A Reference Model For Computer Integrated Manufacturing (CIM)

A Description from the Viewpoint of Industrial Automation

Prepared by
CIM Reference Model Committee
International Purdue Workshop on
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Edited by
Theodore J. Williams

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Foreword

The CIM Reference Model Committee of the International Purdue Workshop on Industrial Computer Systems is happy to present this *Reference Model for Computer Integrated Manufacturing (CIM), A Description From the Viewpoint of Industrial Automation* to their compatriots of the Workshop and their associates throughout the manufacturing and process industries and education who are interested in this increasingly important field. The members hope that their efforts documented here will be of interest and help in advancing the technology of computer integrated manufacturing and in solving some of the problems plaguing our industries today.

We welcome the readers' review of our work and would appreciate receiving any corrections, comments, additions, etc., which you may care to propose.

The work of the Committee in preparing this Reference Model was carried out as a set of continual updates of the Committee's working document. To accomplish this the Committee depended on the secretarial staff of the Purdue Laboratory for Applied Industrial Control, Purdue University, to update and republish this document for each meeting of the Committee (12 in number). We are grateful beyond expression to Mrs. Sharon K. Whitlock, Administrative Assistant for the Laboratory; and to Mrs. Zilla M. Capper and Ms. Janice E. Napier, Secretaries, for their cheerful, rapid and accurate work in keeping this document current with the deliberations of the Committee.

A full list of the active and contributing members of the CIM Reference Model of the International Purdue Workshop on Industrial Computer Systems as given in Appendix VI. All have made major contributions to the present model and its description as contained within these covers. Despite the important work of all members, the special contributions of several of these and of others not active members of the Committee to major parts of the text of this report must be especially acknowledged. These and their special contributions are as follows:

Peter F. Elzer

Chapter 6 - Essential Aspects of Software Development, pp 89 to 104.

J. J. McCarthy

Chapter 1 - The Generic Goals in the Design and Operation of Any Production Plant, pp 1 to 3 (With R. P. Ruckman).
Chapter 7 - Databases in the Process Industries and the Factory, pp 109 to 121 (With Krishna Mikkilineni).

William R. Kunes

Chapter 10 - An Example of Participative Management, pp 168 to 176.

Edgar H. Bristol and Raymond D. Sawyer

Chapter 4 - The Data Flow Model, pp 45 to 73.

H. Van Dyke Parunak and John F. White

Appendix VI - Definition of Terms, pp 196 to 201.

Robert F. Carroll

Chapter 4 - Table 4-III, pp 74 to 84.
Numerous Other Review and Coordination Tasks.

Gerald R. White

Appendix IV - A Glossary of the Field of CIM Reference Models-pp 202 to 213.

D. C. Sweeton and R.S. Crowder

Chapter 9 - Mini-MAP and Process Control Architecture, pp 149 to 156.

Mark Eckard

Chapter 9 - Some Commercially Available Plant Data Communications Systems, pp 140 to 146. (Adapted from *The Use of Digital Computers in Process Control* by T.J. Williams; used with permission.)

James Ventresca

Chapter 9 - Modular Structure of the Communications Interface, pp 157 to 162.

Bailey Squier and WG 1 of ISO TC 184

Chapter 1, pp 7 to 8, Appendix III.

Clyde Van Haren

Chapter 1, pp 10 to 12.

The Committee is indebted to the Steel Industry Project of the Purdue Laboratory for Applied Industrial Control, Purdue University, entitled, *Hierarchy Computer Control of Energy Savings and Productivity Improvements in the Metals Industry*, which over the period of 1973-86 established many of the basic concepts and their generic nature which made the *Reference Model for Computer Integrated Manufacturing (CIM)* possible.

Theodore J. Williams

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Introduction

It has long been the dream of the industrial systems engineer to integrate the operating units of the plant in order to be able to produce that plant's products at minimum unit cost and at maximum overall profit for the company involved. Early work in this field was based on plant design techniques that: (1) closely coupled production units, (2) minimized in-process inventories and work in progress, and (3) made maximum use of in-plant energy sources to supply plant energy needs. While excellent in initial concept these techniques floundered because of lack of, (1) unit coordination, (2) dynamic response, and (3) market sensitivity. Lack of unit coordination is exemplified by the presence of unpredictable plant interruptions and breakdowns in plant production processes which occur randomly in time and location thus wreaking havoc with the productivity of such a close-coupled, low-inventory plant. Unforeseen changes in customer requirements, often obsoleting an inflexible manufacturing system characterize the lack of dynamic response. A lack of market sensitivity is exhibited through limited flexibility in responding to changes in competition, in production cost items (such as energy and raw materials), and in regulatory requirements, any of which can invalidate the initial optimization criteria of the plant's design.

Despite these setbacks to the effort to design integration into the plant's initial construction, the dream of system integration has continued because of its obvious intellectual challenge and the enormous economic gains to be achieved if it were successful.

More recently, the trend in systems integration has been toward the use of automatic control in its broadest sense (including dynamic control, scheduling and the closure of information loops) to integrate all aspects of the plant's operations including closing the information loops within the plant. This latter trend then allowed the plant to compensate for the unforeseen interruptions and breakdowns in its production processes and also allowed it to modify its product mix and its production rate as its customer's needs and desires changed. All of this must be done while continually minimizing overall production costs to match the current plant condition. Thus we have the substitution of control and management techniques for initial design procedures in an attempt to counteract the forces that invalidated the original concept and therefore to still accomplish the original goals.

While we have long known the tasks which such a system had to be able to carry out to accomplish these goals, it has only been since the advent of the modern digital computer that it has been possible to handle the enormous computational load involved in carrying out these functions in *real time* and thus hoping to compensate for all of the factors affecting plant productivity and economic return.

Where successful these new techniques have shown the same high economic gains envisioned for the design integrated plant.

Current trends in electronics, computer science, and control system technology are providing the technical capability to greatly facilitate the development of integrated industrial control systems. These trends include: (1), distributed, digital, microcomputer based, first level dynamic control systems; (2), standard real-time programming languages such as Real-Time FORTRAN and

ADA; (3), standardized high speed serial data links such as MAP and PROWAY; and, (4), corresponding major developments in database management techniques. Most of these latter will result in large scale, hierarchically arranged computer systems integrating the plant management, plant production scheduling, inventory management, individual process optimization, and unit process control for all of the plant's operating units treated as a whole.

The success of the International Standards Organization (ISO) in the development of a series of communications standards through the use of its Reference Model on Open Systems Interconnection, the OSI/ISO model [8], has encouraged many groups to develop and apply such models to other problems. The International Purdue Workshop on Industrial Computer Systems, based at Purdue University, West Lafayette, Indiana, USA, has carried out such a development for *computer integrated manufacturing* (CIM) as applied to all industries.

Any organization, group or individual who dedicates the time and effort necessary to initiate, pursue and eventually complete a project as extensive as this *Reference Model for Computer Integrated Manufacturing* must be, obviously has a major motive which is driving it to accomplish that goal. So that others may truly appreciate this (to us) important goal and correctly consider it in their review and evaluation of the resulting product, it is necessary that goal be articulated clearly, completely and early in the description of the CIM Reference Model. This shall be attempted now.

Both the International Purdue Workshop on Industrial Computer Systems and its parent organization, The Purdue Laboratory for Applied Industrial Control of Purdue University, West Lafayette, Indiana, are involved in this effort. Both have the basic technical objective of promoting, to the extent possible, the overall field of the automation of industrial equipment and processes up to and including complete industrial plants. This automation would be carried out through the media of the applications of digital computers and their related technology. The Workshop has sought to further this overall objective through international standards development pertaining to and the dissemination of technical information about the design, implementation and application of industrial computer control systems. The Laboratory has over the past 20 years mounted a major university research program in this area whose results are well known.

Therefore the present *Reference Model for Computer Integrated Manufacturing* is another major effort in our work to further the field of industrial computer control systems looking toward the eventual automation (in its broadest sense) of the equipments, processes and manufacturing plants of any and all industries wherever such technology is economically and socially applicable. This *Reference Model for Computer Integrated Manufacturing* gives both organizations the opportunity of expressing their technical opinions of the overall generality of applications of industrial computer control systems to all types of manufacturing plants at this time. The CIM Reference Model Committee of the Workshop has carried out this work.

The goal as expressed above does put a definite bias on the emphasis, content and presentation of the resulting Reference Model. It is our intent to discuss the overall generic functional requirements of any manufacturing facility, regardless of industry, that are amenable to computerization within the foreseeable future and to define the viable relationships between these "automatable" functions and the other many functions of a manufacturing system for which, to our eyes, no such possibility is attainable with currently foreseen technology.

One of the criteria for assessing whether or not a particular function is *automatable,* in the broadest sense of the word, is *whether or not the operation of the function and its related physical equipment can be expressed in mathematical or computer program terms.* Those functions which are not systematically expressible, particularly those which require human innovation for their implementation, are considered nonautomatable. Chapter 2 and Appendix V consider this last item further.

Therefore, there are two concepts or principles which are paramount to our work. These are *automatability* and *innovation:*

Automatability requires that the operation of the function and its related physical equipment be expressible in mathematical or computer program terms.

If this is not possible, then by definition a human being must supply the information or action which would otherwise be lacking. This is *human innovation.*

The resulting factory must be organized such that it interfaces with its customers, its suppliers, its neighbors and its own workers in a manner which makes it indistinguishable from the outside world as to whether it is "automated" or not (a la the Turing Machine).

As is noted below, there are many forms in which the *Reference Model for Computer Integrated Manufacturing* could be expressed and many ways of describing the interrelationship of the functional requirements to be discussed. Again as part of the bias engendered by our objective as expressed above, the committee has chosen to describe a definite control and information system structure and to treat the requirements so generated as firm. This is for emphasis only and to present one basic story. It is realized by all that there are many ways the model could be accomplished - this being only one of these. The reader is encouraged to view our work in this light, especially when it is impossible in a work such as this to include all of the possible viewpoints and considerations which might arise.

Such a model must be a list of all of the truly generic tasks of the CIM system we are discussing here and would arrange them in their proper relationship to each other (temporal, spatial and subordination). It would detail the generic units required to carry out these tasks, both the application entities (process units) and the service entities (computer system communications, database, etc.). In addition, the model should also allow one to develop the best structure for the automatic control system (scheduling and dynamic control) for the plant, and to specify the best location or locations (within the structure) for carrying out each task.

The resulting model must have the following characteristics [38]:

1. Simply structured, flexible, modular, and generic.
2. Based upon readily understandable and acceptable terminology.
3. Able to be applied to a wide range of manufacturing operations and organizations.
4. Independent of any given, predetermined, realizations in terms of system configurations or implementations.
5. Open-ended in its ability to be extended and in its ability to encompass new technologies without unreasonably invalidating current realizations.
6. Independent of existing technologies in manufacturing automation and computer science.

Successful completion of such a model will prove the concept of manufacturing plant commonality expressed above. It will also show whether or not the hierarchical structural arrangement shown below, or another, is the proper structure for the overall, plant-wide, control and information system.

The CIM Reference Model Committee of the International Purdue Workshop on Industrial Computer Systems has met twelve times over the past two years in order to bring the relevant information together to produce a suitable CIM Reference Model.

Many types of reference models have been evaluated. At the present time no one model type seems to be perfect. Originally this was an alarming note for the Workshop.

What is being proposed for the CIM Reference Model is a blending of two types; the hierarchical and the data flow. The hierarchical is the oldest and has had the most exposure and use over the years. This fits many of the existing plants such as chemical, steel and paper. The data flow type model helps define the interrelationship of all the functions required of the system which is not possible using the hierarchical model alone.

This is a calculated choice on the part of the group and is not meant to detract from other model types that have been proposed. It is hoped that other persons will determine if other types will perform as well as those chosen for the Purdue CIM model and share their thoughts with the Committee.

To accomplish this task a great deal of effort must be expended to provide all of the necessary features for the proposed model. The hierarchical model type has already had a great deal of this work completed. To reach our goal of completing this model within a reasonable time it was not possible to continue to use each of the different model types presently available. Thus the choice indicated above was made by the Committee.

This model discusses the automation system and information handling requirements of the CIM system as diagrammed in the central box of Figure 1-2 of Chapter 1, (p 7). While process equipment, machine tools and material handling equipments are considered parts of the CIM system in many circles they are not so considered in this model because of their non-generic nature, (i.e., these are not included as a separate level in the model diagrams). Also excluded are the enterprise functions such as R & D, Engineering, Corporate Management, Sales, etc., listed here as external entities.

This subject of CIM reference models is also itself the subject of a major standardization effort. Working Group 1 (Reference Models Working Group) of Subcommittee 5 of Technical Committee 184 (Industrial Automation Systems) of the International Standards Organization (ISO/TC184/SC5/WG1) has been organized to develop a standard reference model of the manufacturing process for eventual standardization by the ISO. Their model will be for the purpose of evaluating the need for additional or modified standards in order to promote industrial growth and development. As such, it will not be as extensive as the present model. Thus the continuing need for a model such as that being developed here.

In addition to its own development work, Working Group 1 has established liaison with other groups around the world who are engaged in similar activities including the Purdue Group. This liaison has been of major help in this work.

1

Why a CIM Reference Model? Its Potential Uses and Benefits

THE GENERIC GOALS IN THE DESIGN AND OPERATION OF ANY PRODUCTION PLANT [79]

The first step in the development of a statement of plant needs is a comprehensive list of long range plant goals (i.e., such as a five year plan). The goals to be stated here are truly generic for any production plant regardless of the industry involved. In view of this fact it is the thesis of the CIM Reference Model Committee that such a set of generic goals can best be satisfied by a Computer Integrated Manufacturing (CIM) System for the plant whose requirements are similarly generic in nature. Further, these requirements and the nature of the CIM system can be defined by a reference model which would thus be applicable to any industry or any plant in that industry. This report will specify such a model.

The principal goal is to achieve a lower cost of operations or a higher process throughput for the plant through the application of process control and information systems technologies. The mill-wide or plant-wide system will be the basis for the plant's Computer Integrated Manufacturing system.

In the process industries, the term "CIM" is not used as often as the phrase "Plant-wide Control." The meaning is the same: the interconnection of information and control systems throughout a plant in order to fully integrate the coordination and control of operations. Since process plants in the paper, steel, sugar and textile industries are known as "mills", these industries refer to "Mill-wide Control." In this model, the term "Plant-wide Control" will be used generically to mean both plants and mills.

Improved human operator productivity will be realized through the implementation of individual workstations which provide the tools for decision-making as well as information that is timely, accurate and comprehensible.

Timeliness of data will be assured through the interconnection of all workstations and information processing facilities with a high-speed, plant-wide local area network, and a global relational database.

The human resource aspect is a major factor in introducing new technology. The plant-wide control and information system will utilize and support the cultural resources of the organization as it moves to adapt to changing business conditions.

As new automation system technology is introduced, standard network interfaces will be specified to permit its integration with the plant-wide system (thus avoiding islands of automation). The broad goal is to improve the overall process and business operations by obtaining the benefits that will come from a completely integrated plant information system. The continual growth of the linkage of the process operations data with product line, project and business systems data will be supported. The system will make such data readily available, interactively in real-time, to any employee with a need to know, at workstations scattered throughout the plant and, above all, easy to use. The resulting comprehensive plant information management system will be the key to long-range improvements to: process control; product line management; plant management; and, support of business strategies.

OBJECTIVES OF THE PLANT INFORMATION AND CONTROL SYSTEM

In order to support the broad objectives of the plant, a more specific set of objectives is needed for the various technology systems projected to meet the long-range needs of the plant. These include database management systems, communications networks, process control, process optimization, process improvement and decision support systems. They are further defined in the following paragraphs [79].

Database Management Systems should be global in nature and must interconnect, interrelate and integrate all department and area databases of the plant, including corporate, business, research and marketing strategies as well as plant operations and production control. The following supporting goals must be included:

1. Industry standard relational database structures and systems must be employed to permit easy integration;

2. Ease of access through a user-friendly, ad hoc query language must be supported to permit timely analysis of plant operations problems;

3. Integrity of temporal data must be maintained via high-speed network access rather than large-scale collection and copying;

4. Security of the data must be maintained while providing access to all users with a need; and,

5. Support of plant-wide information gathering for formulation of management decisions with simultaneous access of a single user program or person to multiple databases as the system grows.

Communication Networks must provide plant-wide information exchanges with appropriate interactive work stations and permit ready access to plant information by all users of data. The following supporting goals must be included:

1. Connectivity and interoperability between systems of different vendors must be provided for adaptability and ease of expansion;

2. Integrity and security of data in transmission and access to databases must be assured for reliable plant operation;

3. Delay or latency in transmission must be minimized with highest economic speed for timely analysis and decisions;

4. Inter-network bridges, routers and gateways must be supplied where needed to provide connectivity; and,

5. Voice, data and video image transmission must be integrated where needed to provide consistency of information.

Process control must make computer-automated control available in all areas on all processes. In addition, the technology must expand the scope of conventional control to include the following supporting goals:

1. Minimize the manual entry and recording of all measurements and operational decisions to minimize errors and expedite data acquisition;

2. Simplify the conducting of economic and operational studies to permit quick analysis of unusual operating conditions;

3. Increase the process and system engineer's productivity through readily accessible, efficient and comprehensive analysis and design tools;

4. Increase the scope and interactive access to history data to permit thorough analysis of process and operational problems; and

5. Expedite the process of system expansion and growth.

Process optimization must permit the expansion of efforts in simulation, optimization and scheduling of process operations, including the following supporting goals:

1. Support of execution of process analysis and modelling tools from all levels to extend their use throughout the plant;

2. Support of effective management of materials with timely and comprehensive real-time inventory, demand and supply data;

3. Provide for dynamic acquisition of energy and material balance information to support the optimization of their utilization and reduction of overall costs;

4. Support access to process modelling systems from throughout the mill to permit more thorough analysis; and,

5. Expand total processing power available throughout the mill.

Process improvement must make use of the available plant-wide information to modify the overall process so as to reduce the unusable products (rejects) which are produced. Included in this group are the following supporting goals:

1. Provide for collection of product-related data from all plant processes to permit a thorough control of product quality;

2. Support the application of statistical analysis techniques and tools to determine overall quality trends of processes and units;

3. Provide for the implementation of control feedback mechanisms to cause the automatic modification of process operations to improve the quality of the product; and,

4. Provide for reporting of the results of process quality analysis and improvement to the areas or levels of management affected.

Decision support tools must be provided to assist people in accessing, manipulating, analyzing, displaying and documenting data. Included in this group are the following:

1. A broad and flexible database management system for comprehensive versatile problem analysis;

2. A user-friendly, multiple access, database query method or language to permit rapid access to plant-wide data;

3. All-purpose report generators, capable of combining text, graphics, data tables, calculations and formatting to permit effective presentations of process conditions and problems;

4. Structured data analysis (spread sheets) to afford extensive extrapolations of plant data to determine plant operating conditions;

5. Statistical analysis packages to determine operational and demand characteristics (trends); and,

6. Support for long-range decision making with market and business simulation systems.

The CIM Reference Model should convert the above listed goals of the operation of the manufacturing plant into a set of functional tasks and a related architecture to carry them out in order to accomplish those stated goals for a particular plant.

THE CIM REFERENCE MODEL

A *reference model* is a previously agreed-upon or "standard" definitive document or conceptual representation of a system. The reference model defines requirements common to all implementations but is independent of the specific requirements of any particular implementation.

The CIM Reference Model is thus a reference for computer integrated manufacturing. It is a detailed collection of the generic information management and automatic control tasks and their necessary functional requirements for the manufacturing plant.

The CIM Reference Model should be descriptive rather than prescriptive. Figure 1-1 diagrams the

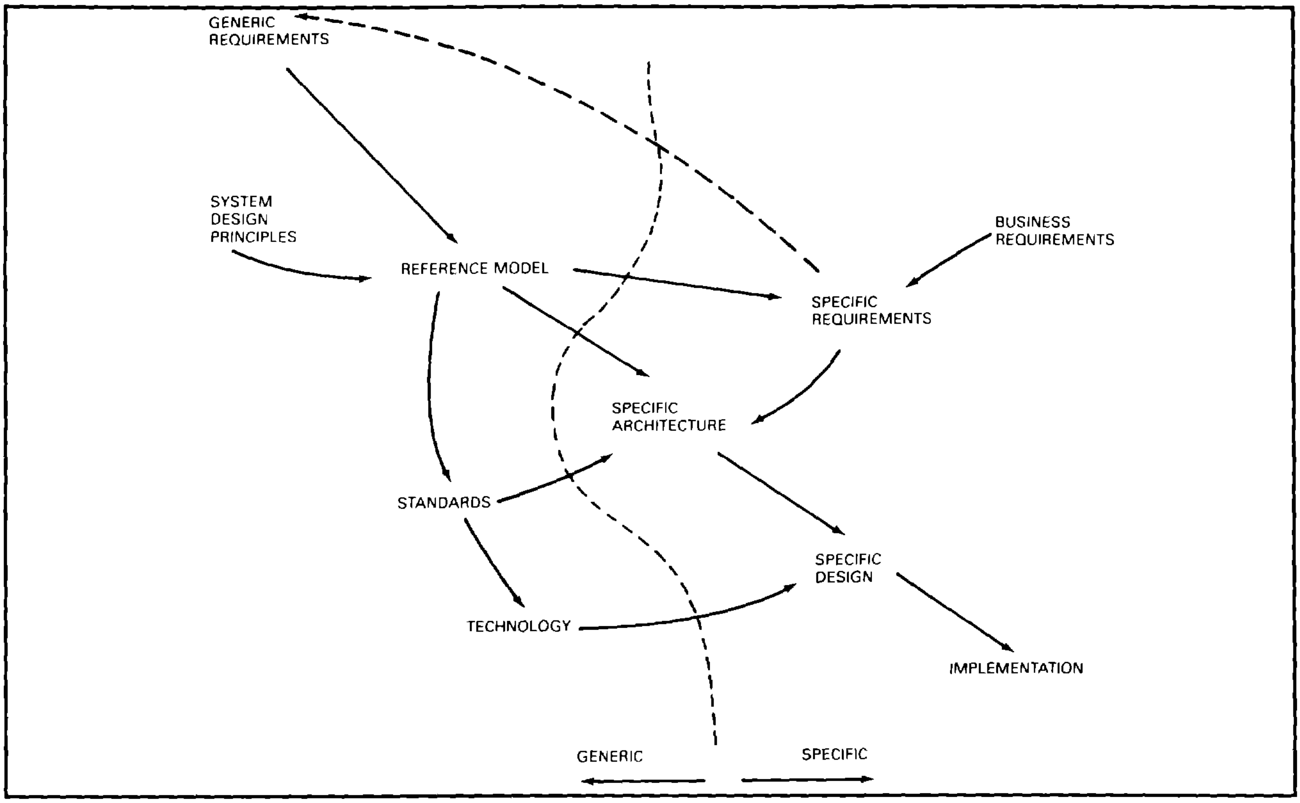


Figure 1-1 The usage context of a Reference Model.

context in which a Reference Model in general and the CIM Reference Model in particular is generated and used [85]. Note that the generic model, when amplified by the specific requirements of a particular plant, becomes the Specific Reference Model for that particular plant.

A CIM Reference Model is a tool to be used by the implementors of the CIM management strategies. To use the Reference Model effectively, a thorough understanding of the implications of introducing a CIM strategy must first be appreciated by the management team charged with its development.

These implications include:

1. An ill-defined and ambiguous integrated management system in place in any organization will be attacked by a CIM model. If total integration is to be effective a long term commitment by the organization is mandatory.

3. Major changes in organization, and in personnel responsibilities will result.

4. Overlap of responsibilities will tend to be eliminated as authority and function are clarified.

If these are appreciated and accepted by the senior management team the probability of success is improved immeasurably.

The model attempts to clarify for management the strategy considerations in solving the organizational communication problem. As identified in the several views of the model as developed here, the modern organization is highly complex and confusing in its present operational mode.

Computer systems which have little tolerance at present for the ambiguities of today's organizations need well-defined information flows.

To aid management in defining an approach to this perplexing, shifting and frustrating problem is one of the main uses of the model.

Table 1-I outlines the uses to which the Committee expects the CIM Reference Model will be put. Table 1-II continues this by outlining the expected

TABLE 1-I

USES OF THE CIM REFERENCE MODEL

1. THE REFERENCE MODEL IS THE BASIC DESCRIPTIVE MEDIUM TO BE USED FOR FUTURE DISCUSSIONS OF THE SUBJECT AREA (HERE COMPUTER INTEGRATED MANUFACTURING (CIM)).

2. IT SHOULD ALLOW ANY MANUFACTURING SYSTEM AND ITS ASSOCIATED INFORMATION MANAGEMENT AND AUTOMATION ARCHITECTURE TO BE EVALUATED FOR COMPLETENESS, CAPABILITY, AND EXTENSIBILITY.

3. IT CAN ALSO SERVE AS A DESIGN GUIDE FOR THE DEVELOPMENT OF A NEW INFORMATION MANAGEMENT AND AUTOMATION ARCHITECTURE FOR A NEW ("GRASS ROOTS") OR RETROFITTED PLANT.

4. IT SERVES TO HIGHLIGHT THOSE FUNCTIONS WHICH ARE AMENABLE TO THEIR ESTABLISHMENT AS STANDARDS.

5. THE MODEL SHOULD HELP PROVIDE A MIGRATION PATH FROM THE CURRENT PLANT SYSTEM TO A NEW SYSTEM BY MAKING EVIDENT THE CRITICAL FUNCTIONS FOR EARLY IMPLEMENTATION AND BY PROVIDING A FRAMEWORK FOR THE REQUIREMENTS DEFINITION PHASE OF THE PROJECT.

6. SOME OTHER IMPORTANT USES ARE:

   A. EDUCATION — TO GET THE ORGANIZATION DIRECTED TOWARD A COMMON STRATEGY AND APPRECIATION OF THE STEPS REQUIRED TO ACHIEVE INTEGRATION.

   B. GUIDE — TO MEASURE PROGRESS TOWARD THE FINAL GOAL.

   C. MODULARIZATION OF THE STRATEGY — TO DIVIDE THE ATTACK ON THE PROBLEM INTO READILY SOLVABLE PIECES.

   D. ORGANIZATIONAL SUPPORT — TO DEVELOP A COMMITTED TEAM APPROACH TO THE PROBLEM.

TABLE 1-II

WHO ARE THE CUSTOMERS FOR THE PROPOSED CIM REFERENCE MODEL?

1. MANUFACTURING COMPANY PERSONNEL WHO ARE RETROFITTING INFORMATION MANAGEMENT AND AUTOMATION SYSTEMS FOR EXISTING INDUSTRIAL PLANTS.

2. MANUFACTURING COMPANY PERSONNEL WHO ARE DESIGNING NEW FACTORIES AND PARTICULARLY THE COMPUTER-BASED INFORMATION MANAGEMENT AND AUTOMATION SYSTEMS FOR THESE FACTORIES.

3. FACTORY INFORMATION MANAGEMENT AND AUTOMATION SYSTEM VENDORS AND THEIR PERSONNEL.

4. TEACHERS PRESENTING STUDY MATERIALS RELATED TO COMPUTER INTEGRATED MANUFACTURING TO THEIR STUDENTS.

5. STANDARDS MAKING BODIES.

customers who will take advantage of these capabilities. Table 1-III lists some of the benefits expected from the use of this model. See also Appendix II which discusses additional aspects of the model.

THE MANUFACTURING PLANT IN TERMS OF THE CIM REFERENCE MODEL

The manufacturing plant is a collection of *application functional entities* which carry out the primary mission of the factory in producing marketable product and the associated information streams. The *plant production media* are supported by an integrated information and automation system composed of *foundation* and *manufacturing specific functional* entities which support the means of production. The plant interfaces the external world through a set of *external influences* or *external entities*. The latter are not integrated into the CIM Reference Model being developed here since their future actions and thus their future influence on the factory is not mathematically definable in the model (but interfaces to them are provided).

TABLE 1-III

BENEFITS OF THE USE OF THE CIM REFERENCE MODEL

1. IMPROVED PROBABILITY THAT A TRULY INTEGRATED INFORMATION SYSTEM IS ACHIEVED.
2. A TOTAL ORGANIZATIONAL UNDERSTANDING AND COMMITMENT TO THE STRATEGY.
3. RAPID ACHIEVEMENT OF SYSTEM INTEGRATION AND THUS REALIZATION OF THE MOST SIGNIFICANT CIM BENEFITS OF:

   A. INCREASED CUSTOMER SERVICE OR AWARENESS.

   B. REDUCTION IN INDIRECT LABOR AND OVERHEAD.

   C. IMPROVED RESPONSIVENESS TO TECHNICAL, ECONOMIC AND ENVIRONMENTAL CHANGES.

   D. IMPROVED PRODUCT QUALITY AT A LOWER COST.

The manufacturing mission and the *established manufacturing policy* of the company are articulated through the set of tasks and *functional specifications* assigned to each of the functional entities of the plant.

The CIM Reference Model is a generic description of the collection of functional entities which make up a particular factory and of their interaction through their assigned *tasks* and *functional specifications.*

See the definitions section (Appendix IV) for definitions of the underlined terms above and similar terms in succeeding sections. Table 1-IV defines the objective of the development of the CIM Reference Model by defining the idealized plant which is to be modelled. Figure 1-2 along with Appendix IV defines the interrelationships of the terms noted above which are necessary in defining the CIM Reference Model. Note that the external influences and the manufacturing equipment of the plant interact with the present model through appropriate interfaces to transmit all necessary information and commands.

As noted above the CIM Reference Model developed here is concentrated on the definable parts of the industrial manufacturing plant or factory. As such it comprises those items generally included under the acronym CAM (computer-aided manufacturing).

Another acronym involved in computer applications to industry is CAD (computer-aided design). It is assumed here that CAD is an engineering function carried out as an external entity and that the results of a CAD study would be transmitted to the factory as the process plan for a new product, for example, or other modification of the manufacturing operation.

CAPP (computer-aided process planning) comprises an intermediate stage, the use of the com-

TABLE 1-IV

BASIS FOR THE FORMULATION OF THE CIM REFERENCE MODEL

THE CIM REFERENCE MODEL AND ITS RELATED SET OF GENERIC FUNCTIONAL REQUIREMENTS WILL TAKE AS THEIR IDEALIZATION:

1. THE FULLY AUTOMATED PLANT (I.E., STAFFED BY *AGENTS (HUMAN OR MACHINE) WHOSE DECISIONS ARE EFFECTIVELY COMPUTABLE).*
2. THE TOTALLY RESPONSIVE (I.E., CONTROLLABLE) MANUFACTURING SYSTEM CARRYING OUT THE *ESTABLISHED MANUFACTURING POLICY* OF THE COMPANY.
3. AN ALLOWANCE FOR HUMAN IMPLEMENTED PROCESSES IN THE PRODUCTION SYSTEM BY ASSURING THE NECESSARY FUNCTIONAL COMMUNICATIONS FOR THOSE PROCESSES OF THE FACTORY.
4. A SYSTEM THAT WILL BE FLEXIBLE ENOUGH TO ALLOW FORESEEABLE CHANGES IN THE ESTABLISHED MANUFACTURING POLICY.

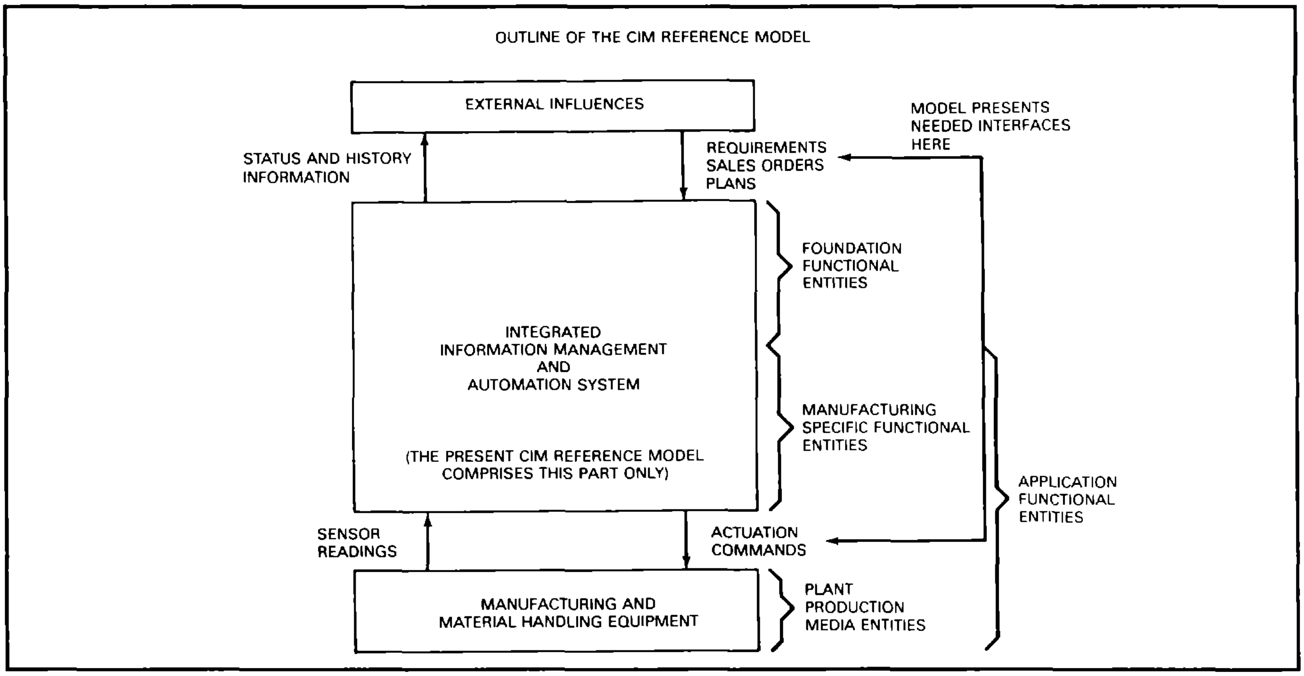


Figure 1-2 Relationship of the several classes of functional entities which comprise the CIM Reference Model and computer integrated manufacturing itself.

puter to develop or amend process plans for the factory. Where the changes contemplated can be accomplished within the established factory system without serious interruption of production, they are included in this reference model via a process support engineering function. Such changes could range from relatively minor modifications or corrections to process plans to even whole new products if such products can be manufactured readily with the current plant equipment and control system. See Figure 1-3 and those of Chapters 2 and 4 and Appendix V to further define this function.

PRINCIPLES INVOLVED IN DEVELOPING A CIM REFERENCE MODEL [38]

In the development of command/status standards related to the control of manufacturing automation systems the following principles should be considered:

1. Control is hierarchical, although the number of levels used in a factory model is arbitrary. The six levels (see Figures 1-3, 3-4, 3-5 and associated discussion) used by the Factory Automation Model (FAM) only serve as an aid in the process of identifying areas where standardization work is required. Real factory automation implementations may quite likely use a different number of levels and interrelations between the levels.

2. Control "functions" should be standardized, perhaps through languages to express control actions and through a standard terminology.

3. Items such as parts, materials, tools, machines, energy, time, personnel, etc., used in manufacturing processes should be assigned standard codes for identification and classification.

4. The methods of acquiring and processing information for control functions should be transparent.

5. Interfaces and interactions across all levels of the management systems should be standardized for control, data input/output and communication.

6. Data to be used by processes generating control commands should have a standardized format.

7. Recovery procedures for hardware components and software systems should be standardized.

8. Recognizing the facts that:

   (a) A system always has faulty parts;

   (b) A system, or parts of it, will continually cycle through operation, maintenance and growth; and,

   (c) A system continually tries to meet its objective;

   the control architecture and functions should allow for:

   (d) Distribution of control to autonomous or semi autonomous units;

   (e) "Autonomous coordinability" i.e., the ability of surviving units to recognize and adapt themselves to the failure of others;

   (f) "Autonomous reconfigurability" i.e., the ability of control units to functionally reconfigure themselves to achieve a set of assigned goals.

9. *Control* only flows within a level or down through the levels of the FAM, never upwards. The required feedback is in the form of data or information.

Figure 1-3 presents the scope of the CIM Reference Model as used by the CIM Reference Model Working Group ISO/TC184/SC5/WG1 [38]. Items to the upper left of the dashed line are considered external entities in the Purdue model. These interact with the Purdue modelled factory system through appropriate interfaces at this boundary (the dashed line).

