Case Studies

Modeling for CIM information systems architecture definition: An information engineering case study

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Many fundamental problems exist in the development and implementation of computer-integrated manufacturing information systems: for example, lack of integration, islands of automation, sub-optimization of resources, inability to migrate to future technology. Moreover, few methodologies have been developed for dealing with these issues. In this paper we outline an information engineering approach to plan, design and implement this class of information systems, which addresses many of the fundamental problems.

Keywords: Computer-integrated manufacturing, Information Systems Architecture, Manufacturing information systems, Information engineering.

1. Introduction

For several years researchers and practitioners have been struggling with the problem of developing effective computer-integrated manufacturing information systems (CIMIS). In this paper CIMIS is defined as computer-based integrated, user–machine, and machine–machine information systems for supporting the operations, management, and decision making in a manufacturing environment. Although much progress has been made over the years, there are few methodologies to assist with systematic planning and development of CIMIS [1–4]. This lack of methodologies has led to ad-hoc development practices which are associated with several organizational problems, such as lack of integration, system incompatibility, and sub-optimization of resources [1,2,5–8].

CIMIS technologies by themselves are complex. They include electronic data processing (EDP), management information systems (MIS), decision support systems (DSS), expert systems (ES), computer-aided design (CAD), computer-

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aided manufacturing (CAM), computer-aided process planning (CAPP), flexible manufacturing systems (FMS) and so on. Developing effective manufacturing support and management environments with these technologies in the absence of appropriate planning and development methodologies is an intractable problem. We believe that methods and techniques developed to solve enterprise-wide information management problems can be adapted to the special requirements of CIMIS development.

In this paper we present a case-study of the application of an *information engineering* (IE) approach to CIMIS planning and development. The approach focuses on systematically modeling the global information requirements needed to plan, design, and develop an integrated manufacturing environment based upon a global CIMIS architecture. It provides a philosophy, methods, and techniques for identifying all the CIM processes, information flows, and data entities which are relevant to the manufacturing goals and objectives of the enterprise. The IE approach assists in narrowing the gap between planning and implementation, and provides a comprehensive review of the information requirements, critical interfaces, and functional dependencies across the organization [9,10]. The IE approach offers an alternative to ad-hoc CIMIS development, accommodates incremental development of systems, and supports the integration process.

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2. The organizational context of CIMIS

The fundamental objective of CIMIS is the integration of the business and manufacturing processes to achieve cost-efficient, effective, and timely production and distribution of products in response to competitive market demands. In this regard, CIMIS must support information exchange among the various organization levels (*strategic, managerial* and *operational*) and business functions (*marketing, purchasing, production, distribution* etc.) of the organization. For CIMIS to be effective several organizational variables must be considered as relevant to their design. Several of these variables have been studied in earlier work on factory automation [11] and more recently in information systems (IS) [12–16]. CIMIS development and implementation seem to remain insulated from the influence of this type of research.

In order to convey the complexity of the CIMIS problem space we will briefly outline the organizational variables—*Task, Technology, People, Communication*, and *Structure*—which we believe to be important for the development and implementation of effective CIMIS.

From one perspective organizations may be conceived of as a complex of interrelated sets of *tasks*. These tasks may be performed by people, computers or machines working independently or in collaboration.

Technology has become an essential component of modern manufacturing. Intense competitive pressures are forcing more manufacturers to adopt a wider variety of manufacturing technologies than ever before. These technologies often impact the organization structure, its task components, and their human users. The efficient and effective integration and application of new technologies to the manufacturing process is vital to survival of the firm.

In as much as automation has advanced considerably, people remain vital to manufacturing. They are required to manage the manufacturing process, monitor and control computers and machines. People must be considered an important variable that must be accounted for during the conceptualization of any human activity system. Their skills, competences, and training are important parameters when deciding on the tasks to be performed, the technology to be used, the type of user interface to use, or the type of organizational structure to adopt.

Communication is extremely important in CIMIS development from two points of view: technical communication and human communication. Technical communication concerns the ability of different types of technology to effectively communicate. Human communication concerns the ability of people to communicate with each other, computers, and machines. Technical communication is very important for CIMIS development because CIMIS is about trying to integrate different types of IS, CIM technologies and people. This integration is achieved by linking these different types of technologies through the use of a computer networks. Failure to address these human concerns have led to other implementation problems which contribute to CIMIS failures.

Structure is concerned with organizing, i.e., how people, technology, and task complexes are arranged to achieve specific objectives of the enterprise. The type of technology, i.e., tools and processes, the manufacturing and management philosophy of the firm are important parameters in determining organization structure. With regard to CIMIS there is another important aspect of structure; the configuration and design of technology complexes. To effectively control and monitor an integrated CIMIS, levels of computer and machine control and monitoring are necessary.

