format, such as STEP, IGES, DXF; define unified product data model to exchange product information.

Figure 3.5 is a STEP based CAD/CAPP/CAM integration system developed at State CIMS Engineering Research Center of China (located at Tsinghua University, Beijing), it is developed as a part of the CIMS application integration platform (Fan and Wu, 1997) for manufacturing enterprises. This system focuses on part-level CAD/CAPP/CAM integration. XPRESS language and STEP development tool SD-developer are used to define and develop the integration interfaces. Different kinds of CAD, CAPP, and CAM system can be integrated using the interfaces provided.

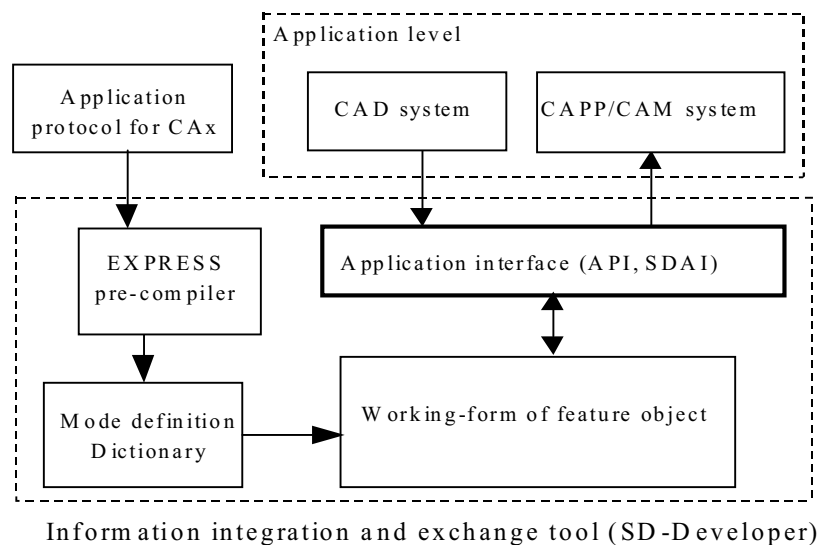


Figure 3.5 CAD/CAPP/CAM integration system

3.2.3 Manufacturing Automation System

Manufacturing Automation System is the value-added system. The material flow and information flow comes together in MAS. For discrete manufacturing company, MAS consists of a number of manufacturing machines, transportation system, high-bay store, control devices, computers, and MAS software. The whole system is operated under the control and monitor of MAS software system. For process industry,

MAS consists of a number of devices controlled by DCS, monitor system, and control software system. The objectives of MAS are to increase the productivity, reduce cost, reduce work-in-progress, improve product quality and reduce production time.

MAS can be described from three different aspects: structural description, function description, and process description. Structural description defines the hardware, software system associated with the production processes. Function description defines the MAS with a number of functions that combine together to finish the task of transforming raw material into products. The input-output mapping presented by every function associates with a production activity of the MAS. Process description defines the MAS with a series of processes covering every activity in the manufacturing process.

In the research field of MAS, a very important topic is the study of the control methods for manufacturing devices, from NC machine to automatic guided vehicle. But in this chapter, our focus is to study MAS from the system point of view of CIM. In the following, we will describe the shop-floor control and management system functions and components.

Shop-floor control and management system is a computer software system that is used to manage and control the operations of MAS. It is generally composed of several modules as shown in Figure 3.6. It receives production plan from MRPII (ERP) system weekly. It optimizes the sequence of jobs using production planning and scheduling algorithms, assigns jobs to specific devices and manufacturing groups, controls the operation of material handling system, and monitors the operations of

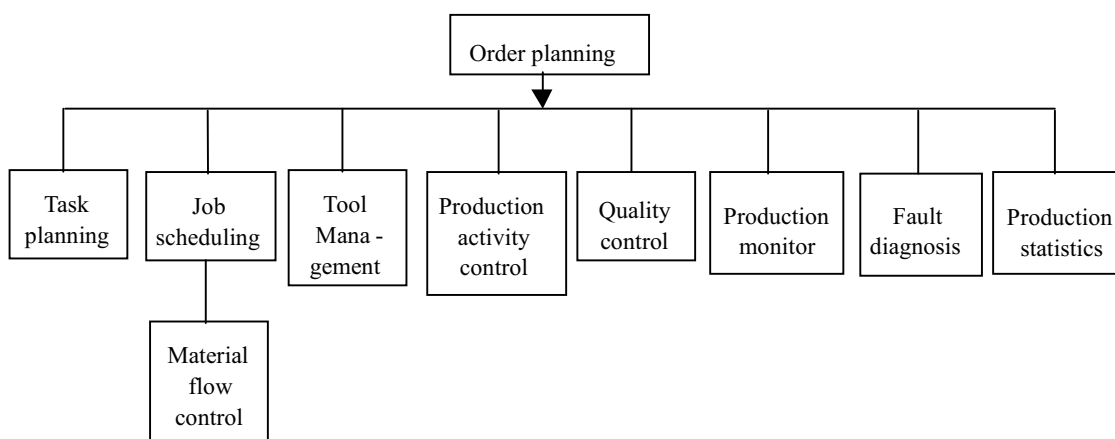


Figure 3.6 Function modules of shop-floor control and management system

manufacturing process.