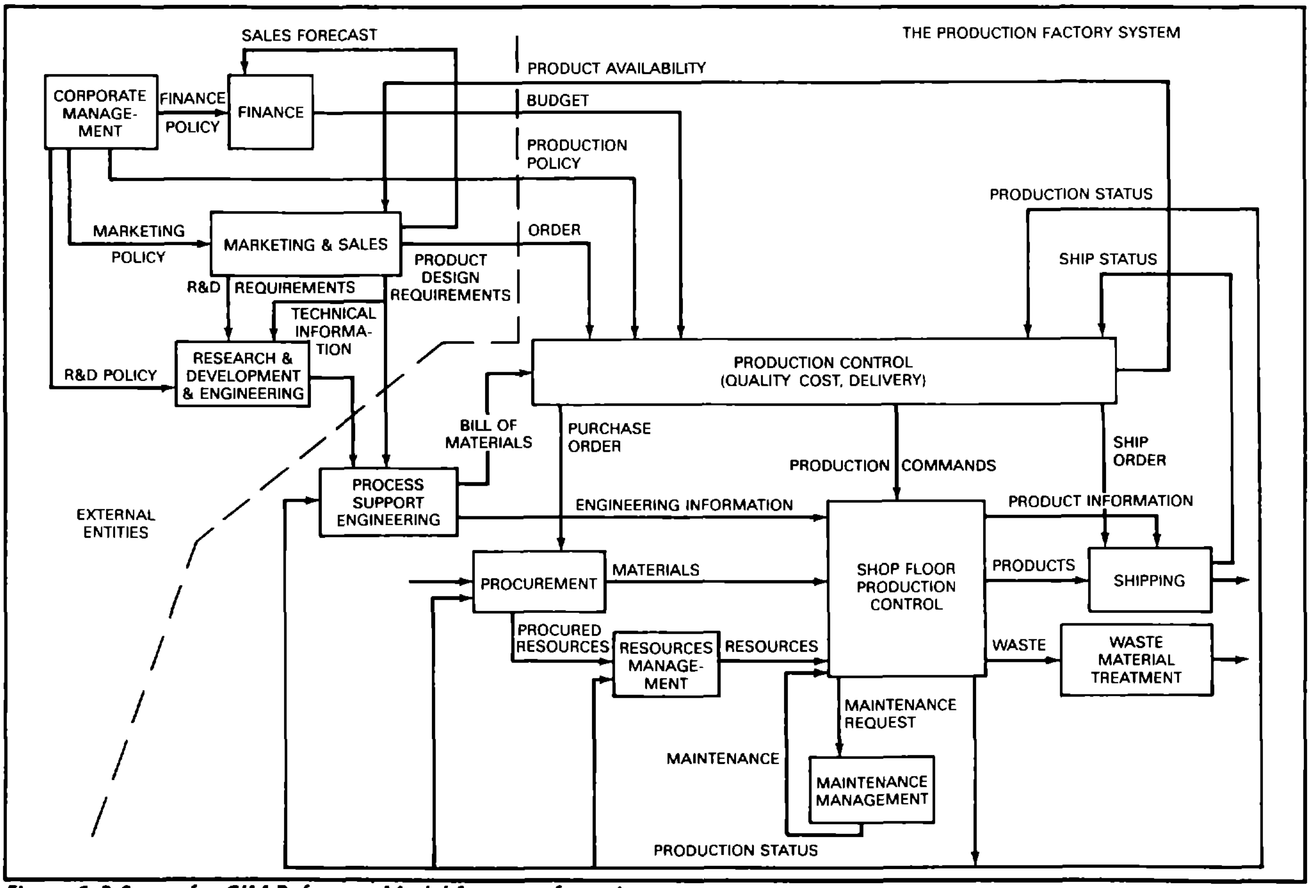


Figure 1-3 Scope for CIM Reference Model for manufacturing.

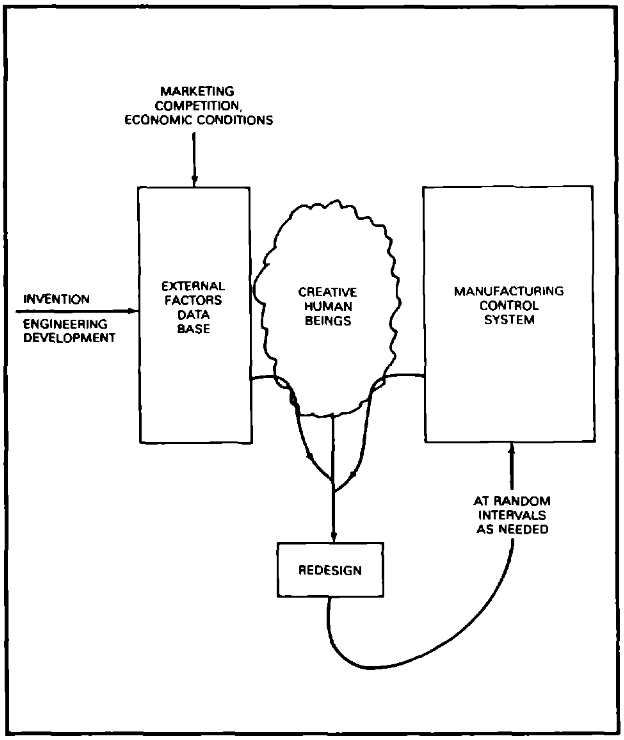


Figure 1-4 Definition of the redesign function for the CIM Information Management and Automation System Configuration which cannot be included in the Reference Model.

SOME LIMITATIONS IN THE CIM REFERENCE MODEL

As noted many times in the discussion of this report the CIM Reference Model Committee of the International Purdue Workshop on Industrial Computer Systems, as described herein, has been limited to the elements of the Integrated Information Management and Automation System of Figure 1-2. The company's management (future planning function); financial; purchasing; research, development and engineering; and marketing and sales have all been treated as external influences as described earlier here and in Chapter 2. That is, they can receive data and information from the plant's integrated information management and automation system and can send requests and commands to it. However, no attempt is made here to model the operations or results of any of these functions because of the innovation which is always assumed to reside in such functions.

The reason for this is aptly portrayed in Figures 1-4 and 1-5. Such influences as marketing studies of new products, engineering development, new inventions, competitors' actions, and changing na-

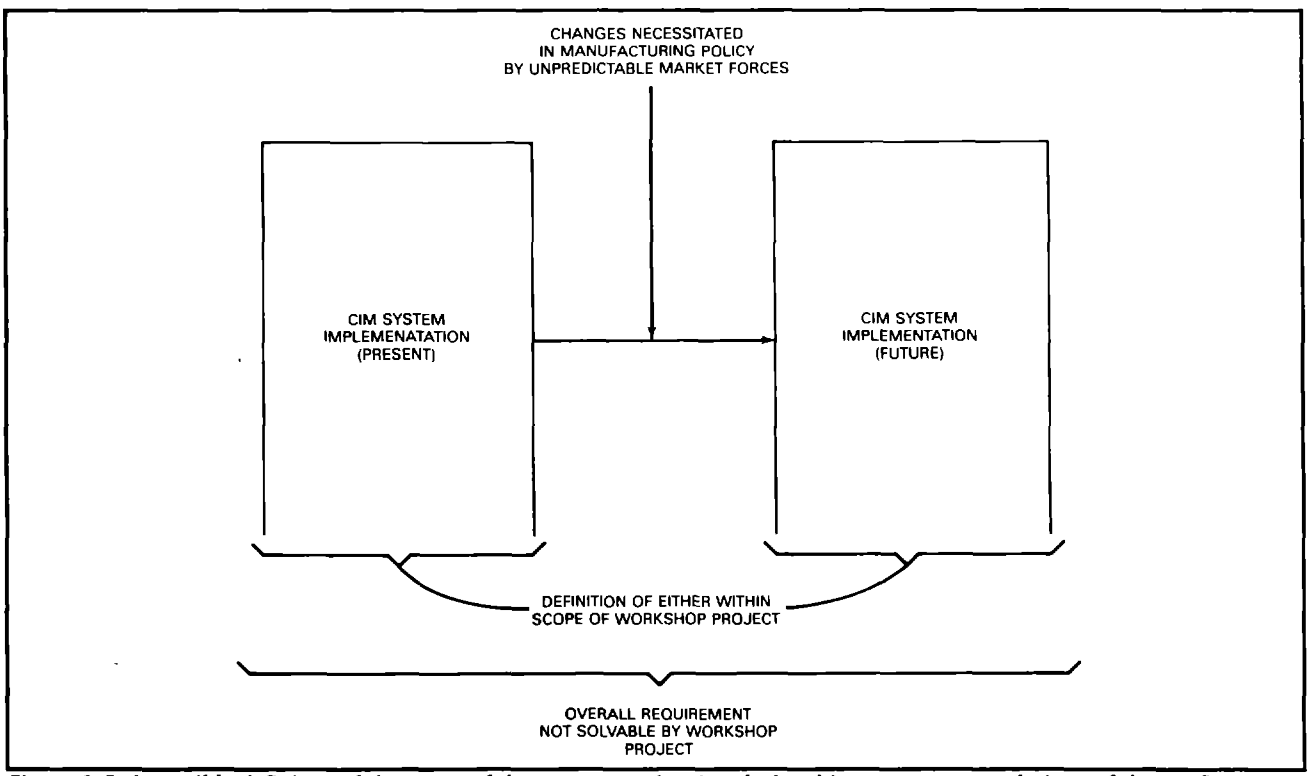


Figure 1-5 A possible definiton of the scope of the present project in relationship to necessary redesigns of the configuration.

tional and world economic conditions can all have influences on the manufacturing plant of an unknown degree. The net effect of these may require a complete redesign of the Integrated Information Management and Automation System to keep it and its products competitive in the marketplace. Since the extent and magnitude of these influences cannot be predicted (otherwise they would be accounted for a priori) they must be excluded from the defined model and treated, as noted, as external influences.

As Figure 1-5 shows, where these changes have a relatively small influence which can be accommodated in the current model, no redesign or reworking of the plant is required. However, once the limit of accommodation has been exceeded, a redesign and modification of the plant is necessary if the company is to respond positively to the influence of the said external factors.

As noted in Chapter 4, "The Data-Flow Graph, A Functional View of the CIM Reference Model", Figures 4-1 and 4-2, pp 46 to 47, most of the management and staff functions of a manufacturing company are considered External Influences to the Manufacturing Facility of the Company which is the object of the CIM Reference Model being developed here by the International Purdue Workshop on Industrial Computer Systems.

As just noted this is because these units of the company are defined as follows in relation to the manufacturing facility itself.

1. They satisfy the definition of an External Influence, see p 209 and Figure AVI-1.

2. As noted on pp 206 to 207 as policy makers they are required to innovate to carry out their assigned tasks. The innovation function is not capable of being definitively modelled at the present time.

CONCERNS AND ISSUES BEFORE CIM PLANNING

A CIM program must be considered and integrated with other manufacturing strategic programs such as (Participative Management, Total Quality Control, Just-In-Time (JIT) and Process Modernization), since CIM is only a portion of a modern manufacturing strategy. Since it is a program it will require a commitment of the company's resources and capital over a considerable length of time, thus differentiating it from the usual manufacturing improvement projects.

Upper management must be familiar with CIM technology, enough so that they understand its potential and can support it as an integral part of an overall manufacturing strategic program. Such understanding is measurable when upper management:

a) Can talk knowledgeably about the benefits, challenges and on-going requirements of such a change effort; from organizational as well as process perspectives,

b) Provides clear leadership, including goals and objectives for both business(es) and manufacturing,

c) Sanctions the need to include CIM when planning the future Established Manufacturing Policy Planning (See also p. 206),

d) Builds understanding within middle management for new requirements and cooperation across departmental and organizational boundaries,

e) Sponsors and identifies a CIM champion(s),

f) Commits the resources to do CIM master planning in a quality manner,

g) Provides on-going sponsorship and leadership to the program.

Much of this strategic program interaction and understanding is further described in the participative management example beginning in Chapter 10, page 168.

Along with clear goals and objectives, upper management must require that middle management become familiar with the CIM program goals. The scope of the program must be clearly understood so that all departments will provide the necessary cooperation. Change resistance must be overcome whether an individual, a department, or unit loses or gains responsibility. It is paramount that all personnel and departments (staff and line) be aware that the underlying aim of this CIM program is to continually improve the overall mill or plant performance.

A champion will be required, not only to direct the program toward the proper goals but to overcome the day-to-day problems and barriers that will impede a program of this magnitude. This requires vigilance as well as the upper management sponsorship to keep the program on track. The champion must have an in-depth understanding of process control, simulation and optimization and be familiar with the other elements of CIM technology.

STEPS IN THE IMPLEMENTATION OF A CIM SYSTEM

The overall job of manufacturing strategic planning requires a comprehensive look at the process, equipment, facilities, personnel structure and roles, plus the scheduling and control requirements (The CIM Component).

The development of a CIM Master Plan requires a critical look at the current plant scheduling and control hierarchy (if an existing facility), a detailed description of the desired future plant scheduling and control hierarchy, and a plan to manage the transition from the current state to the desired future state. This is called The CIM Master Plan, here after called Master Plan. See Figure 1-6. Strongly related to this, but not covered in any detail in this text, are:

1. Production Equipment, Layouts, Process Flows.

2. Personnel Structures, Functions and Roles.

Transition plans must also be addressed for these, and managed in concert with the CIM Master Plan.

Of those projected uses for the *Reference Model for Computer Integrated Manufacturing* (CIM) presented in Table I-1 probably the most important are the ones listed as Number 3, "-Design Guide For the Development of a New Information Management and Automation Architecture-", and Number 5, "-Help Provide a Migration Path-". They best fulfill these necessary functions through the develpment of a Master Plan for carrying out all the steps

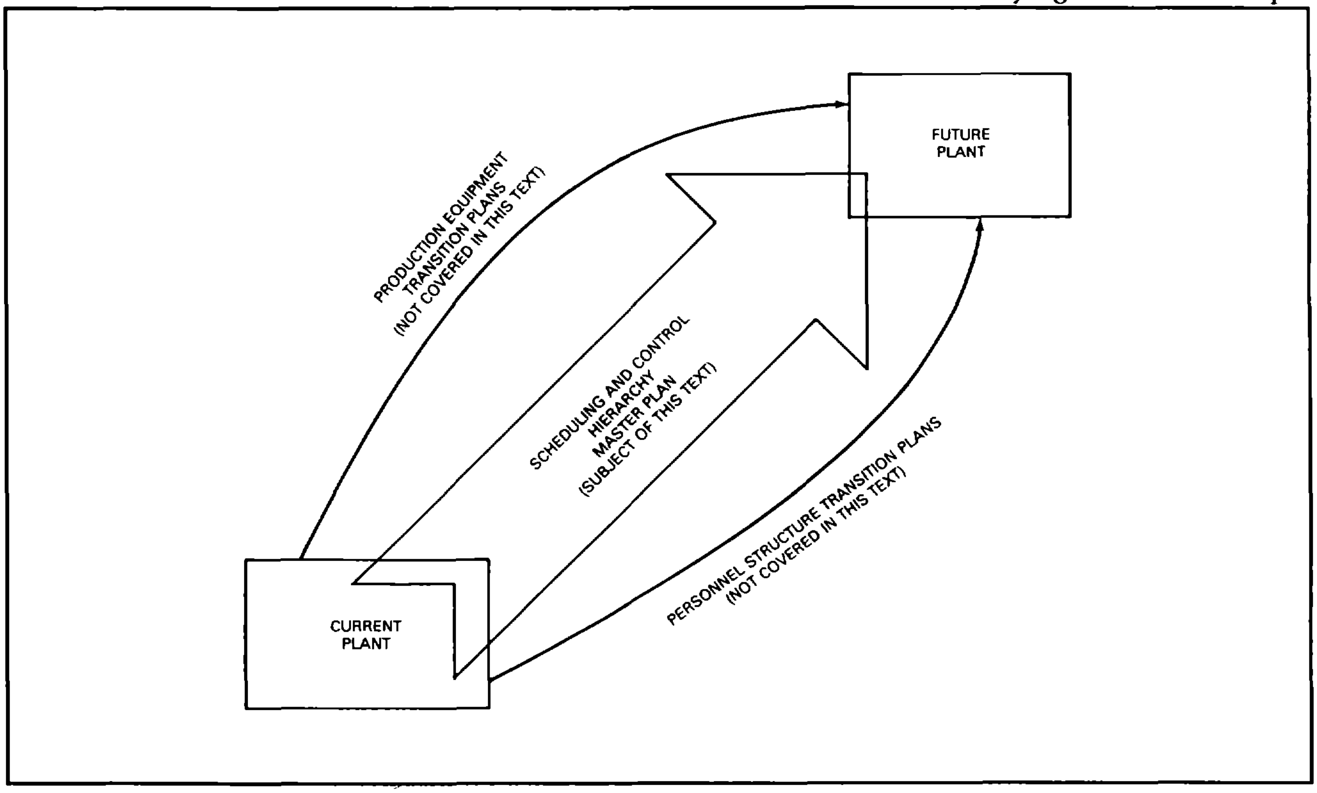


Figure 1-6 Requirements for the establishment of a Computer Integrated Manufacturing System versus the topics of this text.

necessary for implementing each specific CIM project. The Reference Model then serves as the basis for assuring the accuracy and completeness of the resulting Master Plan.

As noted above concerning the definition of the CIM Reference Model, the Master Plan should be the Reference Model for the specific manufacturing plant of the CIM Project. As such it must be the list of all of the tasks to be carried out by the proposed CIM System. It must detail all of the application entities (processing units and their associated units), and service entities (computer systems, communications units, databases, etc.) involved. It must list all primary process variables (input and output) and their associated computational algorithms; all internal systems variables showing their relationship to the primary system variables, computations involved, database locations, etc. In case of a currently existing plant this must include not only the computer-based scheduling and control systems but also any necessary changes in the processing equipment to take advantage of the capabilities of the proposed CIM System as noted above.

Table 1-V briefly outlines the above requirements in tabular form. Table 1-VI goes into detail to summarize all necessary data related to system primary and internal operational variables and their relationship to each other.

Please note that the totality of the data comprising the Master Plan description of the CIM system provides several ways of presenting the same basic data from different aspects and thus provides many possibilities for cross checking the content of the resulting plan and thereby assuring its accuracy and completeness.

DATABASES

The content, location in the system, and anticipated use of all databases to be established in the CIM system need to be detailed in the Master Plan. Table 1-VII lists the data necessary to properly complete the planning for the databases involved.

IMPLEMENTATION HIERARCHIES

A set of Implementation Hierarchy diagrams (as discussed in Chapter 5) should be developed for each Task to be carried out by the proposed CIM System. Each of these diagrams needs to detail the software and hardware of the system needed to carry out that task.

DEFINITION OF INTERFACE STANDARDS

It has long been the policy of the International Purdue Workshop on Industrial Computer Systems that the establishment of a set of interface standards (communications and programming) would be the easiest and best way of assuring the interconnectivity of the elements of a CIM scheduling and control hierarchical computer system and the transportability of all computer programs between the several computer nodes of the system.

Chapter 9 of this text presents the latest information available at this writing concerning the trends in the developing communications standards for industrial control systems, particularly the MAP proposals [22, 27, 104] and the related IEEE 802 standards [10, 12-14] and their international equivalents.

Chapter 6 presents the story concerning the status of programming languages at the time of the preparation of this text. It points out the large number of languages available for use for industrial control systems (Section on Technological Aspects) and the lack of total adequacy of any one of them for the overall industrial control task (Figure 6-10).

In addition to the above, there is a decided trend in industrial control at this time to develop the concept of "configuration" rather than direct computer programming for many of the vendors' products in the industrial control field, particularly microprocessor-based systems for use at Level 1. While these latter systems are very easy to use, they do generally prevent the user from directly programming the system, i.e., altering the available menu of possible functions. They also tend to be less standard than the languages from which they have been developed.

The developer of a CIM Master Plan for a proposed CIM program should therefore prepare a specification for the *communications interface* between CIM system units and a companion specification for the *programming interface* between the systems developer and the implementation of the system itself. An example of some of the important points in such a dual specification is presented in Table 1-VIII. This specification becomes part of the CIM Master Plan and should be agreed to by all vendors involved.

SYSTEM COMPATIBILITY

Once the Master Plan has been completed and accepted by company management the Program can proceed as finances, personnel availability and equipment procurement permit. It should be noted that, as long as all communications and programming interfaces are religiously observed, system (sub)projects can be completed in any order appropriate to company desires and needs since overall operability of the final system is insured by the established interface rules and provisions.

Further, should potential system technology change during the implementation period, equipment following the new technology can be readily substituted for that previously specified so long as the above mentioned communications and programming (or software) interfaces rules and provisions continue to be observed.

TABLE 1-V

MAJOR STEPS IN THE IMPLEMENTATION OF A CIM SYSTEM

I. Analysis of the Existing Manufacturing System (If a Retrofit Plant) or New Facility Design for Compatibility With CIM Technology.

1. Simplification of Process Paths and Numbers of Process Steps Where Possible.
2. Need for More Advanced Technology for Certain Process Steps.
3. Adequate Material Handling and Inventory Management Facilities.

II. Analysis of the Existing and Proposed Management and Personnel Structure for the Plant in View of Its Compatibility With the Proposed CIM System.

continued

Table 1-V continued

1. Appropriate Distribution of Tasks between Personnel and the Computer System to Take Advantage of the Capabilities of Each.
2. Do Present Personnel Possess All Needed Technical Skills and Educational Background? What Additional Training Is Necessary and Appropriate?

Note: The Above Two Items Will Not Be Considered Further in This Text Discussion but Must Be Handled in Any Overall CIM Implementation Strategy.

III. Development of the System *Master Plan* for Designing and Implementing the CIM Scheduling and Control Hierarchy

(The Master Plan is the Specific Reference Model for the Plant Involved in the CIM Program in Question). Prepare It as Follows:

1. Analysis of the Appropriate Specific Scheduling and Control Structure for the Company and Plant in Question and Its Acceptance by Management.
   a. Comparison with the Generic Forms Described in Chapters 3 and 4 and Justification of Any Necessary Changes from Them.
   b. Applicability to Modified Plant Production System of Item I Above.
   c. Relationship to Appropriate Management and Personnel Staffing Structure of the Plant. Are the Personnel and Computer System Structures Compatible?
2. Evaluate All Listed Tasks of Tables 3-VI to 3-X of Chapter 3 against the Specific Requirements of the Proposed Plant.
   a. Supply Specifics Concerning Each Task and Related Plant Unit as Available.
   b. Expand Each Task with Any Increased Detail as Available and Desirable.

continued

Table 1-V continued

3. Prepare the Lists of Input and Computed Process Variables as Noted in Table 1-VI for Each Level of the Scheduling and Control Hierarchy Including All Computations and Algorithms Necessary for Their Utilization by the System.

4. Prepare the Lists of Output Variables of the System as Also Noted in Table 1-VI for Each Level of the Scheduling and Control Hierarchy Including the Methods of Their Development From the System Operating Variables, Coefficients and Parameters.

5. Prepare the Database Dictionary Including Entry and Usage Lists as Called for in Table 1-VII.

6. Prepare the Communications and Programming Standard Interface Requirements as Noted in Table 1-VIII.

IV. Develop Expected Systems Costs and Project Timing in Conjunction with Systems Benefits Projections. Thus the Master Plan Will Also Serve as the Documentation of the System Justification, the Project Development Schedule, and the Justification Concerning Systems Costs and Anticipated Payouts.

V. Iterate the Steps Outlined Above Until Acceptance Obtained From All Personnel Concerned and Company Justification Criteria Satisfied.

TABLE 1-VI

DETAILS FOR IMPLEMENTATION OF THE OPERATIONAL TASKS OF THE CIM SYSTEM

I. At Level (1), Scheduling and Control Hierarchy (Figure 3-1 and 3-2 of Chapter 3)

1. List All Tasks to be Carried Out at Level 1 - Each and Every Individual Process Unit.

2. List All Input and Computed Variables Versus Process Involved - Each and Every Individual Process Unit:

a. Sampling Rate of Raw Variable.

continued

Table 1-VI continued

b. Data Reduction Function for Each Raw Variable.

c. Database Storage Location of Each Reduced Variable.

3. List All Output Variables Versus Process Involved - Each and Every Individual Process Unit:

a. Output Rate of Each Variable.

b. Storage Location of Each Computer Output Variable.

4. List the Desired Dynamic Control Function Connecting Each Individual (Set of) Input(s) and Each Individual (Set of) Output(s).

5. List the Designations of All System Parameters and Coefficients Necessary for the System's Computations Noted Above, Including Their Default Values.

6. List All Needed Communication Facilities Including Relevant Standards Applicable.

II. At Level (2), Scheduling and Control Hierarchy (Figures 3-1 and 3-2, Chapter 3)

1. Prepare a Detailed List of All Tasks to be Carried Out at Level 2 - Each and Every Individual Processing Zone (Collection of Related Processing Units).

2. List All Computed Functions Versus Task and Processing Zone Involved. For Each Function:

a. List Each Individual (Set) of Process or Computed Variables Used With Each Computed Function.

b. List the Designation and the Use Expected for Each Computed Function Result.

c. List Database Element or Storage Location Assigned for Each Computed Result.

3. List the Designations of All System Parameters and Coefficients Necessary for the Systems Computations Noted Above Including Their Default Values.

continued

Table 1-VI continued

4. List All Needed Communications Facilities Including Relevant Standards Applicable.

III. At Level (3), Scheduling and Control Hierarchy (Figures 3-1 and 3-2, Chapter 3)

1. Prepare a Detailed List of All Tasks to be Carried Out at Level 3 - Each and Every Individual Processing Area (Collection of Related Processing Zones).

2. List All Computed Functions Versus Task and Processing Area Involved. For Each Function:

   a. List Each Individual (Set) of Process or Computed Variables Used With Each Computed Function.

   b. List the Designation and the Use Expected for Each Computed Function Result.

   c. List Database Element or Storage Location Assigned for Each Computed Result.

3. List the Designations of All System Parameters and Coefficients Necessary for the Systems Computations Noted Above Including Their Default Values.

4. List All Needed Communications Facilities Including Relevant Standards Applicable.

IV. At Level (4A), Scheduling and Control Hierarchy (Figures 3-1 and 3-2, Chapter 3).

1. Prepare a Detailed List of All Tasks to be Carried Out at Level 4A - For the Entire Factory.

2. List all Computed Functions Versus Task Involved. For Each Function:

   a. List Each Individual (Set) of Process or Computed Variables Used With Each Computed Function.

   b. List the Designation and the Use Expected for Each Computed Function Result.

   c. List Database Element or Storage Location Assigned for Each Computed Result.

continued

Table 1-VI continued

3. List the Designations of All System Parameters and Coefficients Necessary for the Systems Computations Noted Above Including Their Default Values.

4. List All Needed Communications Facilities Including Relevant Standards Applicable.

5. List All Data and Information Necessary From External Entities Versus the Task to be Accomplished:

   a. List Name of Variable or Data Block Involved.

   b. Access Rate for Each Variable or Data Block.

   c. Storage Location(s) or Database Element(s) for Each Variable or Data Block.

V. At Level (5A), Scheduling and Control Hierarchy (Figures 3-1 and 3-2, Chapter 3)

1. Prepare a Detailed List of All Tasks to be Carried Out at Level 5A - For the Entire Company.

2. List All Computed Functions Versus Task Involved. For Each Function:

   a. List Each Individual (Set) of Process or Computed Variables Used With Each Computed Function.

   b. List the Designation and the Use Expected for Each Computed Function Result.

   c. List Database Element or Storage Location Assigned for Each Computed Result.

3. List the Designations of All System Parameters and Coefficients Necessary for the Systems Computations Noted Above Including Their Default Values.

4. List All Needed Communications Facilities Including Relevant Standards Applicable.

continued

Table 1-VI continued

5. List All Data and Information Necessary From External Entities Versus the Task to be Accomplished:
   a. List Name of Variable or Data Block Involved.
   b. Access Rate for Each Variable or Data Block.
   c. Storage Location(s) or Database Element(s) for Each Variable or Data Block.

VI. At Levels (4B) or (5B) Scheduling and Control Hierarchy (Figures 3-1, 3-2 and 3-3, Chapter 3).

1. Prepare a Detailed List of All Tasks to be Carried Out at Level 5B and 4B - Management Levels of the Company or Factory.
2. List All Computed Functions Versus Task Involved. For Each Function:
   a. List Each Individual (Set) of Process or Computed Variables Used With Each Computed Function.
   b. List the Designation and the Use Expected for Each Computed Function Result.
   c. List Database Element or Storage Location Assigned for Each Computed Result.
3. List the Designations of All System Parameters and Coefficients Necessary for the Systems Computations Noted Above Including Their Default Values.
4. List All Needed Communications Facilities Including Relevant Standards Applicable.
5. List All Data and Information Necessary From External Entities Versus the Task to be Accomplished:
   a. List Name of Variable or Data Block Involved.
   b. Access Rate for Each Variable or Data Block.
   c. Storage Location(s) or Database Element(s) for Each Variable or Data Block.

TABLE 1-VII

PLANNING FOR THE DATA DICTIONARY AND USE REFERENCES

For each storage entry in each and every separate database of the system, list the following data (Refer to Chapter 7. Note that this is more extensive than most Data Dictionaries):

1. Name or Designation of Each Entry
2. List Variable (Raw or Modified) Needed for Each Entry. Indicate Database Where Located.
3. For Each Database Entry Show:
   a. Source of Original Function Values of Entry Variable,
   b. Data Reduction Function or Algorithm Used to Develop Each Function,
   c. Use to be Made of Each Entry.

It is noted that the above data duplicates that entered for each task. This then provides the Master Plan Development System utility for checking the completeness of both the Task listings and the database entry listings.

TABLE 1-VIII

A SUGGESTED SET OF PROGRAMMING AND COMMUNICATIONS INTERFACE STANDARDS*

I. Programming Interfaces (Refer to Chapter 6)

1. Level 1 - All work at this level should be carried out by "configuration" using the available configuration aids developed by the control system vendors. These programs tend to be proprietary and restricted to one model of control system. They are subject to change by the manufacturers as competition dictates. They comprise a set of menus of possible functions from which the user chooses those desired for the case at hand.

continued

Table 1-VIII continued

2. Level 2 - Some configuration tools are available at this level but more actual programming is required of the users. All necessary programming should be carried out using high level languages as discussed in Chapter 6. The minimum possible number of such languages should be specified to minimize the learning required for system developers and to promote the transportability of the resulting programs between the computer nodes of the overall system.

3. Levels 3 and 4 - As one progresses higher in the hierarchy menu type programming aids become less available and more direct programming is necessary. In many cases, however, preprogrammed packages are available from vendors to carry out single tasks or groups of tasks at these levels. Compatibility of these "packages" with each other and with the overall system becomes the overriding factor in their selection. The selection of languages may be somewhat modified for these levels compared to Level 2 because of the differing tasks and the different backgrounds of the personnel involved. Again the overall list of languages involved should be kept to a minimum.

II. Communications Interfaces (Refer to Chapter 10)

1. Levels 1 and 2 - The distributed, microprocessor-based, control system now comprising the major offerings of the control system vendors usually incorporate a proprietary communications system unique to that vendor's offering and often to the particular models involved. These are usually bit serial systems closely resembling the MAP and IEEE 802 systems discussed in Chapter 10. Efforts are underway to make them completely compatible with the standards being developed by the MAP/TOP group. In any case, the CIM program developer must assure himself that the chosen Level 1 system is or can be made readily adaptable to the other computers and communications systems with which it must communicate either by adherence to accepted standards or through "gateways" which achieve the same purpose. Chapter 10 outlines the standards and interfaces involved.

2. Levels 3 and 4 - The MAP/TOP proposals handle these levels as well as those discussed above. Here we are generally discussing computer to computer interfaces because of the types of tasks involved. Again the CIM program developer must assure himself that the chosen computer communications systems follow the MAP/TOP proposed and accepted standards discussed in Chapter 10 or that suitable "gateways" are made available by the respective manufacturers to assure the same compatibility of communications promised by the standards themselves.

3. As noted in the Programming Interfaces section above, these above standards or alternate gateway solutions should be specifically stated in a CIM specification as part of the Master Plan and agreed to by all vendors involved.

*Note: At the writing of this text some of the discussed interface standards are still under preparation. The reader should consult the latest versions of these documents before attempting to establish his own company's standards in these areas.

2

The Computer Integrated Enterprise

THE OVERALL ENTERPRISE VERSUS THE CIM REFERENCE MODEL

It is the ultimate aim of computer applications technology to bring all aspects of company operations, i.e., the overall enterprise, within the computer system. However, as noted earlier, there is, at least at present, a major difference in the functions which computers can carry out among the various operational units or entities which make up the enterprise.

In some cases, as with corporate management, engineering design, marketing and sales, etc., the computer system operates as a decision support tool to the individuals carrying out the functions assigned to them. In other cases, the computer can operate relatively independently of human intervention to carry out the assigned functions itself such as in process control.

It is the thesis of the CIM Reference Model Committee of the International Purdue Workshop on Industrial Computer Systems that the amount of human innovation that is involved in carrying out that task is the key into which category the par-

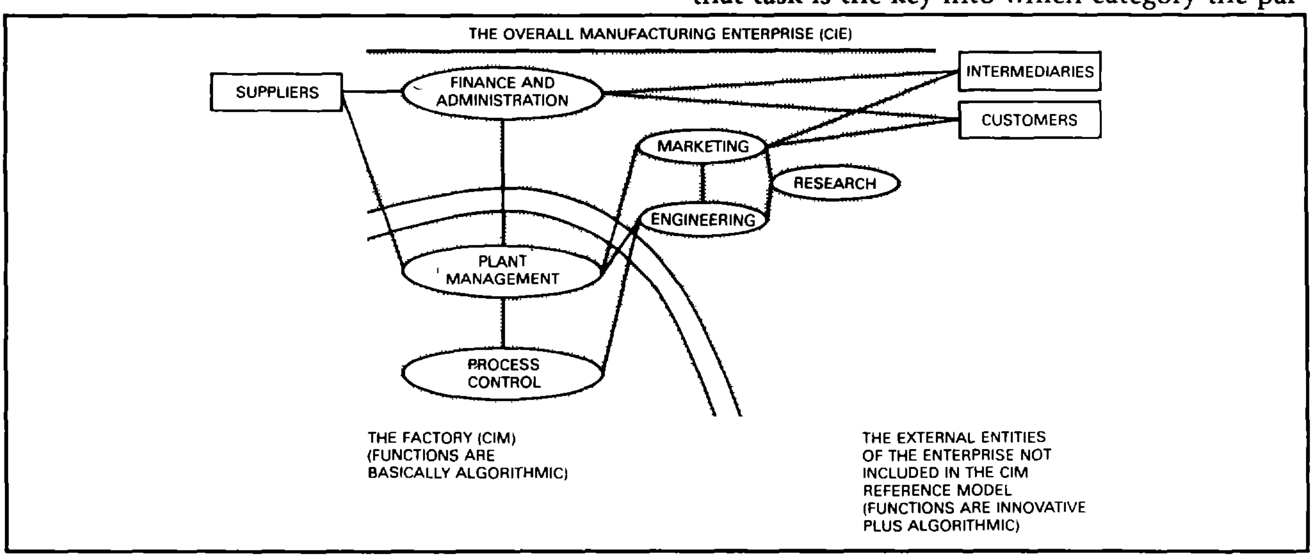


Figure 2-1 Relation of the Computer-Integrated Enterprise (CIE) to Computer Integrated Manufacturing (CIM) as Interpreted in this text.

ticular industrial task fits. In the first group of tasks listed just above, innovation is paramount. In the second set the fact that the computer can carry them out relatively independently indicates that human innovation is not needed or is minimal at best.

It is a further thesis of the CIM Reference Model Committee that there is a relatively sharp boundary in the enterprise between those functional units where the computer serves primarily only as a decision support tool and those where it primarily exercises the control function in its own right.

As stated in the Introduction and in Chapter 1 of this text, it is our decision in developing this exposition of the CIM Reference Model to restrict the definition of the term *Computer Integrated Manufacturing (CIM)* to those functions falling within the second category. Fortunately, these (again in our opinion) comprise the whole of the manufacturing functions of the enterprise. Thus our definition will differ little, if any, from the other popular definitions of the term. We will assure the overall integration of the enterprise by making certain that all data developed within the manufacturing functions is made readily available to all other operational and administrative units of the plant to aid the decision support requirements at those latter locations. This is exemplified by Figures 1-2 and 1-3 of the previous chapter.

In order to further clarify our decision and to make clear the distinctions presented, it is important at this point to develop a model of the overall enterprise and to show clearly where our specific model fits within it. The overall model is often referred to as that for the *Computer Integrated Enterprise* or CIE [106]. Figure 2-1, modified from the same reference, shows in an abbreviated manner the overall enterprise versus the manufacturing plant which is the main subject of this text. The dashed line in Figure 1-3 separating the external entities from the manufacturing elements of the production factory system also emphasizes this difference. Figure 2-2 is a modification of Figure 1-2 to further illustrate this point.

Again, in those elements of the enterprise included in the CIM Reference Model, the computer system, in general, takes actions (process control, production scheduling, sequencing, etc.) directly on the plant equipment to accomplish the needed task. As noted earlier, the actual manufacturing

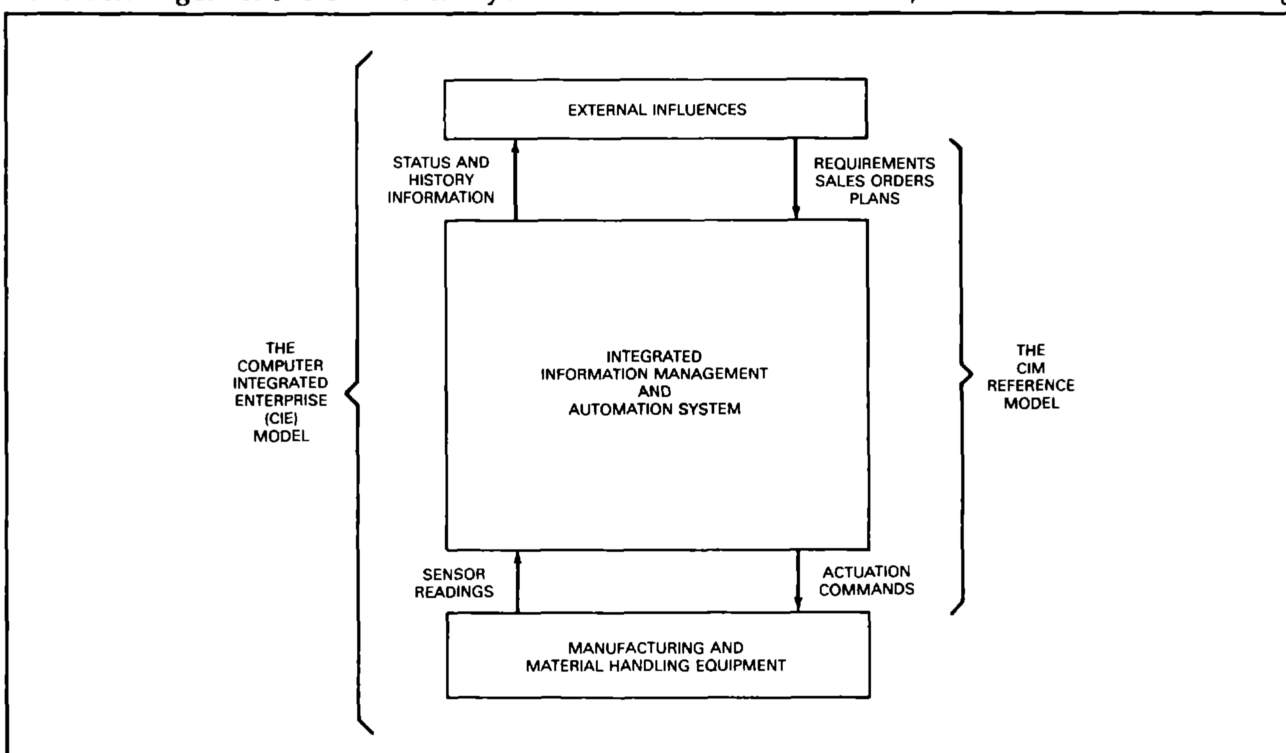


Figure 2-2 A further illustration of the distinctions between the Computer Integrated Manufacturing Model and that for the Computer Integrated Enterprise.

machinery itself is not treated here since it is by definition non-generic.