In a manufacturing enterprise these variables are interconnected. Figure 1 shows conceptually the relations among these variables and the levels of management in the manufacturing enterprise. Any intervention into this complex network of relationships must be carefully thought out, because changes in any variable have implications at the enterprise level. The development and implementation of CIMIS is a change process which intervenes in the manufacturing enterprise, and as such, must give close attention to each vari-

MGMT LEVELS ↓	CIMIS ASPECTS				
	TASK	TECHNOLOGY	PEOPLE	COMM	STRUCTURE
Strategic					
Managerial					
Operational					

Fig. 1. CIMIS framework.

able. In the next section we show how the IE approach addresses the entire problem space for CIMIS architecture development.

3. The information engineering approach

Information engineering, conceptual modeling, and analysis have contributed much to the state-of-the-art of IS development [17–20]. Information engineering provides a philosophy, methods, tools and techniques for describing and analyzing relevant aspects of the organization, and deriving a conceptual architecture upon which the development and implementation of IS could be based. The application of IE approaches to conceptual architecture development vary widely. We suggest a strategy in which seven conceptual models are synthesized to derive a CIMIS architecture. The seven models are developed to describe the five organizational variables outlined above, as well as the information process and exchange aspects (cf. Fig. 2). The models are needed for representing various views of reality we feel are important for the comprehensive integration of CIMIS. It is impossible to achieve a comprehensive representation of the enterprise information requirements by using a single model. To derive the CIMIS architecture wc draw on several different approaches. These include BSP [21], BIAIT [22], SASS [23], IE [24,25], and SADT [26,27].

An overview of the CIMIS architecture is shown in Fig. 2. The arrows in the center of each box indicate the primary flow for developing the seven models of the architecture. Because the development of a single model may be influenced by or dependent upon another, the arrows shown on the side of the boxes indicate the secondary flows. Therefore, for some models to be completely specified both the primary and secondary flows are needed. Table 1 shows how the seven models of the CIMIS architecture are related to the five organizational variables outlined earlier in Section 2. In the rest of this section we outline the derivation and application of the CIMIS architecture by using a case illustration.

Table 1
Relation between CIMIS models and organizational variables

CIMIS models	CIM variables covered
Business Model	Task
Data Model Message Flow Model DB & Application Portfolio Model	Communication/People /Task
Technology & Data Communication Model Responsibility Model	Communication/ Technology Structure/People

3.1. A case illustration

The universe of discourse of this case study is the Engineering Release Function of our host organization. This organizational function is responsible for pre-manufacturing activities, which focus on the processing, management, and distribution of engineering design information. It is a specialized information resource management function which serves as the interface between engineering design and manufacturing.

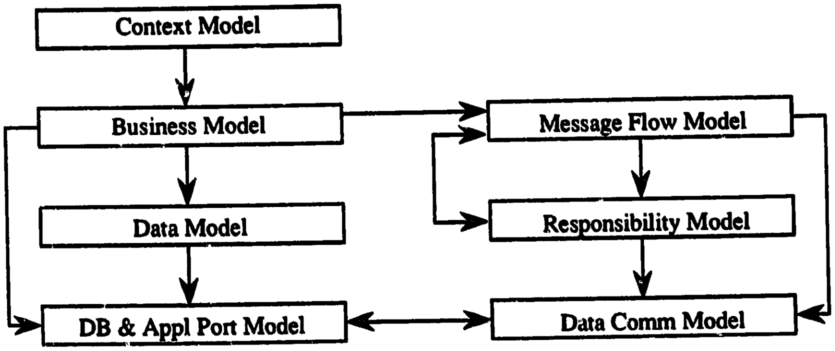

Fig. 2. Overview of CIMIS architecture models.