Task planning decompose the order plan from MRPII system into daily task. It assigns job to specific work group and a set of machines according to needed operations. Group technology and optimization technology are used to smooth the production process, better utilize the resources, reduce production setup time, balance the load for manufacturing devices. Hence good task planning is basis for improving productivity and reducing cost of production.

Job scheduling is used to determine the entry time and sequence for different production jobs. It consists of three main functions: static scheduling, dynamic scheduling, and real time resource scheduling. Material flow control is one of the task for real time resource scheduling. Static scheduling is a off line scheduling method, it determines operation sequences before the production starts. The aim of static schedule is to reduce the makespan (the time duration is between when the first task enters the system and when the last task leaves the system). Operation research is a major method in generating static scheduling. Since there may be errors and uncertainties caused by machine breakdown, task priorities change, dynamic scheduling is needed to rescheduling the operation sequences and production routes. It is the best method to increase the flexibility of production system. Heuristic rules are normally used in generating dynamic scheduling. Job scheduling aims to optimize the operation of production system and increase the system flexibility.

Production activity control is used to control the operations of tasks, material flow, and manufacturing resources. Real time data collecting, processing, and decision making are major tasks of production activity control. It aims to regulate and smooth the production processes even when some errors and disturbances are occurred.

Tool management is also a very important task for shop-floor control and management system. In a manufacturing system, there are a large number of tools needed, the supply of necessary tools on time has vital importance in improving productivity. The quality of tool is important to the product quality. The parameters of every tool should be maintained in a correct and real time fashion, because these parameters will be used by machine centers in controlling the manufacturing

processes.

Quality control, production monitor, fault diagnosis, and production statistics are important supplementary functions for the shop-floor control and management system to be operated efficiently and effectively.

3.2.4 Computer Aided Quality Management System

Since 1970s, quality has become a vitally important factor for a company to win market competition. The customers always want higher product quality for their investment. The computer aided quality management system of CIMS is a system used to guarantee the product quality. It covers a wider range from product design, material supply, to production quality control. The international standard organization (ISO) has established a series of quality insurance standards, such as ISO9000, 9001, 9002, 9003, and 9004. Someone also calls the computer aided quality management system the integrated quality system.

The computer aided quality system consists of four components: quality planning, inspection and quality data collection, quality assessment and control, and integrated quality management.

The quality planning system completes two kinds of functions: computer aided product quality planning and inspection plan generating. According to the historical quality situation, production technology status, the computer aided product quality planning first determines the quality aims, assigns responsibility and resources to every step. Then it determines the associated procedure, method, instruction file, and quality inspection method, generates quality handbook. The computer aided inspection planning determines inspection procedures and standards according to the quality aims, product model, and inspection devices. It also generates automatic inspection programs for automatic inspection devices, such as 3-dimension measuring machine.

Under the guidance of quality plan, the computer aided quality inspection and quality data collection gets quality data during different phases. The phases include purchased material and part quality inspection, part production quality data collection, and final assembly quality inspection. The methods and techniques used in the quality

inspection and data collection are discussed in special books regarding quality control (Taguchi, Elsayed, and Hsiang, 1990).

Quality assessment and control fulfils the tasks of manufacturing process quality assessment and control, supply part and supplier quality assessment and control. Integrated quality management includes the functions of quality cost analysis and control, inspection device management, quality index statistics and analysis, quality decision making, tool and fixture management, quality personal management, and product using quality problem feedback information store and quality problem back track into manufacturing steps.

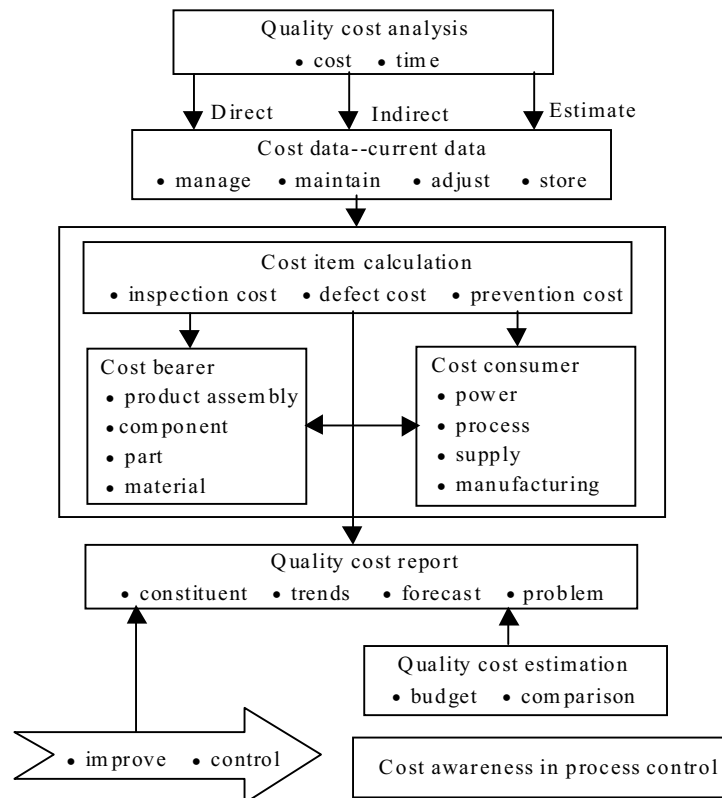


Figure 3.7 Quality cost analysis flow chart

Quality cost has an important role in a company's operation. The quality cost analysis needs to determine the cost bearer and the cost consume point, to generate quality cost plan and calculate real cost. It also optimizes the cost in the effort to solve quality problem. Figure 3.7 presents the quality cost analysis flow chart.