An excellent descriptive model of the Computer Integrated Enterprise is that developed by Nippon Steel Corporation [20] and presented in Appendix V. This is a data-flow diagram model like that of Chapter 4 for our present model. Distinctions between the factory elements and external entities are indicated. The data flow diagram (Figure AV-1) is due to the CIM Reference Model Committee. The Committee has also extensively revised the tables presented there.

3

The Generic Duties of a CIM System and Their Expression via the Hierarchical Form of the Reference Model (Scheduling and Control Hierarchy View) of the System

THE GENERIC TASKS OF A PLANT-WIDE COMPUTER CONTROL SYSTEM

Overall automatic control of any large modern industrial plant regardless of the industry concerned involves each of the requirements listed in Table 3-I.

Thus the automation of any such industrial plant becomes the managing of the plants' information systems to assure that the necessary information is collected and used wherever it can enhance the plants' operation - true information systems technology in its broadest sense.

Another major factor should also be called to our attention here. It has been repeatedly shown that one of the major benefits of the use of digital computer control systems in the automation of industrial plants has been in the role of a *control systems enforcer*. In this mode, one of the control computer's main tasks is to continually assure that the control system equipment is actually carrying out the job that it was designed to do in keeping the units of the plant production system operating at some best (near optimal) level. That is, to be sure that in the continuous process plant, for instance, the controllers have not been set on manual, that the optimal set points are being maintained, etc. Likewise, it is the task of dynamic control to assure that the plant's production schedule is carried out, i.e., to *enforce* the task set by the production scheduling function.

Often the tasks carried out by these control systems have been ones which a *skilled* and *attentive* operator could have readily done himself. The difference is the degree of attentiveness to the task at hand which can be achieved over the long run.

As stated earlier, all of this must be factored into the design and operation of the control system which will operate the plant, including the requirements for maximum productivity and minimum raw material and energy usage. As the overall requirements, both energy and productivity based, become more complex, more sophisticated and capable control systems are necessary.

While the above tasking list is truly generic for any manufacturing plant - continuous or discrete - it is necessary to rearrange it in order to come up with a more compact set of tasks for further discussion.

TABLE 3-I

DUTIES (FUNCTIONAL REQUIREMENTS) OF ALL INTEGRATED INFORMATION AND AUTOMATION SYSTEMS A GENERIC LIST

1. AN EXTENSIVE SYSTEM FOR THE AUTOMATIC MONITORING OF A LARGE NUMBER OF DIFFERENT PLANT VARIABLES OPERATING OVER A VERY WIDE RANGE OF PROCESS OPERATIONS AND OF PROCESS DYNAMIC BEHAVIOR. SUCH MONITORING WILL DETECT AND COMPENSATE FOR CURRENT OR IMPENDING PLANT EMERGENCIES OR PRODUCTION PROBLEMS.

2. THE DEVELOPMENT OF A LARGE NUMBER OF QUITE COMPLEX, USUALLY NONLINEAR, RELATIONSHIPS FOR THE TRANSLATION OF SOME OF THE ABOVE PLANT VARIABLE VALUES INTO CONTROL CORRECTION COMMANDS.

3. THE TRANSMISSION OF THESE CONTROL CORRECTION COMMANDS TO ANOTHER VERY LARGE SET OF WIDELY SCATTERED ACTUATION MECHANISMS OF VARIOUS TYPES.

4. IMPROVEMENT OF ALL ASPECTS OF THE MANUFACTURING OPERATIONS OF THE PLANT BY GUIDING THEM TOWARD LIKELY OPTIMA OF THE APPROPRIATE ECONOMIC OR OPERATIONAL CRITERIA. RESULTS MAY BE APPLIED TO THE CONTROL CORRECTION COMMANDS OF ITEM 2 ABOVE AND/OR TO THE PLANT SCHEDULING FUNCTIONS OF ITEM 8 BELOW.

5. RECONFIGURATION OF THE PLANT PRODUCTION SYSTEM AND/OR OF THE CONTROL SYSTEM AS NECESSARY AND POSSIBLE TO ASSURE THE APPLICABLE PRODUCTION AND/OR CONTROL SYSTEM FOR THE MANUFACTURING SITUATION AT HAND.

6. KEEPING PLANT PERSONNEL, BOTH OPERATING AND MANAGEMENT, AWARE OF THE CURRENT STATUS OF THE PLANT AND OF EACH OF ITS PROCESSES AND THEIR PRODUCTS INCLUDING SUGGESTION FOR ALTERNATE ACTIONS WHERE NECESSARY.

7. REDUCTION OF PLANT OPERATIONAL AND PRODUCTION DATA AND PRODUCT QUALITY DATA TO FORM A HISTORICAL DATABASE FOR REFERENCE BY PLANT ENGINEERING, OTHER STAFF FUNCTIONS AND MARKETING.

8. ADJUSTING THE PLANT'S PRODUCTION SCHEDULE AND PRODUCT MIX TO MATCH ITS CUSTOMER'S NEEDS, AS EXPRESSED BY THE NEW ORDER STREAM BEING CONTINUALLY RECEIVED, WHILE MAINTAINING A HIGH PLANT PRODUCTIVITY AND THE LOWEST PRACTICAL PRODUCTION COSTS. THIS FUNCTION MUST ALSO PROVIDE FOR APPROPRIATE PLANT PREVENTIVE OR CORRECTIVE MAINTENANCE FUNCTIONS.

9. DETERMINATION OF AND PROVISION FOR APPROPRIATE INVENTORY AND USE LEVELS FOR RAW MATERIALS, ENERGY, SPARES, GOODS IN PROCESS AND PRODUCTS TO MAINTAIN DESIRED PRODUCTION AND ECONOMICS FOR THE PLANT.

10. ASSURING THE OVERALL AVAILABILITY OF THE CONTROL SYSTEM FOR CARRYING OUT ITS ASSIGNED TASKS THROUGH THE APPROPRIATE COMBINATION OF FAULT DETECTION AND FAULT TOLERANCE, REDUNDANCY, AND FAIL-SAFE TECHNIQUES.

11. MAINTAIN INTERFACES WITH THE EXTERNAL ENTITIES WHICH INTERACT WITH THE PLANT PRODUCTION SYSTEM SUCH AS CORPORATE MANAGEMENT; MARKETING; ACCOUNTING; CORPORATE RESEARCH, DEVELOPMENT AND ENGINEERING; EXTERNAL TRANSPORTATION; SUPPLIERS AND VENDORS; PURCHASING; CUSTOMERS; AND CONTRACTORS.

Therefore, what is needed is an overall system for any manufacturing plant which has the capabilities shown in Table 3-II.

In view of Item 2 of Table 3-II, Table 3-III presents some observations of the differences in process improvement technologies (i.e., near optimization) for continuous versus discrete optimization.

Because of the ever-widening scope of authority of each of the first three requirements in turn, they effectively become the distinct and separate levels of a superimposed control structure, one on top of the other. Also in view of the amount of information which must be passed back and forth among the above four "tasks" of control, a distributed computational capability organized in a hierarchical fashion would seem to be the logical structure for the required control system. This must be true of any plant regardless of the industry involved.

As just noted, a hierarchical arrangement of the elements of a distributed, computer-based control system seems an ideal arrangement for carrying out the automation of the industrial plant just described. Figures 3-1 and 3-2 lay out one possible form of this distributed, hierarchical computer control system for overall plant automation. Note that Figure 3-1 uses the nomenclature common to the continuous process industries while Figure 3-2 presents the computer integrated manufacturing system or CIMS commonly used in the discrete manufacturing industries to represent the hierarchy. Note that the levels represented here are "functional" levels. Whether or not they represent actual physical hardware levels depends on how large and complex the actual manufacturing plant is. Nevertheless it is our thesis that the two diagrams of Figures 3-1 and 3-2 are exactly functionally equivalent.

Figures 3-1 and 3-2 represent the simplest situation - that of a company with only one manufacturing plant. The corresponding situation with a multi-plant company is represented in Figure 3-3 in that an additional level is necessary to separate the company's distribution or assignment of orders to the various plants from the plant's own production scheduling activities. In addition, the company management functions of Level 4B are now transferred to a new Level 5B. With this simple discussion of potential expansion of the model, continuing discussion of the model in this document will concentrate, for ease of consideration, on the single plant company, i.e., Figures 3-1 and 3-2. The tasks carried out at Level 5B would be the same as those assigned here at Level 4B in Table 3-VI with suitable allowance for the wider horizon of interest of the management of the larger company.

TABLE 3-II

AN OVERALL PLANT AUTOMATION SYSTEM MUST PROVIDE

1. AN EFFECTIVE DYNAMIC CONTROL OF EACH OPERATING UNIT OF THE PLANT TO ASSURE THAT IT IS OPERATING AT ITS MAXIMUM EFFICIENCY OF PRODUCTION CAPABILITY, PRODUCT QUALITY AND/OR OF ENERGY AND MATERIALS UTILIZATION BASED UPON THE PRODUCTION LEVEL SET BY THE SCHEDULING AND SUPERVISORY FUNCTIONS LISTED BELOW. THIS THUS BECOMES THE *CONTROL ENFORCEMENT* COMPONENT OF THE SYSTEM. THIS CONTROL REACTS DIRECTLY TO COMPENSATE FOR ANY EMERGENCIES WHICH MAY OCCUR IN ITS OWN UNIT.

2. A SUPERVISORY AND COORDINATING SYSTEM WHICH DETERMINES AND SETS THE LOCAL PRODUCTION LEVEL OF ALL UNITS WORKING TOGETHER BETWEEN INVENTORY LOCATIONS IN ORDER TO CONTINUALLY IMPROVE (I.E., OPTIMIZE) THEIR OPERATION. THIS SYSTEM ASSURES THAT NO UNIT IS EXCEEDING THE GENERAL AREA LEVEL OF PRODUCTION AND THUS USING EXCESS RAW MATERIALS OR ENERGY. THIS SYSTEM ALSO RESPONDS TO THE EXISTENCE OF EMERGENCIES OR UPSETS IN ANY OF THE UNITS UNDER ITS CONTROL IN COOPERATION WITH THOSE UNITS' DYNAMIC CONTROL SYSTEMS TO SHUT DOWN OR SYSTEMATICALLY REDUCE THE OUTPUT IN THESE AND RELATED UNITS AS NECESSARY TO COMPENSATE FOR THE EMERGENCY. IN ADDITION, THIS SYSTEM IS RESPONSIBLE FOR THE EFFICIENT REDUCTION OF PLANT OPERATIONAL DATA FROM THE DYNAMIC CONTROL UNITS, DESCRIBED JUST ABOVE, TO ASSURE ITS AVAILABILITY FOR USE BY ANY PLANT ENTITY REQUIRING ACCESS TO IT AS WELL AS ITS USE FOR THE HISTORICAL DATABASE OF THE PLANT.

3. AN OVERALL PRODUCTION CONTROL SYSTEM CAPABLE OF CARRYING OUT

continued

Table 3-II continued

THE SCHEDULING FUNCTIONS FOR THE PLANT FROM CUSTOMER ORDERS OR MANAGEMENT DECISIONS SO AS TO PRODUCE THE REQUIRED PRODUCTS FOR THESE ORDERS AT THE BEST (NEAR OPTIMUM) COMBINATION OF CUSTOMER SERVICE AND OF THE USE OF TIME, ENERGY, INVENTORY, MANPOWER AND RAW MATERIALS SUITABLY EXPRESSED AS COST FUNCTIONS.

4. A METHOD OF ASSURING THE OVERALL RELIABILITY AND AVAILABILITY OF THE TOTAL CONTROL SYSTEM THROUGH FAULT DETECTION, FAULT TOLERANCE, REDUNDANCY, UNINTERRUPTIBLE POWER SUPPLIES, MAINTENANCE PLANNING, AND OTHER APPLICABLE TECHNIQUES BUILT INTO THE SYSTEM'S SPECIFICATION AND OPERATION.

TABLE 3-III

SOME NOTES REGARDING OPTIMIZATION (IMPROVEMENT) OF MANUFACTURING EFFICIENCY

IN DISCRETE MANUFACTURING OPTIMIZATION (IMPROVEMENT) IS GENERALLY CARRIED OUT IN SCHEDULING.

IN CONTINUOUS MANUFACTURING OPTIMIZATION (IMPROVEMENT) IS GENERALLY CARRIED OUT BOTH IN CONTROL AND SCHEDULING.

Figure 3-4 compares the model described here with that developed by ISO Working Group 1 (Reference Models Working Group) [38]. Note that Levels 1 and 6 of that model are omitted in the Purdue model for the reasons given on the figure. The remaining levels have been correspondingly renumbered. Figure 3-5 continues this analysis by showing the corresponding hierarchical computer system diagram with similar notation on the differences between the two models. Task definitions are essentially the same in both models at all levels. See also Figure 1-3.

As noted, the International Purdue Workshop Model has a narrower scope than the ISO Reference Model Committee's work for two major reasons:

1. The Shop Floor is not specifically included in the IPW model since it is strictly an Information Management and Control Model and because shop floor equipment can vary so widely between different industries. The ISO Committee's model is restricted to Discrete Products plants.

2. The Corporate Management tasks are considered innovative in the IPW study and are therefore considered External Entities since innovative procedures cannot be mathematically modelled with present technology.

Working Group 1 has been mandated by the International Standards Organization (ISO) to develop a CIM Reference Model. However, their scope of work at present calls only for using the resulting model as a means for helping develop needs for additional international standards to facilitate the field of CIM [38].

Working Group 1 has developed three separate views of the CIM Reference Model in their work. These are the model of Discrete Parts Manufacturing (DPM) reproduced here as Figure 1-3 (a modified data-flow or functional analysis view); a six level hierarchical control Factory Automation Model (FAM) for manufacturing activities reproduced here as Figure 3-5 (a modified scheduling and control view); and a Generic Production Activity Model (GPAM) which described a set of generic activities which occur at all levels of the hierarchy (a physics view and discussed here in Appendix III).

DISCRETE PARTS MANUFACTURING ENVIRONMENT (DPM)

As established by WG1 for their study, the scope of manufacturing automation was perceived to be all-inclusive, from customer order through delivery of the product. Twelve major activities have been identified as being a part of this scope.

1. Corporate Management
2. Finance
3. Marketing and Sales
4. Research, Development and Engineering

(Items 1–4: Considered External Influences in the Purdue Model)

5. Process Support Engineering
6. Procurement
7. Resources Management
8. Production Management
9. Shipping
10. Shop Floor Production
11. Waste Material Treatment
12. Maintenance Management

Included in the Purdue Model (bracket at right of items 5–12)

Figure 1-3 depicts the important relationships and interfaces among these activities. It provides an "environment" for Discrete Parts Manufacturing and forms the basis for the other models.

FACTORY AUTOMATION MODEL (FAM)

As just noted WG1 restricted its scope to those activities which are included in and directly related to Shop Floor Production (see Figure 1-3). A

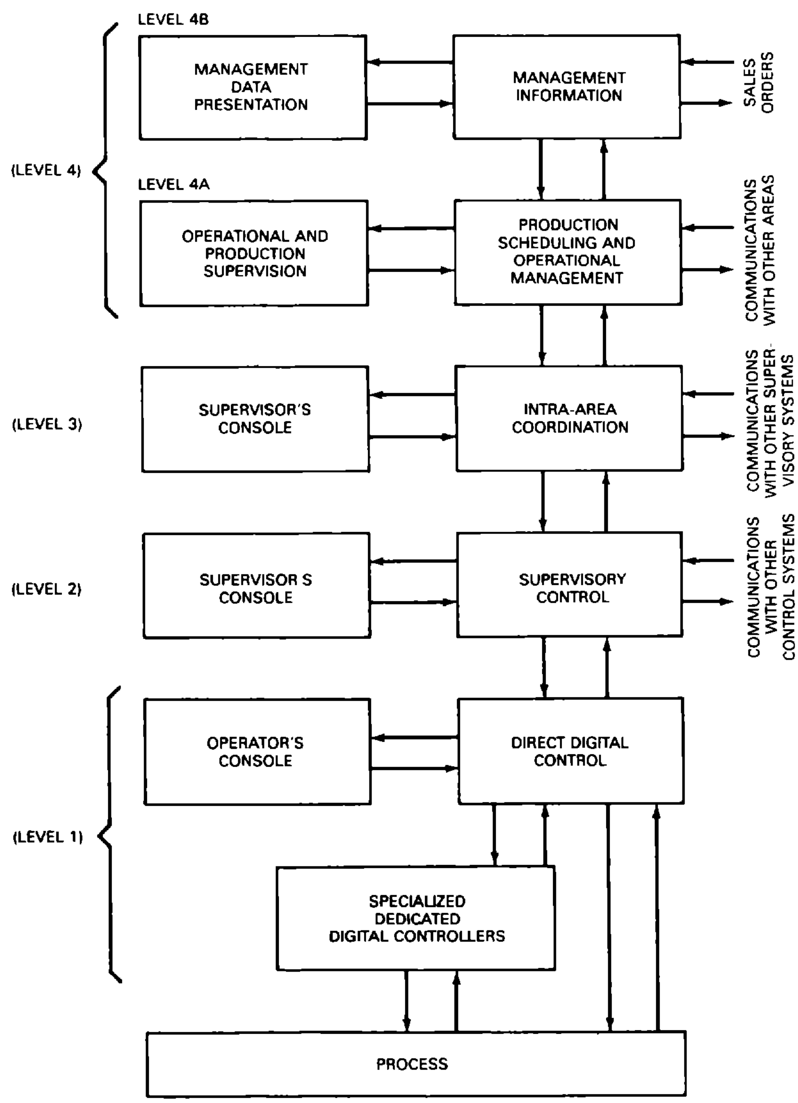


Figure 3-1 Assumed functional hierarchical computer control structure for an industrial plant (continuous process such as petrochemicals).

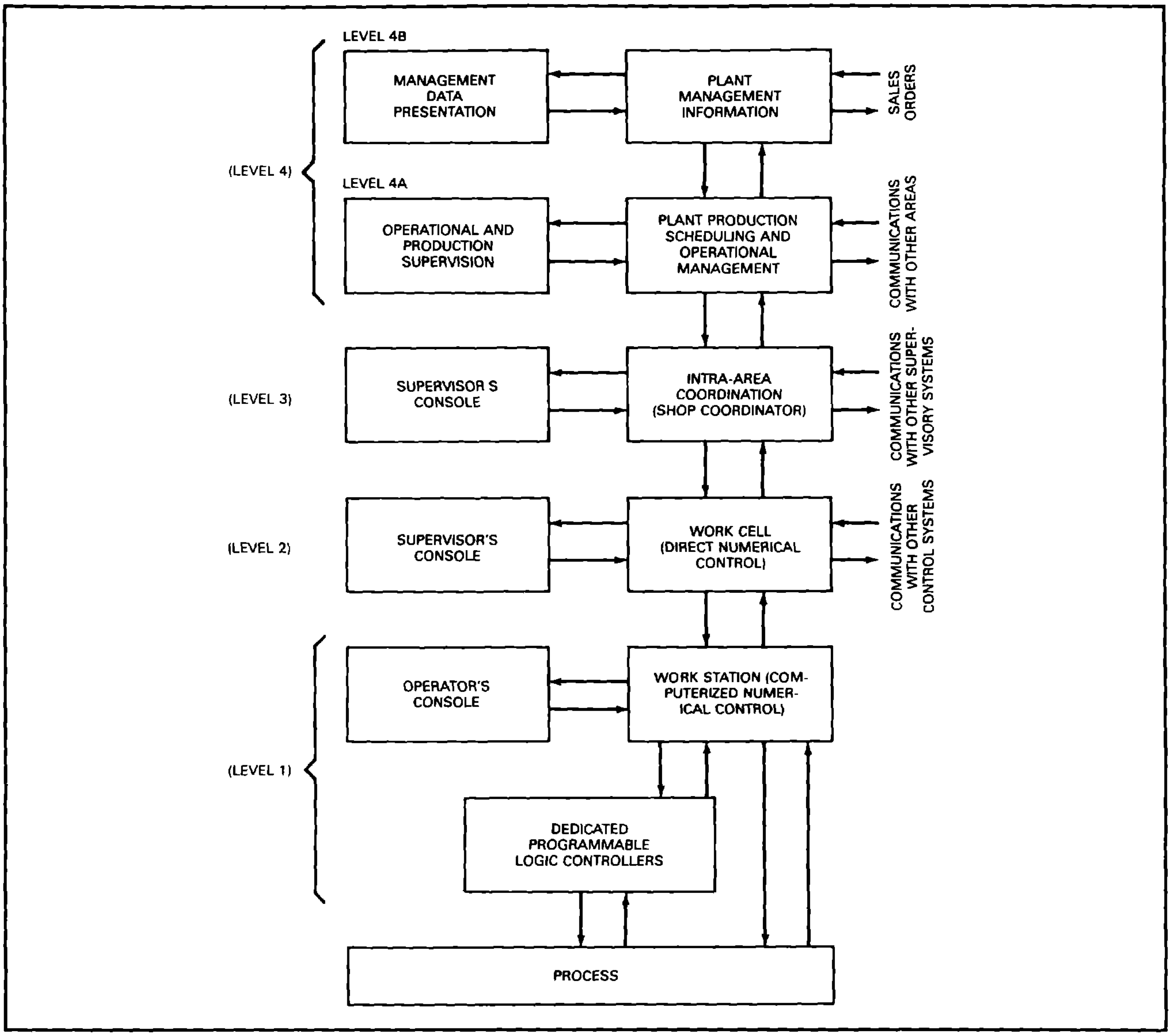


Figure 3-2 Assumed functional hierarchy computer system structure for a large manufacturing complex (Computer Integrated Manufacturing System (CIMS)).

six level hierarchical model was selected to represent those activities (see Figures 3-4 and 3-5). It is quite likely that specific applications may require more or fewer than six levels. But, six was deemed sufficient for the purposes of identifying where integration standards are required. The following table shows the name of each level and gives its major responsibility. More detail is shown in Figure 3-4.

LEVEL 6 ENTERPRISE — CORPORATE MANAGEMENT (EXTERNAL INFLUENCES)

LEVEL 5 FACILITY — PLANNING PRODUCTION

LEVEL 4 SECTION — MATERIAL/RESOURCE SUPERVISION

LEVEL 3 CELL — COORDINATE MULTIPLE MACHINES

LEVEL 2 STATION — COMMAND MACHINE SEQUENCES

LEVEL 1 EQUIPMENT — ACTIVATE SEQUENCES OF MOTION (PLANT MACHINERY AND EQUIPMENT)

These activities apply to manual operations, automated operations, or a mixture of the two at any level. Figure 3-5 shows a sample implementation of these six levels.

As noted above these two figures describe very well the Purdue Scheduling and Control View of their CIM Reference Model except for WG1 Levels 1 and 6 which are not included in the Purdue Model for the reasons noted just above.

In the context of large industrial plants or of a complete industrial company based in one location, the detailed tasks that would be carried out at each level of the hierarchy can be readily described. These tasks are easily subdivided into those related to production scheduling, control enforcement, systems coordination and reporting, and reliability assurance (Table 3-IV).

It is the Committee's contention that such lists can outline the tasks which must be carried out in any industrial plant, particularly at the upper levels of the hierarchy. Details of how these operations are actually carried out may vary drastically, particularly at the lowest levels, because of the nature of the actual process being controlled. We all recognize that a distillation column will never look like or respond like an automobile production line. But the operations themselves remain the same in concept, particularly at the upper levels of the hierarchy.

Thus it is our contention that despite the different nomenclature of Figures 3-1 and 3-2 that the major differences in the control systems involved is concentrated in the details of the dynamic control technologies used at Level 1 and the details of the mathematical models used for optimization at Level 2.

The differences are thus concentrated in the details of the control and operation of the individual production units (the application entities) of the factory. Commonality is in the support functional entities (computational services, communications, database technology, management structure, etc.). Sensing and communication techniques are exactly the same in both systems. The same optimization algorithms can be used. Computer systems technology and programming techniques should be the same and production scheduling technology should be identical to name only a few.

Thus the duties of the hierarchical computer system can be established as outlined in Table 3-IV and in Figure 3-6. Therefore Levels 1 and 2 will

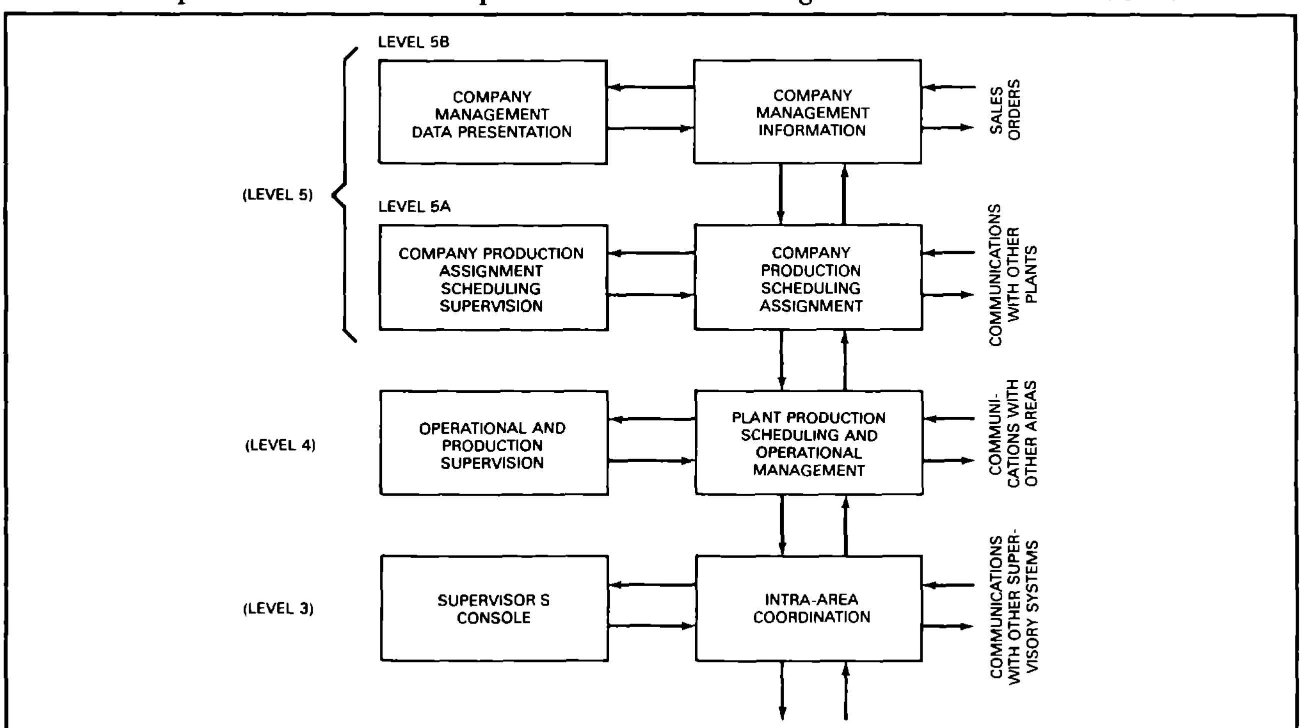


Figure 3-3 Assumed functional hierarchical computer control structure for an industrial company (multi-plant).

IPW LEVEL NOTATION	WG1 LEVEL	HIERARCHY	CONTROL	RESPONSIBILITY	BASIC FUNCTIONS	
NULL	6	ENTERPRISE	CORPORATE MANAGEMENT	Achieving the mission of the enterprise and managing the corporate	— CORPORATE MANAGEMENT — FINANCE — MARKETING & SALES — RESEARCH & DEVELOPMENT	CONSIDERED AN EXTERNAL ENTITY IN THE IPW WORK
4	5	FACILITY/ PLANT	PLANNING PRODUCTION	Implementation of the enterprise functions, and planning and scheduling the production	— PRODUCT DESIGN & PRODUCTION ENGINEERING — PRODUCTION MANAGEMENT (Upper Level) — PROCUREMENT (Upper Level) — RESOURCES MANAGEMENT (Upper Level) — MAINTENANCE MANAGEMENT (Upper Level)	
3	4	SECTION/ AREA	ALLOCATING AND SUPERVISING MATERIALS & RESOURCES	Coordinate the production and supporting the jobs and obtaining and allocating resources to the jobs	— PRODUCTION MANAGEMENT (Lower Level) — PROCUREMENT (Lower Level) — RESOURCES MANAGEMENT (Lower Level) — MAINTENANCE MANAGEMENT (Lower Level) — SHIPPING — WASTE MATERIAL TREATMENT	
2	3	CELL	COORDINATE MULTIPLE MACHINES AND OPERATIONS	Sequencing and supervising the jobs at the shop floor, and supervising various supporting services	— SHOP FLOOR PRODUCTION (Cell Level)	
1	2	STATION	COMMAND MACHINE SEQUENCES AND MOTION	Directing and coordinating the activity of the shop floor equipments	— SHOP FLOOR PRODUCTION (Station Level)	
0	1	EQUIPMENT	ACTIVATE SEQUENCES AND MOTION	Realization of commands to the shop floor equipments	— SHOP FLOOR PRODUCTION (Equipment Level)	NOT INCLUDED BECAUSE OF WIDE DIFFERENCES OF EQUIPMENT AND FUNCTIONS BETWEEN DIFFERENT INDUSTRIES

Figure 3-4 Factory automation model.

concentrate on performing Task II of Table 3-IV, Levels 3 and 4 will carry out Task I and all will be involved in assuring the implementation of Task III and the integrity of Task IV, overall reliability and availability.

Possibilities of major reduction in the costs, development manpower effort, and time required to produce an integrated industrial control system then devolves upon the factors listed in Table 3-V [81].

TASKS OF EACH OF THE LEVELS OF THE HIERARCHY

In the context of any large industrial plant, or of a complete industrial company based in one location, the tasks that would be carried out at each level of the hierarchy are as described in Tables 3-VI to 3-X. Note that these tasks are subdivided within each table into those related to production scheduling, control enforcement, systems coordination and reporting, and reliability assurance (Table 3-IV). As was mentioned above, these tables outline the tasks which must be carried out in any industrial plant, particularly at the upper levels of the hierarchy.

Figures 3-7 to 3-10 present another form of the same information as presented in the tables listed just above to show the relationships and the interactions of the tasks given.

Figures 3-11 to 3-16 show the application of the Scheduling and Hierarchy View to a variety of industries showing also that the computer control system discussed here is pyramidal as well as hierarchical. Figure 3-16 is an entirely different appearing diagram as originally developed by the Cincinnati-Milacron Company. However with the current CIM hierarchy levels imposed it can be readily seen that this diagram converts directly to the others.

Figures 3-11 to 3-16 also bring out an important aspect of this model in relation to those proposed by some other developers, that is, inventories and associated material handling equipments in relation to the manufacturing processes themselves are treated just like any other process. Thus they are considered to have process control inputs and outputs and their dynamic behavior can be modelled mathematically in order to develop the appropriate overall control system for the functions served by the inventory and its associated material handling equipment.

TABLE 3-IV

SUMMARY OF DUTIES OF CONTROL COMPUTER SYSTEMS

I. PRODUCTION SCHEDULING

II. CONTROL ENFORCEMENT

III. PLANT COORDINATION AND OPERATIONAL DATA REPORTING

IV. SYSTEM RELIABILITY AND AVAILABILITY ASSURANCE

ITEM I OF THE ABOVE LIST (PRODUCTION SCHEDULING) CORRESPONDS TO ITEM 3 OF THE LIST OF TABLE 3-II.

ITEM II OF THE ABOVE LIST CORRESPONDS TO MUCH OF ITEMS 1 AND 2 OF THE LIST OF TABLE 3-II.

ITEMS III AND IV OF THE ABOVE LIST REQUIRE THE COOPERATIVE OPERATION OF ALL ITEMS OF THE LIST OF TABLE 3-II. THE PLANT COORDINATION PART COMPRISES THE DETAILED INTERPRETATION AND EXPANSION OF THE OVERALL PRODUCTION SCHEDULE OF ITEM 3 OF TABLE 3-II.

TABLE 3-V

POTENTIAL FACTORS FOR FACILITATING INTEGRATED CONTROL SYSTEM DEVELOPMENT AND USE

1. POTENTIAL COMMONALITY OF CONTROL SYSTEM STRUCTURES IN TERMS OF THE:

   A. COMPUTER SYSTEMS,

   B. COMMUNICATIONS SYSTEM,

   C. DATABASE ORGANIZATION

   D. RELATIONSHIP TO PLANT MANAGEMENT AND OPERATIONAL STRUCTURE (PERSONNEL).

POTENTIAL FACTORS FOR FACILITATING INTEGRATED CONTROL SYSTEM DEVELOPMENT AND USE (CONT.)

2. COMMONALITY OF THE TECHNIQUES OF APPLICATION OF:

   A. SOFTWARE ENGINEERING AND PROGRAMMING,

   B. COMMUNICATIONS,

   C. DATABASE MANAGEMENT,

   D. CONTROL SYSTEMS ENGINEERING,

   E. PRODUCTION SCHEDULING,

   F. OPERATIONS RESEARCH AND OPTIMIZATION.

TABLE 3-VI

REQUIRED TASKS OF THE INTRA COMPANY COMMUNICATIONS CONTROL SYSTEM (LEVEL 4B OF FIGURE 3-1)

III SYSTEM COORDINATION AND REPORTING

1. MAINTAIN INTERFACES WITH

   (A) PLANT AND COMPANY MANAGEMENT,

   (B) SALES AND SHIPPING PERSONNEL,

   (C) ACCOUNTING, PERSONNEL AND PURCHASING DEPARTMENTS,

   (D) PRODUCTION SCHEDULING LEVEL (LEVEL 4A).

2. SUPPLY PRODUCTION AND STATUS INFORMATION AS NEEDED TO

continued

Table 3-VI continued

(A) PLANT AND COMPANY MANAGEMENT.

(B) SALES AND SHIPPING PERSONNEL.

(C) ACCOUNTING, PERSONNEL AND PURCHASING DEPARTMENTS

(D) THIS INFORMATION WILL BE SUPPLIED IN THE FORM OF

(1) REGULAR PRODUCTION AND STATUS REPORTS

(2) ON-LINE INQUIRIES

3. SUPPLY ORDER STATUS INFORMATION AS NEEDED TO SALES PERSONNEL.

IV. RELIABILITY ASSURANCE

4. PERFORM SELF CHECK AND DIAGNOSTIC CHECKS ON ITSELF.

NOTES:

1. THERE ARE NO PRODUCTION SCHEDULING OR CONTROL ACTIONS REQUIRED AT THIS LEVEL. THIS LEVEL IS SOLELY FOR USE AS AN UPPER MANAGEMENT AND STAFF LEVEL INTERFACE.

2. ROMAN NUMBER SUBDIVISIONS OF TABLES 3-VI TO 3-X CORRESPOND TO THE SAME HEADINGS IN TABLE 3-IV.

TABLE 3-VII

DUTIES OF THE PRODUCTION SCHEDULING AND OPERATIONAL MANAGEMENT LEVEL (LEVEL 4A)

I. PRODUCTION SCHEDULING

1. ESTABLISH BASIC PRODUCTION SCHEDULE.

2. MODIFY THE PRODUCTION SCHEDULE FOR ALL UNITS PER ORDER STREAM RECEIVED, ENERGY CONSTRAINTS, POWER DEMAND LEVELS, AND MAINTENANCE REQUIREMENTS.

3. IN COORDINATION WITH REQUIRED PRODUCTION SCHEDULE DEVELOP OPTIMUM PREVENTIVE MAINTENANCE AND PRODUCTION UNIT RENOVATION SCHEDULE.

4. DETERMINE THE OPTIMUM INVENTORY LEVELS OF RAW MATERIALS, ENERGY SOURCES, SPARE PARTS, ETC., AND OF GOODS IN PROCESS AT EACH STORAGE POINT. THE CRITERIA TO BE USED WILL BE THE TRADE-OFF BETWEEN CUSTOMER SERVICE (I.E., SHORT DELIVERY TIME) VERSUS THE CAPITAL COST OF THE INVENTORY ITSELF, AS WELL AS THE TRADE-OFFS IN OPERATING COSTS VERSUS COSTS OF CARRYING THE INVENTORY LEVEL. THIS FUNCTION WILL ALSO INCLUDE THE NECESSARY MATERIAL REQUIREMENTS PLANNING (MRP) AND SPARE PARTS PROCUREMENT TO SATISFY THE PRODUCTION SCHEDULE PLANNED. (THIS IS AN OFF-LINE FUNCTION.)

5. MODIFY PRODUCTION SCHEDULE AS NECESSARY WHENEVER MAJOR PRODUCTION INTERRUPTIONS OCCUR IN DOWNSTREAM UNITS, WHERE SUCH INTERRUPTIONS WILL AFFECT PRIOR OR SUCCEEDING UNITS.

III. PLANT COORDINATION AND OPERATIONAL DATA REPORTING

6. COLLECT AND MAINTAIN RAW MATERIAL AND SPARE PARTS USE AND AVAILABILITY INVENTORY AND PROVIDE DATA FOR PURCHASING FOR RAW MATERIAL AND SPARE PARTS ORDER ENTRY AND FOR TRANSFER TO ACCOUNTING.

7. COLLECT AND MAINTAIN OVERALL ENERGY USE AND AVAILABILITY INVENTORY AND PROVIDE DATA FOR PURCHASING FOR ENERGY SOURCE ORDER ENTRY AND FOR TRANSFER TO ACCOUNTING.

continued

Table 3-VII continued

8. COLLECT AND MAINTAIN OVERALL GOODS IN PROCESS AND PRODUCTION INVENTORY FILES.

9. COLLECT AND MAINTAIN THE QUALITY CONTROL FILE.

10. COLLECT AND MAINTAIN MACHINERY AND EQUIPMENT USE AND LIFE HISTORY FILES NECESSARY FOR PREVENTIVE AND PREDICTIVE MAINTENANCE PLANNING.