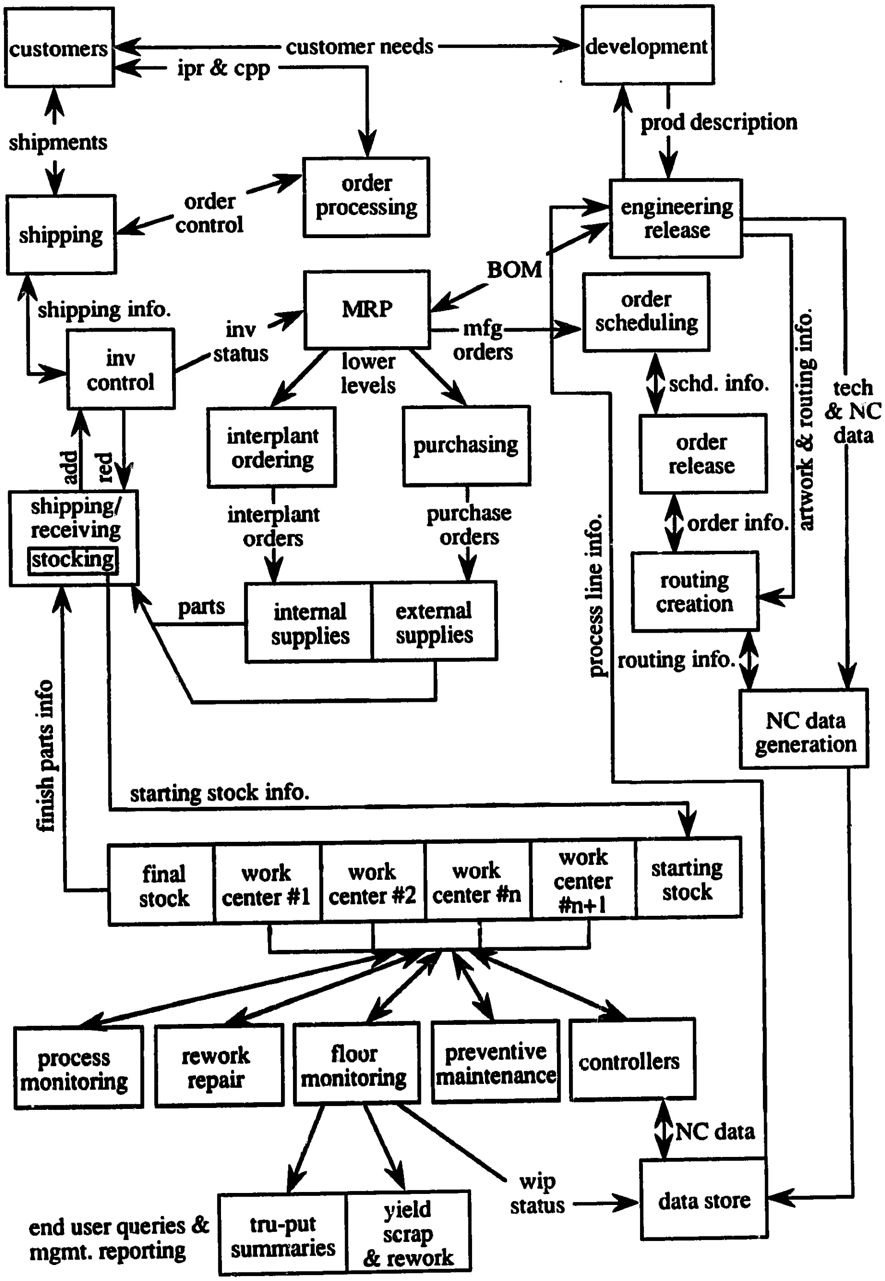

Fig. 3. Context model.

The Engineering Release Function is comprised of six departments, D1 through D6, eight managers, and over one hundred employees, most of whom are engineering and information systems specialists. Each department is responsible for a distinct set of information processing activities: D1 assembles engineering design data, develops, generates, and distributes reports to other departments. D2 further processes the design data adding more manufacturing process information and instruction. D3 creates process routings and their accompanying data. D4 and D5 collaborate on generating artwork NC data, and manufacturing materials requirements information. The artwork information is a description of the various features (holes, lands etc.) that make up the "card", the image of printed circuit boards which will be produced in the manufacturing stage. The design information is produced by design engineers, who work at various geographically dispersed Research and Development laboratories and transmitted over a wide area communications network to the Engineering Release Function. D6 ensures the manufacturability of the pre-manufacturing product. The six departments are highly interactive and perform a large amount of collaborative work.

The various types of information produced by the Engineering Release Function are called pre-manufacturing products. The pre-manufacturing products are inputs to the Manufacturing Function which produces intermediary products (glass prototypes) and final products (printed circuit boards). The glass prototypes or intermediary products serve as templates for the manufacture of the printed circuit boards.

3.2. The modeling process

The information engineering process is a five-phase process:
(1) Requirements Definition;
(2) Conceptual Design;
(3) Planning;
(4) Development; and
(5) Implementation.
The products of the IE modeling exercise were developed in an iterative and loop-linear manner as described in Fig. 2. The iterations are important because the development of some models required information derived from other models. Before we discuss the IE modeling process we will briefly outline the IE project team structure.

3.2.1. Project team structure

A multi-disciplined development team of fifteen to twenty members from the six departments worked continuously on the CIMIS architecture project. It consisted of varying numbers of IS professionals, pre-manufacturing experts, and three managers from the Release Function, experts from design engineering and manufacturing, and external specialists (action researchers). The skill and experience of team members varied: the experience of the application programmers range from ten to twenty five years, while the experience of the expert users range from fifteen to twenty five years. Most of the expert users work in the Release Function most their life. The experience of the managers ranged from seven to fifteen years. Most had worked as application programmers in other areas of the business before joining the Release Function. The primary responsibility of the pre-manufacturing and other experts was model development and validation. They worked closely with the IS professionals to ensure that the models adequately represented the functions and activities within the universe of discourse. The responsibility of the IS professionals was application design, development, and implementation. The primary responsibility of the analyst was to model the process using IDEF0 and to serve as an interface between programmers and users. It was the responsibility of the managers to administer the project, i.e., provide financial and other resources required by the project and report back to higher-level management.