3.2.4 Computer Network and Database Management Systems

Computer network and database management systems are supporting systems

for CIMS. The computer network consists of a number of computers (called nodes in the network), network devices, and network software. It is used to connect different computers together, so as to enable the data communications between different computers. The computer network can be classified as local area network (LAN) and wide area network (WAN). LAN is normally refers to a restricted area network, such as in a building, in a factory, or in a campus. WAN is referred to a much wider area network, it may be across a city, or in international area. Today, network technology is being rapidly developed. The introduction of Internet concept has changed the manufacturing company's operation method greatly. Global manufacturing, agile manufacturing, and network based manufacturing paradigms have been under rapid development. Computer network is the infrastructure for these new manufacturing paradigms can be realized in a cost effectively way.

Database management system provides a basic support for the data store and information sharing of manufacturing company. Currently relational database management systems are the major databases used. The information integration of a company is concerned with integration data sources in different locations and with different kinds of database management systems. The heterogeneous properties of computer operating systems and database management systems are the major difficulties in the information integration. Now some advanced software technique have been developed to cope with the heterogeneity problem. One technique is CORBA. Other techniques are OLE/DCOM developed by Microsoft company, Java language developed by SUN computer company.

There are hundreds of books discussing computer network and database techniques. Readers can find them in almost any bookstore.

4. FLEXIBLE MANUFACTURING SYSTEMS

Flexible Manufacturing System (FMS) is a manufacturing system with high degree of flexibility. It is developed due to the need to increase the productivity, improve product quality, and reduce cost for product production under the constraints of various uncertainties or disturbances both internal in and external to the

manufacturing system.

4.1 FLEXIBILITY AND COMPONENTS OF FMS

4.1.1 Flexibility of Manufacturing System

A number of papers have been published to study FMS from different aspects. Gupta and Goyal provide a comprehensive review of the literature on flexibility (Gupta, and Goyal, 1989). Flexibility can be defined as a collection of properties of a manufacturing system that supports changes in production activities or capabilities (Carter, 1986).

In a manufacturing system, various types of flexibility are needed to fulfil different requirements. Types of flexibility that are mostly discussed are machine flexibility, routing flexibility, process flexibility, product flexibility, production flexibility, and expansion flexibility. Machine flexibility refers to the capability of a machine to perform a variety of operations on a variety of part types and sizes. Machine flexibility can reduce the changeover frequency, setup time, and tool changing time, hence reduce the lead time and make the small lot size production more economic. Machine flexibility is the basis for routing and process flexibility.

Routing flexibility provides the chances for a part to be manufactured or assembled along alternative routes. Routing flexibility is required to manage shop floor uncertainties caused by machine breakdown, tool error, controller failures, and others. It can also be used to tackle the problems caused by external events, such as the change of product mix, product due date, or emergency product introduction. These changes alter machine workloads and cause bottlenecks, the use of alternative routing helps to solve these problems and finally increase productivity.

Process flexibility, also called mix flexibility, refers to the ability to absorb changes in the product mix by performing similar operations or producing similar products or parts on multipurpose, adaptable, CNC machining centers. Product flexibility, also known as mix-change flexibility, is referred to the ability to change over to a new set of products economically and quickly in response to markets or engineering changes or even to operate on a market-to-order basis. In the current

global market, high product flexibility is a very important factor for a company to win the competition.

Expansion flexibility is referred to the ability to change a manufacturing system with a view to accommodating a changed product envelope. It is even more important in the current agile manufacturing era, improving expansion flexibility can significantly reduce system expansion or change cost, shorten system reconfiguration time, and hence shorten the delivery time for new products.

4.1.2 FMS Definition and Components

An FMS is an automated, mid-volume, mid-variety, central computer-controlled manufacturing system. It can be used to produce a variety of products with virtually no time lost for changeover from one product to the next. Sometimes FMS can be defined as “a set of machines in which parts are automatically transported under computer control from one machine to another for processing”(Jha, 1991).

A more formal definition about FMS is “a flexible manufacturing system” consists of a group of programmable production machines integrated with automated material handling equipment and under the direction of a central controller to produce a variety of parts at non-uniform production rates, batch sizes, and quantities” (Jha, 1991).

