Progress in the journey developing SB-CIMS

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Abstract. CIM as a sophisticated manufacturing paradigm has been widely accepted and has been recognized as an effective way to enhance competitive forces of enterprises. In this paper the design of a CIM system, known as SB-CIMS, and to be implemented in Shenyang Blower Factory, is introduced. The CIM system, which aims at providing an integrated manufacturing environment, is expected to increase the factory’s market competitive forces. An open CIM system architecture is developed based on consideration of the factory’s unique features and based on references to CIM-OSA proposed by the ESPRIT programme. In order to meet the requirements of the factory and to get justifiable benefits, we have elaborately defined the scope and objectives of the CIM system with a thorough survey of the factory operation. Then, step by step, the CIM objectives are decomposed into functional modules. Information models describing information flows among these modules are developed. A computer network with the necessary supporting software components is developed to perform information processing. Personnel involved in system development and future system maintenance are deliberately organized.

1. Introduction

Intensive market competition compels manufacturing factories to produce high quality and cost-effective products at the proper time. Unfortunately, many factors including new processes, high quality requirements, urgent deliveries and fluctuations in raw materials make it difficult to meet customers’ demands. This situation demands much more sophisticated manufacturing systems. Having been developed over a decade, computer integrated manufacturing systems (CIMS) have gained wide acceptance as a philosophy of production management throughout the world. China has also launched a National High Technology Programme where the researches on and developments of CIMS occupy a dominant place. In China, more and more factories have accepted CIMS concepts and migrated to CIMS solutions for their problems. Shenyang Blower Factory is one of the pioneers that decided to implement a CIMS with the support of the National High Technology Programme in China. Shenyang Blower Factory is the largest factory in China producing various turbine air compressors, turbine blowers and ventilators. The factory, with 4000-plus employees, consists of nine manufacturing shops and several managemental departments in charge of production planning, product design, process planning, sales and purchasing. Within the variety of its products, each one is assembled by from 1000 to 3000 parts. These parts are very complicated and exert very high requirements on accuracy, quality and cost of design and manufacturing. These factors cause many difficulties for the factory in trying to satisfy customers requirements. One of the most serious problems for the factory is the long lead times of products from acceptance of orders, through design, process planning, manufacturing to delivery. To increase market competitiveness the factory has made the decision to introduce a CIMS. Consequently more than 30 researchers with different academic backgrounds from several universities and institutes, and engineers representing all departments and shops of the factory came to form a joint design force.

Since the introduction of a CIMS involves high technical and financial risks, the design methodology is of great importance to the implementation and operation of the system. In order to avoid technical disasters and to obtain potential economical benefits, a suitable design methodology or a proper CIMS must be adopted. From comparisons of existing design methods, CIM-OSA has been chosen as a guideline, and the system is analysed and designed from four viewpoints, namely function, information, resource and organization. CIM-OSA is an open-system architecture which defines an integrated methodology to support all phases of CIMS life-cycle from requirement specification, through system design, implementation, operation and maintenance, and even system migration towards a CIMS solution (Jorysz and Vernadat 1990). The development of SB-CIMS is a very long journey where milestones need to be used for measuring progress. Therefore, the SB-CIMS project is divided into five stages, namely feasibility analysis, initial...
design, detailed design, implementation, and system maintenance. The initial design stage was concluded in early 1992 and the detailed design stage was concluded at the end of 1992, so this paper will only address the main issues in SB-CIMS design.

2. Requirement specification and analysis

With a structured design methodology, user requirement specification and analysis is an indispensable step. In the first phase, the design task force made a thorough survey and developed the ‘AS-IS’ picture of the factory. The factory is a large enterprise producing various kinds of turbine air compressors and turbine blowers. Its production belongs to a typical job-shop-type manufacturing and it manufactures products according to customer orders. Figure 1 outlines the manufacturing process of the Shenyang Blower Factory. From this figure one can see that the manufacturing process is not only a transformation of raw materials into products, but also a process of information manipulation. In this factory all material processings are accomplished within the nine manufacturing shops. These shops, equipped with different manufacturing facilities, perform different material processing. Shop 1 prepares all production materials; it performs initial rough cutting on raw materials and provides rough workpieces to other shops. Shop 2 does all the related heat treatments to change the physical and chemical properties of parts and products. Shop 3 is a welding shop where components such as casings, bases, etc. are welded. Shop 4 produces a variety of containers, condensers, filters and sets of lubrication equipment. Shop 5 produces gears and transmissions. Shop 6 manufactures all types of rotating parts such as three-dimensional impellers and shafts. Shop 7 produces all the fixed-type parts or stators such as cases, bases and boxes. Shop 8 is responsible for product assembly and testing. Finally all products are packed in shop 9. Each manufacturing shop consists of several sections, and in turn, each section consists of several functional groups. A functional group consists of some machines with the same functionalities. Although the factory has devoted some effort to developing automated facilities, there are still many factors that hinder the development of the factory because of a lack of integration of these automation islands. There is a big gap between capacity requirements and the present manufacturing capacities of the factory. Most of the machines are human operated and production information is manually collected. Generally the material flows on the shop floor are scheduled by veteran foremen.