The development team was divided into subgroups of three to four members to address specific problems. Members who were most knowledgeable about particular aspects of manufacturing usually ended up on related p.ojects. Team responsibilities ranged from requirements analysis to implementation. Special teams, referred to as action teams, were responsible for conducting fact finding missions about obscure aspects of the business. Weekly meetings were held to allow members to report back to the development and management team on the status of project activities.

3.2.2. Requirements definition phase

The fact-finding missions of the action teams were part of the requirements phase. The missions were initiated from discussions which emerged from the development and analysis of the model of the Release Function. Because no individual possessed a sufficient understanding of the entire Release Function, a decision was made to model it using IDEF0. This was to aid the group's understanding of the problem domain and to provide insight for problem resolution. As one analyst commented, "it is amazing how much learning and understanding was derived from the modeling exercise." He went on to say, "this level of understanding could not have been possible in the absence of the modeling exercise." One manager commented, "probably the most important product of the modeling exercise is the process (i.e., the learning and understanding that occurred among team members), and not the product (i.e., the actual model)." The model served as a communication vehicle for debate and discourse among members of the project team. By analyzing aspects of the model and with further analysis, lower-level requirements such as data entities, minispects, application programs, database design and so on were derived.

The results of modeling the case-organization are now presented in summary. It is not practical to show in detail all the models we developed because this would require several pages and lead to information overload. In this regard, we present high-level representations to give the reader a feel for the process. For example, in the case of the Business Model we will show only the first level of decomposition and omit the remaining six lower levels which are several pages long.

The process started with the development of the *Context Model* (Fig. 3), which defined the universe of discourse of our modeling exercise. The term context model as used here differs from the traditional notion of a context model even though the objective may be similar. The context

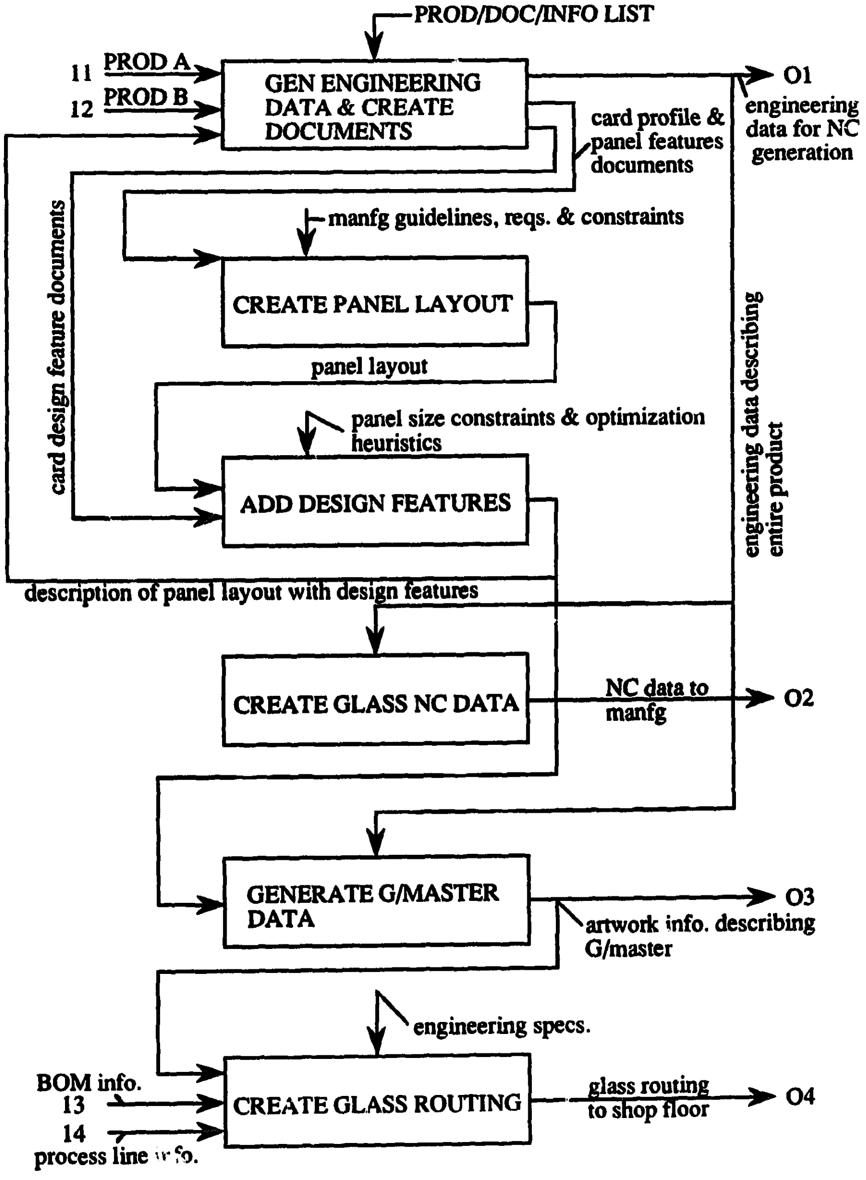
PROD/DOC/INFO LIST
I1 PROD A
I2 PROD B
GEN ENGINEERING DATA & CREATE DOCUMENTS
O1
engineering data for NC generation
card profile & panel features documents
card design feature documents
manfg guidelines, reqs. & constraints
CREATE PANEL LAYOUT
panel layout
panel size constraints & optimization heuristics
ADD DESIGN FEATURES
engineering data describing entire product
description of panel layout with design features
CREATE GLASS NC DATA
NC data to manfg
O2
GENERATE G/MASTER DATA
O3
artwork info. describing G/master
engineering specs.
BOM info.
I3
I4
process line info.
CREATE GLASS ROUTING
glass routing to shop floor
O4