11. COLLECT AND MAINTAIN MANPOWER USE DATA FOR TRANSMITTAL TO PERSONNEL AND ACCOUNTING DEPARTMENTS.

12. MAINTAIN INTERFACES WITH MANAGEMENT INTERFACE LEVEL FUNCTION AND WITH AREA LEVEL SYSTEMS.

IV. RELIABILITY ASSURANCE

13. RUN SELF-CHECK AND DIAGNOSTIC ROUTINES ON SELF AND LOWER LEVEL MACHINES

NOTE:

THERE ARE NO CONTROL FUNCTIONS AS SUCH REQUIRED AT THIS LEVEL. THIS LEVEL IS FOR THE PRODUCTION SCHEDULING AND OVERALL PLANT DATA FUNCTIONS.

TABLE 3-VIII

DUTIES OF THE AREA LEVEL (LEVEL 3)

I. PRODUCTION SCHEDULING

1. ESTABLISH THE IMMEDIATE PRODUCTION SCHEDULE FOR ITS OWN AREA INCLUDING MAINNTENANCE, TRANSPORTATION AND OTHER PRODUCTION RELATED NEEDS.

2. LOCALLY OPTIMIZE THE COSTS FOR ITS INDIVIDUAL PRODUCTION AREA WHILE CARRYING OUT THE PRODUCTION SCHEDULE ESTABLISHED BY THE PRODUCTION CONTROL COMPUTER SYSTEM (LEVEL 4A) (I.E., MINIMIZE ENERGY USAGE OR MAXIMIZE PRODUCTION FOR EXAMPLE)

3. ALONG WITH LEVEL 4A MODIFY PRODUCTION SCHEDULES TO COMPENSATE FOR PLANT PRODUCTION INTERRUPTIONS WHICH MAY OCCUR IN ITS AREA OF RESPONSIBILITY.

III. SYSTEM COORDINATION AND OPERATIONAL DATA REPORTING

4. MAKE AREA PRODUCTION REPORTS INCLUDING VARIABLE MANUFACTURING COSTS

5. USE AND MAINTAIN AREA PRACTICE FILES

6. COLLECT AND MAINTAIN AREA DATA QUEUES FOR PRODUCTION, INVENTORY, AND MANPOWER, RAW MATERIALS, SPARE PARTS AND ENERGY USAGE

7. MAINTAIN COMMUNICATIONS WITH HIGHER AND LOWER LEVELS OF THE HIERARCHY

8. OPERATIONS DATA COLLECTION & OFF LINE ANALYSIS AS REQUIRED BY ENGINEERING FUNCTIONS INCLUDING STATISTICAL QUALITY ANALYSIS AND CONTROL FUNCTIONS

9. SERVICE THE MAN/MACHINE INTERFACE FOR THE AREA

10. CARRY OUT NEEDED PERSONNEL FUNCTIONS SUCH AS:

    (A) WORK PERIOD STATISTICS (TIME, TASK, ETC.)

    (B) VACATION SCHEDULE

    (C) WORK FORCE SCHEDULES

    (D) UNION LINE OF PROGRESSION

    (E) IN-HOUSE TRAINING AND PERSONNEL QUALIFICATION

continued

Table 3-VIII continued

IV. RELIABILITY ASSURANCE

11. DIAGNOSTICS OF SELF AND LOWER LEVEL FUNCTIONS

NOTE:

NO CONTROL ACTIONS ARE REQUIRED HERE. THIS LEVEL HANDLES DETAILED PRODUCTION SCHEDULING AND AREA COORDINATION FOR THE MAJOR PLANT SUBDIVISIONS.

TABLE 3-IX

DUTIES OF THE SUPERVISORY LEVEL (LEVEL 2)

II. CONTROL ENFORCEMENT

1. RESPOND TO ANY EMERGENCY CONDITION WHICH MAY EXIST IN ITS REGION OF PLANT COGNIZANCE

2. OPTIMIZE THE OPERATION OF UNITS UNDER ITS CONTROL WITHIN LIMITS OF ESTABLISHED PRODUCTION SCHEDULE. CARRY OUT ALL ESTABLISHED PROCESS OPERATIONAL SCHEMES OR OPERATING PRACTICES IN CONNECTION WITH THESE PROCESSES

III. SYSTEM COORDINATION AND OPERATIONAL DATA REPORTING

3. COLLECT AND MAINTAIN DATA QUEUES OF PRODUCTION, INVENTORY, AND RAW MATERIAL, SPARE PARTS AND ENERGY USAGE FOR THE UNITS UNDER ITS CONTROL

4. MAINTAIN COMMUNICATIONS WITH HIGHER AND LOWER LEVELS

5. SERVICE THE MAN/MACHINE INTERFACES FOR THE UNITS INVOLVED

IV. RELIABILITY ASSURANCE

6. PERFORM DIAGNOSTICS ON ITSELF AND LOWER LEVEL MACHINES

7. UPDATE ALL STANDBY SYSTEMS

NOTE:

THIS LEVEL AND THOSE BELOW IT CARRY OUT THE NECESSARY CONTROL AND OPTIMIZATION FUNCTIONS FOR THE INDIVIDUAL PRODUCTION UNITS TO ENFORCE THE PRODUCTION SCHEDULE SET BY LEVELS 4A AND 3.

TABLE 3-X

DUTIES OF THE CONTROL LEVEL (LEVEL 1)

II. CONTROL ENFORCEMENT

1. MAINTAIN DIRECT CONTROL OF THE PLANT UNITS UNDER ITS COGNIZANCE

2. DETECT AND RESPOND TO ANY EMERGENCY CONDITION WHICH MAY EXIST IN THESE PLANT UNITS

III. SYSTEM COORDINATION AND REPORTING

3. COLLECT INFORMATION ON UNIT PRODUCTION, RAW MATERIAL AND ENERGY USE AND TRANSMIT TO HIGHER LEVELS

4. SERVICE THE OPERATOR'S MAN/MACHINE INTERFACE

IV. RELIABILITY ASSURANCE

5. PERFORM DIAGNOSTICS ON ITSELF

6. UPDATE ANY STANDBY SYSTEMS

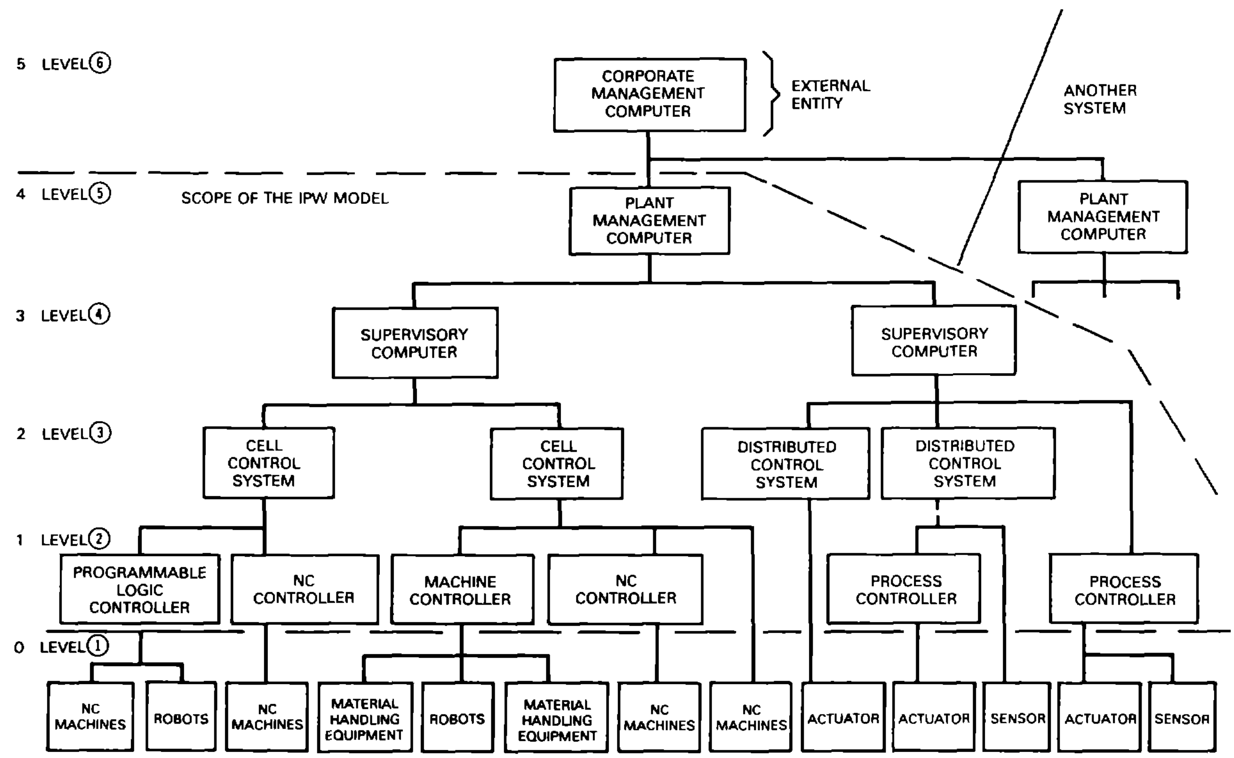


Figure 3-5 Example for system implementation of manufacturing.

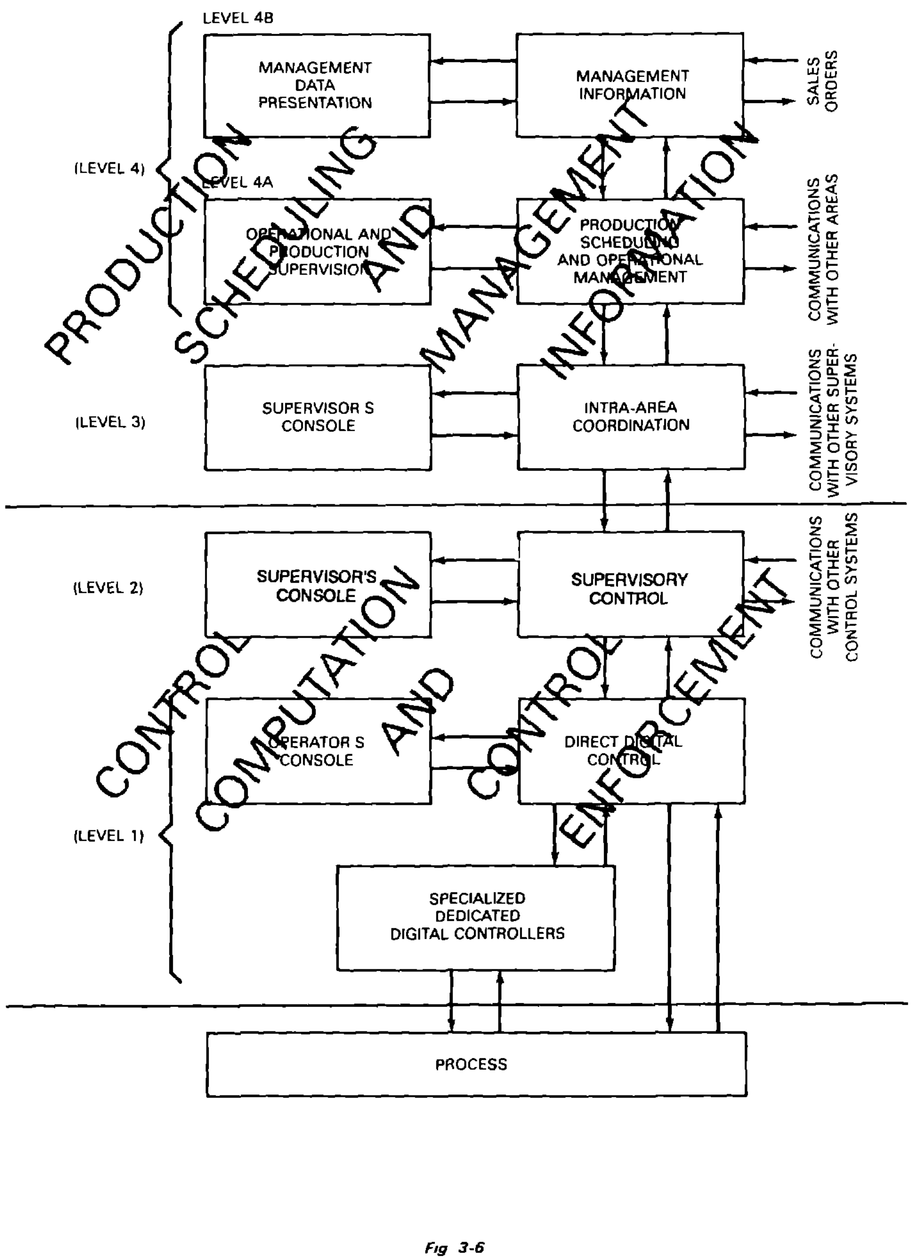


Figure 3-6 Definition of the real tasks of the hierarchical computer control system.

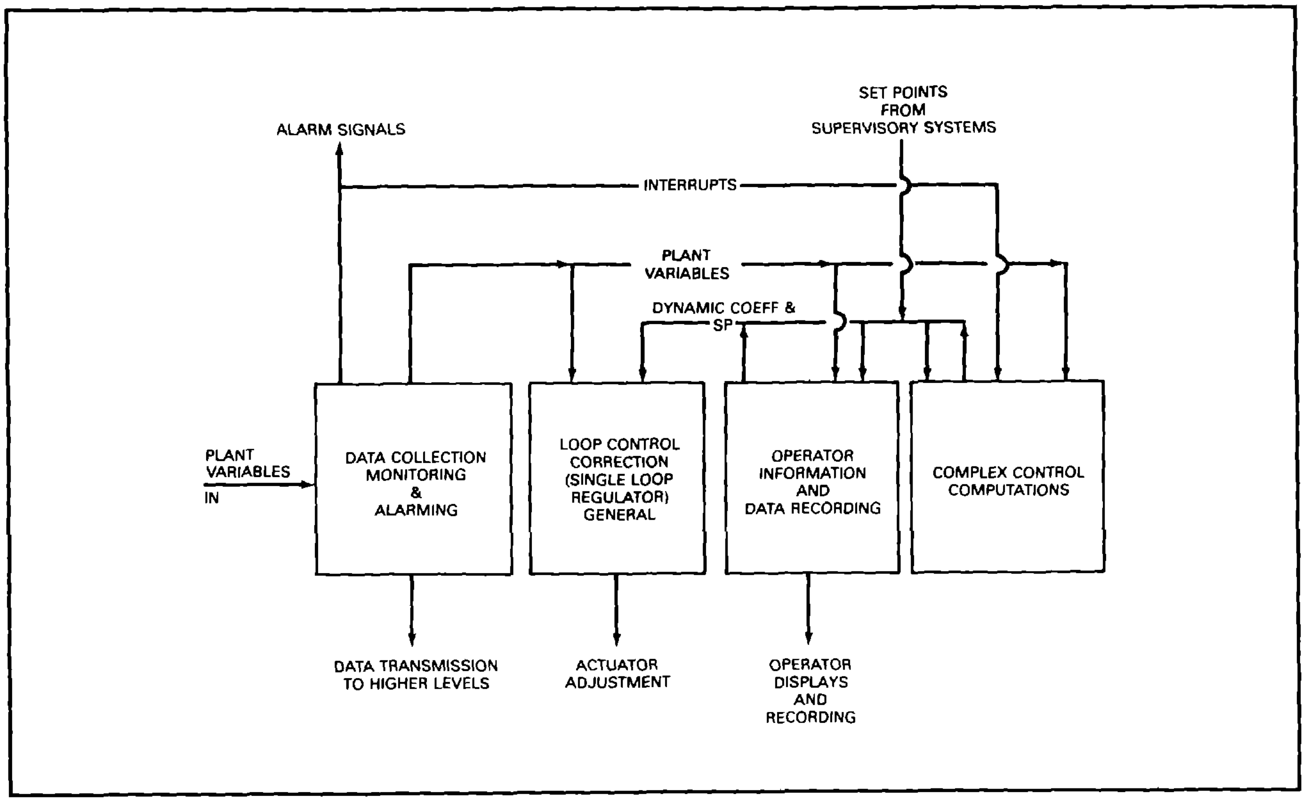


Figure 3-7 A block diagram of a generalized primary level (Level 1) control system.

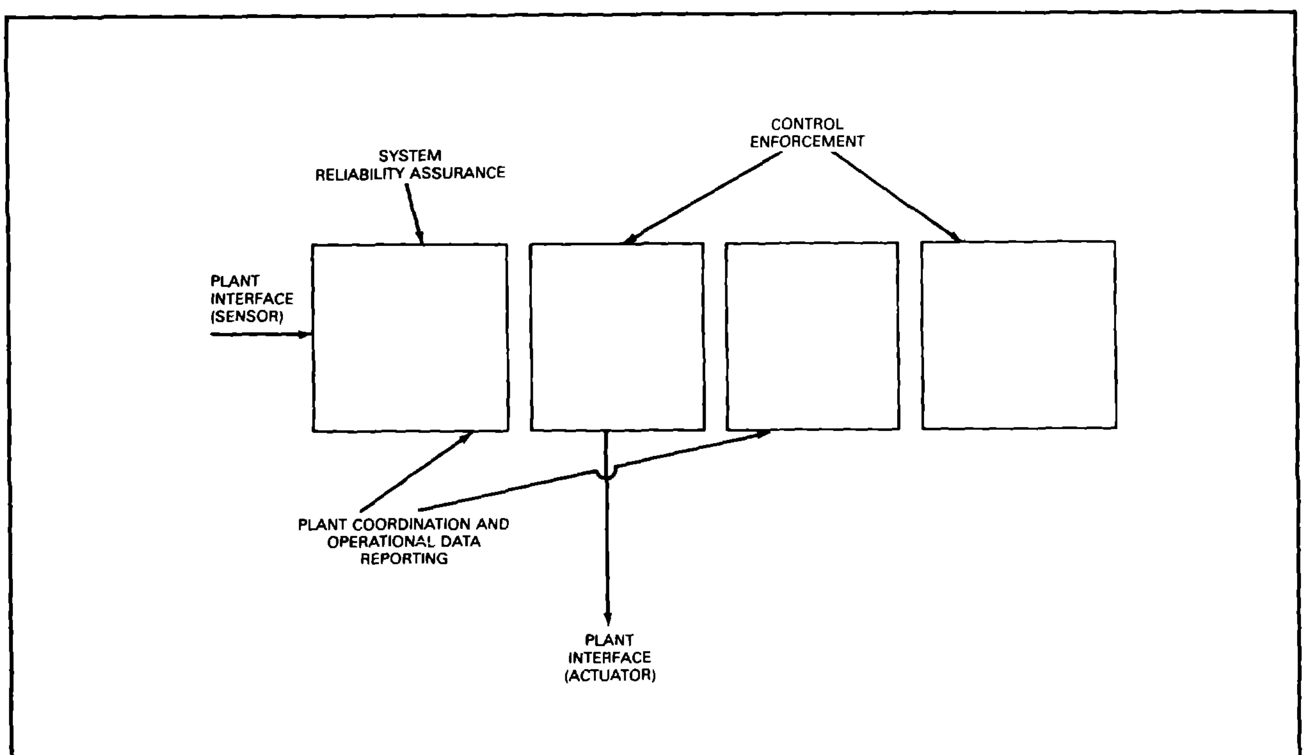


Figure 3-7A Explanation of the tasks of hierarchical Level 1 versus material of Tables 3-IV, 3-VI–3-X and Figure 3-6.

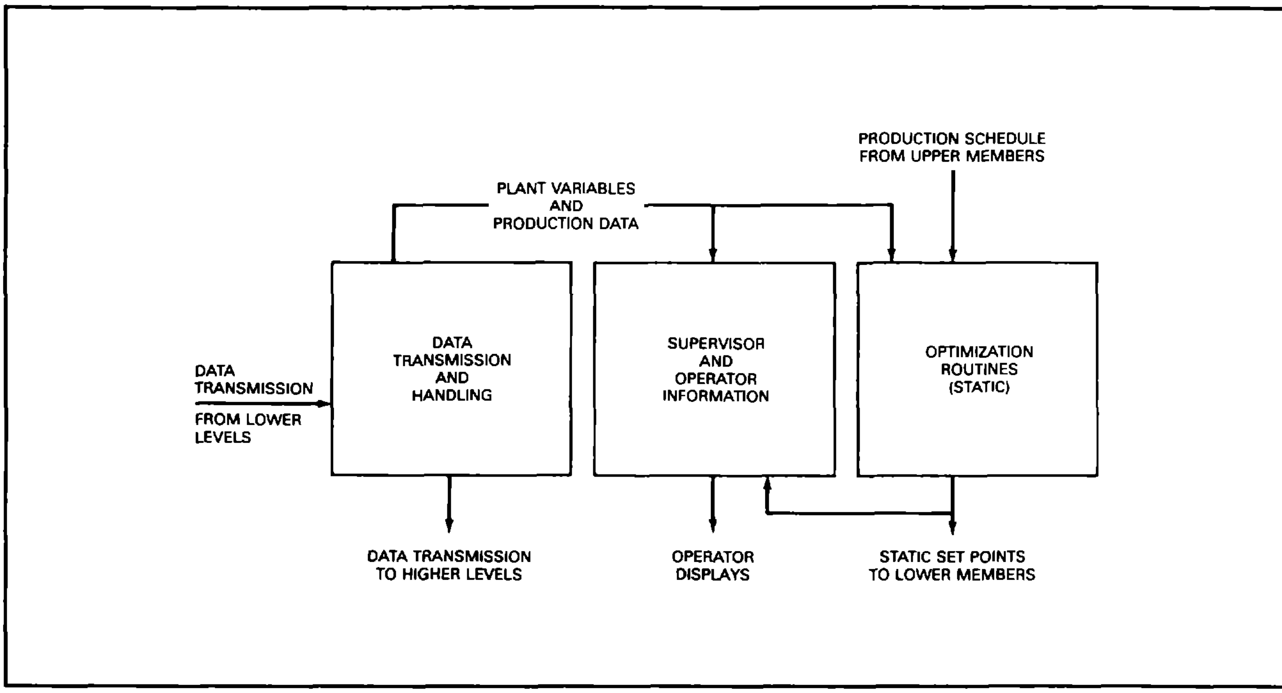


Figure 3-8 A block diagram of the supervisory control level (Level 2) of an overall proess control system.

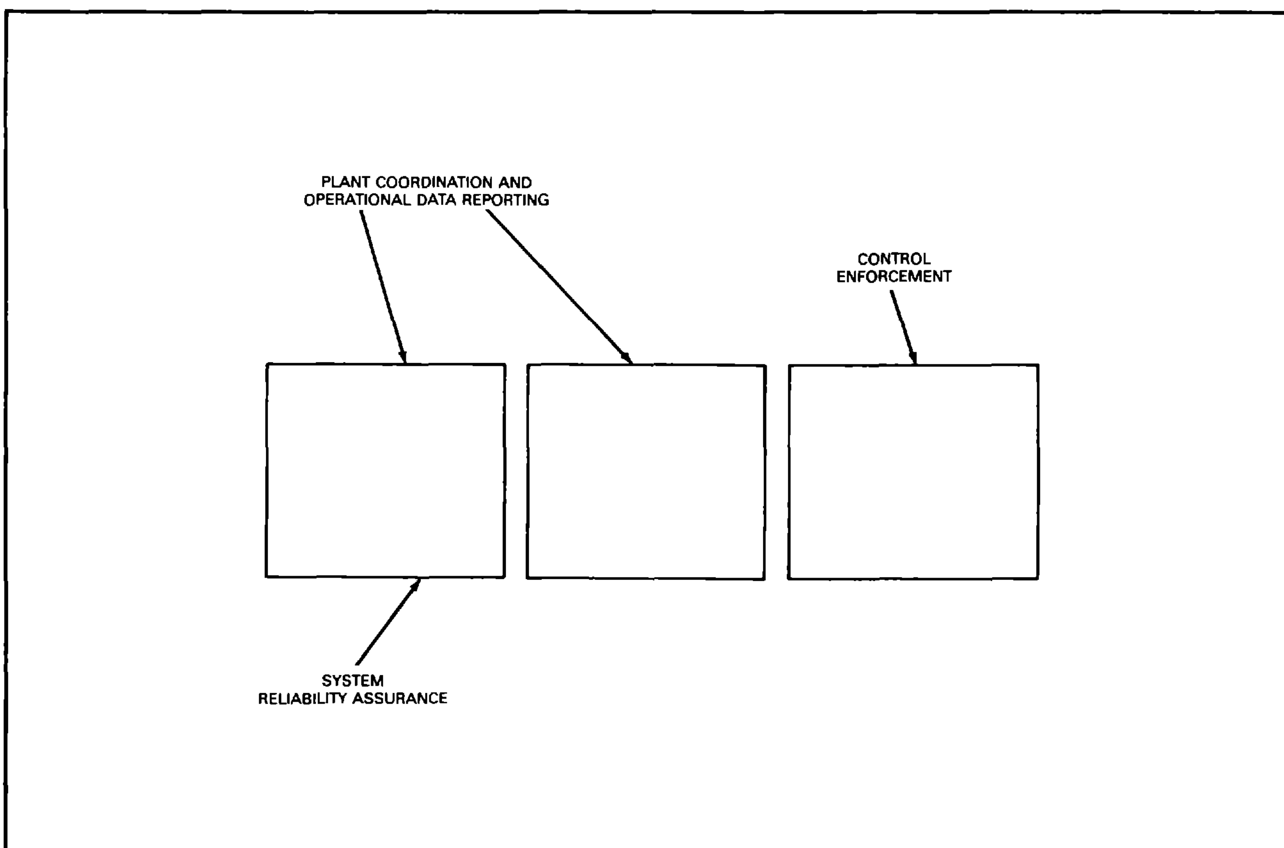


Figure 3-8A Explanation of the tasks of hierarchical level two versus material of Tables 3-IC, 3-VI–3-X and Figure 3-6.

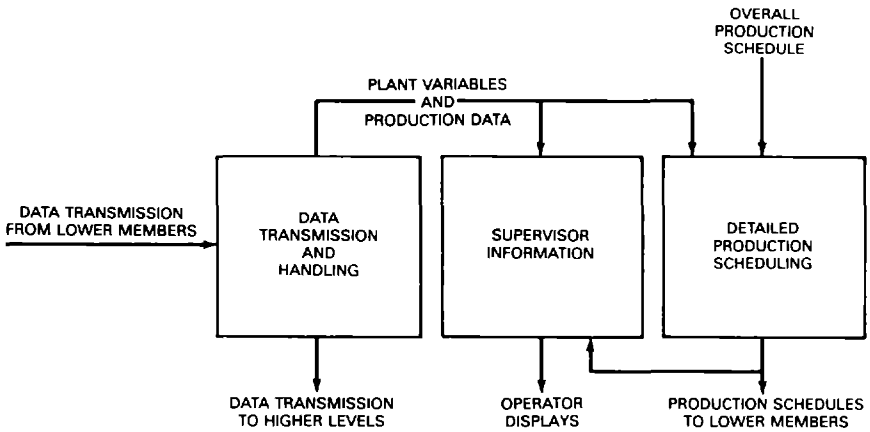


Figure 3-9 A block diagram of the intermediate production scheduling level (Level 3) of an overall process control system.

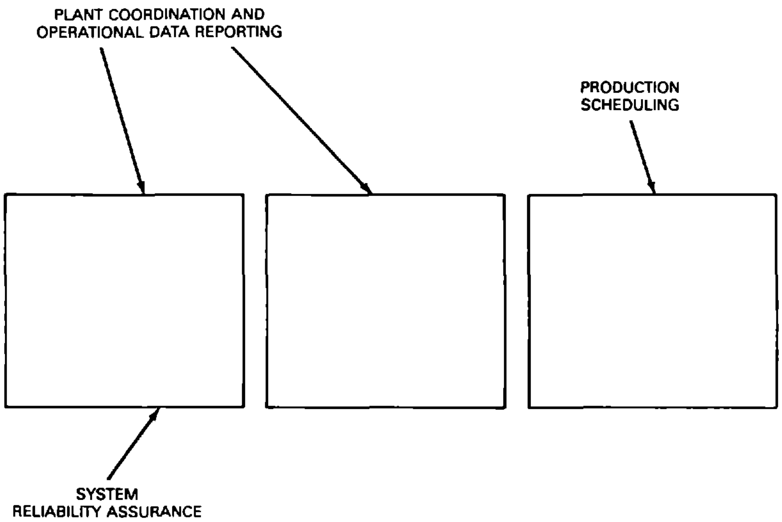


Figure 3-9A Explanation of the tasks of hierarchical levels three and four versus material of Tables 3-IV, 3-VI–3-X and Figure 3-6.

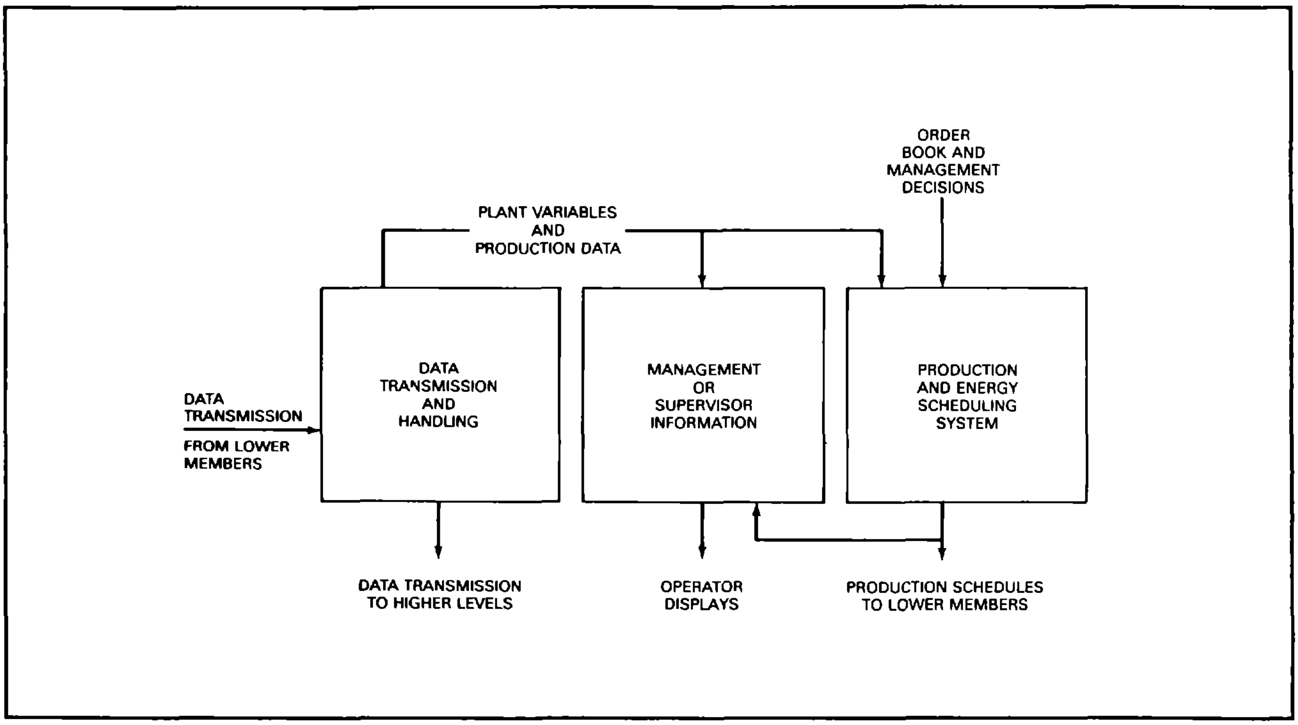


Figure 3-10 A block diagram of the production sheduling level (Level 4A) of an overall process control system.

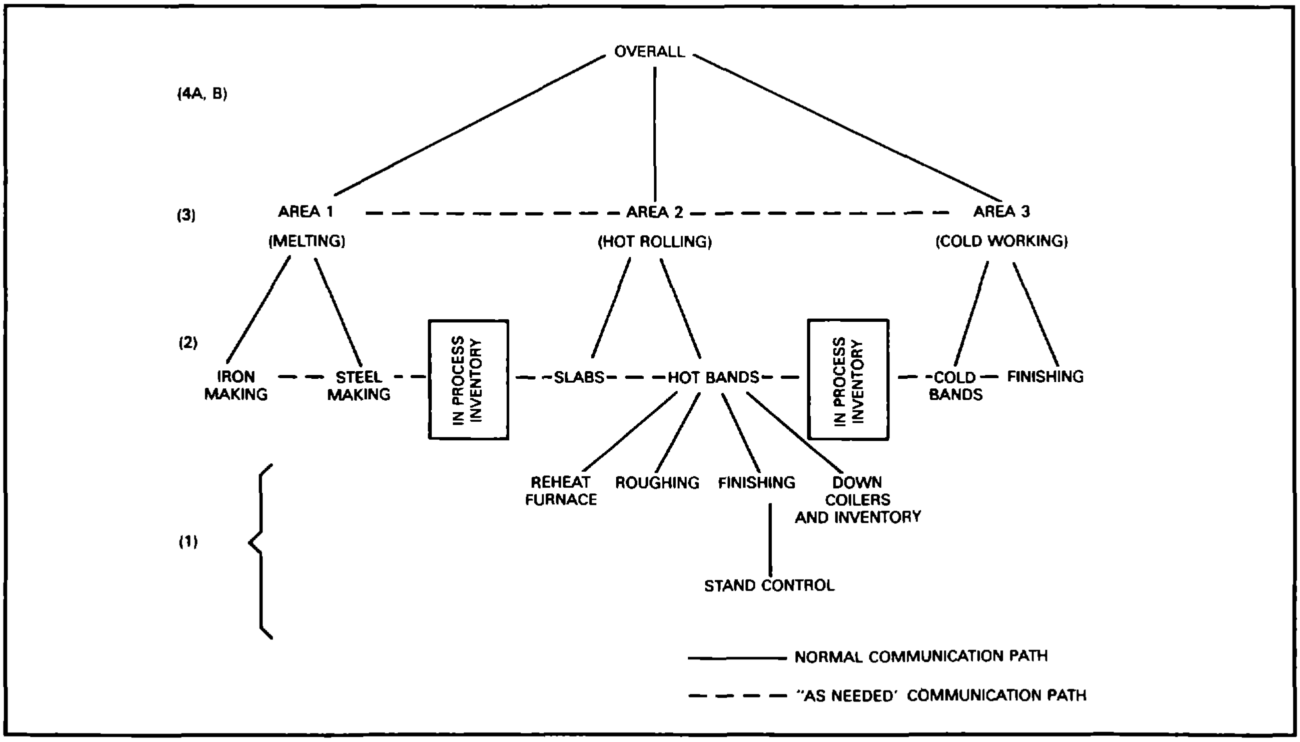


Figure 3-11 Hierarchy arrangement of the steel plant control to show relationship of hierarchy to plant structure.

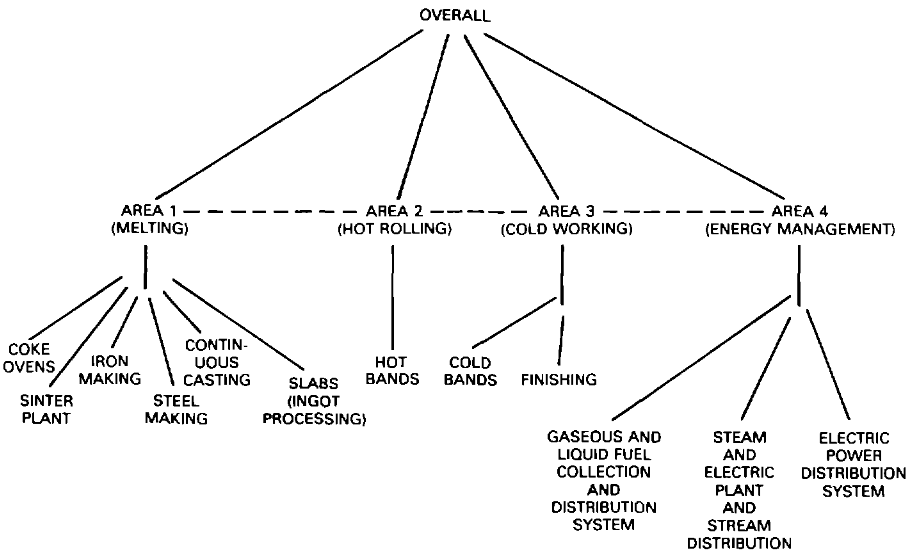


Figure 3-12 Hierarchy arrangement of the Steel Plant control system as studied for energy optimization.

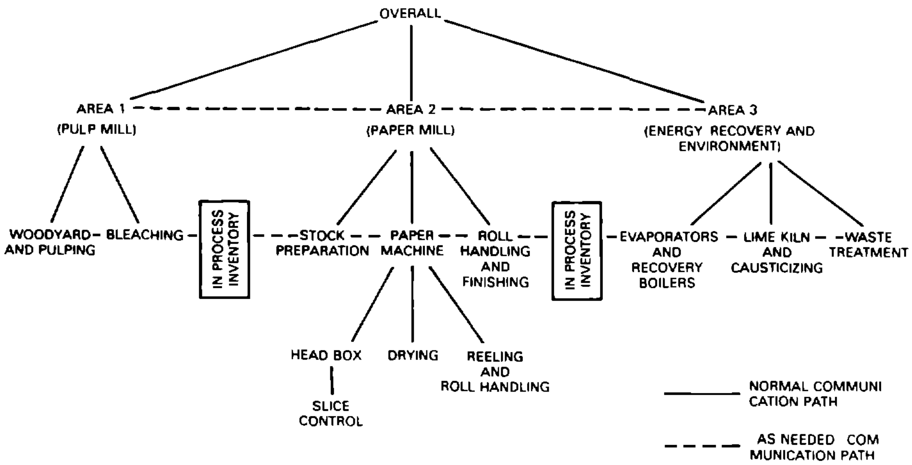


Figure 3-13 Hierarchy arrangement of the Paper Mill control to show relationship of hierarchy to plant structure.