According to the long-term manufacturing strategies, its mainstream products will be confined to turbine blowers, centrifugal compressors and hermetic centrifugal water chillers. Generally all these products are made from rotating components and fixing components. As mentioned above these two types of components are manufactured in shop 6 and shop 7, respectively. Therefore, the manufacturing operations in these two shops are crucial to the production enterprise.

The CIMS design task force has decided that manufacturing automation will be confined to these two shops initially. The factory has made some progress in CAD but little in CAPP and CAM. Quality of products largely depends on the skills of workers, and the product lead times are very long. It usually takes 18 months from order acceptance to delivery of the product, while some leading companies in the world take only 12 months.

At second phase, the ‘TO-BE’ analysis of the factory is performed. The business strategy of the enterprise is to continue to dominate the domestic market and to participate in world market competition. In order to realize the enterprise business objectives and increase market competitiveness, the factory intends to enhance the automation level of all the related sections and to provide an integrated manufacturing environment. With detailed requirement specifications and analysis, the joint design task force reached an agreement that developing a CIMS in the factory is necessary and feasible. Then the scope and objectives of the CIMS were determined. The CIMS will cover the following aspects.

(1) Business administration, production management, resource management, quality management, overall information management, office automation, etc.
(2) Product structure design, engineering analysis, detailed design, process planning, fixture design and generation of NC codes.
(3) Management of shops, cell control of DNC and FMC, control of workstations and machines.
(4) Integration of all these functions with the support of computer networks.

Consequently, the objectives or general functionalities of
the CIMS in the four areas are set by the joint design task force. Following the CIM-OSA methodology, we have represented the CIMS design from function, information, resource and organization viewpoints.

3. Functional design viewpoint

The functional design view describes functions and tasks to be accomplished by the SB-CIMS and their relationships. Here a five-level functional hierarchy, similar to the AMRF model proposed by NBS (O’Grady 1986, Jones and McLean 1986), is adopted to accommodate these functions or tasks.

3.1. Factory level

This is the top level of the functional hierarchy, where long-term global managerial strategies are made. Specifically, functions including business decision-making, production planning, financial accounting, office information supporting, product design, process planning and NC programming are performed at this level. For the convenience of design and implementation, these functions are divided into two systems; namely production administration and decision information system (PADIS) and engineering information system. 

The PADIS, consisting of six functional modules, is designed to solve the business administration and production management problems by using CIMS philosophy.

(a) **Business administration**: Based on the state government policies, market status and customer orders, this functional module determines the long-term enterprise goals, performs sales management, and develops the annual master production schedule.

(b) **Production management**: The main tasks of this functional module are to develop material requirement plans, to accomplish rough-cut capacity balances, to pass down production orders, and to trace the production processes.

(c) **Quality control**: The quality objectives is set in accordance with annual master production schedule and customer requirements, and product quality is controlled by this functional module. Trouble-shooting and failure-cause analysis are also performed here.

(d) **Resource management**: Manufacturing resources required including human workers, finance assets, and facilities are managed here.

(e) **Information management**: This module provides related departments with means to facilitate access to information and correspondences to inquiries.

(f) **Office support**: By using computers and other facilities, this module supports the management of enterprise files and documents including word processing, agenda arrangement and handling of mail.

The engineering information system is a bottleneck of the SB-CIMS project; it involves the product design, process planning and producing NC programs. With the help of this system, the productivity of technical personnel can be increased, quality of products can be maintained at a very high level, and lead times can be reduced. In SB-CIMS the engineering information system is composed of the following four subsystems.

(a) **Product CAD**: Where geometric shapes of products are generated and the engineering databases relating to specifications of geometric features and materials are created for manufacturing. The main CAD activities include optimal pneumatic design, structure design, engineering analysis, reliability design, detailed design and generation of bills-of-materials (BOM).

(b) **CAPP**: This function develops the detailed process plans both for the cutting machines and for the material handling devices according to the part geometric information, such as BOM and GT codes.

(c) **Fixture CAD**: Where jigs, measuring tools and assembling tools are designed to meet the requirements of manufacturing.

(d) **CAM**: It generates NC programs for metal-cutting machines and trajectory controlling programs for material handling devices based on information generated by CAD and CAPP.

3.2. Shop level

Shop level forms the second highest level in the SB-CIMS functional hierarchy and is mainly involved in receiving production plans from the factory level and splitting these into goals, for each cell. Each manufacturing shop of the factory will have one shop controller to perform these tasks. The SB-CIMS shop controller consist primarily of the following functions.