Fig. 4. Business model.

model was used to provide the foundation for integration. The primary objective of the context model was to capture, at the highest level of abstraction, the interactions among the organization systems and/or subsystems of interest. It shows the primary information links upon which the systems/subsystems are to be integrated. These links represent the natural flow of information or data among the different systems. Developing the context model required the definition of the major operating systems that are embedded in the enterprise without regard to artificial boundaries such as departments, and defining the primary information flows among them.

The *Business Model* (Fig. 4) documents the minimum set of activities or tasks that must be performed if the organization is to function efficiently. A business model may be conceived as a related set of tasks/activities that are performed to support some aspect of the business. It also documents the information flows that are necessary to support various tasks. The model is then analyzed to identify missing activities, information flows, to add process control mechanisms or to eliminate redundant and unnecessary activities. The purpose of undertaking this analysis is to eliminate, from the business model, the complexities that have been built into the business over the years [28]. The idea is to make the business model simple and more efficient especially if the tasks or activities performed by people are to be automated.

The *Message Flow Model* (Fig. 5) describes information flows that are used or created by different activities or systems at various levels of abstraction. The natural starting point for constructing the Message Flow Model is the Business Model. The interactions among the business activities are documented in detail, describing the content of data exchanged and timing.

The *Responsibility Model* (Fig. 6) documents the role responsibility for information at various levels of the organization. This model makes explicit the organizational role relationship and control of information. The Business Model is also used to aid analysts and users in mapping organizational role responsibility to sets of activities.

3.2.3. Conceptual design phase

Conceptual design is the second major phase of the IE process following requirements definition. It is the process of constructing the detailed architecture models (Data Model, Data Base and Applications Model, and Data Communications Model) that are independent of implementation details, such as target communications network and data base management systems. The primary input to conceptual design is the information requirements derived from the Business Model.

The *Data Model* (Fig. 7) is a description of the data which are used and generated by the tasks and their relationships. The data model is used to derive the database schema during database design. To develop the data model, the analyst with the help of users, focused on the Business Model activities to identify the necessary supporting data objects. This identification process is aided by documents such as memos, forms, and reports used by individuals who perform the activities. A list of object classes is compiled and analyzed to remove redundancies and resolve naming prob-

Input	Release Function Subsystems	Outputs
Product descriptions single image	Design subsystem	Product design data
Technical data	Design subsystem	Restructured engineering
Product description unit image	Product subsystem	Panel layout information
Process line info.	Artwork subsystem	Artwork descriptions Artwork instructions
Machine availability Process line information Cost information Artwork description of product	Routing subsystem	Routing information to shop floor
Restructured engineering data	NC subsystem	NC data to manufacturing

Fig. 5. Message flow model (sub-system level).

lems. Depending upon the number of object classes, clustering may be necessary to arrive at logical sets of objects which may be represented in several databases. The final step is to model each of the logically related sets of objects using a data or object model.

The *Database Model* (Fig. 8) describes the set of databases needed to support the business activities of the organization. It also identifies the applications that should run against each of the databases. The data clustering done in the earlier Data Modeling phase now becomes the basis for deciding which database(s) to develop. Each cluster of objects may give rise to the design of separate subject databases [25,29]. With further analysis, the information flows between databases may be derived. Based upon the type of information needed to support some aspect of the business the team, with the help of users and managers, could then decide upon the types of application software required to perform business functions.