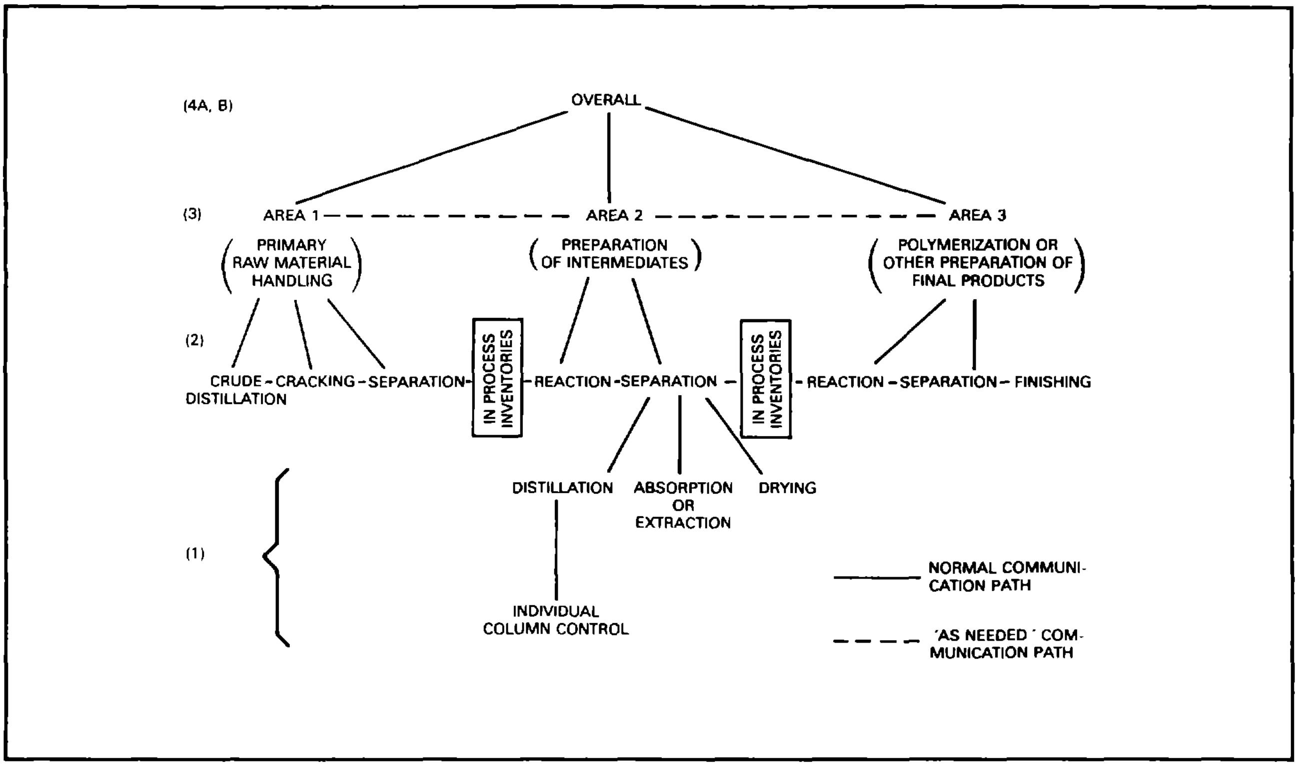


Figure 3-14 The hierarchy control scheme as applied to a Petrochemical Plant.

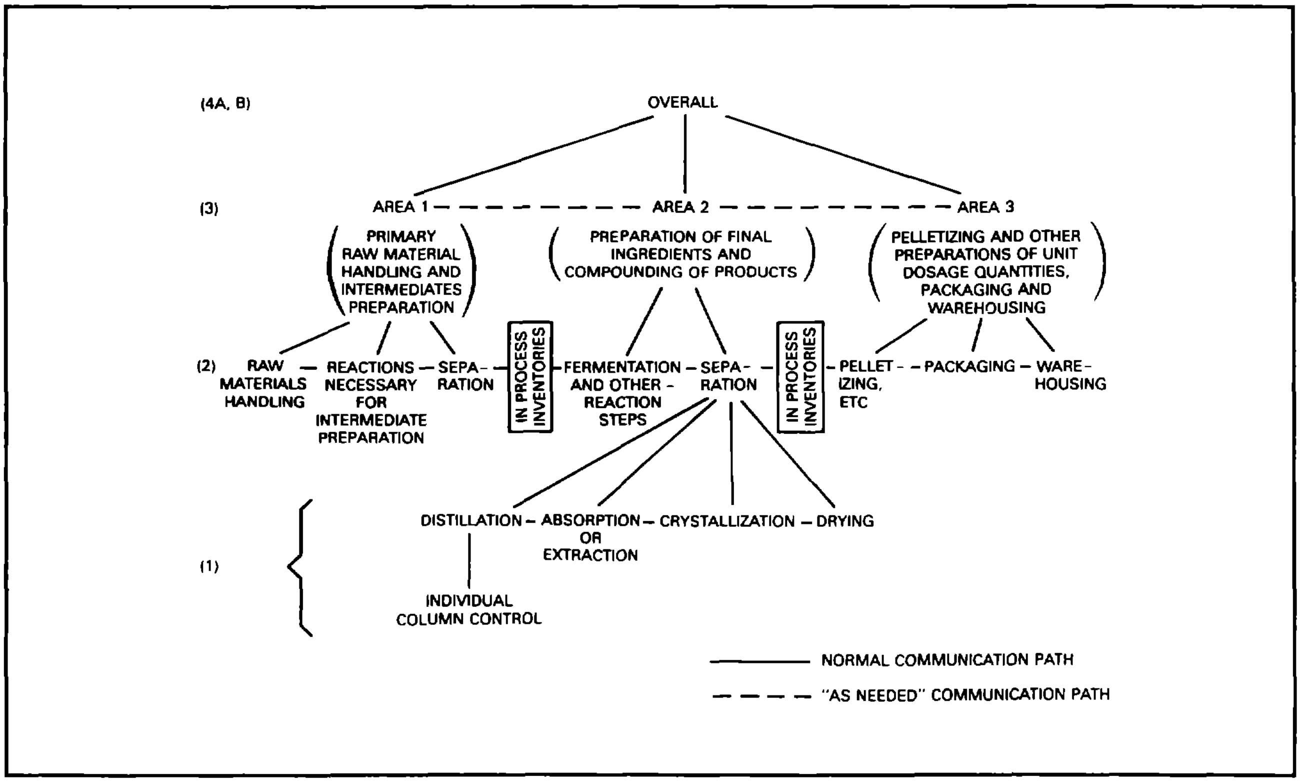


Figure 3-15 The hierarchy control sheme as applied to a Pharmaceuticals Plant.

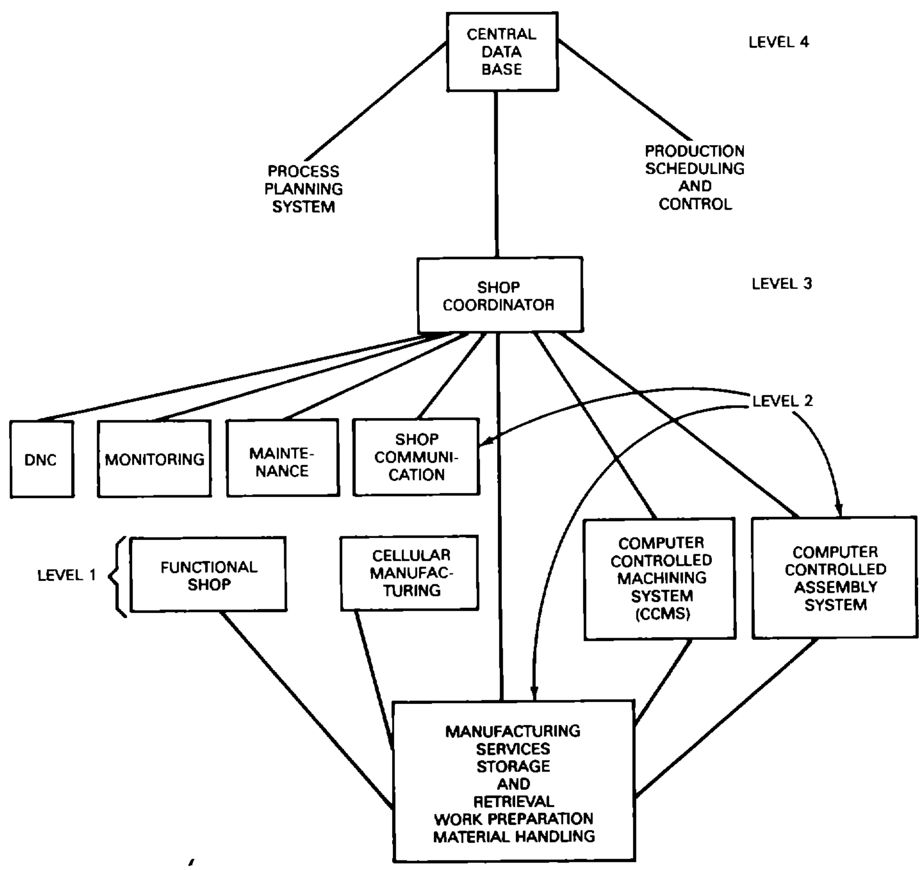


Figure 3-16 Computer Integrated Manufacturing System (CIMS) (Cincinnati-Milacron proposal).

4

The Data-Flow Graph, A Functional Network View of the CIM Reference Model

INTRODUCTION

There is need in the CIM Reference Model to have a mechanism to show the interconnection and precedence of the several tasks assigned to the overall mill-wide control system. An excellent method for showing this is the so-called Data-Flow Graph or Information-Flow Graph using a technique known as Structured Analyses [43] also known as the Yourdon-DeMarco technique.

This Chapter will develop such a representation for the CIM Reference Model. The basis for this work will be a Data-Flow Model entitled, *Information Flow Model of Generic Production Facility,* contributed to this project by The Foxboro Company in August 1986 [15]. The original document has been considerably modified by the Workshop CIM Committee to match the nomenclature, etc., of other parts of the model's documentation.

As noted above this method diagrams the interconnection of the several tasks carried out by the control system and allows the potential for an ever greater detailing of these tasks in the form of subtasks and the resulting interconnections of these subtasks with each other and the main tasks. These diagrams are restricted to the model as defined in Chapter 1 (i.e., the definable scheduling and control system for the manufacturing facility and including only interfaces to the external influences). For a discussion of the data flow between the several external influences please see the material of Chapter 2.

The set of diagrams begins with the interconnection of the influencing external entities on the factory itself (Figure 4-1). In the present model one very important external influence on the factory is the company management itself. As noted in Figure 4-2, management interfaces through the staff departments who provide services to the factory itself or express managements' policies in sets of requirements to be fulfilled by the factory.

Tables 4-I and 4-II present the functions and tasks listed on the diagrams of Figures 4-1 to 4-15. Table 4-III makes a comparison of the tasks listed in Tables 3-VI to 3-X versus those on Figures 4-1 to 4-15.

SOME INADEQUACIES OF THE DATA-FLOW-GRAPH-MODEL

Foundation functional entities cannot be shown on the data flow diagram, i. e., the data flow diagram mainly shows the interconnection of manufacturing-specific functional entities.

The data-flow graph will accommodate all functional entities which exhibit the principle of locality. Those which are diffuse cannot be accommodated because of the number of lines involved. The principle of locality may be a virtual location for the functional entity (i.e., real or virtual consolidation of operations for the sake of the diagram).

Most foundation functional entities are diffuse, e.g., database, communications, management, etc.

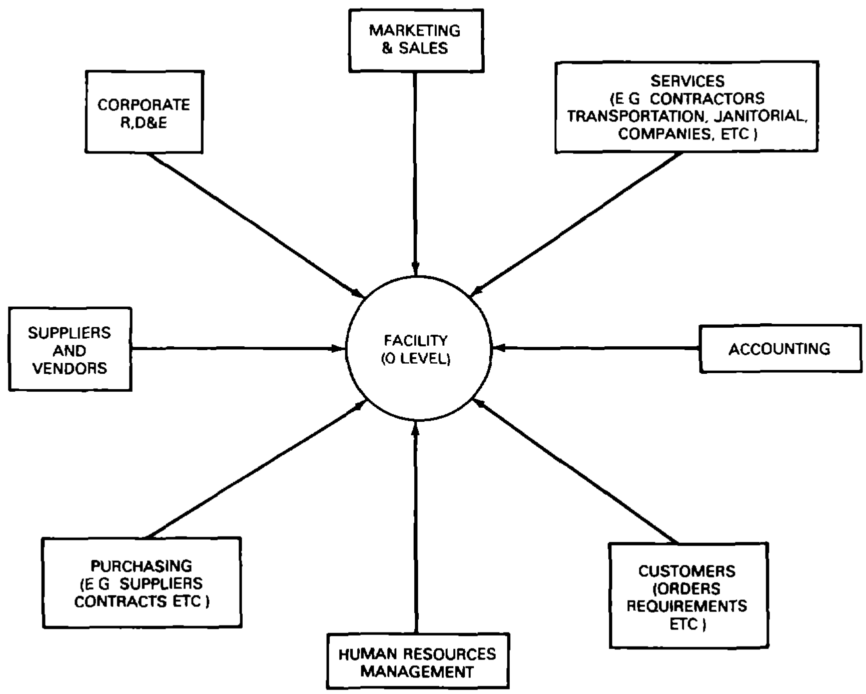


Figure 4-1 Major external influences.

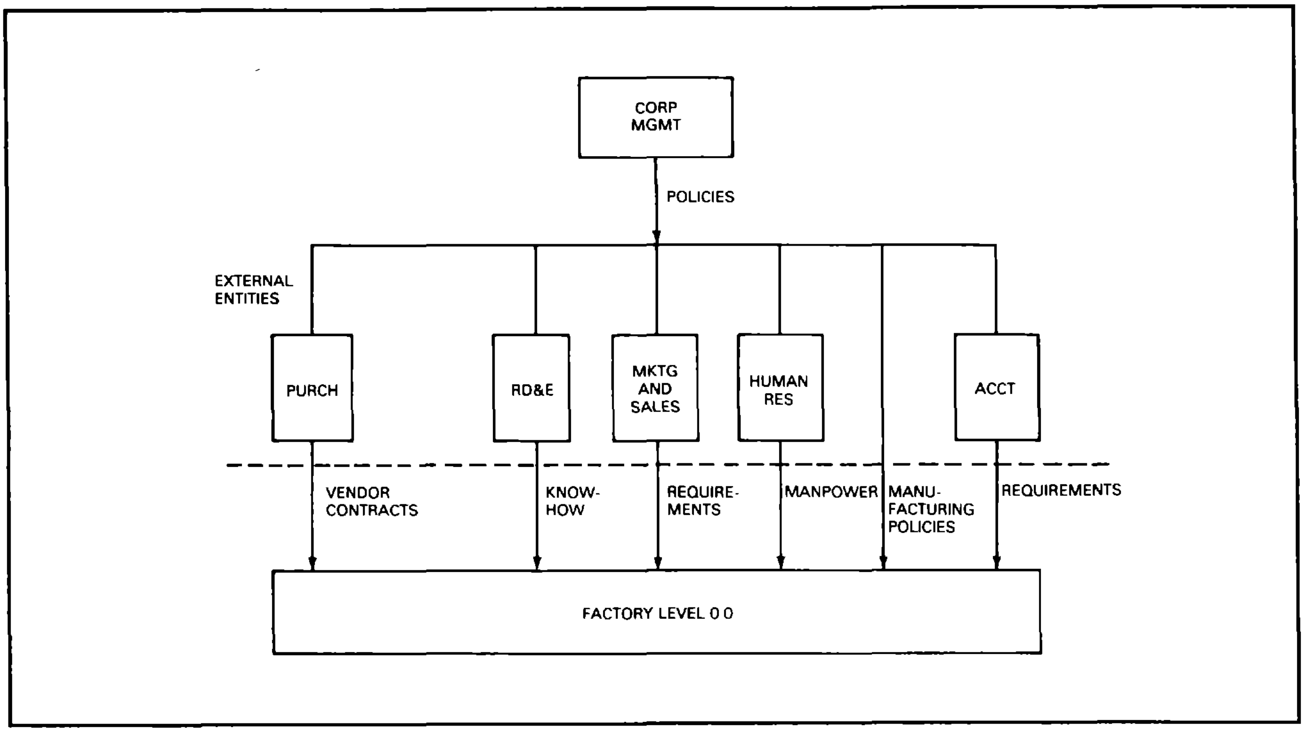


Figure 4-2A Requirements interfacing of corporate management and staff functional entities to the factory.

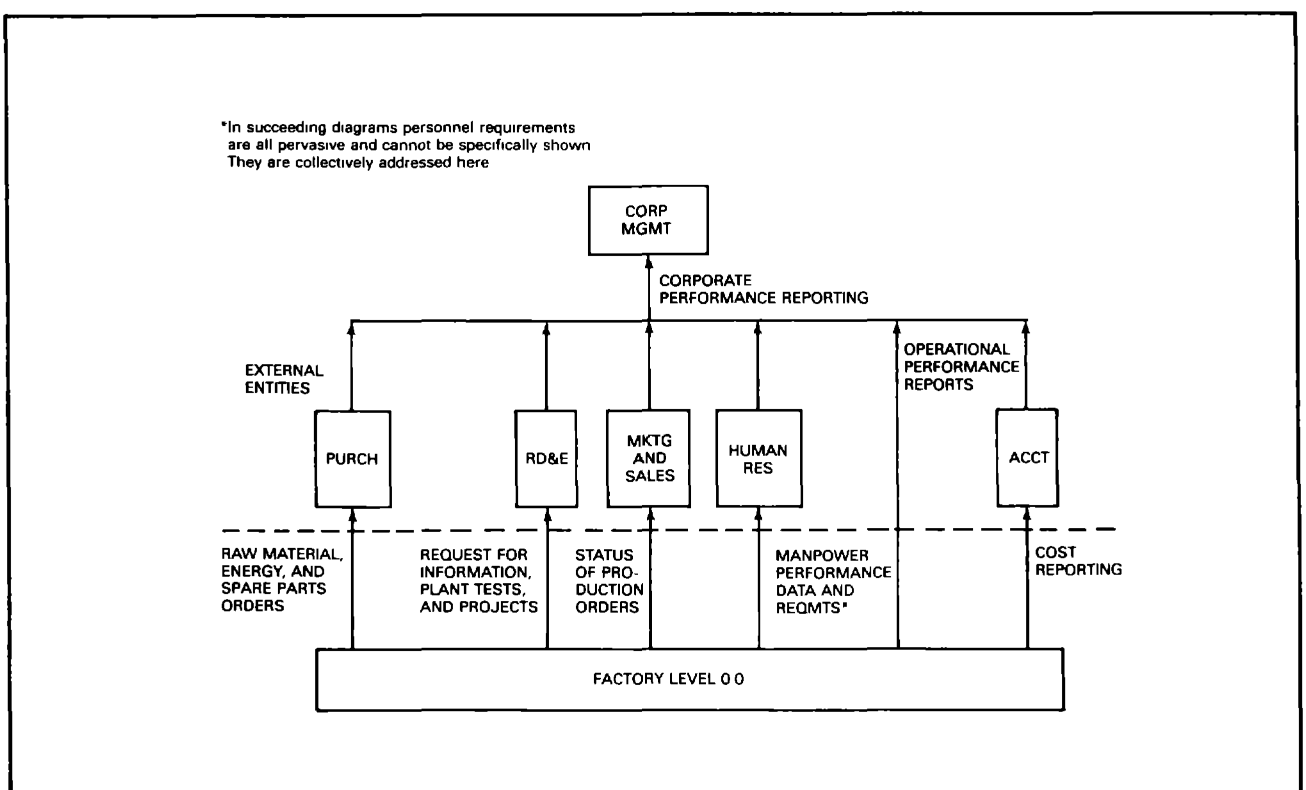


Figure 4-2B Report interfacing to corporate management and staff functional entities from the factory.

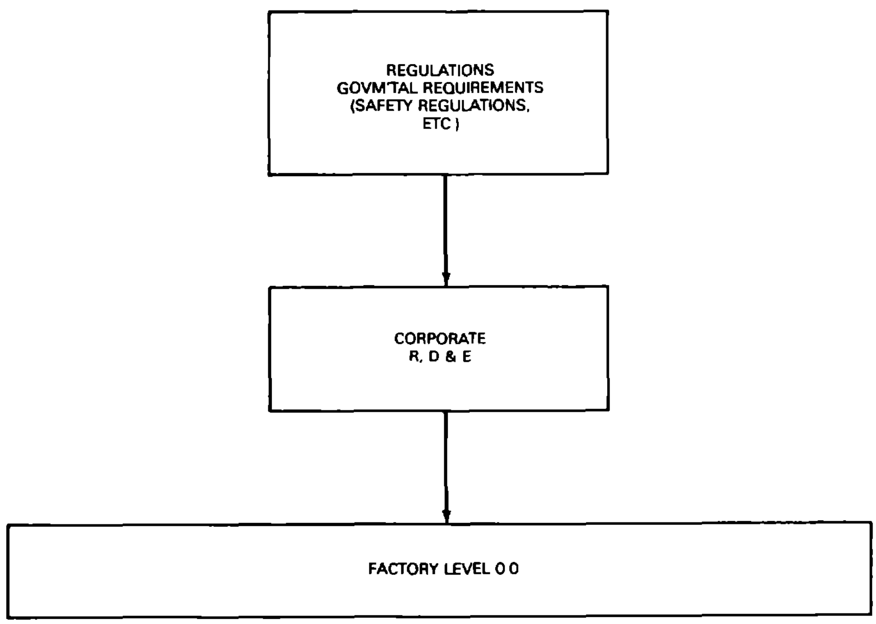


Figure 4-2C Interface of government regulations etc. to the factory

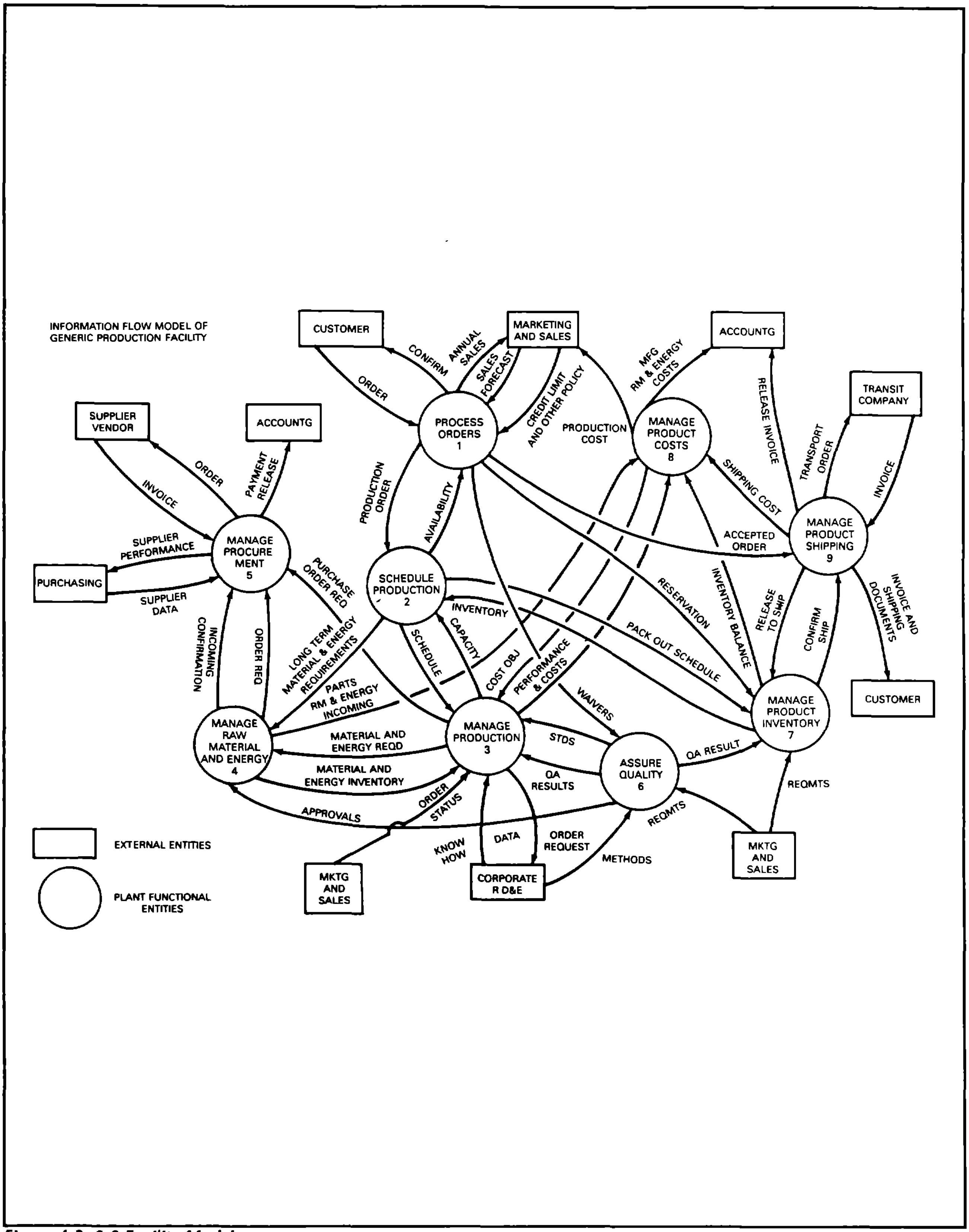


Figure 4-3 0.0 Facility Model

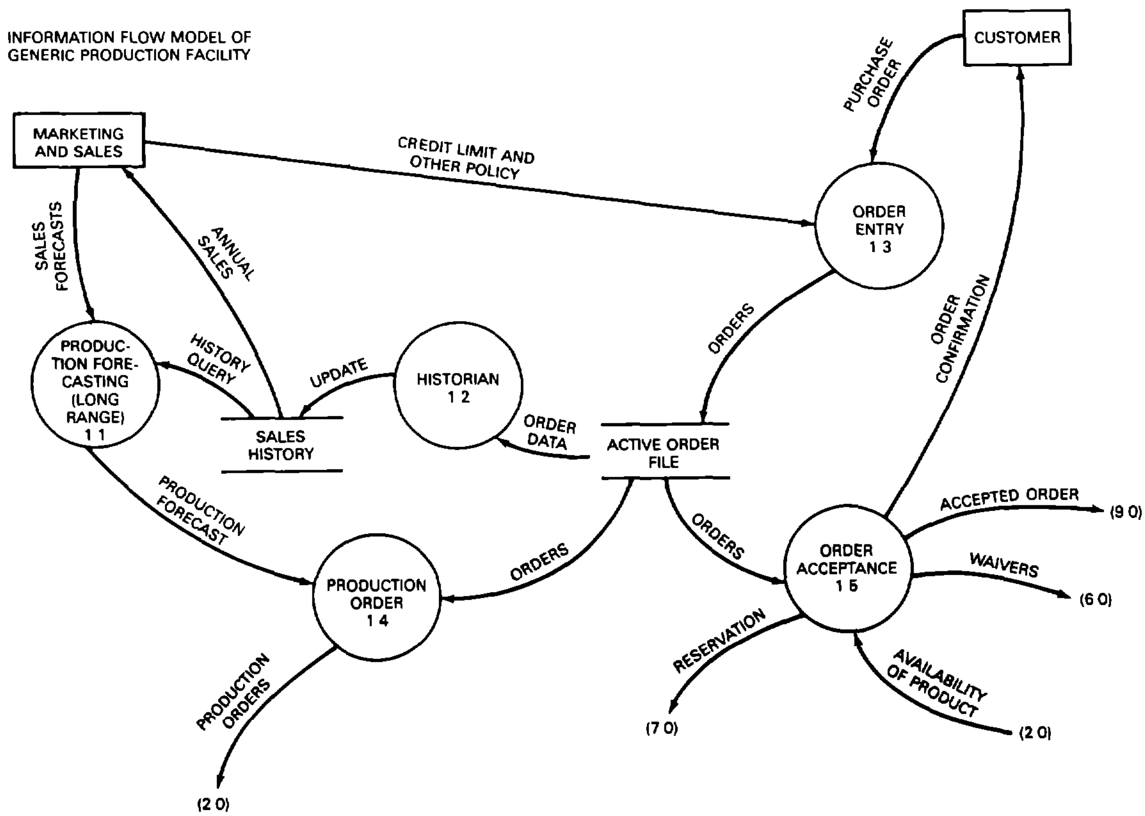


Figure 4-4 1.0 Order Processing.

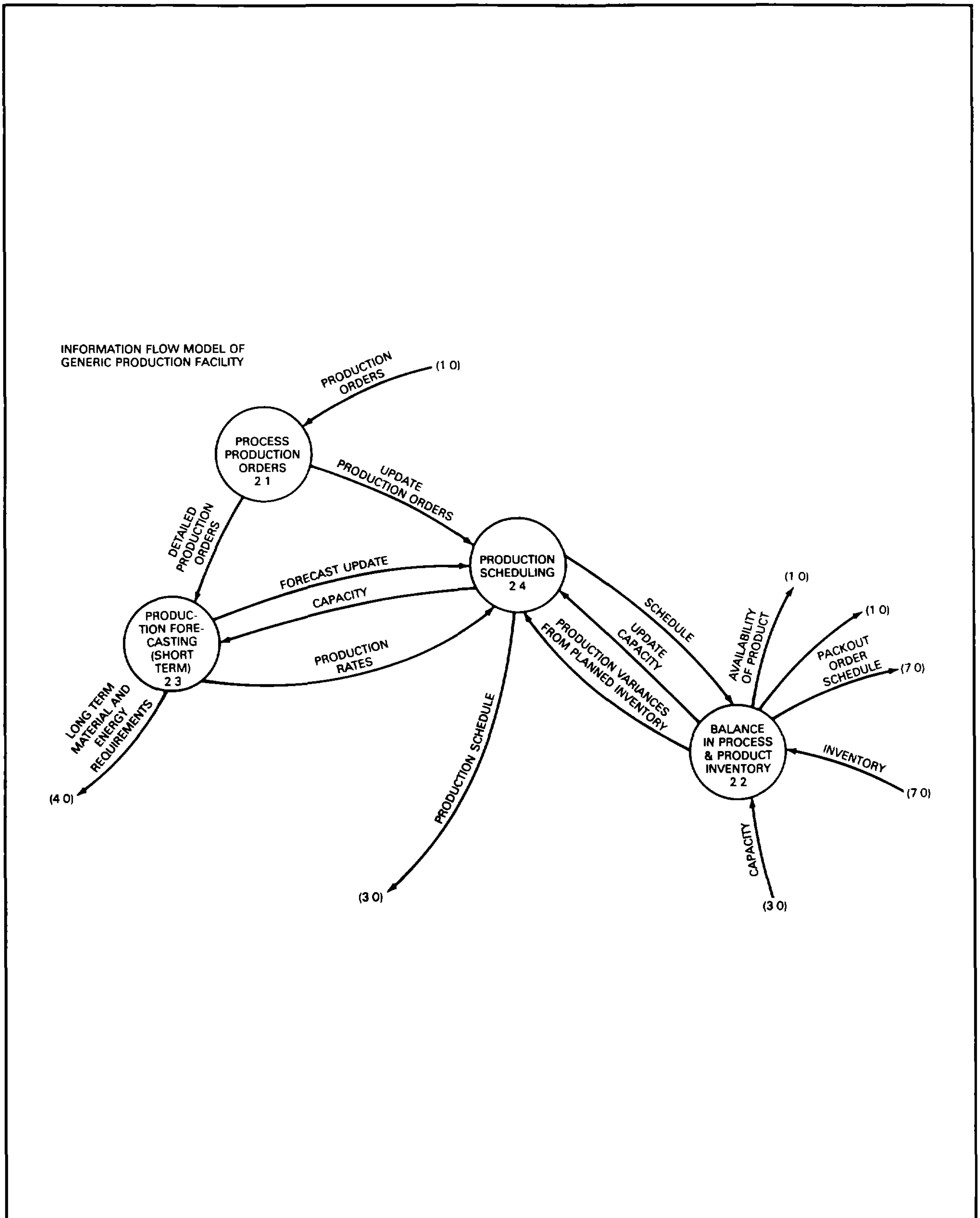


Figure 4-5 2.0 Production Scheduling.

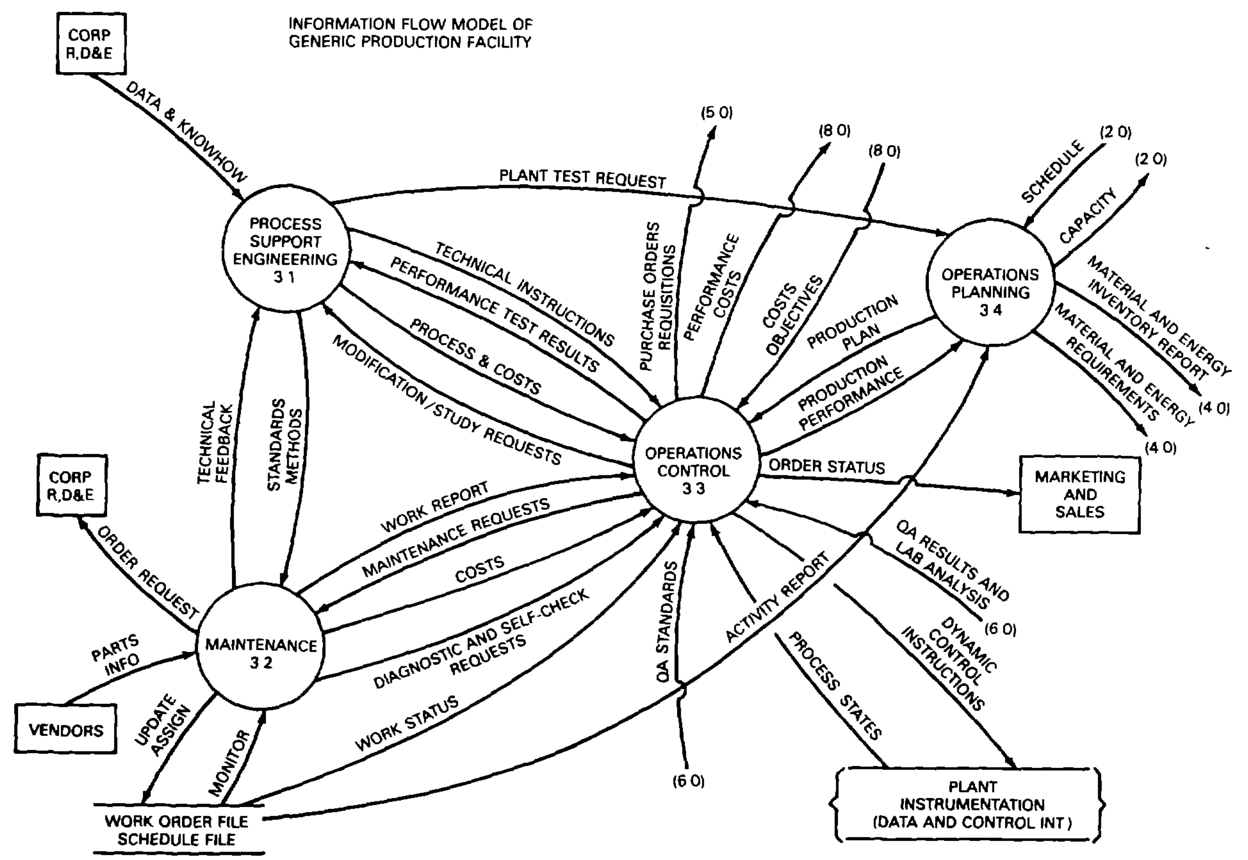


Figure 4-6 3.0 Production Control

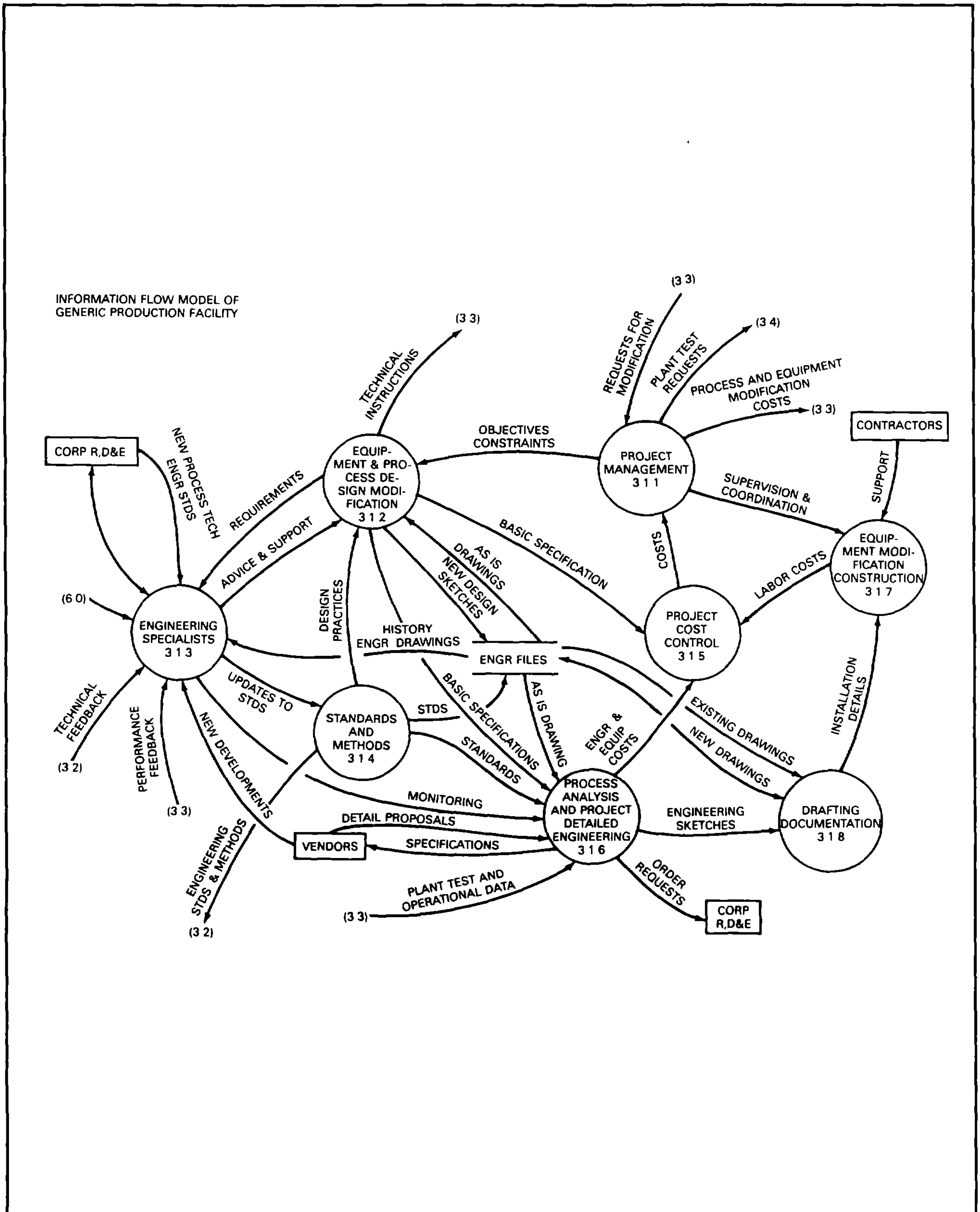


Figure 4-7 3.1 Process Support Engineering.