From the above definition, it can be seen that an FMS is composed of automated machines, material handling systems, and control systems. In general, the components of an FMS can be classified as follows:

- 1) **Automated manufacturing devices:** include machining centers with automatic tool interchange ability, measuring machines, and washing machines. They can perform multiple functions according to the NC instructions, thus fulfil parts fabrication task with a great flexibility. In an FMS, the number of automated machining centers is normally greater than or at least equal to 2.
- 2) **Automated material handling system:** includes load/unload station, high-bay storage, buffers, robot, and material transfer devices. The material transfer devices can be automatic guided vehicle, transfer line, robots, or the combination of these devices. The automated material handling systems are used to prepare, store, and

transfer materials (raw materials, unfinished parts, and finished parts) between different machining centers, load/unload stations, buffers, and high-bay storage.

- 3) **Automated tool system:** it is composed of tool setup devices, central tool storage, tool management systems, and tool transfer systems. They are used to prepare tools for the machining centers as well as transfer tools between machining centers and the central tool storage.
- 4) **Computer control system:** it is composed of computers and control software. The control software fulfils the functions of task planning, job scheduling, job monitoring, and machine controlling of the FMS.

Figure 4.1 is the FMS layout at the State CIMS Engineering Research Center (CIMS-ERC) of China. In Figure 4.1, HMC stands for horizontal machining center, VMC stands for vertical machining center.

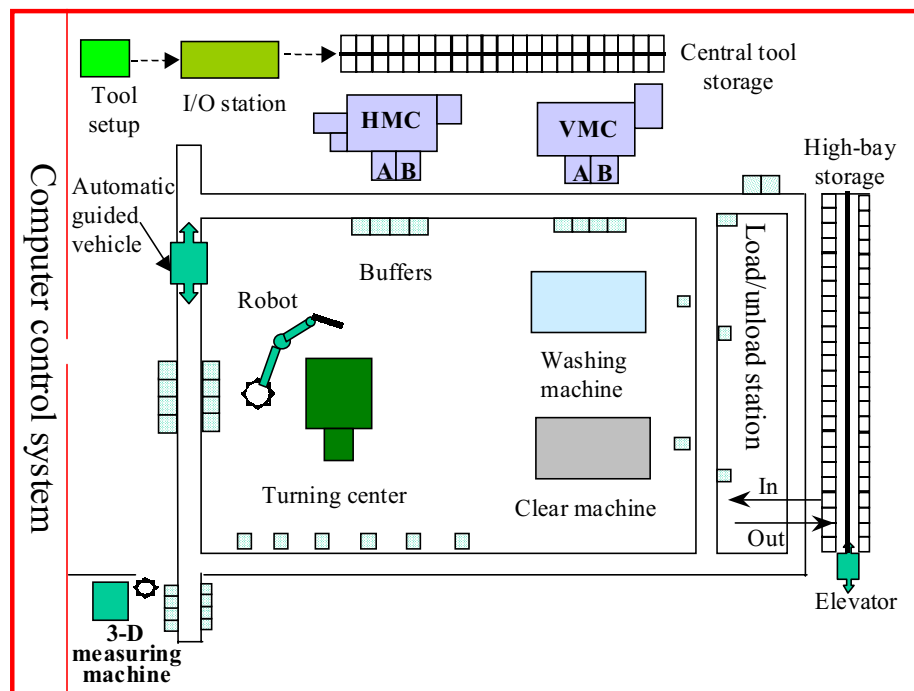


Figure 4.1 FMS layout at State CIMS-ERC of China

Another example of FMS is shown in Figure 4.2 that is drawn from Kingdream public limited company. It produces oil well drill nits, mining bits, hammer drill, high pressure drilling, etc.



Figure 4.2 FMS for oil well drill production

4.2 GENERAL FMS CONSIDERATIONS

Although FMS was originally developed for metal-cutting applications, the principles of FMS are more widely applicable. Now, it covers a wide spectrum of manufacturing activities such as machining, sheet metal working, welding, fabricating, and assembly.

The research areas regarding the design, implementation, and operation of an FMS are very broad, they have attracted many researchers' interest, many results have been obtained. In this section, we just present the research topics, problems to be solved, and methods that can be used in solving the problems.

4.2.1 FMS Design

FMS is a capital-investment intensive and complex system. In order to get the best economic benefits, the design of FMS should be carefully made. The design decisions regarding to the FMS implementation are the system configuration and layout, manufacturing devices, material handling system, central tool storage, buffers and high-bay storage.

Before these decisions can be made, the part types to be made, the processes needed to make them, and the possible numbers of processing parts (workload) should be first determined. Based on these basic requirements, the number of machines, its

abilities, tools, buffers, and storage system can be roughly determined. A rough system layout and material handling system can be designed. The designed FMS is simulated using FMS simulation tool to test its ability to fulfil the requirements.

The design of an FMS is a system approach. Besides the above mentioned basic requirements to meet the part manufacturing ability. There are many other factors that should be considered when designing an FMS. The economic assessment should always be done for every FMS plan obtained. System reliability, productivity, and performance evaluation should be done also for every FMS plan. So, the design of FMS is an iterative process that needs many experts from different disciplines work together. Many alternative plans are compared and modified before an optimized plan is determined.