(a) **Job management**: receives production orders, part design files and process plans from the factory level, checks the completeness and integrity of these documents, and makes detailed capacity balances under the constraints of the manufacturing resources available.
and load the NC programs into these machines. They also feed back manufacturing information to the cell controller.

3.5. Equipment level

Equipment level is the lowest level in the SB-CIMS functional hierarchy, where the objectives are specified and the timespans are very short. The SB-CIMS is composed of a great variety of facilities concerning metalcutting, material handling including loading/unloading, transportation and quality measuring. For instance, in shop 6, there is one flexible manufacturing cell (FMC) producing disc-like parts, two DNC cells producing various shafts, and one welding cell. The FMC consists of three NC machines, one load/unload station, one tool regulator, one washing station, one AGV and one measuring instrument. The disc DNC cell consists of five NC machines, and the shaft DNC cell also consists of five NC machines. Movements inter- or intra-cells are handled by a track crane. The welding cell consists of one robot and some auxiliary devices. The function of equipment controller is to run these facilities and ensures accuracy of trajectory movements.

These main aggregate functions and their relationships are precisely depicted using an IDEF0 method. Then functional boxes in this IDEF0 diagram are gradually decomposed into several sub-boxes layer by layer. The series of IDEF0 diagrams documented during this decomposition form the functional view of SB-CIMS.

4. Information design of SB-CIMS

Information integration is recognized as the key point in the design of SB-CIMS, because the performances of all functions are accompanied by input of information and generation of information. A functional module needs information from other functional modules to carry out its tasks. In turn it also generates information to support other functional modules. Thus information in SB-CIMS flows from one function module to another, forming an information net. The information modelling paradigm used in the CIM-OSA information view is a common umbrella which covers all principles used for information modelling (Jorysz and Vernadat 1990b). The information used in SB-CIMS is divided into three categories according to its structure features, i.e., structured information, semi-structured information and unstructured information. Data representing structured information can be stored in a database. Data representing semi-structured information, including product
geometry and process data, generally can be stored in a database after some data processing. On the other hand, unstructured information including voice, pictures and programs can only be processed by file systems. In the initial design stage, the IDEF1x method is used to develop the SB-CIMS information view, and, this information model is further refined using entity–relation–attribute (ERA) methodology. Finally the ERA-based information model is translated into relational database structures. The information is taken to be composed of entities and relations. For instance, relations between product information entities and process information entities indicate how a product is to be produced. Relations between information entities ‘production plans’ and information entities ‘products’ indicates when the products are to be designed and manufactured. Relations between production entities and resource entities indicate the states of manufacturing resources. Relations between information entities plans and information entities resources indicate when and what machines, raw materials and tools are purchased. To facilitate information communication and management, structured and semi-structured information entities are further classified into local data and global data according to their usage. Data used only by one or a few functional modules are stored in local databases. Data commonly used by many functional modules are stored in global databases. Several database management systems including DB2, SQL/400, AIX/DB and XDB are to be installed to meet the information integration requirements.

A uniform standard coding system is being developed to facilitate information transmission and process. The information coding system adopts an object-oriented hierarchical data classification method. It encodes all the data circulating in the CIMS including product data, process data, manufacturing data, resource data, planning and management data. It arranges information codes into a three-level hierarchy. The codes in the first level are composed of classification codes and identification codes which classify and identify information objects. The codes in the second level are descriptive codes which represent specific properties of the objects. The codes in the third level represent the graphic data. The information codes will be used by all the departments in the CIMS as a common language of communication.

5. Design of resources viewpoint

To meet the function requirements and information requirements, it is necessary to build a support environment with the necessary hardware components and software components. The aims of SB-CIMS resource design are to determine what components to be introduced and to develop a proper system architecture to configure these components.

5.1. Hardware components

At the factory level, an IBM 4381-92E with 89 terminals and 32 printers is used as the host computer to support the majority of the business administration and production management functions. The quality control system and financial management system run on two IBM AS/400 and one PS/2. The development of CAD/CAPP/CAM will be carried out on three RS/6000 and three PS/2.

At the shop level, controllers for shop 6, shop 7 and the tool shop are to be developed on three RS/6000 computers with IBM DAE system enablers installed. Controllers for other shops are to be developed on eight PS/2-M95 computers. At the first stage of implementation, in shop 6 and shop 7 PS/2-M95 computers are to be installed as cell controllers. In shop 6 four 7551 computers which are equipped with ARTICM/2 coordinators are installed to serve as workstation controllers. In shop 7, one 7551 computer and two 7542 computers equipped with ARTIC/A coordinators are installed as workstation controllers. At the equipment level, various NC machines, AGVs, robots for loading/unloading and welding, and other instruments are to be introduced.