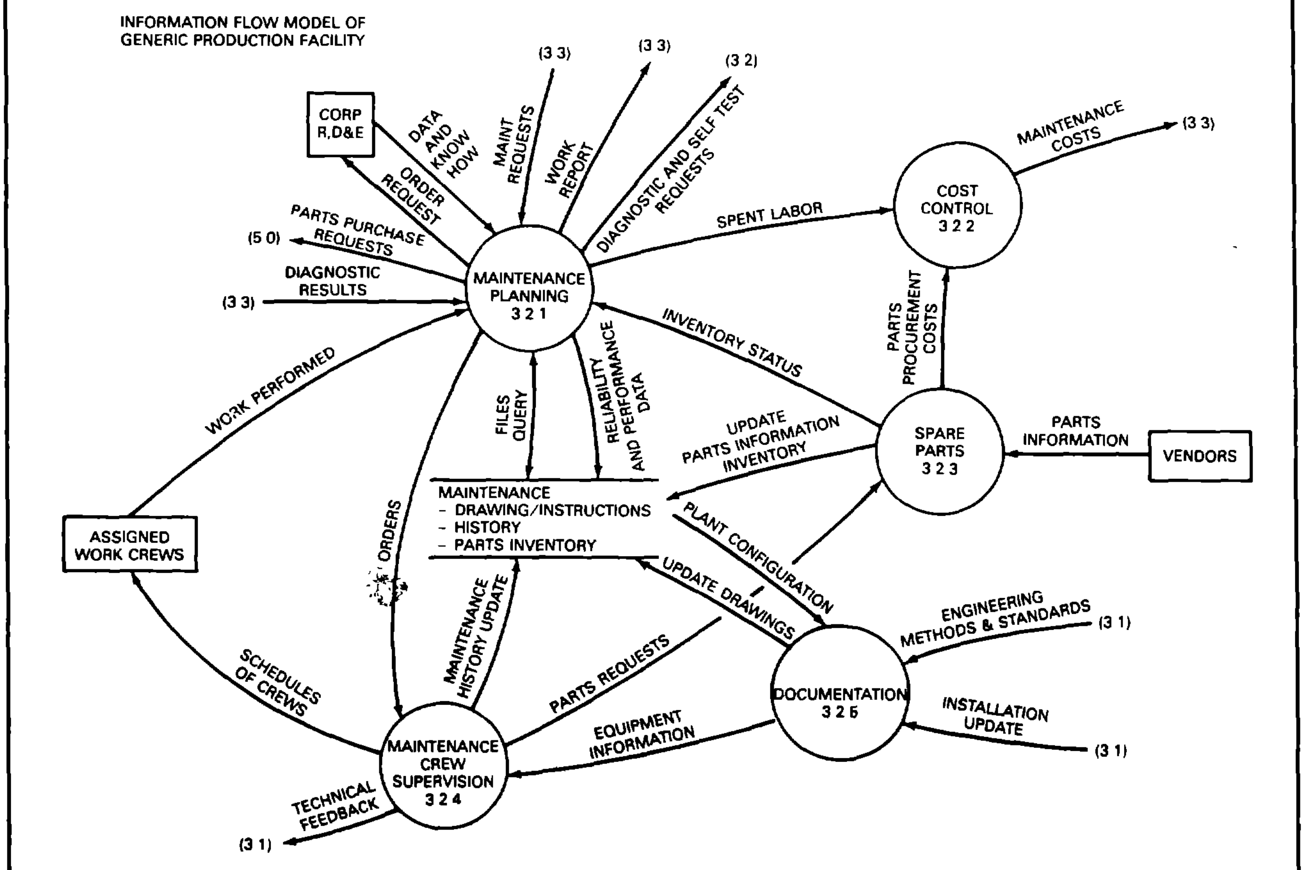


Figure 4-8 3.2 Maintenance.

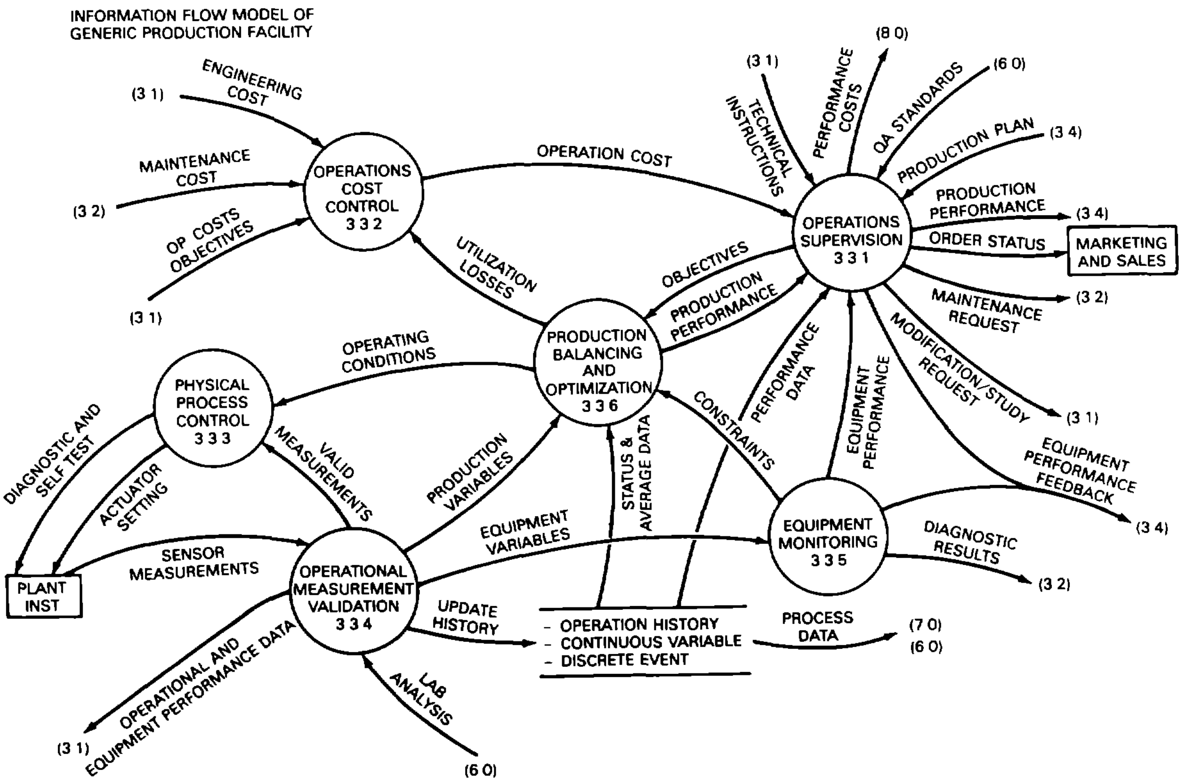
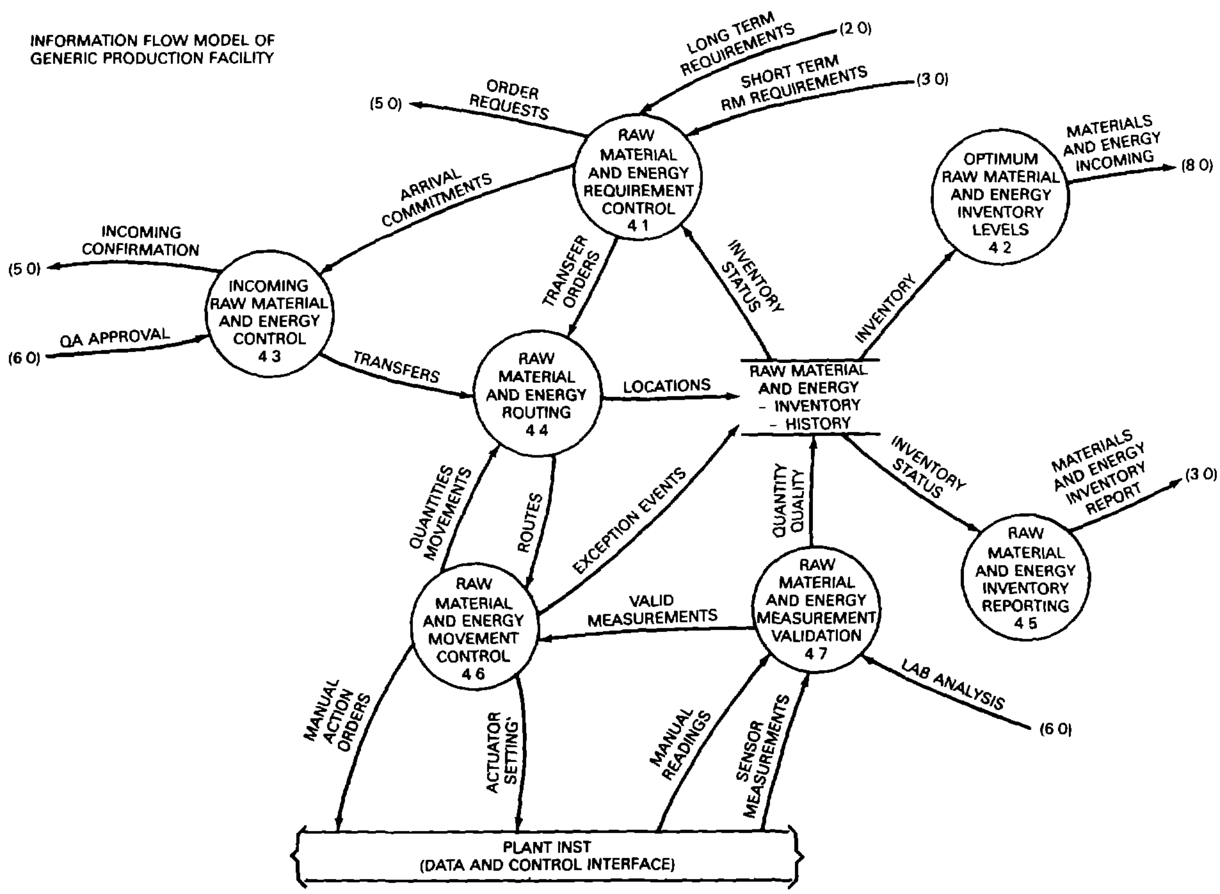


Figure 4-9 3.3 Operations Control.



gure 4-10 4.0 Materials and Energy Control.

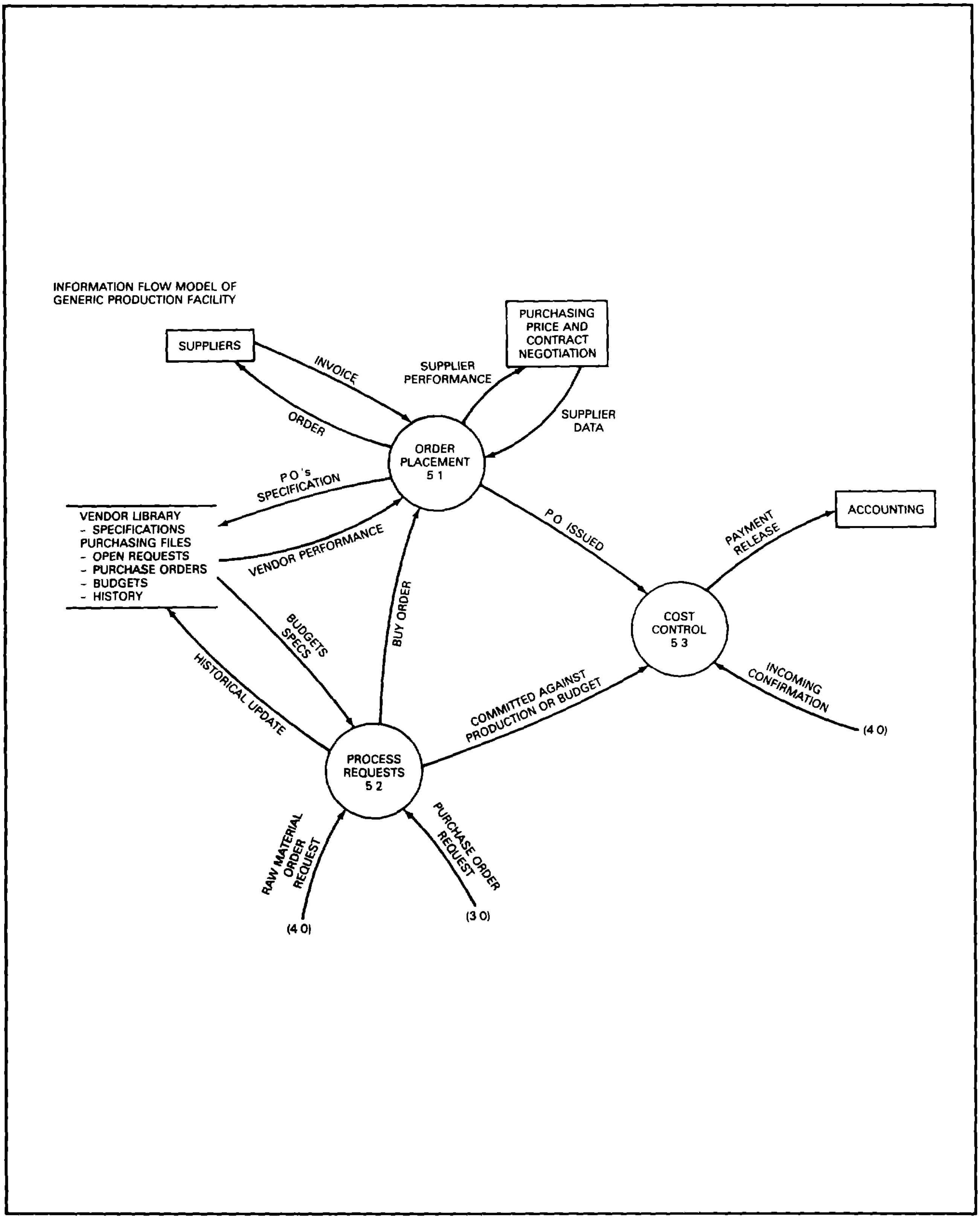


Figure 4-11 5.0 Procurement.

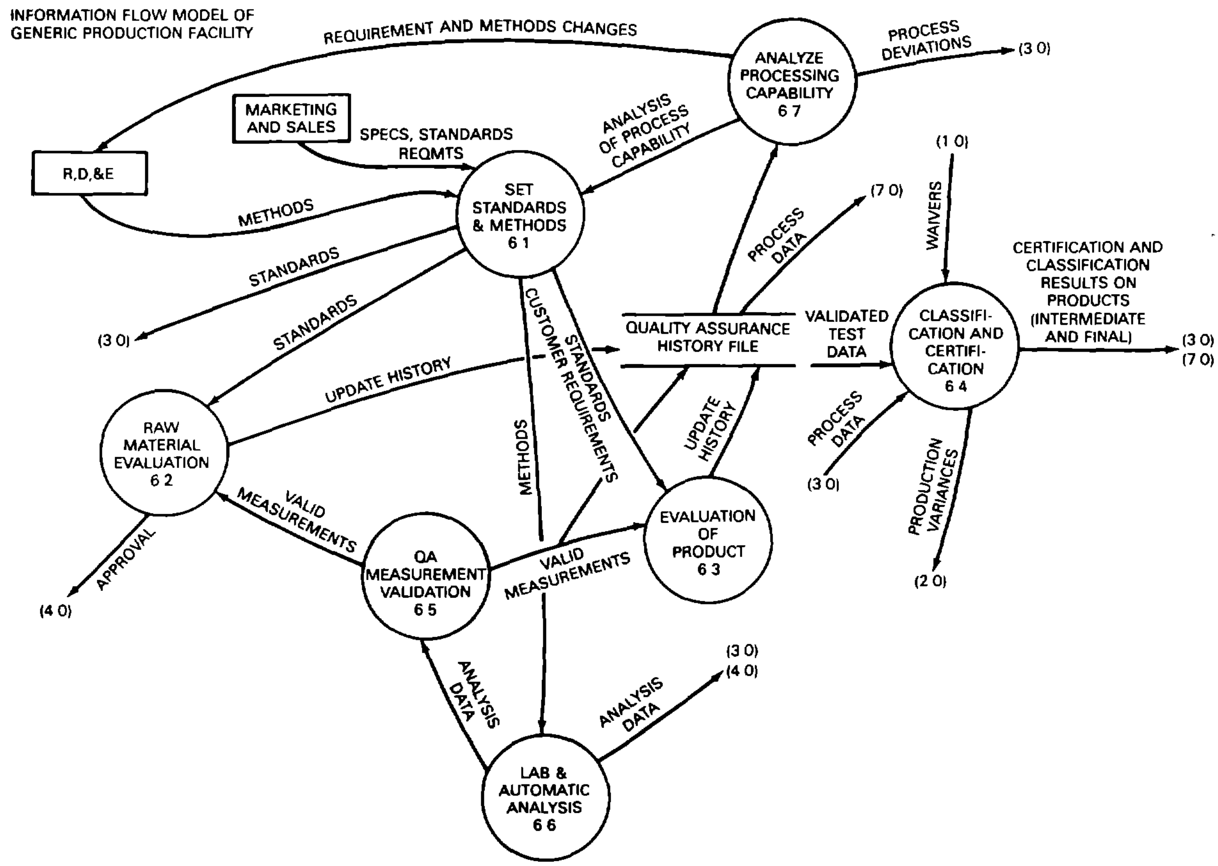


Figure 4-12 6.0 Quality Assurance.

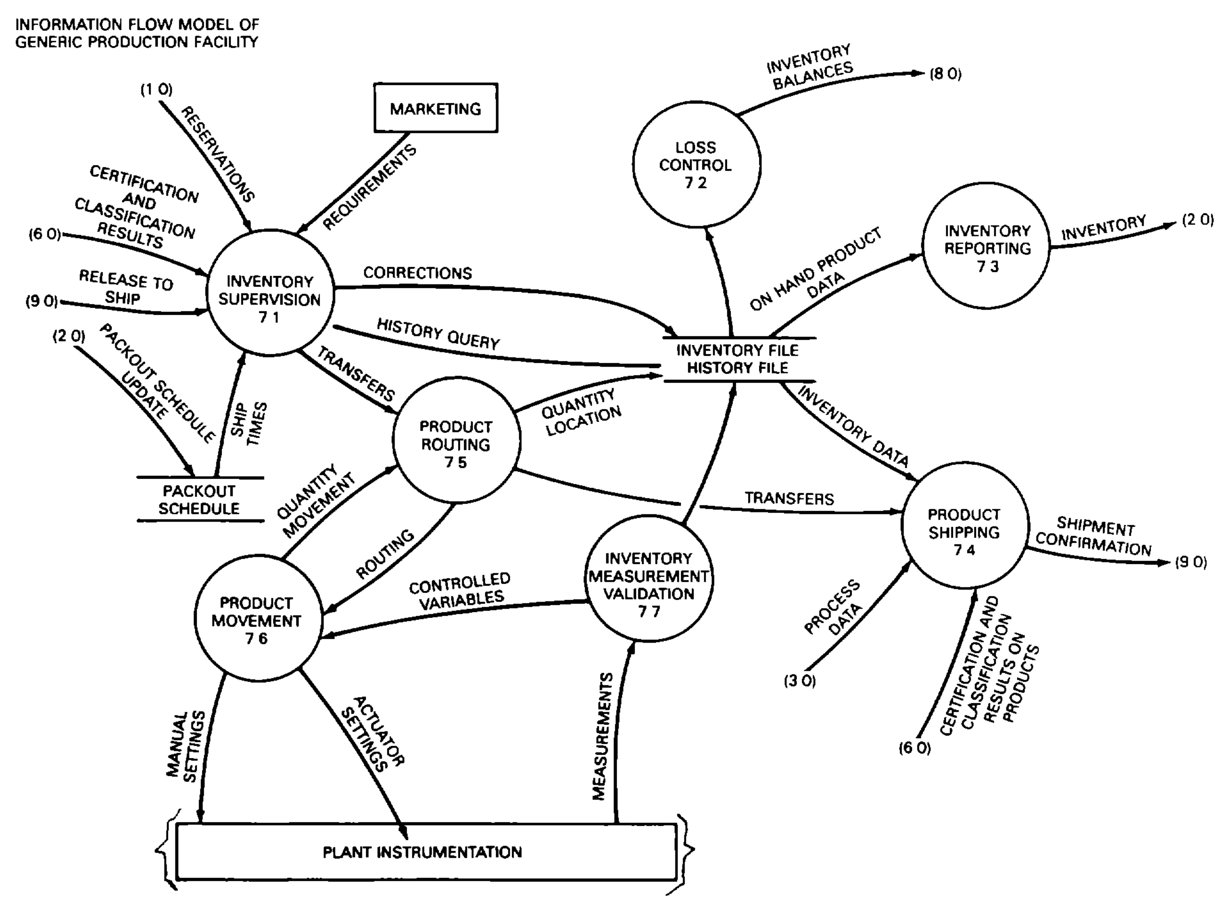


Figure 4-13 7.0 Product Inventory.

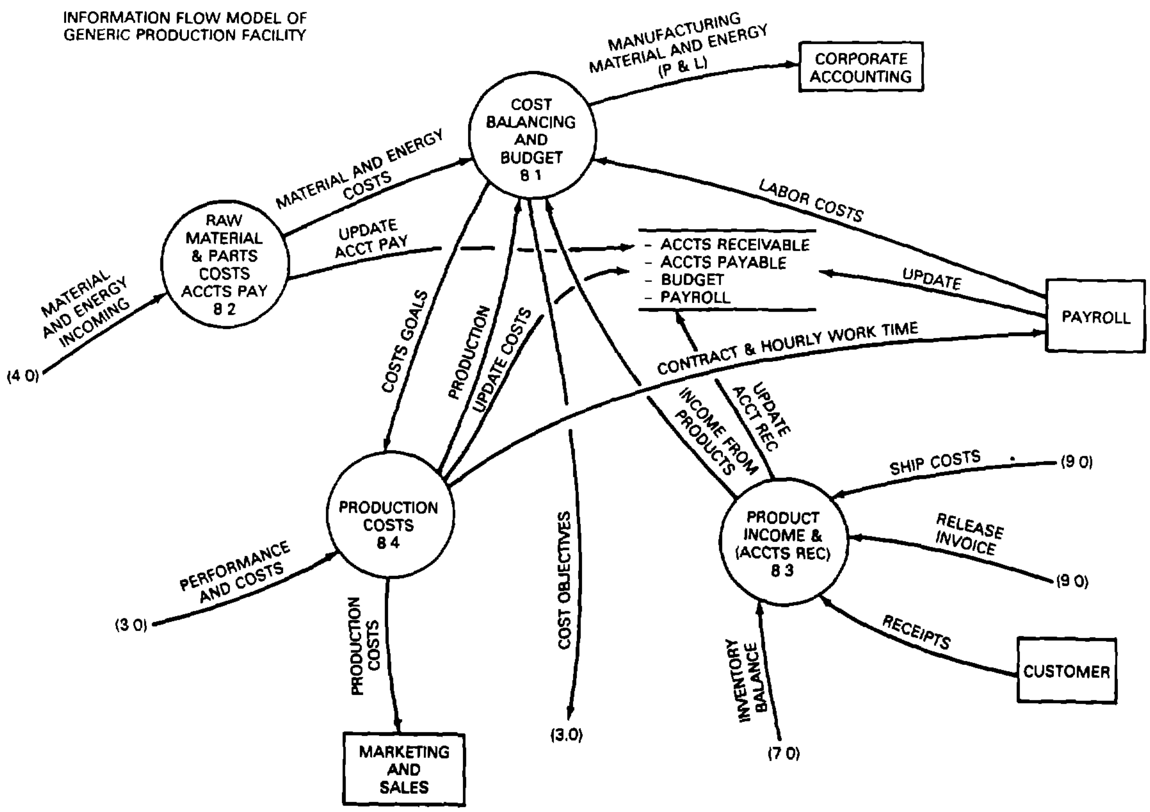


Figure 4-14 8.0 Cost Accounting.

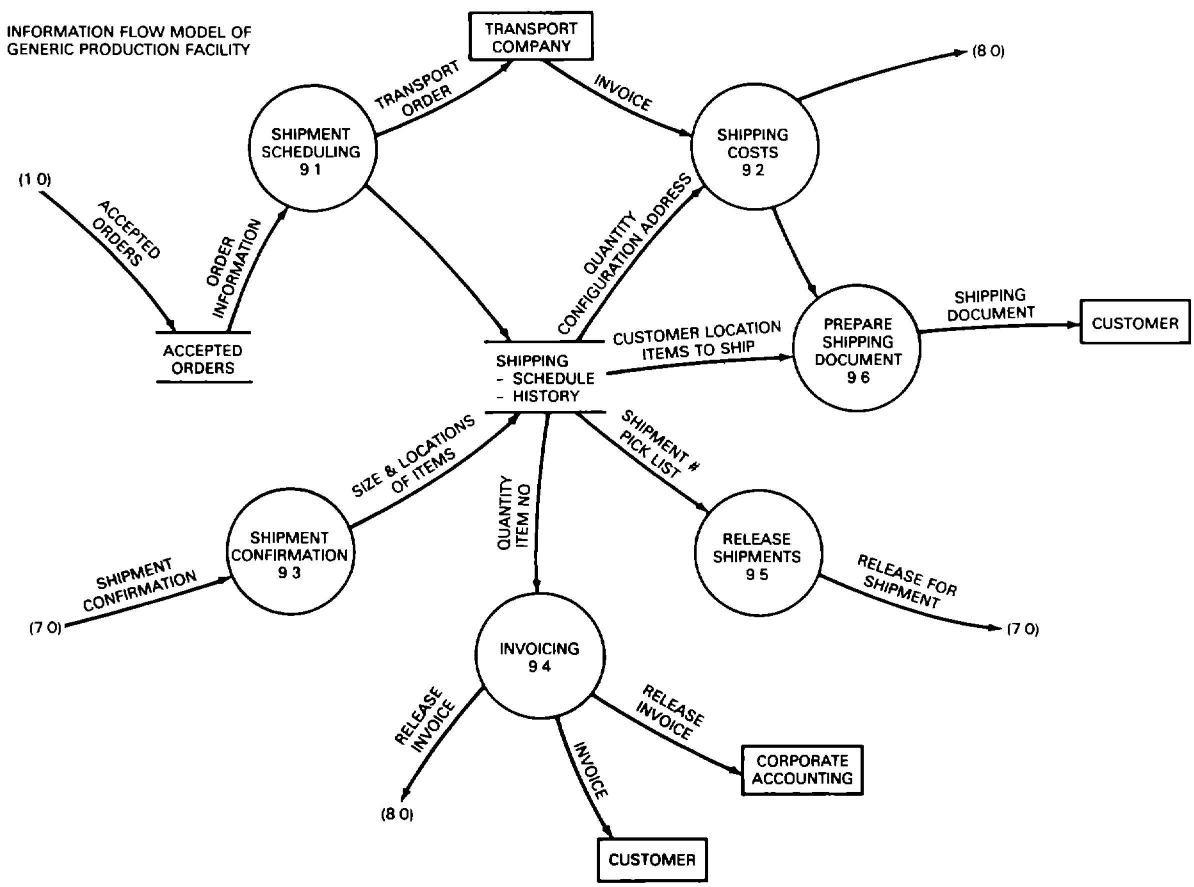


Figure 4-15 9.0 Product Shipping Administration.

TABLE 4-I

INFORMATION FLOW MODEL OF GENERIC PRODUCTION FACILITY MINI-SPECS (DEFINITION OF FUNCTIONS) FIRST ORDER ENTITY DIVISIONS

0. FACILITY MODEL CONTEXT

    Marketing and Sales

    Corporate R. D. & E.

    Suppliers

    Vendors

    Customers

    Transport Companies

    Accounting

    Purchasing

1. ORDER PROCESSING

    Customer Order Handling, Acceptance and Confirmation

    Sales Forecasting

    Waiver and Reservation Handling

    Gross Margin Reporting

    Determine Production Orders

2. PRODUCTION SCHEDULING

    Determine Production Schedule

    Identify Long Term Raw Material Requirements

    Determine Packout Schedule for End Products

    Determine Available Product for Sales

3. PRODUCTION CONTROL

    Control of Transformation of Raw Materials Into End Product in Accordance With Production Schedule and Production Standards.

    Maintenance of Processing Equipment

    Plant Engineering and Updating of Process Plans, etc.

    Issue Requirements for Raw Materials

    Produce Reports of Performance and Costs

    Evaluate Constraints to Capacity and Quality

    Self Test and Diagnostics of Production and Control Equipment

4. RAW MATERIALS CONTROL

    Keep Stock of Raw Materials

    Reorder Raw Materials According to Production Requirements

    Accept Delivery of Raw Materials, Request QA Tests and Release for Utilization After Approval

    Reporting on RM and Energy Utilization

    Reporting on RM Inventory to Production

5. PROCUREMENT

    Place Orders With Suppliers for RM Supplies, Spare Parts, Tools, Equipment and Other Required Materials

    Monitor Progress of Purchases and Report to Requisitioners

    Release Incoming Invoices for Payment After Arrival and Approval of Goods

6. QUALITY ASSURANCE

    Testing and Classification of Incoming Material and End Products

    Set Standard for Production QA in Accordance With Market and Technology Requirements

    Assist Production With Exceptional and Effective QA Tests

7. PRODUCT INVENTORY CONTROL

    Keep Stock of Produced End Products

continued

Table 4-I continued

Make Reservation for Specific Product on List in Accordance With Product Selling Directives

Pack-out End Product in Accordance With Schedule

Report on Inventory to Production Scheduling

Report on Balance and Losses to Product Cost Accounting

Arrange Physical Loading/Shipment of Goods in Coordination With Product Shipping Administration

8. PRODUCT COST ACCOUNTING

Calculate and Report on Total Product Cost

Report Cost Results to Production for Adjustment

Set Cost Objectives For Production

9. PRODUCT SHIPPING ADMINISTRATION

Organize Transport for Product Shipment in Accordance With Accepted Orders Requirements

Negotiate and Place Orders With Transport Companies

Accept Freight Items on Site and Release Material for Shipment

Prepare Accompanying Documents for Shipment (BOL, Customs Clearance)

Confirm Shipment and Release for Invoicing to General Accounting

Report on Shipping costs to Product Cost Accounting

SECOND-ORDER ENTITY SUBDIVISIONS

1.1 FORECASTING

The Orders Expected Within the Next Period of Time are Predicted

The Prediction is Based on the Sales History and Function of the Market Expectation

Forecasting Makes Use of the Traditional Statistical Techniques (Smoothing, Seasonal Indices, etc.)

The Forecasting Period is Set by the Confidence of Market Expectations

Market Expectations are Influenced by Outside Factors, e.g., Economical or Political Situation, or by Inside Factors, e.g., Long Term Contracts, Production Problems

1.2 HISTORIAN

Create and Update a Sales History File with Clarification of Product, Customer, Shipping Method...

1.3 ORDER ENTRY

Main Interface With Customer for Enquiries and Orders

Supply Product Price and Availability

Handle Order Entry and Amendments

Give Confirmation and Progress of Entered Orders

1.4 PRODUCTION ORDER

Based on Active and Forecasted Orders Determine the Required Production

1.5 ORDER ACCEPTANCE

Handle the Acceptance for Delivery of Entered Orders

Acceptance Is Based on Ability to Manufacture and Availability of Product Customer Credibility Is Checked

In Specific Cases the Product Specifications Can be Waived in Accordance With Marketing Policies to Ratify a Particular Customer or Market Need

continued

Table 4-I continued

2.1 PROCESS PRODUCTION ORDERS

- Produce Detailed Production Requirements From Sales Production Orders
- Highlight Specification Requirements for Non-Standard Requests
- Produce Production Order Entry in Scheduling File and Append Shipment Requirements

2.2 BALANCE INPROCESS PRODUCTION INVENTORY

- Identify Ordered Quantities Against Produced Products and Initiate Packout of Specific Shipments
- Identify Availability of On-Hand Product
- Highlight Variance in Production Schedule
- Maintain Capacity Estimates for Production Facility in Terms of Products

2.3 PRODUCTION FORECASTING

- From Existing Production Orders and Known Capacity, Produce Specific Schedule Entries for Production Rates and Specifications
- Set Long Term Raw Material Order Rates to Meet Production Schedule
- Produce a Long Term Forecast Report

2.4 PRODUCTION SCHEDULING

- Produce Formal Production Schedule
- Modify Production Schedule to Account for Production Variances and Interruptions
- Modify Production Schedule to Account for Inventory and Shipments

3.1 PROCESS SUPPORT ENGINEERING

- Issue Request for Modification or Maintenance
- Coordinate Maintenance and Engineering Activities
- Provide Technical Standards and Methods to Maintenance Function
- Follow-up on Equipment and Process Performance
- Provide Technical Support to Operators
- Follow-up on Technological Developments
- Provide Specifications for Purchase Order Requests

3.2 MAINTENANCE

- Provide Maintenance for Existing Installations
- Provide Preventative Maintenance Program
- Provide Equipment Monitoring Program to Anticipate Failure Including Self-Check and Diagnostic Programs
- Place Purchase Order Request for Materials and Spare Parts
- Develop Maintenance Cost Reports
- Coordinate Outside Contract Work Effort

3.3 OPERATIONS CONTROL

- Supervise the Operations of Production Process
- Keep Track and Report on Production Costs and Performance
- Interpret the Production Plan in Terms of the Setpoints to Individual Units
- Diagnostics and Self-Check of Production and Control Equipment

3.4 OPERATIONS PLANNING

- Set up a Daily Production Plan as Function of the Production Schedule
- Check Schedule Against Raw Material Availability and Product Storage Capacity

continued

Table 4-I continued

Determine Percent of Capacity Status

Modify Production Plan Hourly to Account for Equipment Outage, Manpower and Raw Materials Availability

4.1 MATERIAL AND ENERGY REQUIREMENTS CONTROL

Determine Supplier of New Materials Based on Short and/or Long Term Requirements From Planning or Manufacturing Taking Existing Inventory Into Account

Set Up Transfers of Materials and Energy to Manufacturing

Issue Purchase Request for New Material and Energy Supplies

Notify Incoming Material and Energy Control on Expected Incoming Orders

4.2 OPTIMUM MATERIAL AND ENERGY INVENTORY LEVELS

Continuously Calculate and Report Inventory Balance and Losses of RM and Energy Utilization

4.3 INCOMING MATERIAL AND ENERGY CONTROL

Receive Incoming Material and Energy Supplies and Request QA Tests

Transfer Material and Energy to Storage and/or Classify for Use After QA Approval

Notify Purchasing of Accepted Material and Energy Supplies to Release Payment

4.4 MATERIAL AND ENERGY ROUTING

Set up and Monitor the Movement of Material and Energy in Storage

Update Inventory of All Movements and Changes

4.5 MATERIAL AND ENERGY INVENTORY REPORTING

Reporting of Inventory to Production

4.6 MATERIALS AND ENERGY MOVEMENT CONTROL

Control and Monitor Transfer of Materials

4.7 MATERIALS AND ENERGY MEASUREMENT VALIDATION

See 3.3.4

5.1 ORDER PLACEMENT

Order Preparation for Raw Materials, Spare Parts, etc., for Presentation to the Vendors Based on Procurement Contracts Negotiated by Company Purchasing

Updating of Vendor Library and Purchasing Files of Vendors Performance on Orders

5.2 PROCESS REQUESTS

Collection and Processing of Unit Requests for Raw Materials, Spare Parts, etc., for Order Placement to Vendors

Checking of Requests for Those Materials Versus Historical Files and Budgets to Assure Correctness of Requests

5.3 COST CONTROL

Certification of Invoices on Raw Materials and Spare Parts Based on Satisfactory Receipt of Requested Materials or Parts

6.1 SET STANDARDS AND METHODS

Issue Standards to Manufacturing and Testing Laboratories in Accordance With Requirements From Technology, Marketing and Customer Services

6.2 RAW MATERIALS EVALUATION

Testing of Incoming Raw Materials and Approval for Use if in Accordance With Set Standards

Collect and Maintain Quality Control File for Data for Quality Control Analysis

continued

Table 4-I continued

6.3 EVALUATION OF END PRODUCT

Test of Final Product and Report Results to Classification

Collect and Maintain Quality Control File for Data for Quality Control Analysis

6.4 CLASSIFICATION AND CERTIFICATION

Classify Quality and Properties of End Product in Accordance With Set Marketing Standards

Waiver Classification on Exceptional Basis as Per Request from Product Selling

Report QA Results and Classification to Finished Product Inventory Control

Certify that Product was Produced According to Standard Process Conditions

Report Process Data and Certification to Finished Product Inventory Control

6.5 QA MEASUREMENT VALIDATION

Checking of Product Data Versus Customer's Requirements and Statistical Quality Control Routines to Assure Adequate Quality Before Shipment

Maintenance of Quality Statistics on Each Item Checked for Continuing Quality Control Studies.