In the research of FMS design methodology, Talavage and Hannam(1988) summarize other persons work and present a five steps approach to FMS design. The five steps are: ① Development of goals; ② Establishment of criteria on which goal achievement can be judged; ③ Development of alternate candidate solutions; ④ Ranking of alternatives by applying the criteria to the alternate solutions; ⑤ Iteration of the above four steps to obtain a deeper analysis of alternate solutions and to converge on an acceptable solution.

The detailed description about the five steps are described in Talavage and Hannam (1988). The other considerations regarding FMS design can be found in Tetzlaff (1990).

4.2.2 FMS Planning, Scheduling, and Control

Planning, scheduling, and control are the important and difficult problems in FMS operations. A good planning and scheduling system will improve the FMS operation efficiency, and get high economic benefits, the research and development of FMS planning and scheduling have been done extensively. The general optimization indexes are: ① Maximizing the productivity at certain period of time; ② Minimizing the makespan for a group of parts; ③ Minimizing the cost for parts manufacturing; ④ Maximizing the utility for key manufacturing devices; ⑤ Minimizing the work in progress; ⑥ Minimizing the production time for certain parts; 7) Satisfying the due

dates of parts?

Figure 4.3 presents the function model for FMS planning, scheduling, and resource management.

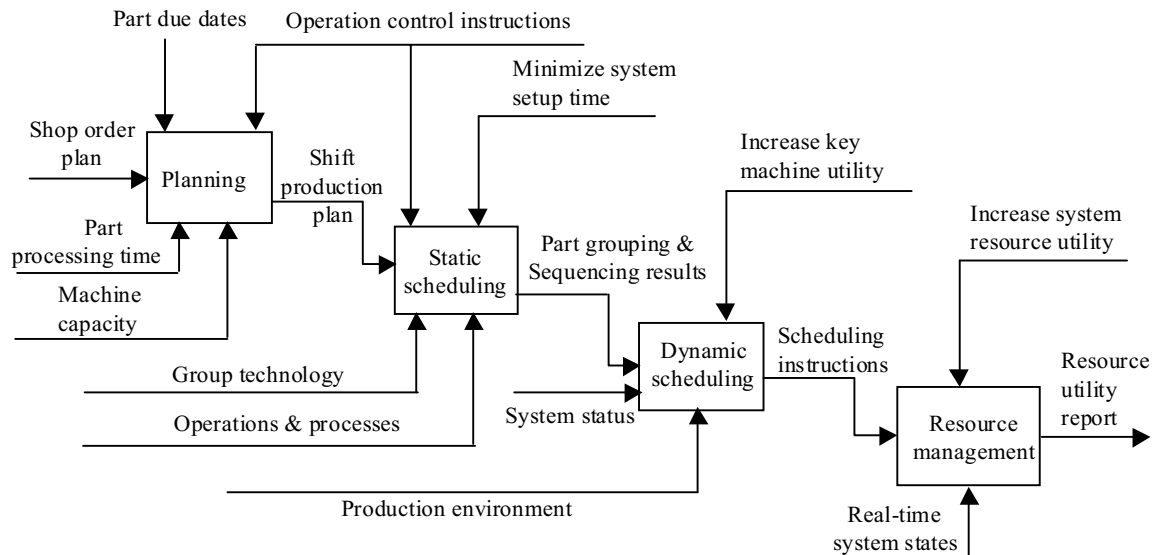


Figure 4.3 Function model of FMS planning and scheduling

The resource management and real-time control functions of FMS are closely related to dynamic scheduling system. The resource management system should be activated by a dynamic scheduling system to allocate resources to production process to achieve a real-time control for FMS. The resources to be controlled involve tools, automatic guided vehicle, pallets and fixtures, NC files, and human resources.

● Planning

Planning seeks to find best production plan for the parts entered into the FMS. Its aim is to make an optimized shift production plan according to the shop order and part due dates. FMS planning system receives shop order plan in the weekly time scale from MRPII system, according to the product due dates, it analyzes the shop order, and generates daily or shift production plan. Group technology is used in grouping parts into families of parts. For every shift plan generated, its capacity requirement is calculated, and capacity balance and adjustment work should be carried out if the required capacity is higher than that provided by machines.

After feasibility analysis, capacity balancing, and optimization, a shift plan is then generated. The shift plan gives detailed information for the following questions:

① What kind of parts will be machined? ② In what sequence will be the parts

entering the FMS? ③ What operations are needed to process the parts? What is the operation sequence? ④ What are the start time and complete time for processed parts? ⑤ What materials are needed? In what time? ⑥ What kinds of tool are needed?

● **Static Scheduling**

Static scheduling is the refinement of shift production plan, it seeks to optimize the machine utility and reduce system setup time. Three functions are performed by a static scheduling system. The three functions are part grouping, workload allocating and balancing, and part static sequencing. Since all these functions are performed before the production starts, the static scheduling is also called off-line sequencing.

A number of factors affecting production sequence should be taken into account for static scheduling. For example, the part process property, FMS structure, and optimization index. The part process property determines what kind of production method should be used. Flow-shop, flexible-flow-line, and job-shop are three major forms to produce parts. There are different methods that can be used in generating static scheduling for the different production forms.

The second factor affecting static scheduling is FMS structure. The main structure properties are whether there is a central tool system, whether there is a fixture system, or whether there are bottleneck devices. The third factor is the optimization index chosen. The general optimization index is a combination of several optimization indexes, i.e., the FMS static scheduling is a multi-objectives optimization process.