Role	Information flow [a]
Operator who generates engineering data:	
	Description of product A (u) A1[1]I1
	Description of product B (u) A1[1]I1
	Technical data (u) A1[1]I2
	Panel layout with design features description (u) A1[1]I3
	Engineering data passed to NC type database (c) A1[1]O1
	Information needed to decide type of document to generate (u) A1[1]O3 = I1[2]
	Engineering data required to create documents (u) A1[1]O2 = I1[3]
	Decision concerning type of documents to be generated (c) A1[2]O1
Operator who generates documents:	
	Engineering data required to create documents (u) A1[3]I1
	Decision concerning type of documents to be generated (u) A1[3]I2
	Created documents (c) A1[3]O1 = A1[4]I1
Operator responsible for verifying and distributing documents:	
	Created documents (u) A1[4]I1
	Card profile and panel features documents (c) A1[4]O1
	Card design features document (c) A1[4]O2
Panel designer:	
	Information about panel features (u) A2[1]I1 and A2[2]I2
	Card overall dimensions (u) A2[3]I2
	Card panel layout information (u) A2[4]I1
	Acceptable panel layout (c) A2[4]O2
	List of panel sizes (u) A2[2]C1
	Manufacturing constraints (u) A2[2]C1
	Manufacturing guidelines for panel layout (u) A2[3]C1

[a] Legend: name of information flow+(u)se or (c)reate+node#-[process#]-Input# or Output# or Control#

Fig. 6. Responsibility model.

The *Technology and Data Communication Model* (Fig. 9) describes the type of technology to be used and how they are linked via a data communication network or set of networks. It makes explicit which systems are to communicate with each other, and how the communication is to be handled. This provides support for the analysis and selection of the network, the type of software required, the communication protocols and standards to adopt, and the general topology of the communication network [30]. This model allows for the pressing concerns mentioned above to be addressed early in the development process.

To derive the Technology and Data Communication model the team made an assessment of the type and quantity of data, the distance over which the data is to be transmitted, the performance of the network, the reliability of the network and so on. In light of these concerns the technology was chosen. The operating systems (OS) were chosen so they are compatible. This may seem trivial but it may have severe implications. Take the simple example where two operating systems are to communicate with each other. One supports sixteen decimal places after the point while the other supports twelve. As we pass data back and forth we may loose four places of accuracy. This may provide sufficient error to cause a fatal accident in critical situations. In other situations it may be sufficient to corrupt the data, thus problems of data integrity arise. The next step was to decide on the best local area network (LAN) configuration. This involved decisions regarding the reliability of the network, the performance and so on.

3.2.4. Planning phase

From the information gathered in the requirements definition phase and the conceptual design phase a strategic plan and several tactical plans were developed. The strategic plan had a five-year horizon of implementation. The goal of which was to reduce the cycle-time for generating data required to manufacture the glass prototype from

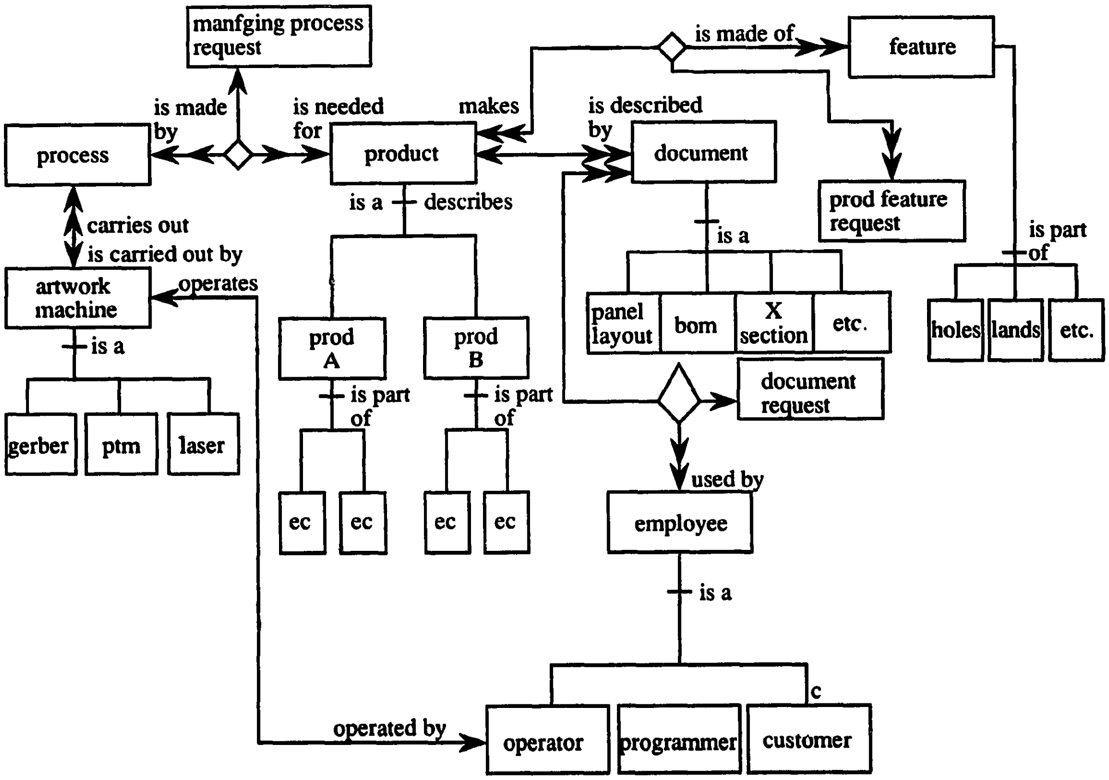

Fig. 7. Data model.

twelve days to four hours. This strategic goal led to the identification of several tactical plans. Each tactical plan produced one or more projects which were evaluated to ensure that they were congruent with the overall strategic goal. These information systems projects were:

(1) an on-line document distributing system;

(2) a work-in-process tracking system;

(3) an automatic manufacturing process routing generation system;

(4) a real-time document and data generating system and

(5) a comprehensive pre-manufacturing product generating system.