6.6 LABORATORY AND AUTOMATIC ANALYSIS

Conduct of Metric, Chemical and Physical Tests on Sample Product Items to Obtain Data for On-Going Quality Control Tests

Transmission of This Data to Analysis Facilities and Quality Control Systems to Assure Future Quality of Product

6.7 ANALYZE PROCESS CAPABILITY

Use SQC Methodology to Examine Product Data to Determine Process Capability of Meeting Product Specifications

Relay Process Deviations to Process Engineering for Reevaluation to Upgrade Process

Relay Methods Deviation to Standards and Methods Group for Corrective Action

7.1 INVENTORY SUPERVISION

Coordinate All Activities in Product Inventory Control

Set up Transfers of Material to Packing Unit in Accordance to Packout Schedule

Request Replenishment of Packing Materials

Handle Reservations and Update Inventory Accordingly

7.2 LOSS CONTROL

Continuously Calculate and Report on Inventory Balance and Losses

7.3 INVENTORY REPORTING

Generate Daily, Weekly ... Reports on Actual Amounts of Materials in Storage

7.4 PRODUCT SHIPPING

Set up and Monitor Transfers of Products to Customer in Accordance With Requirements From Shipping Administration

Report Confirmation of Shipment for Release of Invoicing

7.5 PRODUCT ROUTING

Set up and Monitor the Routes of Product Transfer
Update Inventory on Changes

7.6 PHYSICAL PRODUCT MOVEMENT CONTROL

See 4.6

7.7 MEASUREMENT VALIDATION

See 3.3.4

8.1 BALANCING AND BUDGET

Establishment of Criteria and Tests to Assure That Operational Budget is Being Followed

continued

Table 4-1 continued

Collection of Raw Material, Labor, Energy and Other Costs for Transmission to Accounting

8.2 RAW MATERIAL AND PARTS COSTS (ACCOUNTS PAYABLE)

Collection of Cost Data on All Raw Materials and Spare Parts in Inventory or Procured for the Plant

8.3 PRODUCT INCOME (ACCOUNTS RECEIVED)

Collection of Data of Product Shipped or in Inventory

Release Invoice Data to Cost Accounting at Standard Cost

8.4 PRODUCTION COSTS

Collection of Data on Costs of Production in the Plant - Labor, Energy, Raw Material Usage, Spare Parts Usage, etc.

9.1 SHIPMENT SCHEDULING

Classify Accepted Order and Produce Shipping Schedule

9.2 SHIPPING COSTS

Calculate and Report Cost of Shipping

9.3 SHIPMENT CONFIRMATION

Update Shipping Schedule to Indicate That Shipping has Been Done and Configuration of Shipments

9.4 RELEASE FOR INVOICING

Notify Accounting of Shipment in Order to Release Invoice

9.5 RELEASE SHIPMENT

Send Information for Shipment to Product Shipping

9.6 PREPARE SHIPPING DOCUMENTS

Issue Bill of Lading, Customer Clearance, Documents That are Required with Shipment

THIRD-ORDER ENTITY SUBDIVISIONS

3.1.1 PROJECT MANAGEMENT

Management of Engineering Function

Coordination of Equipment and Process Modification

Cost and Progress Reporting

Project Planning

Design Follow-up With Corrective Action

3.1.2 EQUIPMENT AND PROCESS DESIGN MODIFICATIONS

Establish Design Basis of New Project

Supply Necessary Information to Allow Cost Estimating

Report and Coordinate Specialists' Assistance

Provide Technical Information to Operators

3.1.3 ENGINEERING SPECIALISTS

Provide Support and Advice in Special Area

Follow-up on State of the Art in Technology

Assess Plant Process and Equipment Performance

Adjust Standards and Methods to Needs and Progress

Monitor the Interpretation of Design Basis During Detailed Engineering

3.1.4 STANDARDS AND METHODS

Establish Standards for Process Equipment, Design Techniques and Process Operational Methods (Practice Files)

Promulgate Such Standards Within the Process Support Engineering Functions and Within the Operational Groups of the Factory

continued

Table 4-I continued

3.1.5 PROJECT COST CONTROL

Provide Cost Estimates of Planned Projects

Follow-up and Report on Costs of Projects in Execution

3.1.6 PROCESS ANALYSIS AND PROJECT DETAILED ENGINEERING

Conduct Plant Performance Studies

Provide Details for the Construction of Equipment or Process Modification Project in Accordance to Design Basis

Issue Report for Ordering of New Equipment

Issue Specifications to Vendor

Report on Engineering and Committed Equipment Costs

3.1.7 EQUIPMENT MODIFICATION CONSTRUCTION

Provide for Construction of Project

Report on Cost and Labor

3.1.8 DRAFTING DOCUMENTATION

Maintain Master Copies of All Plant Drawings for Units Under Its Cognizance

Responsible for Updating Drawings and Associated Documentation as Units Are Modified

Supply Copies as Needed

3.2.1 MAINTENANCE PLANNING

Organization and Supervision of Requested Maintenance

Reporting on Performed Maintenance

Coordinate Planned Work With Operators and Plant Supervision

Monitor and Update Maintenance History File

3.2.2 MAINTENANCE COST CONTROL

Follow-up on Used Spare Parts, Report Maintenance Labor and Report on Maintenance Costs

3.2.3 SPARE PARTS

Supervise Spare Parts Warehouse

Supply Necessary Parts to Maintenance Crews

Report on Inventory to Planning for Reordering

Report to Cost Control on Used Parts

Accept and Control New Delivered Parts From Vendors

3.2.4 MAINTENANCE CREW SUPERVISION

Perform Requested Maintenance Work

Supervise and Coordinate With Outside Contractors

Report on Technical Activities to Files

Report on Installation and Equipment Performance to Engineering

3.2.5 DOCUMENTATION

See Item 3.1.8

3.3.1 OPERATIONS SUPERVISION

Set Objectives for Process Operation

Supervise People in Operation of the Process and Equipment

Deal Directly in the Resolution of Exception Conditions

Issue Modification or Maintenance Requests

Set and Report Production Capacity Limits

Monitor and Report on Production Cost and Performance

3.3.2 OPERATIONS COST CONTROL

Calculate Total Operating Costs

continued

Table 4-I continued

Maintain Short Term Economic Balances of Energy and Materials

Capture Maintenance and Engineering Costs Chargeable to Operations

3.3.3 PHYSICAL PROCESS CONTROL

Stabilize Process Variables to Defined Operating Setpoints

Alarming of Operating Variables for Exceptional Conditions

Maintain Operation Against Constraints or at Specifications

Response to Operators and Process Engineers Requests

Response to Emergencies

3.3.4 OPERATIONAL MEASUREMENT VALIDATION

Assess the Validity of the Measurements for Further Use Within Their Limits of Confidence

Tag Measurement Data With Quality and Time

3.3.5 EQUIPMENT MONITORING

Assess the Operating Performance and Limits of Process Equipment

Alarming of Equipment Status Variables Against Constraints

Indicate Performance Against Expected Equipment Life Cycles

3.3.6 PRODUCTION OPTIMIZATION AND BALANCING

Optimization of Production Process to Set Objectives Within Equipment Constraints

Maintain Material and Energy Balance to Indicate Exceptional Conditions

Perform Performance Tests Where Necessary to Determine Capacity

Monitor Product Quality Against Specifications and Standards

TABLE 4-II

INFORMATION FLOW MODEL OF GENERIC PRODUCTION FACILITY

DATA DICTIONARY

ACCEPTANCE

=*Updating of Active Order to Indicate Acceptance of Order*

ACTIVE ORDERS

=*Details of all Entered Orders (Customer ID, Product Type, Quantity, Delivery Date, Shipping Requirements ...)*

ACTUATOR SETTINGS

=Output to Process Equipment, Valve Position, Motor Status

ADVICE SUPPORT

=Assistance From Engineering Specialists*

AVAILABLE PRODUCT

=*Inventory + Planned Production - Accepted Orders*

CONSTRAINTS

=Actual Operating Limits of Process Equipment

CONTACTS

=Inquiries, Orders, Information, Confirmation

CONTRACTOR PLANNING

=Schedules of Requests for Outside Contractor Assistance

CONTROLLED VARIABLES

=Validated Measurements for Direct Control of Pressure, Temperature, Flow, etc.

COST OBJECTIVES

=Cost Goals Determined by Product Cost Accounting

continued

Table 4-II continued

COST SPECIFICATIONS

=*Details to Allow Cost Estimating, Gross Layout, Preliminary Equipment List....*

COSTS POLICIES

=Marketing Costs + Profit Margin

CREDITS AND LIMITS

=*Information on Credibility of Customer, Financial Situation...*

CUSTOMER DETAILS

=*Customer Information (Name, Address, Shipping Address, Credibility, Special Needs....*

DATA KNOWHOW

=*Technical Information on State-of-the-Art of Technology, RD

DESIGN BASIS

=*Document That Contains the Basis of a Design to Allow Further Detailed Engineering

DESIGN PRACTICES

=*Engineering Methods, Standards, Practices*

DETAILS

=Technical Details of New Equipment

DIAGNOSIS REPORT

=Technical Report on Malfunction Reasons

ENGINEERING EQUIPMENT COSTS

=Total Cost of Engineering and Purchased Equipment

ENGINEERING DETAILS

=*Documents and Information to Vendors or Contractors

ENTRY

=Order Details (Customer ID + Product Type and Quantity + Required Delivery Date + Special Requirements, etc...)

EQUIPMENT INFORMATION

=Drawings, Instructions, Data on Installed Equipment

EQUIPMENT ORDER REQUEST

=Purchase Order Request for New Equipment

EQUIPMENT PERFORMANCE

=Actual Operating Performance of Process Equipment, Power, Temperatures, Overall Condition

EQUIPMENT VARIABLES

=Validated Measurements Related to Equipment Performance, Vibration, Displacement, Pressures, Temperatures, Corrosion Analysis

EXCEPTION POLICIES

=*Rules and Guidelines FromMarketing to Handle Waiver and Special Requirements When Accepting an Order

FORECASTED ORDERS

=*Expected Orders to Deliver Within a Period of-Time*

GROSS MARGIN

=Selling Price – ProductCost

INCOMING CONFIRMATION

=Updating of Incoming Material Status to Release Payment

INSTALLATION DETAILS

=Documentation, Drawing Information and Instructions for Construction

INSTALLATION UPDATES

=Documentation, Drawing Information and Instruction for New Installed Equipment

INVENTORY

=Actual Quantities, Specifications, Location of Materials in Storage

continued

Table 4-II continued

INVOICE

=Invoice of Performed Transport, of RM or Other Supplies

LABOR COSTS

=Cost and Labor Reporting on Construction Activities

MAINTENANCE COSTS

=Total Calculated Maintenance Cost Report by Work Order, Time Period...

MAINTENANCE HISTORY

=Technical Details on Performed Work, Diagnosis, Used Parts, etc.

MAINTENANCE REQUEST

=Request for Repair of Equipment Identification Systems, Reason...

MARKET EXPECTATIONS

=*Assessment of the Market Situation of the Products*

MEASUREMENTS

=Data From Process Sensors

MODIFICATION REQUESTS APPROVALS

=Requests, Approval, Basic Information for Modification of Equipment or Design of New Facilities

MONITORING

=Follow up of Engineering Work to Ensure Adherence to Standards and CorrectInterpretation of Design Basis

OBJECTIVES

=Throughput, Yield, Rates, Quality

OBJECTIVES CONSTRAINTS

=*Basic Information and Limits of New Projects, Project Adjustments, Cost Control Adjustments*

OPERATING CONDITIONS

=Calculated Optimum Process Operating Conditions and Targets

OPERATING COSTS

=Total Operating Costs=Maintenance + Engineering + Operation + RM + Energy + Looser Costs

ORDER INFORMATION

=*Information on Accepted Order (Confirmation, Due Date, Changes...)*

ORDERS INQUIRIES

=*Request for Information on Product or Formal Purchase Order*

OVERHEAD COSTS

=*Costs of Non-Productive Services (Accounting, Administration, Management...)*

PART SUPPLIES

=Delivery of Parts to Maintenance Crews

PARTS ORDER REQUEST

=Purchase Order Request for Spare Parts Replenishment

PARTS REPLENISHMENTS

=Supply of Reordered Parts to Replenish Inventory

PARTS REQUEST

=Request to Spare Parts Warehouse for Parts by Work Order

PERFORMANCE AND COSTS

=Operating Performance and Cost Reporting, Rates, Utilization, Yield, Quality...

PERFORMANCE FEEDBACK

=Feedback on Plant Equipment and Process Performance

PERFORMED WORK

=Time Reports per Work Order

PRICE

=Product Cost and Marketing Cost

continued

Table 4-II continued

PRODUCT COST

=*Total Manufacturing Cost of Product Excluding Sales, Marketing and Company Overhead*

PRODUCT INFORMATION

=*Product Related Sales Information (Price, Availability, Documentation...)

PRODUCTION LIMITS

=Actual Rate of Production Capacity by Unit, per Product

PRODUCTION ORDERS

=Forecasted and Accepted Orders

PRODUCTION PERFORMANCE

=Throughput, Yield, Rates, Quality

PRODUCTION PLAN

=Detailed Production Planning by Unit, Equipment, Product...

PRODUCTION VARIABLES

=Validated Measurement Related to Production Performance Weights, Rates, Analysis, Levels

PROGRESS COSTS

=*Progress Cost Reporting of Running Projects*

PROJECT COSTS

=*Project Costs, Estimates, Projected Cost*

PROJECT PLANNING

=Project Schedule Work Planning*

QA APPROVALS

=Classification of QA Results After Testing

QA RESULTS

=Classification and Test Results for Finished Product

QA STANDARDS

=Limits, Specifications and Standards for In-Process Quality Control

QUANTITIES LOCATIONS

=Updates to Inventory of Locations, Quantity, Specification of RM

QUANTITIES MOVEMENTS

=Actual Quantities and Status of Transfer

RELEASE FOR SHIPMENT

=Quality, Location, Destination of Product to be Shipped

REPORTING

=Customer Credit Limits, Gross Margin Reporting Overhead Costs Reports

RM ENERGY UTILIZATION

=Total of Raw Materials,

Parts, Tools and Incoming Energy, Consumed or Transferred on Hourly, Daily, Monthly Basis

RM ORDER REQUEST

=Request to Order Raw Materials, Quality, Type Specifications, Special Requirements...

ROUTES

=Routing and Commands to Initiate a Physical Transfer of Materials

SALES HISTORY

=*Sales Performance of the Product Over the Past

SAMPLES

=Samples of Materials Sent to QA for Testing

SHIPMENT CONFIRMATION

=Signal to Product Administration That Actual Shipment Has Been Done

SHIPPING COSTS

=Total and Actual Cost of Transport per Shipment, per Month, etc....

SHIPPING DOCUMENTS

=Bill of Lading, Customer Clearance.....

continued

Table 4-II continued

SPARES INVENTORY

=Inventory of Spare Parts

SPECIALIST REQUIREMENTS

=*Outlines of Needs for Specialist Assistance*

SPECIFICATIONS

=Technical Specifications for New Equipment

SPENT LABOR

=Total Spent Labor Per Work Order

STANDARDS

=Limits, Specifications, Standards and Testing Methods for Quality Control

STANDARDS UPDATES

=Updating of Standards, Methods and Practices to Actual Need and State-of-the-Art

STATUS

=Actual Values of Operating Variables, Flows, Pressures, Temperatures, etc..

SUPERVISION

=*Supervision and Coordination of Construction Activities*

SUPERVISION COORDINATION

=Supervision of Outside Contractors

SUPPORT

=Labor and Services Report From Outside Contractors

TECHNICAL FEEDBACK

=Feedback on Installation and Specific Equipment Performance

TECHNICAL INSTRUCTIONS

=Operation Instructions Data on Process and Equipment

TEST RESULTS

=Report on Performed Tests, Including Quality

TIME

=Time of Spent Work of Individual, by Work Order

TRANSFERS

=Source, Destination, Route, Quantity of Material to be Transferred

TRANSPORT ORDER

=Order to Transport Company to Arrange Transportation

UPDATE

=*Updating Information for Rates History File

USED PARTS

=Cost Report on Used Parts for Each Work Order

UTILIZATION LOSSES

=Utilization and Unbalances of Raw Materials and Energy

WAIVERS

=*Exceptional Changes to the Quality Classification of a Specific Quantity of an End Product*

WORK ORDER

=Transmittal to Maintenance of Order to Perform Work (Work Description, Symptoms, Special Precautions, Clearance Procedures...)

WORK REPORT

=Reporting on Performed Maintenance Time, Diagnosis, Used Parts...

TABLE 4-III
CORRELATION OF INFORMATION-FLOW TASK WITH THE TASKS OF THE SCHEDULING AND CONTROL HIERARCHY

DATA FLOW DIAGRAM LISTING		SCHEDULING AND CONTROL HIERARCHY	
FIGURE NO. AND LOCATION	TITLE	TABLE NO. AND ENTRY	TITLE
Figure 4-3 Task 1.0	Order Processing	Table 3VIII Item I(2)	Production Scheduling
Figure 4-3 Task 2.0	Production Scheduling	Table 3VII Item I (1-3, 5)	Production Scheduling
		Table 3VIII Item I (1,3)	Same
Figure 4-3 Task 3.0	Production Control	Table 3VIII Item I (2)	Area Optimization
		Table 3IX Item II	Control Enforcement
		Table 3X Item II	Same
Figure 4-3 Task 4.0	Raw Material Control	Table 3VIII Item I (4)	Optimum Inventory Levels
		Item III (6,7)	Procurement Order Entry
Figure 4-3 Task 5.0	Procurement	Table 3VII Item III (6,7)	Procurement Order Entry
Figure 4-3 Task 6.0	Quality Assurance	Table 3VIII Item III (9)	Quality Control File
		Table 3VIII Item III (8)	Statistical Quality Analysis and Control Functions

TABLE 4-III cont.

DATA FLOW DIAGRAM LISTING		SCHEDULING AND CONTROL HIERARCHY	
FIGURE NO. AND LOCATION	TITLE	TABLE NO. AND ENTRY	TITLE
Figure 4-3 Task 7.0	Product Inventory Control	Table 3VII Item I (4)	Optimum Inventory Levels
		Item III (8)	Goods in Process Inventory
Figure 4-3 Task 8.0	Product Cost Accounting	Table 3VII Item III (6-8)	Production and Raw Material, Energy Source and Spare Parts Use Data Plus Inventory Data
		Table 3VIII Item III (4,6)	Same
		Table 3IX Item III (3)	Same
		Table 3X Item III (3)	Same
Figure 4-3 Task 9.0	Product Shipping Adm	Table 3VI Item III (1B, 2B)	Product Inventory and Production Status and Data
		Table 3VIII Item III (8)	Same
Figure 4-4 Task 1.1	Production Forecasting	Table 3VII Item I (1)	Basic Production Schedule (See also Table 8-II and Figure 8-5)
Figure 4-4 Task 1.2	Historian	Table 3VII Item I (1)	Basic Production Schedule (See also Table 8-III and Figure 8-5)

TABLE 4-III cont.

DATA FLOW DIAGRAM LISTING		SCHEDULING AND CONTROL HIERARCHY	
FIGURE NO. AND LOCATION	TITLE	TABLE NO. AND ENTRY	TITLE
Figure 4-4 Task 1.3	Order Entry	Table 3VII Item I (1)	Basic Production Schedule (See also Table 8-III)
Figure 4-4 Task 1.4	Production Order	Table 3VII Item I (1-3, 5) Table 3VIII Item I (1-3)	Production Scheduling Same
Figure 4-4 Task 1.5	Order Acceptance	Table 3VI Items III (1B, 2B, 3)	Sales Coordination
Figure 4-5 Task 2.1	Process Production Orders	Table 3VII Items I (1,2)	Production Scheduling
Figure 4-5 Task 2.2	Balance In-Process and Product Inventories	Table 3VII Item I (4)	Inventory Management
Figure 4-5 Task 2.3	Production Forecasting	Table 3VII Item I (1)	Basic Production Schedule (See also table 8-II and Figure 8-5)
Figure 4-5 Task 2.4	Production Scheduling	Table 3VII Item I (1-3, 5) Table 3VIII Item I (1, 3)	Production Scheduling Same
Figure 4-6 Task 3.1	Process Support Engineering	Table 3VIII Item III (8)	Engineering Functions

TABLE 4-III cont.

DATA FLOW DIAGRAM LISTING		SCHEDULING AND CONTROL HIERARCHY LISTING	
FIGURE NO. AND LOCATION	TITLE	TABLE NO. AND ENTRY	TITLE
Figure 4-6 Task 3.2	Maintenance	Table 3VII Item I (3)	Maintenance Scheduling
		Item III (10)	Maintenance Data
		Table 3VIII Item I (1)	Immediate Production Schedule
Figure 4-6 Task 3.3	Operations Control	Table 3VIII Item I (2)	Area Optimization
		Table 3IX Item II	Control Enforcement
		Table 3X Item II	Same
Figure 4-6 Task 3.4	Operations Planning	Table 3VIII Item I (1, 3)	Production Scheduling
Figure 4-6 Task 3.1.1	Project Management	Table 3VIII Item III (8)	Engineering Functions
Figure 4-6 Task 3.1.2	Equipment and Process Design Modification	Table 3VIII Item III(8)	Engineering Function
Figure 4-6 Task 3.1.3	Engineering Specialists	Table 3VIII Item III(8)	Engineering Function
Figure 4-6 Task 3.1.4	Standards and Methods	Table 3VIII Item III(8)	Engineering Function

TABLE 4-III cont.

DATA FLOW DIAGRAM LISTING		SCHEDULING AND CONTROL HIERARCHY LISTING	
Figure 4-6 Task 3.1.5	Project Cost Control	Table 3VIII Item III(8)	Engineering Functions
Figure 4-7 Task 3.1.6	Project Detailed Engineering	Table 3VIII Item III(8)	Engineering Functions
Figure 4-7 Task 3.1.7	Equipment Modification Construction	Table 3VIII Item III(8)	Engineering Functions
Figure 4-7 Task 3.1.8	Drafting Documentation	Table 3VIII Item III(8)	Engineering Functions
Figure 4-8 Task 3.2.1	Maintenance Planning	Table 3VII Item I (3) Item III (10) Table 3VIII Item I (1)	Maintenance Scheduling Maintenance Data Immediate Production Schedule
Figure 4-8 Task 3.2.2	Cost Control	Table 3VII Item III (10, 11) Table 3III Item III (6, 10)	Cost Reporting Same
Figure 4-8 Task 3.2.3	Spare Parts	Table 3VII Item I (4) Item III (6)	Procurement Same

TABLE 4-III cont.

DATA FLOW DIAGRAM LISTING		SCHEDULING AND CONTROL HIERARCHY	
FIGURE NO. AND LOCATION	TITLE	TABLE NO. AND ENTRY	TITLE
Figure 4-8 Task 3.2.4	Maintenance Crew Scheduling	Table 3VIII Item III (10)	Personnel Functions
Figure 4-8 Task 3.2.5	Documentation	Table 3VII Item III (10) Table 3VIII Item III (6)	Maintenance Data Same
Figure 4-9 Task 3.3.1	Operations Supervison	Table 3VII Item I, III Table 3VIII Item I, III	Production Scheduling and Management Information
Figure 4-9 Task 3.3.2	Operations Cost Control	Table 3VII Item III Table 3VIII Item III (4, 6-10)	Cost Reporting Same
Figure 4-9 Task 3.3.3	Physical Process Control	Table 3IX Item II Table 3X Item III	Control Enforcement Same
Figure 4-9 Task 3.3.4	Operational Measurement Validation	Table 3IX Item II Table 3X Item II	Control Enforcement Same

TABLE 4-III cont.

DATA FLOW DIAGRAM LISTING		SCHEDULING AND CONTROL HIERARCHY	
FIGURE NO. AND LOCATION	TITLE	TABLE NO. AND ENTRY	TITLE
FIGURE NO. AND LOCATION	TITLE	TABLE NO. AND ENTRY	TITLE
Figure 4-9 Task 3.3.5	Equipment Monitoring	Table 3VII Item III (10)	Maintenance Data
		Table 3VIII Item III (1)	Immediate Production Schedule
		Table 3IX Item II (1)	Emergency Response
		Item IV	Reliability Assurance
		Table 3X Item II (2)	Emergency Response
		Item IV	Reliability Assurance
Figure 4-9 Task 3.3.6	Production Balancing Opimization	Table 3VII Item I	Production Optimization
		Table 3VIII Item I (2)	
		Table 3IX Item II (2)	

TABLE 4-III cont.

DATA FLOW DIAGRAM LISTING		SCHEDULING AND CONTROL HIERARCHY	
FIGURE NO. AND LOCATION	TITLE	TABLE NO. AND ENTRY	TITLE
Figure 4-10 Task 4.1	Raw Material Requirement Control	Table 3VII Item I (4)	Raw Material Procurement
Figure 4-10 Task 4.2	Inventory Balancing	Table 3VII Item III Table 3VIII Item III (6)	Raw Material Use Data Same
Figure 4-10 Task 4.3	Incoming Raw Material Control	Table 3IX Item III (3)	Same
Figure 4-10 Task 4.4	Materials Routing	Table 3X Item III (3)	Same
Figure 4-10 Task 4.5	Inventory Reporting		
Figure 4-10 Task 4.6	Material Movement Control		
Figure 4-10 Task 4.7	Raw Material Measurement Validation		

TABLE 4-III cont.

DATA FLOW DIAGRAM LISTING		SCHEDULING AND CONTROL HIERARCHY	
FIGURE NO. AND LOCATION	TITLE	TABLE NO. AND ENTRY	TITLE
Figure 4-11 Task 5.1	Order Replacement	Table 3VII Item I (4)	Procurement
Figure 4-11 Task 5.2	Process Requests		
Figure 4-11 Task 5.3	Cost Control		
Figure 4-12 Task 6.1	Set Standards and Methods	Table 3VII Item III (9)	Quality Control Analysis
Figure 4-12 Task 6.2	Raw Material Evaluation	Table 3VIII Item III (8)	Quality Control Analysis
Figure 4-12 Task 6.3	Evaluation of Product		
Figure 4-12 Task 6.4	Classification		
Figure 4-12 Task 6.5	QA Measurement Validation		
Figure 4-12 Taske 6.6	Lab and Automatic Analysis		
Figure 4-12 Taske 6.7	Analyze Process Capability		

TABLE 4-III cont.

DATA FLOW DIAGRAM LISTING		SCHEDULING AND CONTROL HIERARCHY	
FIGURE NO. AND LOCATION	TITLE	TABLE NO. AND ENTRY	TITLE
Figure 4-13 Task 7.1	Inventory Supervision	Table 3VII Item I (4)	Product Inventory
Figure 4-13 Task 7.2	Loss Control	Table 3VII Item III (8) Table 3VIII Item III (6)	Product Inventory Same
Figure 4-13 Task 7.3	Inventory Reporting	Table 3IX Item III (3)	Product Inventory
Figure 4-13 Task 7.4	Product Shipping	Table 3X Item III (3)	Same
Figure 4-13 Task 7.5	Product Routing		
Figure 4-13 Task 7.6	Product Movement		
Figure 4-13 Task 7.7	Inventory Measurement Validation		
Figure 4-14 Task 8.1	Cost Balancing and Budget	Table 3VI Item III (2C)	Cost Reporting
Figure 4-14 Task 8.2	Raw Materials and Parts (Costs and Acct's Payable)	Table 3VII Item I (4)	Same

TABLE 4-III cont.

DATA FLOW DIAGRAM LISTING		SCHEDULING AND CONTROL HIERARCHY	
FIGURE NO. AND LOCATION	TITLE	TABLE NO. AND ENTRY	TITLE
Figure 4-14 Task 8.3	Product Income (Acct's Receivable)	Table 3VII Item III	Same
Figure 4-14 Task 8.4	Production Costs	Table 3VIII Item III (4, 6-10)	Cost Reporting
		Table 3IX Item III	Same
		Table 3X Item III	Same
Figure 4-15 Task 9.1	Shipment Scheduling	Table 3VI Item III (1B, 2B)	Product Inventory and Availability
Figure 4-15 Task 9.2	Shipping Costs	Table 3VII Item I	Production Scheduling
Figure 4-15 Task 9.3	Shipment Configuration	Table 3VII Item III (8)	Product Inventory and Availability
Figure 4-15 Task 9.4	Invoicing	Table 3VIII Item III (6)	Same
Figure 4-15 Task 9.5	Release Shipments	Table 3IX Item III (6)	Same
Figure 4-15 Task 9.6	Prepare Shipping Documents	Table 3X Item III (3)	Same

5

The Implementation Hierarchy View of the CIM System

GENERAL

Figure 5-1 represents one concept of the components or elements required for the implementation of the CIM system for each "bubble" or Manufacturing Specific Functional Entity of the data-flow diagram of Chapter 4 or each Task of Chapter 3.

This concept allows each task to be expressed in as many layers as required (11 maximum). Layers may be used or nulled as necessary. Thus such a model needs to be developed in specific form for each "bubble" of the data-flow diagrams presented in the previous chapter using the generic model of Figure 5-1 as a base and supplying the appropriate implementation details. Likewise this would be done for each task in Tables 3-VI to 3-X since these are equivalent to the above. Only examples of such models will be presented in this Chapter.

Just as the ISO-OSI model (Figure 9-6) [8] breaks the tasks of the communications between systems into layers, this model breaks the tasks of plant control into functional layers. A brief discussion of each layer of the model follows.

DESCRIPTION OF THE LAYERS

As diagrammed in Figure 5-1 the CIM model is represented in the implementation hierarchy view by an eleven layered structure. The hardware elements of the system are represented by the lower five layers of the system (1-5), while the software elements are represented by the top six layers (6-11).

Layer 1 — Physical Environment (Including Humans)

This layer would typically represent the process equipment (i.e., reactors and distillation columns), machine tools (i.e., CNC and human operators) and supporting areas such as utilities and packaging. As noted often earlier, these elements would be non generic in any specific case and are included here for completeness.

Layer 2 — A - Data Input/Checking/-Output
B - Links to Other Levels

2A. The detection and measurement of the status and of the actions occurring in Layer 1 are contained in this layer. This layer represents the eyes and ears of the CIM System. This includes the determination of the values of such variables as temperature, level, pressure, chemical analysis, position, weight, etc., from sensors and detectors. Also included are inputs from touch screens, mice, bar code readers, etc. Typical system actuators would include valves and valve positioners, hydraulic drives, solenoids, relays, CRTs, printers, etc.

2B. Where higher level functions are involved such as overall production scheduling in large industrial production plants (Figure 5-2), then Layer 2 represents the link to other computer and control equipment involved in implementing the task described. In the case of Overall Production Scheduling (which itself takes place in Levels 4A and 3 of the hierarchical system of Figure 3-1 or 3-2) this would include all elements of Levels 1 and 2 of the latter diagram.

Layer 3 — Communications

Layer 3 moves the data within the system. The clients of this communication system would be the various computer systems and databases which manipulate and store this information and the various functional entities which use the resulting information. Likewise data to and from the operating units of the plant must be brought back to Layers 1 and 2 and other layers by the communications systems. Also included in this layer are device gateways and drivers as/if required. Real time and transactional communications are to be determined by the characteristic of the task.

The communications structure should, as far as possible, follow the OSI model and agreed upon industry-wide standards for their implementation.

Layer 4 — Process/Task Database

The global database of the factory or plant resides in this layer. It becomes the collective memory for the CIM system. This database will be distributed as determined by the implementation plan. The authority and responsibility for the several data maintenance functions will be determined by job function.

Layer 5 — Computer System Elements

Exact content at this layer will be determined by the functional requirements of the system, but must encompass the entirety of the intelligent computing devices contained in the CIM System which are required for the task at hand. Examples include computers, disks and database machines.

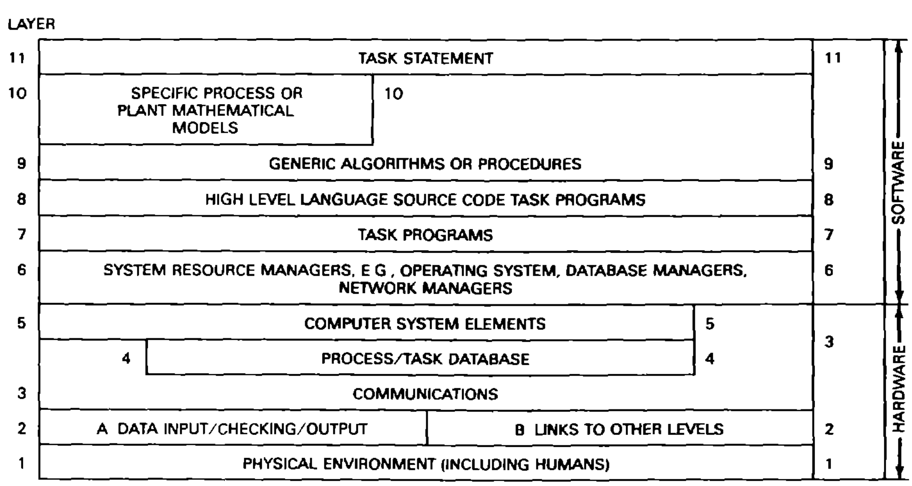


Figure 5-1 Proposed generic form of the implementation hierarchy view of the CIM system.

Layer 6 — System Resource Managers

This layer contains the software which allocates and manages the elements which comprise the system. Examples are operating systems, database management systems, network managers, system utilities and data dictionaries.

Layer 7 — Compiled or Interpreted Code

This layer represents the program as actually executed by the computer system. It may be stored in random access or read only memory as required by the application at hand.

In some special applications, programs may need to be cross compiled and run on two or more different machines under different operating systems.

Layer 8 — High Level Language Source Code

This layer contains the source code in the form of a high level language such as Ada, FORTRAN, C or 4th generation languages.

Layer 9 — Generic Algorithms/Procedures

Each process has calculation, algorithmic or modelling requirements. These would reside in this layer and service the lower layers. Examples would be linear programs as used for a catcracker optimization routine or a dynamic optimization technique as used for robot optimal path determination.

Layer 10 — Specific Process or Plant Mathematical Models

For certain applications models must be included as required. These models allow simulation of the process to generate information not otherwise

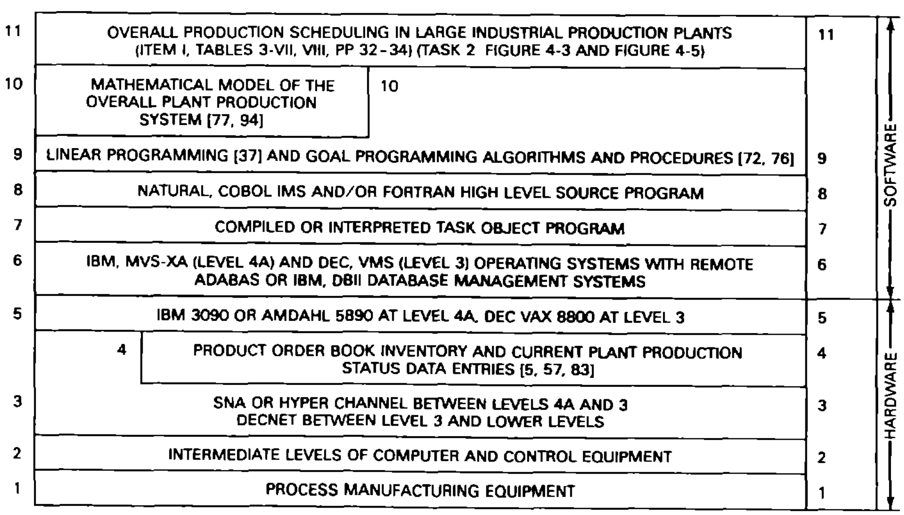


Figure 5-2 Use of the implementation hierarchy view to illustrate the overall production scheduling task [89].

available. Uses would be supplying unmeasurable data, verify existing data or predicting future data. Examples are process unit models for advanced control systems or business models for scheduling functions.

Layer 11 — Task Statement

Description or specification of the task or function to be accomplished (the application functions of the manufacturing plant) would reside at this layer.

SOME EXAMPLE IMPLEMENTATION HIERARCHY VIEWS

Figures 5-2 and 5-3 present two examples of Implementation Hierarchy Views from among the tasks developed in Chapters 3 and 4. Those chosen are Overall Production Scheduling (Item I, Tables 3-VII, VIII, and Task 2, Figure 4-3 and Figure 4-5) in Figure 5-2 [89] and Control Enforcement (Item II, Table 3-X and Task 3.3.3, Figure 4-9) in Figure 5-3. As noted above these are presented as examples and no attempt will be made here to produce examples for all the possible functions since they tend to be implementation specific as shown by Figures 5-2, and 5-3.

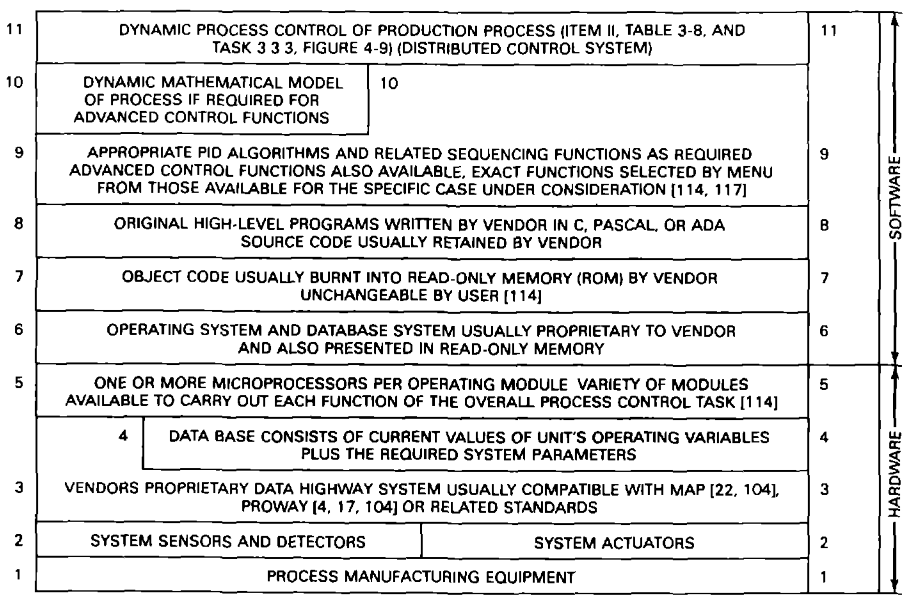


Figure 5-3 The Implementation hierarchy view of the dynamic process control task in the manufacturing plant.