5.2. Computer network

In order to meet the requirements of physical integration, a three-level hierarchical computer network architecture is developed in SB-CIMS. In the top level of the SB-CIMS computer network, the IBM TOKENRING 16Mbit/s ring-loop net is used to connect the factory-level computers and the shop-level computers. The host computer IBM 4381-92E is used as a network server. Protocols used until 1995 are TCP/IP and IBM SNA, and they will migrate to MAP/TOP architecture after 1995. For data communication at this level, the IBM company provides four software interfaces to support developments of communication and application programs. The data loop control (DLC) and the DIRECT visit interfaces are two low-layer protocol interfaces. They can be used for developing communication software. The net basic input/output system and the advanced program-to-program communication (APPC) are high-layer protocol interfaces which can be used for developing application software. In the middle level of the network architecture, cell-level computers and
workstation-level computer are interconnected by Ethernet. Here, the low-layer protocol used is 802.3 (CSAM/CP), and the high-layer protocols used are similar to those used in IBM Token Ring net. The Token-Ring net and Ethernet are interconnected by true IBM local net bridge 8209 and PS/2 computers which can perform the functions of gateways. Figure 2 shows the architecture of the two upper-level computer networks. For the bottom level of the network architecture, equipment controllers are connected by IBM real-time interface coordinators to support communication between equipment controllers and workstation controllers. FieldBus net will be used for the bottom level when possible.

5.3. Software deployments

According to functionalities, software components within a computer can be divided into several layers including computer operation systems, network service systems, database management systems, system enablers, application enablers, and applications. It is impossible to address in detail the formidable amount of software for SB-CIMS in one paper. Therefore, only the software deployed on the host computers, as an example, will be briefly discussed. As shown in Figure 3 at the first layer, the operating system running on the host computer is MVS/ESA which supports SNA and TCP/IP network protocols and provides VT, FTP and APPC functions. For the second layer, IMS/DB and DB2 database management systems are installed. At the third layer, the system enabler CIM/CDF, an IBM infrastructure product, is installed to support data management, communication, and data modelling. At the fourth level, the following three IBM application enablers are installed. Product Manager is used to facilitate data management and communications between production management applications and engineering databases. CADI and CADAM are used to help data communications between CAD/CAM applications and the CIM/CDF system enabler. At the fifth level, various production management applications and engineering applications are to be developed.

6. Organizational view

To develop the CIMS, we need to consider technical matters, and also pay much attention to human factors. Human integration is crucial to the overall system integration and performance. To accommodate maintenance and operation of the CIMS in the future, the organizational view is developed. The organizational view describes the related human responsibilities and their organizations. The SB-CIMS organizational view consists of two parts; the first part concerns design and implementation, while the second part concerns operation and maintenance. In the first part, an organizational hierarchy is developed, where personnel concerned are divided into levels according to the scope of their responsibility. It decides on the number of system designers and developers from each related research area. It also assigns tasks and responsibilities to the designers and developers. In the second part, to fit the SB-CIMS, existing organizational units are adjusted and some new organizational units are to be established when necessary. Plans for personnel training are also developed to help the employees to get used to the CIMS environment.

7. Conclusions

In this paper the design outline of SB-CIMS is presented. Shenyang Blower Factory, like many other old enterprises, faces very intensive challenges when China gradually migrates to a market economy. Many frus-
trating problems such as long lead times, quality fluctuations and high production costs threaten survival and development of the factory. Implementation of a CIMS is expected to provide a flexible and integrated manufacturing environment. Obviously, the design methodology for such a huge, complex system plays a very important role in system descriptions, design and implementation. The ideologies of CIM-OSA are accepted as guidelines during design of SB-CIMS. The SB-CIMS is composed of four systems. First the PADIS is designed to support long-term decision-making and production management at the top level. Second the engineering information system is designed to create engineering databases concerning product designs and processes in order to reduce product lead times and to improve product design qualities. Third, the manufacturing shop automation system, functionally including shop level to equipment level, is designed to control product manufacturing. Finally, the computer network and database system provides support for the three applicator systems. Continuously, these four systems are decomposed into subsystems, and subsystems are decomposed into functional modules. This functional decomposition is documented with IDEF0 diagrams forming the functional view of SB-CIMS. Based on functional requirements, the information view is developed to depict the information entities, attributes and information flows. The resource view is designed to determine the various facilities needed to carry out the system functions. Finally, human aspects involved in SB-CIMS are considered in the organizational view.

In 1993 some key technologies, including system integration methods and CIMS running mechanisms, will be further studied. The main work of this year is to gradually implement the CIMS. Developing a CIMS is a very challenging job; many tough problems need to be solved. Personnel participating in the project must be well organized and motivated. The functions and goals of the CIMS must be realistically set under the constraints of the investment and technologies available. It is also important for a CIMS to adopt an open architecture to allow for gradual implementation and future modifications.

References