The following parameters have important affection in getting an optimal static scheduling.

- 1) **Time distribution:** such as time distributions for part arrival, tool setup, part fixture, part transfer, machine failure, and delivery time;
- 2) **Shop conditions:** such as device type, transfer system, storage method, shop layout, and device condition;
- 3) **Shop control conventions:** such as priority rule, operation method, hybrid processing route, task decomposition, performance evaluation method, and workload;

4) **Alternate processing route:** such as alternate processing device, alternate processing routing, and alternate processing sequence.

There are a huge number of literatures about static scheduling algorithms and systems that can be found in academic journals of FMS, operational research, manufacturing technology, IEEE magazines on system, robotics, and automatic control.

- **Dynamic Scheduling**

Dynamic scheduling is used to control the operations of FMS according to the real-time status of the AFMS. It is a real-time (on-line) system that focuses on solving the uncertainty problems such as device failures, bottlenecks on certain machines, workload unbalance, and resource allocation conflict. These problems are not anticipated by off-line static scheduling, they can only be solved using real-time dynamic scheduling or re-scheduling.

Three strategies can be used to complete the re-scheduling functions. The first one is a periodical scheduling. In order to make a periodical scheduling, it is needed to set a certain time interval as production cycle. A periodical scheduling system calculates a period operation sequence before the next period starts. The calculated sequence is the job list execution instructions followed by the FMS. The second strategy is continuous scheduling that monitors the FMS and executes scheduling whenever an event (such as an new part arrives, or a machine completes the production of a part) has happened and system states has been changed. Since the calculation of work content is effective to re-schedule the FMS operations for every event (so as to get optimal scheduling at every point), the third strategy called hybrid scheduling is frequently used. The hybrid strategy combines periodical and continuous scheduling in the way that only when an unexpected event has happened, then the continuous scheduling algorithm is used, otherwise periodical scheduling is executed at a certain interval.

For the dynamic manufacturing environment with possible disturbances both internal in and external to the FMS, dynamic scheduling seeks to optimize the sequencing for the queue before manufacturing device. Since the dynamic scheduling

of an FMS is an NP-hard problem, it is impossible to search and get the optimal solution at a short time, especially for the continuous scheduling that has very high speed requirement, normally a sub-optimal solution is used in real-time FMS operations. A number of heuristic rules are frequently used in getting the sub-optimal solutions in dynamic scheduling. The heuristic rules that frequently used are:

- 1) **RANDOM**: assigns a random priority to every part entering the queue, selects a part with smallest priority to be processed;
- 2) **FIFO (LIFO)** : first-in-first-out (last-in-first-out);
- 3) **SPT (LPT)**: selects the part that has the smallest (largest) current operation processing time to be processed;
- 4) **FOPNR (MOPNR)**: selects the part that has the fewest (most) remaining operations to be processed;
- 5) **LWKR (MWKR)**: selects the part that has the smallest (largest) remaining processing time to be processed;
- 6) **DDATE**: selects the part that has the earliest due date to be processed;
- 7) **SLACK**: selects the part that has the smallest slack time (due date minus remaining processing time) to be processed.

In most cases, several rules will be used in a dynamic scheduling system in getting the satisfied sequencing solution. Besides the rule based scheduling, simulation based and knowledge based scheduling systems are also widely used.

4.2.3 FMS Modeling and Simulation

Modeling and simulation are important topics both for design and operation of FMS. The FMS modeling is the basis for simulation, analysis, planning and scheduling. Since FMS is a typical discrete event dynamic system (DEDS), a number of methods for DEDS modeling and analysis can be used to model an FMS, such as Petri nets, network of queue (Agrawal, 1985), Activity-Cycle-Diagram (Carrie, 1988), etc. In this section, we give a brief introduction of Petri nets, its application in FMS modeling, and FMS simulation method.

● **Petri Nets and its Application in FMS Modeling**

A Petri Net (PN) may be identified as a particular kind of bipartite directed

graphs populated by three types of objects. These objects are places, transitions, and directed arcs connecting places to transitions and transitions to places. Pictorially, places are depicted by circles, transitions by bars or boxes. A place is an input place to a transition if there exists a directed arc connecting this place to the transition. A place is an output place of a transition if there exists a directed arc connecting the transition to the place. Figure 4.4 represents a simple PN. Where, places p_1 and p_2 are input places to transition t_1 , place p_3 is the output place of t_1 .