If a project was deemed counter-productive to the strategic plan it was replaced with a better project unless there was good reason for it. For example, several projects were considered incongruent with the strategic goal but were recognized as being important for maintaining certain organizational activities during the disruption caused by the implementation of the projects. At the successful completion of the strategic goal incongruent projects will be eliminated.

3.2.5. Development and implementation phase

Four of the above listed projects have been implemented; Project #5 is ongoing. A brief description of each of the five projects now follow.

(1) The on-line document distributing system is to distribute documents electronically to workers via a computer network. This replaces the printing and distributing of hard-copy documents which was slow, time-consuming, and costly.

(2) The work-in-process tracking system keeps track of work-in-progress. It records the time, place, etc., and the person responsible for work-in-process. It provides a means of accountability and traceability for work-in-process. Before its implementation, there was no efficient and effective way of keeping track of work-in-process.

(3) The automatic manufacturing process routing generation system eliminates or minimizes several levels of human intervention previously

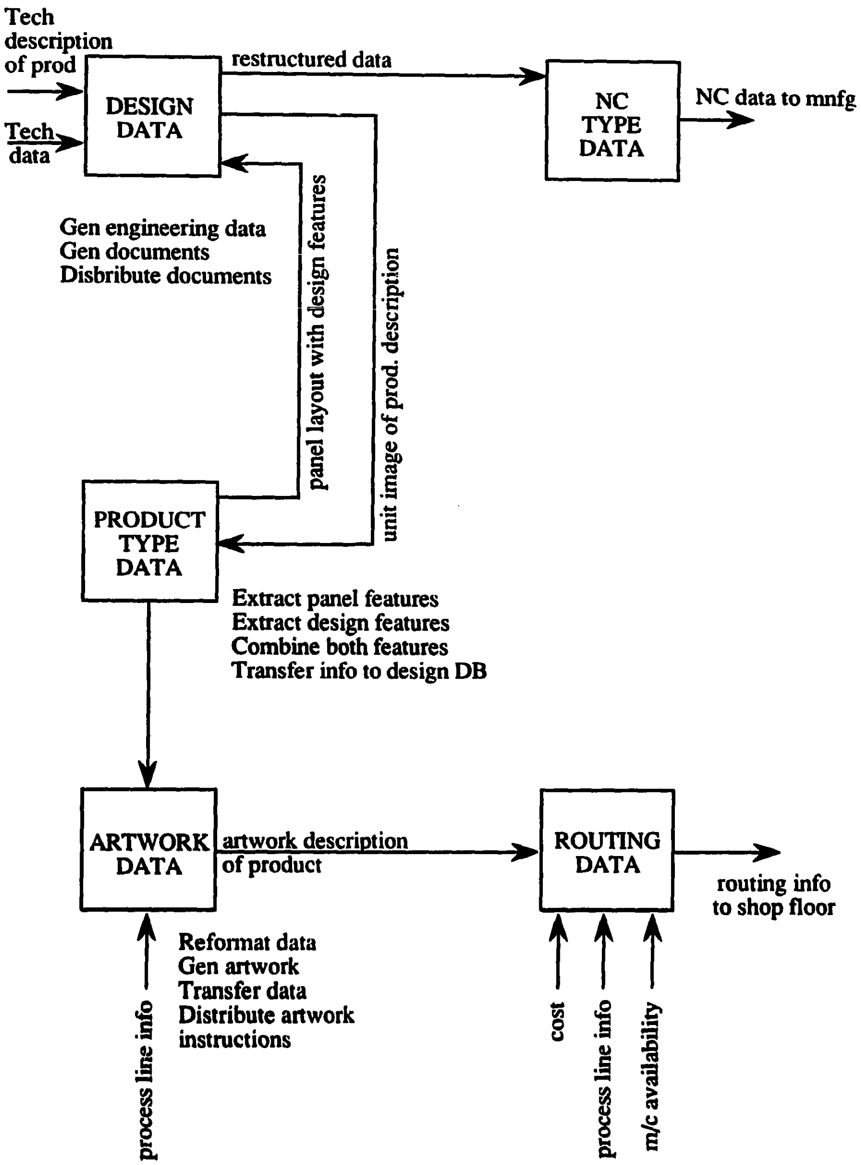

Fig. 8. Database model.

required to generate some of the manufacturing process routings for machines on the shop floor. This has helped to decrease cycle-time by reducing the time required to generate routings. Moreover, it has reduced errors associated with the routing generation process.