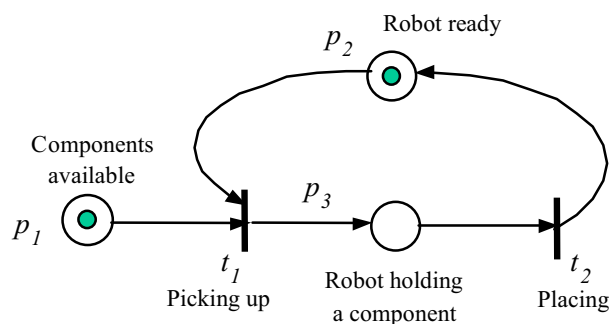


Figure 4.4 A simple Petri net example

Formally, a PN can be defined as a five-tuple $PN=(P, T, I, O, m_0)$, where

- 1) $P=\{p_1, p_2, \dots, p_n\}$ is a finite set of places,
- 2) $T=\{t_1, t_2, \dots, t_m\}$ is a finite set of transitions, $P \cup T \neq \emptyset, P \cap T = \emptyset$,
- 3) $I : (P \times T) \mapsto N$ is an input function that defines directed arcs from places to transitions, where N is a set of nonnegative integers,
- 4) $O : (P \times T) \mapsto N$ is an output function that defines directed arcs from transitions to places,
- 5) $m_0 : P \mapsto N$ is the initial marking.

The state of the modeled system is represented by the tokens (small dots within the places) in every place. For example, in Figure 4.4, a small dot in place p_1 means components available. The change of the states represents the system evolution. State changing is brought by firing a transition. The result of firing a transition is that for every place connected with the transition, after the firing of the transition a token will be removed from its input place and a token will be added to its output place. As an example of Figure 4.4, the firing of transition t_1 will cause the tokens in place p_1, p_2 disappear and a token will be added to place p_3 .

Due to the advantages of its formal theory background, natural link with DEDS,

and mature simulation tool, PN is well suited in FMS modeling. We give a two-machine production line (Figure 4.5) to demonstrate the modeling of FMS using PN.

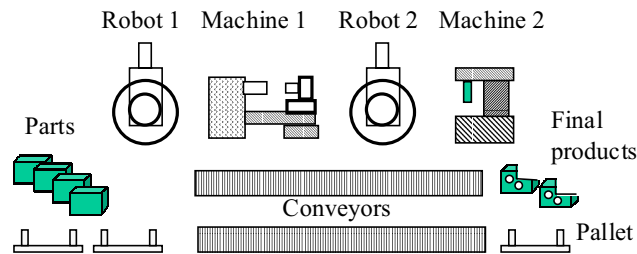


Figure 4.5 A two-machine production line

The production line consists of two machines ($M1$ and $M2$), two robots ($R1$ and $R2$), and two conveyors. Each machine is serviced by a dedicated robot that performs load/unload task. One conveyor is used to transport workpiece, a maximum two at one time. The other conveyor is used to transport empty pallets. There are three pallets available in the system. Each workpiece is machined on $M1$ and then on $M2$. The machining time is 10 time units on $M1$ and 16 time units on $M2$. The load and unload tasks takes 1 time unit.

As the same with modeling general FMS or other systems, the modeling of this system using PN takes several steps.

- 1) Major activities are identified. In this example, they are $R1$ loading, $M1$ processing, $R1$ unloading, $R2$ loading, $M2$ processing, $R2$ unloading. The resources are raw materials with pallets, conveyors, $M1$, $M2$, $R1$, $R2$.
- 2) The relationships between the four major activities form a sequential order.
- 3) A partial PN model is defined to describe the four major activities and their relations as shown in Figure 4.6 (a). Where four transitions are used to represent four short operations, i.e., $R1$ loading, $R1$ unloading, $R2$ loading, $R2$ unloading. Two places are used to represent two long operations, i.e., $M1$ and $M2$ processing.
- 4) Through stepwise process, gradually adding resources, constraints, links into the partial PN model will finally form the refined model as shown in Figure 4.6 (b).
- 5) The model is checked to see whether it satisfies the specification. The PN

simulation tool can also be used in this phase to check the model. If some problems are found, the model will be modified.

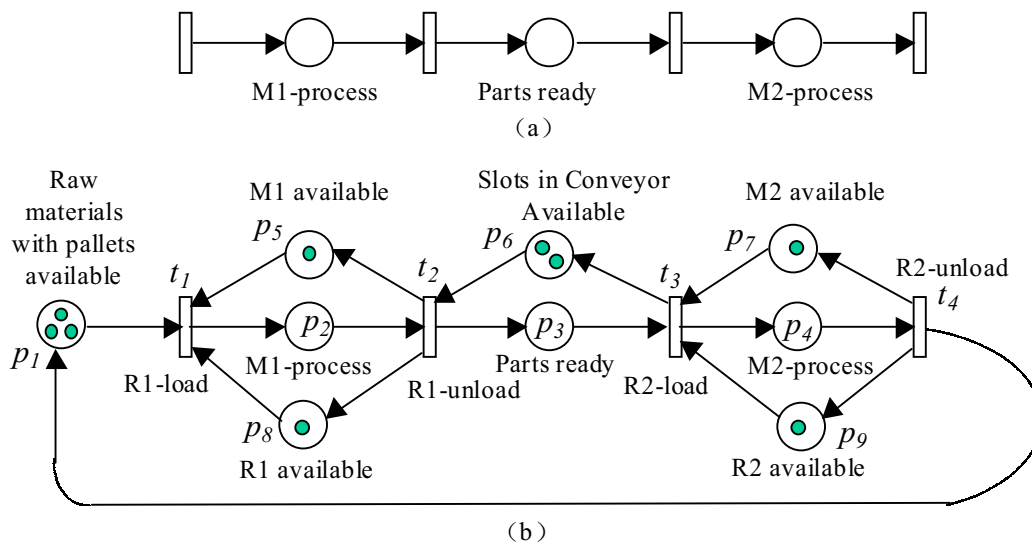


Figure 4.6 Petri net model for the two-machine production line

● **FMS Simulation**

Simulation is a useful computer technology in FMS modeling, design, and operation. Simulation modeling allows one to describe real world objects in FMS, such as moving of workpiece from one place to another. There are three approaches to simulation modeling for FMS. The first one is network or graphical models, where some objects (such as machines) may be represented by graphical symbols placed in the same physical relationship to each other as the corresponding machines are in the real world. The graphical aspects of this kind of models are relatively easy to specify, and once completed, they also provide a communication vehicle for the system design which can be readily understood by a variety of people. SLAM (Pritsker, 1984) and SIMAN (Pegden, 1982) are two widely used network modeling tools for FMS.

The second approach to FMS modeling is called data-driven simulation. The model is consisted of only (or mainly) numerical data. That information usually represents, for example, a simple count of machines in a system, or a table of operation times for each process on the route of a given part type. The nature of this information is such that, if it were collected in the factory information system, it would only be necessary to access it and place it in proper format in order to run a

simulation of the corresponding real world system. This concept is quite close to automated simulation. It has the ultimate easy for use. The first such programs for FMS was developed at Purdue, it was called the General Computerized Manufacturing System (GCMS) simulator (Talavage, and Lenz, 1977).

The third approach for FMS modeling is using a base programming language, such as SIMULA and SIMSCRIPT. These base programming languages provide more model-specific constructs that can be used to build a simulation model. So, it has a much stronger modeling capability. Unfortunately, this approach is not widely used. One reason for this may be that few people know it well enough to use them.

Another method for DEDS simulation called Activity-Cycle-Diagram (ACD) can also be used in FMS simulation. This is a diagram used in defining the logic of a simulation model. It is equivalent to a flowchart of a general-purpose computer program. The ACD shows the cycle for every entity in the model. Conventions for drawing ACDs are as follows: ① Each type of entity has an activity cycle.② The cycle consists of activities and queues.③ Activities and queues alternate in the cycle.④ The cycle is closed.⑤ Activities are depicted by rectangles and queues by circles or ellipses

Figure 4.7 presents an ACD for a machine shop. Jobs are arriving from the outside environment. Jobs are waiting in a queue for the machine. As soon as the

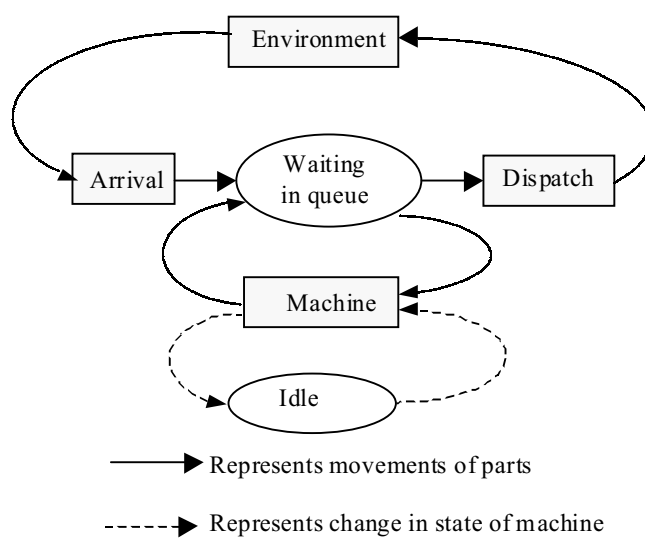


Figure 4.7 Activity cycle diagram

machine is available, a job goes to the machine for processing. Once processing is over, the job again joins a queue waiting to be dispatched.

The ACDs give better understanding about the FMS to be simulated. So it is widely used for FMS simulation.

4.3 BENEFITS AND LIMITATIONS OF FMS

FMS offers manufacturers more than just a manufacturing system that is flexible. It offers a concept to improve productivity in mid-variety, mid-volume production situations, an entire strategy for changing company operations ranging from internal purchasing and ordering procedures to distribution and marketing. The benefits of FMS can be summarized as follows:

- 1) Improving manufacturing system flexibility that is the key advantages of FMS;
- 2) Improving product quality, increasing equipment utility;
- 3) Reducing equipment cost, work-in-progress, labor cost, and floor space;
- 4) Shortened lead times and improving market response speed;
- 5) Financial benefits gained from above advantages.

In Talavage's (1988) book, there is a chapter discussing the economic justification of FMS.

The difficulties with FMS should also be paid much attention. The first difficulty is that FMS is expensive, it normally requires a large sum of capital resources. The small company may not be able to afford the intensive investment, it may even be not financially beneficial if the company does not have much product variety and volume. Second, the design, implementation, and operation of FMS is a quite complex process, it may cause a lost of money if any of the work in this process is not well done. Third, the rapid changing market may urge the company to change its product, this change may also have bad impact on the production system, it may cause the large investment on FMS can not be returned before it comes out of working.