(4) The real-time document and data generating system replaces the batch-run system that was only able to operate once a day. The new system allows documents and data to be generated as they are received by the Release Function. This has helped to decrease cycle time and increase productivity.

(5) The comprehensive pre-manufacturing product generating system is a major project designed to eliminate data integrity problems associated with the generation of the pre-manufacturing product. Because this is a major project re-

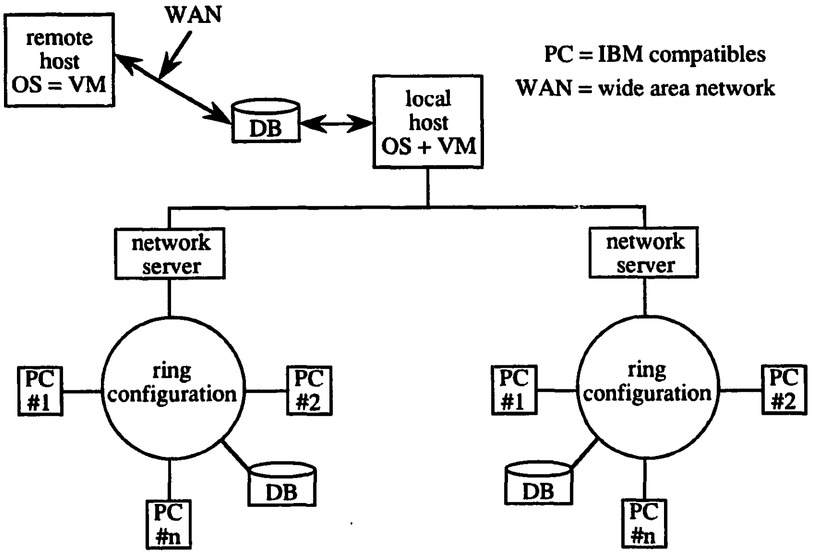

Fig. 9. Technology and data communication model.

quiring a considerable amount of development work, it is still ongoing and it is scheduled to be completed by 1995.

4. Concluding discussion

It became clear from the case study that organizational learning is the most important outcome of our exercise. The process of developing a shared view of the organizational reality that satisfies all the stakeholders is extremely difficult. In any modeling activity where the analyst has to work with several users, s/he must confront several notions of reality. The problem then is how to reconcile these often conflicting views of reality. We found that having a model in a format that every member of the group could understand allowed for a debate where members can challenge apparently conflicting views of reality, eliminate misconceptions, and learn other valid perspectives of which they were not aware. By challenging existing views, much fruitful discussion and, at times, heated debate often resulted.

The participants of the modeling process have claimed that the critical debate process yielded a level of organizational learning that could not have been achieved in the absence of the model. The critical debate process helped to identify limitations of the existing business some of which included: (1) the lack of electronic distribution of documents as opposed to hard copy; (2) the inability to track work in process; and (3) long cycle times and insufficient throughput.

At first, individuals were hesitant to acknowledge that limitations did exist. However, with the passing of time they became convinced and committed to correct such limitations. As a result, global objectives were defined and a five-year plan was developed to implement changes which would improve the efficiency and effectiveness of the design, engineering release, and manufacturing processes. Examples of organizational changes that originated from the five-year plan include: (1) an on-line document distribution system; (2) an on-line work-in-process tracking system; and (3) a decrease in cycle time from twelve to six days. In a recent conversation with one of the managers we were informed that the cycle time is now down to three days.

Related to issues of organizational learning is the need to foster collaboration among team members. It became apparent during the modeling process that methods and techniques to support collaborative group dynamics are needed. Despite attempts to foster camaraderie among the team members issues emerged which were not effectively dealt with, because we had no collaborative process structure. At times the project stalled on issues of politics and competition among team members. On account of this, team members at times left project meetings prematurely. It is important then that the analyst be trained to better handle the group dynamics that normally emerge during project development. Research on collaborative project team processes is being carried out by Ngwenyama [31].

A limitation we faced was inadequate computer support for the modeling and analysis. At the beginning of the project, top management decided that no new software tools would be purchased. We were forced to use CASE tools designed for less complex problem spaces. Although the IE approach is tool-independent, we have found that the lack of appropriate tools results in significant difficulty of documentation, model analysis, and consistency checking. This is not a new finding because these problems have been discussed by Yadav [18] and Laagland [32]. One reason is that many available CASE tools do not cover the entire IE life-cycle [16]. We are currently examining the problem of selecting and re-engineering tools to support the modeling and analysis process.

An important benefit gained from the development exercise was an increased globaly shared understanding of the Release Function and how it relates and impacts other business functions. This increased understanding sensitized Release and other workers about the impact of their decisions on other aspects of design and manufacturing. Consequently, the three organizations now pay more attention to their decision making processes and consult with each other more frequently. This has increased collaboration among project teams across organizational boundaries.

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