6

Software Requirements for Computer Integrated Manufacturing Including Computer Aided Software Engineering

ESSENTIAL ASPECTS OF SOFTWARE DEVELOPMENT [48]

THE INGREDIENTS OF A SUCCESSFUL SOFTWARE PROJECT

The following list comprises some of the important aspects of software development, which have to be considered if a project is to be successful:

1. Technology
   - A. The Design
     - 1) Adequacy
     - 2) Modularity
     - 3) Adaptability
   - B. The Software Development Environment
     - 1) Specification Tools
     - 2) Programming Languages
     - 3) Test and Verification
     - 4) Documentation
   - C. Support Hardware
     - 1) Development Machines
     - 2) Special Test Environment
2. Management
   - A. Organization
     - 1) Project Phases
     - 2) Planning
     - 3) Cost Estimation
     - 4) Teams and Structures
     - 5) Influencing Factors
   - B. Human Factors

C. Support Tools

1) Documentation

2) Reporting

3) Checkpoints

It should always be borne in mind that the technological and the management aspects are of equal importance. It is also a fact that most of these topics have been individually investigated and are well known and covered by literature, courses, etc. But obviously it is not yet common knowledge that they have to all together form a "management system" and that in general they are interrelated.

This can be exemplified by the development of the phase model as given below.

THE PHASE MODEL

The phase model was originally derived from management considerations. It later turned out to be a useful framework for the construction and classification of tools. For some time it was even considered as technological dogma. However, people now understand that both aspects (managerial and technological) are interwoven and interdependent.

It has recently been confirmed that an overly rigid phase planning is counterproductive, but that a reasonably phased structure for a project is necessary and useful. It can be stressed that the usual phase plan has to be extended by a phase of thorough planning. The recommended phase model therefore looks approximately as follows [67]:

1. Planning and establishment of the management structure
2. Establishment of quality assurance mechanisms
3. Definition of the requirements
4. Design specification
5. Design and coding
6. Unit test
7. Integration
8. System test and validation
9. Maintenance

THE IMPORTANCE OF GOOD DESIGN

With good reason the design has been mentioned first on the list in the previous section. In principle it should be a matter of self-understanding that for the development of computer and software systems good design is as important as it is for any other technical product. The best tools and the most capable manager can not save a project whose product design is bad or even wrong. Until now software development has been regarded mainly as an aspect of the development (or production) environment, i.e., programming languages, specification tools, test and verification, and, documentation. Such a view would appear utterly strange to the usual plant engineer. Of course the engineer also has to think about the tools with which to produce the design of, for example, a car but primarily is concerned with designing a good and affordable car. The production facilities are then constructed according to the requirements of the product and the company's financial considerations.

But unfortunately very little is known about what comprises a really good software design! Besides, many believe that this problem can not be solved by software specialists alone. In the first place the quality of software is determined by the properties and the requirements of the application. To stay within the above mentioned example of automobile design, knowledge about production methods may help to make a car cheaper, or, perhaps less prone to rust, but it will certainly not improve its road-holding or its fuel consumption. So the manager will have to apply several criteria against which to check the quality of a design. The most important ones seem to be those listed below.

In the first place the design has to be *adequate to the problem*. It must be neither too futuristic nor overly conservative. One must not take unnecessary development risks by trying an unknown problem solution on, for example, a new generation of computer. But one must also avoid "obsolescence on delivery".

Then a design must be *modular.* This is important for technical reasons as well as for organizational ones. From a technical point of view it is well known that a modular system is easier to design, to understand and to maintain than a monolithic one. Under managerial aspects it is necessary to prepare for the necessity to develop a system using a team, i.e., to be able to assign well separated work modules to different people or different subgroups.

Finally a design has to be *adaptable to change.* This does not only relate to changes "after delivery", which Parnas may have had in mind when he postulated his "Design for Change", but also with changes which will, inevitably, occur even in the development phase. This is inevitable because software projects usually take much longer than everyone expects. Everybody talks about an "innovation rate" which is supposed to be between 2-3 years, but statistics teach us that the average software project of nontrivial size takes between 5-8 years! To appreciate this consider that the average lifetime of a government is usually about four years. Thus one may well face drastic changes of the social or political environment in the middle of the development phase.

ORGANIZATIONAL ASPECTS

PLANNING

Everybody agrees that planning is necessary, and in every project it is done at least to some degree. But some mistakes are quite common.

Firstly, planning is obviously not taken seriously enough. This observation has already been described in the book, *The Mythical Man-Month*, by F. Brooks [36]. Brooks describes how project teams are usually built up too fast and that planning is regarded as a kind of "side-activity" for the manager during the early project phases. Instead the bulk of the manager's time is consumed in instructing all the new people and in assigning work packages to them. Consequently these assignments are only partially thought out and are often incoherent because their planning has not been completed. From this an important rule can be derived: *Do not start a software project of non-trivial size with a fully staffed team, but allow for a planning phase, in which a few - but very good - people prepare the project by thorough planning and architectural design!*

Secondly, planning tools are not used properly. They are either not used at all or to the contrary - adhered to too strictly. This, in turn, leads to inevitable frustrations and to abandoning them after some time. It is generally agreed that it is better to use planning tools than to work without them, but that they should only be loosely connected to the project and used as "guidelines" and "early warning systems". So, for example, PERT-diagrams are not rated very highly, because they require too much detail and are difficult to adapt. Bar-charts or Gantt charts are, on the other hand, generally regarded as very helpful.

COST ESTIMATION

Productivity and Cost Models

This is generally regarded as one of the most important issues in the management of software projects. In the USA it has been discussed in conferences for many years and there is a considerable body of literature dealing with this subject. A number of "cost-models" have been developed which try to take into account as many influencing factors as reasonably possible. Therefore many of these have sometimes become quite complex. Despite the effort expended none of them has succeeded in really giving precise and reliable forecasts.

A "rule-of-thumb" can be developed from a comparison of these cost-models. This is, "estimate the possible size of the code in your project and divide it by the productivity of our team". This yields almost exactly the mean value of the forecasts given by a number of more or less complicated cost-models. The rule-of-thumb performs even better if one applies the usual statistical error boundaries to the estimates of code size. Of course it is common knowledge by now that a linear relationship does not hold between code size and project cost for very large software projects, but the cost models did not do any better there.

This difficulty can be overcome by a modular design with loosely coupled components. The explanation for this can be found in the work of Halstead [59], who had discovered that the effort - which is expressed by cost - for the development of a piece of software is not a linear function of the size of the software, but grows according to some exponential relation. The reason for this is that the true cause for the necessary effort is the internal complexity of the software, which also grows exponentially with the project size. Halstead also showed that modularization can drastically reduce the necessary effort, because the total effort necessary for some large software systems can now be computed as the sum of the effort necessary for all the modules considered together instead of the exponential result one would obtain from applying his formulas to the whole piece of software as a single entity.

Another important principle, which was first described in great detail by Brooks [36], but which is forgotten every time a project becomes critical, is: *"Adding manpower to a late project makes it later"*, or more generally: There is an optimal team size which must not be exceeded if the project is to be completed in a reasonable time. The reason for this is that humans, who work together in a team, have to communicate in order to get the common work properly done. This communication takes time and this use of time decreases the "productivity" (e.g., measured in lines of code per man-year). But as it is clearly impossible to realize a 100 man-year project by one person who is allowed to work 100 years, one has to allow for these "communication losses". But one also has to know that they exist and thus organize the team in such a way that they do not exceed a tolerable amount of the total time budget. Modern cost models obviously take this into account, as Figure 6-1 shows. This figure is taken from [67] and has been computed using the SLIM model [91].

An important aspect of this figure is described by M. Key [67] as follows: "It also shows an Impossible Region. Faced with this evidence it is more difficult for the senior manager to say: 'Well, if you can't do it, I will find someone who can!' Clearly, management must attempt to achieve a required completion date as determined by a market window; what it must not do is go into the 'impossible' region of the graph in an attempt to do this! *Therefore, the plans must be realistic in their time scales and have a degree of flexibility which can accommodate slip."*

But Figure 6-1 also shows another, very important, aspect. From the manpower curves one can see how to do the same work with much less effort just by allowing for a little more time! For example, as shown in Figure 6-1, one can produce 250 K of software using 25 man-years or 100 man-years. In the latter case one has even slipped slightly into the impossible region, i.e., it will be a very difficult project. The resulting saving of time is shown to be less that 30%, whereas from a naive point of view one would have expected 75%. This observation is confirmed by Figure 6-2, which has been taken from a study by IBM [88].

If in Figure 6-2 one locates the team sizes which result from the above figures, i.e., from either approximately 6, or 33 people, on the curve for FORTRAN (empty circles), and looks at the resulting values for productivity and project duration, the values of Figure 6-1 are confirmed: the productivity of an individual in a team of 6 is four times that of the same one in a team of 33, and the gain in project time is approximately 30%. Thus one obviously has detected a rather solid "law of nature". This law was also first described by Brooks, who also found an explanation for it: It is the time for communication between people which is necessary in a team! He also gave a formula describing this effect in quantitative terms. This formula and some of its results are plotted in Figure 6-3, which illustrates in a dramatic way one of the central problems of the management of programming teams.

Even with the modest amount of 1% of time for one team member to be talking to another one, the optimal team size is as small as 6 - 8! Even with this team size there are between 15 - 28 "communications" per person per week. This consumes from 6 to approximately 11 hours per week of *each* person's time. Brooks concludes that, as you can neither forbid communication completely nor have every project team conducted by just one person, one has to *organize communication.* He describes several methods for this purpose in his book [36]. Of course a general caution should be applied in this case as well as in every other one: *Do not try to adapt other people's methods or experience to your problems without reflection and proper adaptation!*

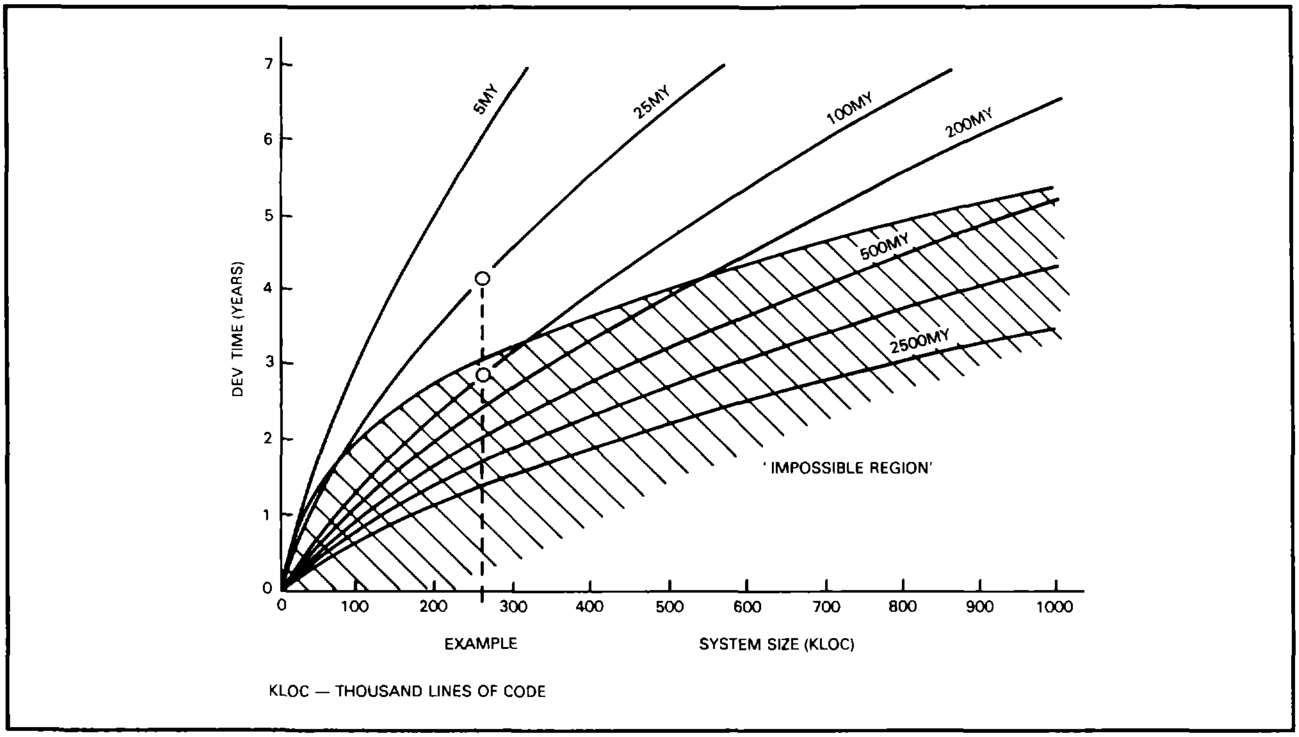


Figure 6-1 Slim—diagram [67].

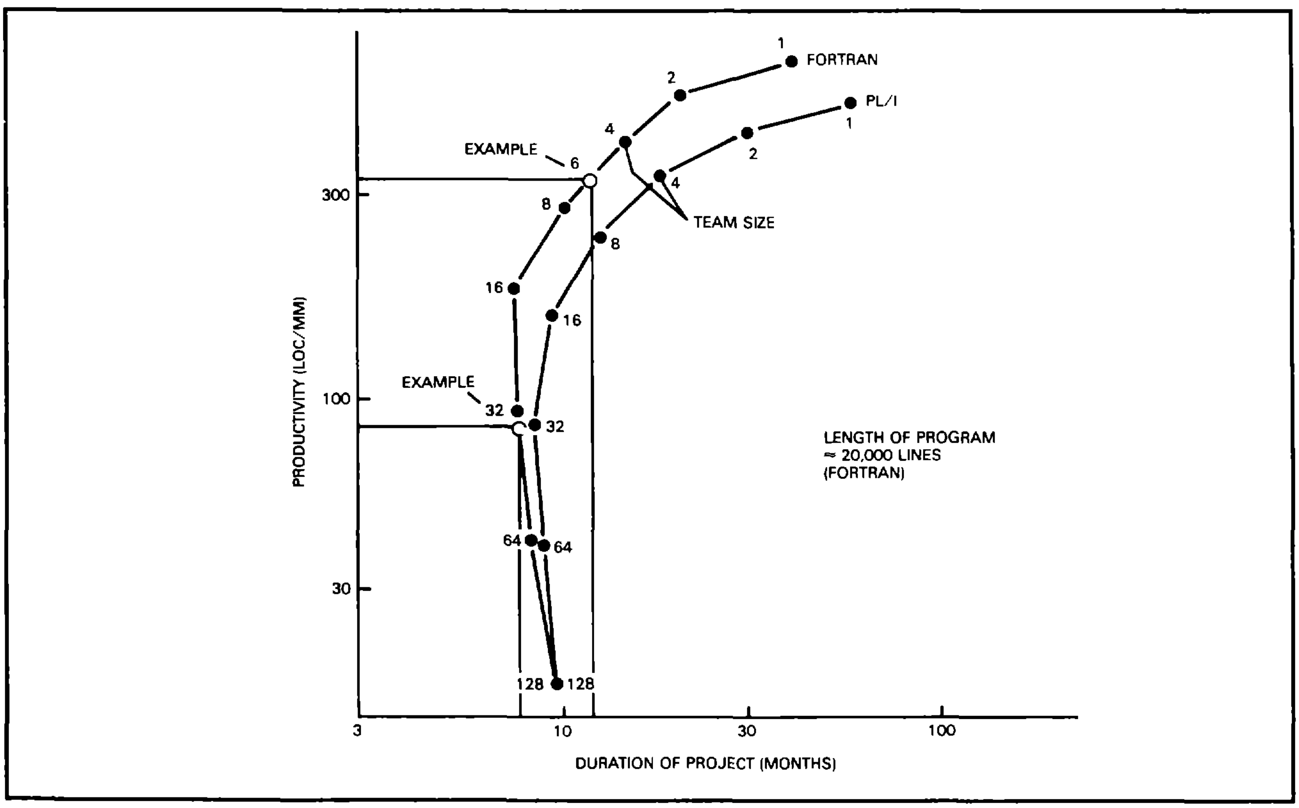
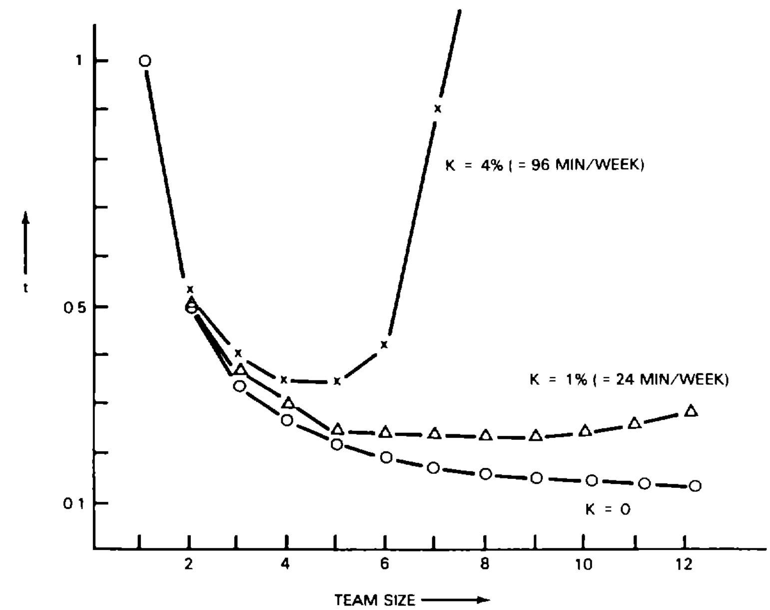


Figure 6-2 Dependence of productivity on team size (adapted from [88]).



Brook s Formula $N_T = \frac{n^2 - n}{2}$

n Number of Team Members
N Number of Unorganized Communications Channels Within Team
t Normalized Duration of a Project
K Percentage of Communication

Figure 6-3 Dependence of project duration on team size.

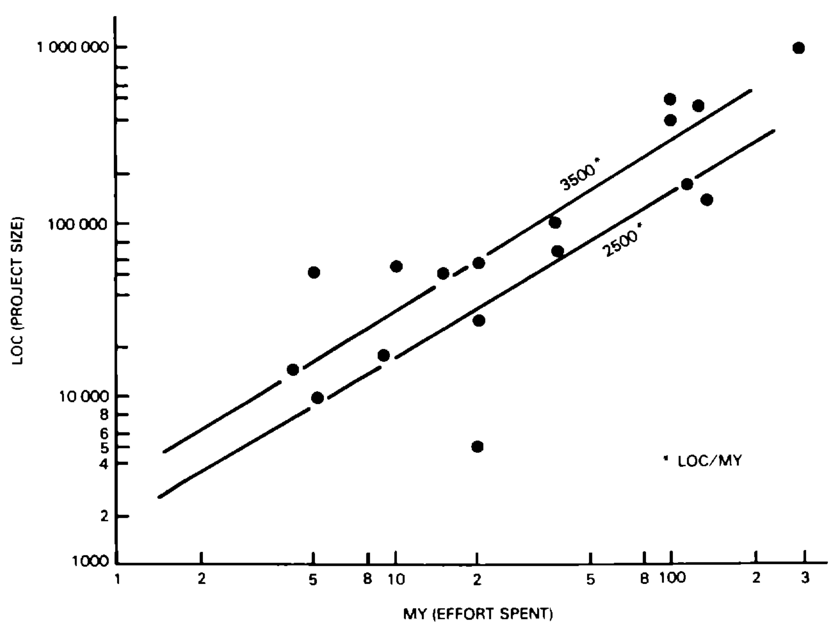


Figure 6-4 Productivity values collected at first IFAC Workshop on SW-Project-Management.

But even if one has thoroughly understood the problems connected with the management of sizable teams and on top of this is a gifted "leader" who really can get people to work, the problem of a reliable original estimate of the costs of a project remains. Obviously really reliable data on programmer productivity do not yet exist. The manager normally has to take recourse to their own experience.

There are possibilities to check this experience for plausibility and to compare the performance of one's own team or company with the outside world. First, one can browse through the published literature for figures, one can talk to colleagues and one can calculate backwards from competitor's prices and/or project durations. But there is also compiled material available: Nearly everything which Barry Boehm publishes (e.g., [32,33]) contains valuable figures and reference information. A less widely known but extremely valuable book has turned out to be a really invaluable source of raw data. This is Montgomery Phister's *Data Processing, Technology and Economics* [88]. This book contains innumerable statistics, collected over a period of approximately 15 years and covers all aspects of data processing from computer production to program development. In addition it is updated at regular intervals.

Figure 6-4 is a plot of productivity figures collected by means of a questionnaire during the Heidelberg workshop on software engineering [48].

The bandwidth of the results corresponds very well with values obtained from other sources:

2500 - 3500	LOC/MY Workshop average 1986
4000	LOC/MY Author's own experience, difficult FORTRAN code, 1984
2000	LOC/MY Author's own experience, difficult Assembler code, 1982
3200	LOC/MY [111], 1977

(A later, more thorough evaluation of the workshop results showed a wider distribution: 2700 900 LOC/MY) (LOC/MY - Lines of code per man year).

Influencing Factors

The above figures cannot be applied uncritically and universally. One also has to take into account the most important factors which influence the productivity of program designers. The most complete collection and evaluation of such factors can also be found in [111]. There 30 influencing factors have been listed and their effect evaluated. Those with the highest values have been listed below:

1. Complexity of customer interface
   4.0/1.0
2. Experience with programming language
   1.0/3.2
3. General qualification of personnel
   1.0/3.2
4. Experience with application
   1.0/2.8
5. Designer participation in specification
   1.0/2.6
6. User participation in requ. def.
   2.4/1.0 (!)
7. Experience with computer used
   1.0/2.1
8. Complexity of application algorithm
   2.1/1.0
9. Percentage of delivered code
   1.0/2.1/1.7 (!)
10. Limitations of working memory
    2.1/1.0

Some other factors, which usually enjoy a high favor among theorists, are of less influence than expected:

29 Complexity of control flow	1.4/1.0(!)
30 Module size	1.25/1.0/1.35

The figures are an indication of productivity and are to be read as follows: The first figure holds if the respective factor is smaller than normal, the last one, if it is greater than normal. The middle figure (if given) describes productivity under normal considerations. Thus very complex relations with a customer, i.e., something which depends on a talent for negotiations and on the quality of the contracting department, can decrease productivity to a quarter of a good value! On the other hand, if one can assemble a team of qualified people who are familiar with the application and with the programming language (factors 2, 3 and 4), one theoretically has a chance to complete a given project 25 times as fast as under adverse conditions. The purely technological factors, i.e., Factors 29 and 30 are of remarkably small influence. The effect of Factors 6, 9 and 29 is counter intuitive, i.e., experience and statistics show different results from what has always been expected from theoretical discussions.

In general this list easily explains why the reported productivity figures of programmers can vary by a factor of 20! And for a manager, who wants to do reliable planning, this means: *Observe your team, keep your own statistics, monitor your influencing factors and apply a reasonable safety margin in your estimates!*

D. Martin [78] also described and evaluated the influencing factors which had been relevant to his projects. Though he did this only qualitatively, the results have confirmed the values given in the above list.

Distribution of Effort Over Project Duration

As already mentioned above, one should never start a sizable project with a fully staffed team. But what, then, is a reasonable distribution of manpower over the duration of a project?

One curve actually observed in a successful project is shown in Figure 6-5 which is taken from [78]. It shows that a successful Project of over 100 man-years has actually been prepared by two people over one year! A more qualitative approach is used in Figure 6-6. This diagram, however, illustrates the reasons for such a curve by indicating the order and the overlapping of activities in a software project. Less detailed, but supported by good statistics, are the values given in [88]:

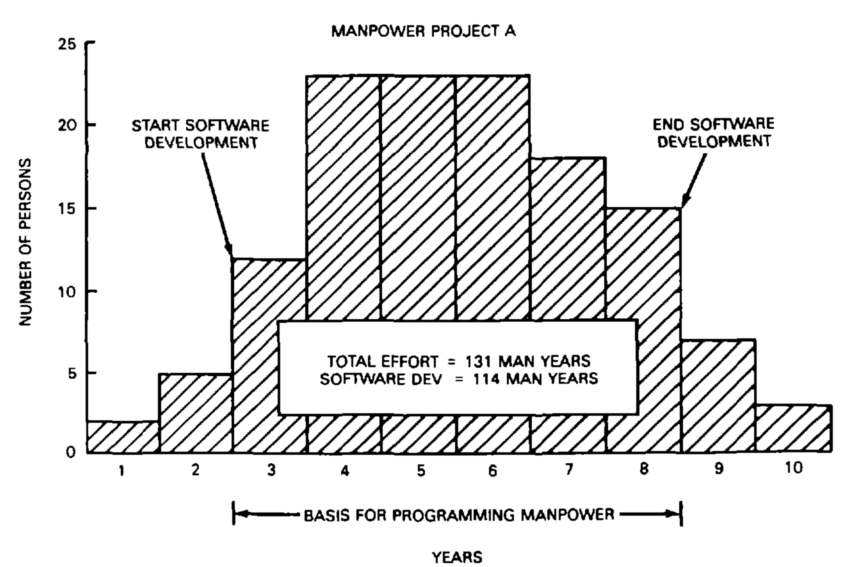


Figure 6-5 Distribution of manpower against time for a successful project [78].

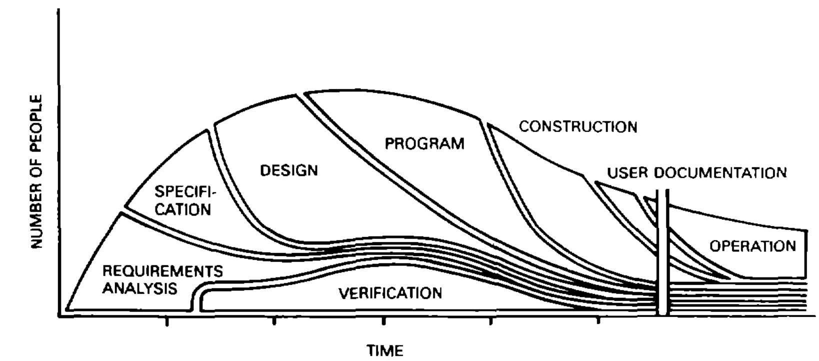


Figure 6-6 Distribution of manpower over project phases [67].

Program design:	26	(% of total project effort)
Coding:	24	
Testing:	36	
Documentation:	14	

However, two aspects should be emphasized here:

Firstly, it is important to know about the average values of such distributions, because one needs them for reliable estimates. The reasons for this are that reliable productivity figures can usually be obtained only for certain phases of the development cycle. One therefore has to extrapolate the total project costs from known figures for certain phases by using the statistical values for the other phases given in such distribution curves.

Secondly, the usual curves illustrate the maintenance problem. In whatever statistics one consults, maintenance costs usually amount to 50% of the total life cycle cost of the software. So, one has to be prepared to set aside a group of 10 people for the maintenance of a software system which cost 100 man-years to develop! Of course this situation is by no means acceptable and therefore every effort should be made to reduce the maintenance costs of the software by the use of better design method and good programming tools.

HUMAN FACTORS

General

This is one of the most important points a manager has to observe. All the planning and statistics will be utterly in vain if the manager does not succeed in keeping the team together and in maintaining a reasonable degree of job satisfaction and productivity.

There are many factors which influence this. The most important of these will be explained in the following paragraphs.

Motivation of the Team

To achieve motivation, the following factors were judged to be most important:

1. The team has to have a *fair chance of success.* That means that plans and schedules have to be feasible and realistic.

2. The individual team member has to have a *feeling of importance.* Never let the feeling arise that they are just regarded as a cogwheel which can be thrown away and replaced at any time.

3. The manager has to show an adequate *response to the needs* of the team. This means in the first place a proper working environment, but also includes the necessity to be able and willing to help people with their private problems as far as reasonably possible.

4. Always *maintain a slight overload.* This aspect was first emphasized by the Japanese, where it is generally accepted that people perform better and feel more satisfied if the manager makes them achieve a little more than they originally expected by themselves.

Team Building

1. The manager should perform a thorough *interest analysis* of the (future) team-members. In a profession like program development, which mainly depends on ideas and organization of thoughts, the performance of an individual obviously can vary by a factor of 10 - 20, depending on whether they are employed in the right place or not. And thus job satisfaction becomes an economically much more relevant factor than in many other more "traditional" professions.

2. Professional *ethics and morality* are more important than usually. Because complete testing and traditional quality control are not very well developed as far as software is concerned and even simply impossible in big systems, the commitment of the individual to do the very best job they can do, becomes an extremely important economic factor. This simply follows from the fact that a thoroughly developed program costs less in maintenance and in the damages caused by malfunctioning.

3. On the other hand, the manager has to maintain the *visibility* of the work of the team members in order to be able to properly perform control functions and to start corrective actions in time.

Dealing with Conflicts

1. Firstly, *identify and solve conflicts soon.* This would seem to be an old and well-known rule for team-leaders. But software people and managers generally have a predominantly technical background with little training in management and human factors, and therefore traditional rules of leadership are not very well known to them.

2. Secondly, *be prepared to create pain.* Technical conflicts can very rarely be resolved by a compromise and somebody has to lose.

3. But, also do not try to avoid conflicts at any price. *Conflicts are good for evolution* (this has long been discovered by philosophers) and, if handled properly, may even help those who lose one. They may win the next time.

Keeping Balance

One of the findings of human factors studies is illustrated in Figure 6-7. The manager has to be aware that humans are controlled by a field of tension in which they try to maintain a kind of equilibrium. It should be an interesting exercise for the reader to interpret this diagram for himself.

Another interesting observation is illustrated by Figure 6-8. There seems to be a correlation between the skill-level of team members and the number of meetings held. The consequences of this observation are not clear, because on the one hand meetings are good for communication, problem solving and conflict resolution, but on the other hand too much communication degrades productivity, as described in a previous section.

Special Properties of Software Teams

For decades a discussion has been going on among software professionals as to whether program development is a production activity like any other or whether it is something special to which traditional rules of management do not apply. However, it would seem that program development is truly comparable to traditional planning activities and that therefore software managers can learn a lot from other managers such as architects who plan large buildings, or from administration in civil service, railroads or military logistics.

One particular aspect of this problem can be stated as follows:

The majority of software professionals hold university degrees, although most are not in the field of software. This means that they have been educated into a tradition where they are judged for obtaining unique results. Usually university graduates also have never learned the necessity of the use of strict rules. Both backgrounds make it difficult to build sizable teams out of such people.

Of course the repetitive, deterministic part has always been much smaller in software projects than in more traditional construction projects. However to aid this situation in the future more emphasis should be given to the establishment of educational programs for a medium level of software people who are more trained in the direction of repetitive skills and the solution of small scale problems than their predecessors.

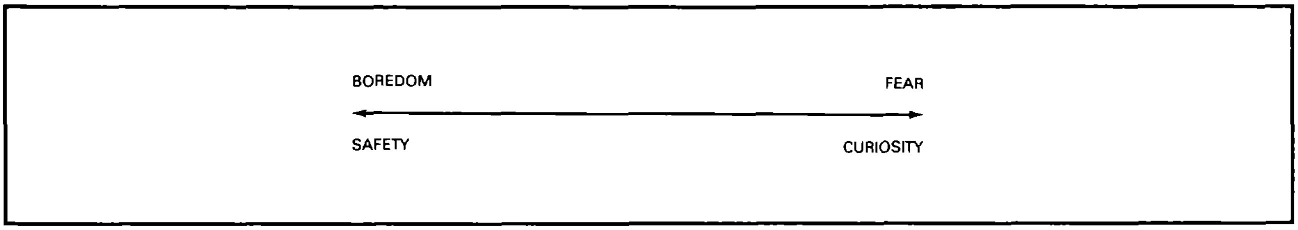


Figure 6-7 The psychological equilibrium.

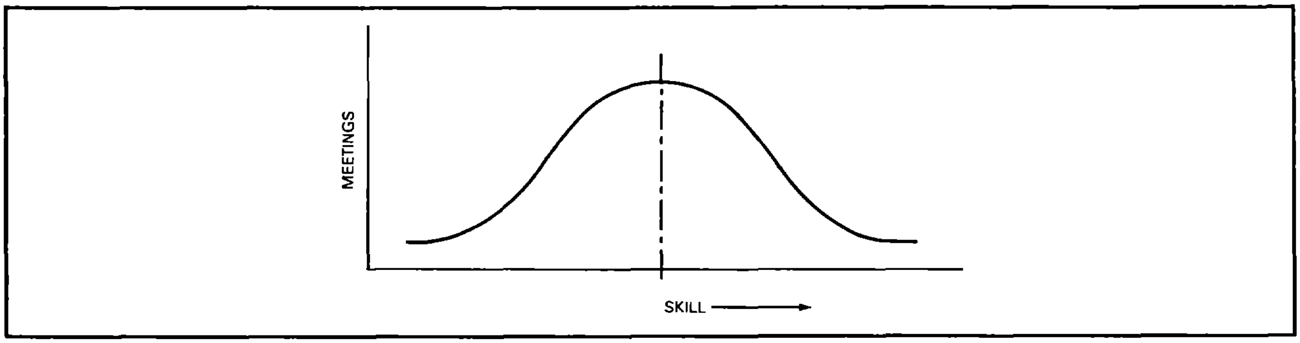


Figure 6-8 Dependence of number of meetings on skill level.

TECHNOLOGICAL ASPECTS

SELECTION OF SUPPORT TOOLS AND PROGRAMMING LANGUAGES

The following list comprises an incomplete list of the tools and languages which have been mentioned as having been successfully used. Intentionally it does not imply any order or ranking except an alphabetic one:

Ada,Ape, APL, AT-Xenix, BIGAM, BOIE, C, CA-DOS, CMS, COBOL, Codasyl, COMPASS, CORE, Dataflow-Diagrams, Debugging, Tools, DOS, EPOS, EXEC, FORTRAN, GMM, GESAL, ISP, JSD, LISP, MASCOT, MODULA2, Module-Management-System, Nassi-Shneiderman, PDL, PEARL, PET-MAESTRO, Petri-Nets, Pretty-Printer, Prolog, RCS, RMX86, RSX, RTE IV, SADT, SINET, SPA-DES, Structured Programming, Test Batch, Test Manager, TURBO-PASCAL, UNIPLEX, UNIX-Tools, VMS, Word Processors, X-tools, XEDIT, etc.

The overall list was compiled from a questionnaire distributed at a recent workshop [48] in which the participants were asked to mention all the tools and languages with which they had had experience and to indicate whether they had found them useful, neutral or counter-productive.

The evaluation of these questionnaires showed some interesting results.

1. 83 methods, tools or languages were mentioned, but only PASCAL, FORTRAN, UNIX, VMS, Structured Programming and Symbolic debuggers were listed more than twice in a positive sense.

2. 14 of them were criticized as counter productive and nine as having had no effect.

This means that it obviously does not matter very much which method or tool is used (if it is not too bad) as long as it is used professionally and in a consequent fashion. This view has been confirmed by several other studies.

It is more important for the success of a project that the team has experience with the support software, that it is readily available, stable and not too complicated to use. A major view of this, which has been formulated in [23] states: *The use of the tool should not require a higher intellectual effort than the solution of the problem at hand.*

It is also important to develop criteria by which software methods, tools and languages can be classified and judged with respect to their usefulness for any given project. Two first attempts in

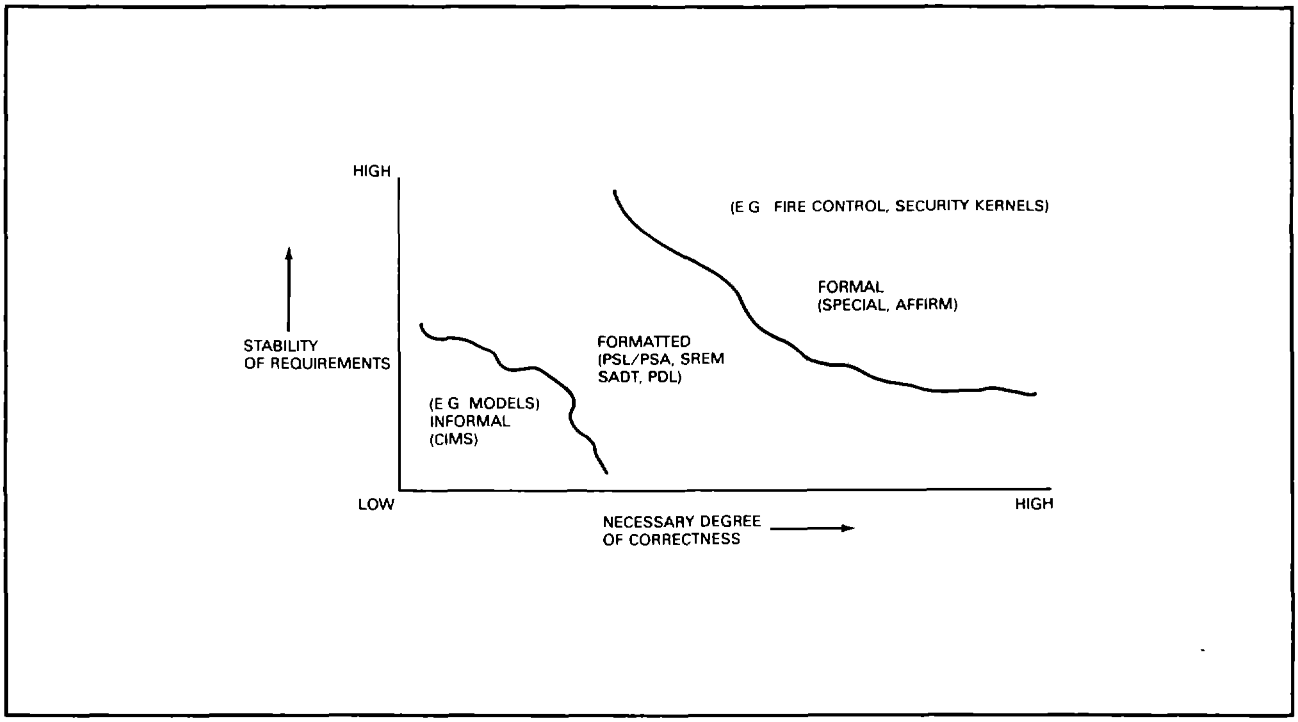


Figure 6-9 Regions of applicability of design tools [48].

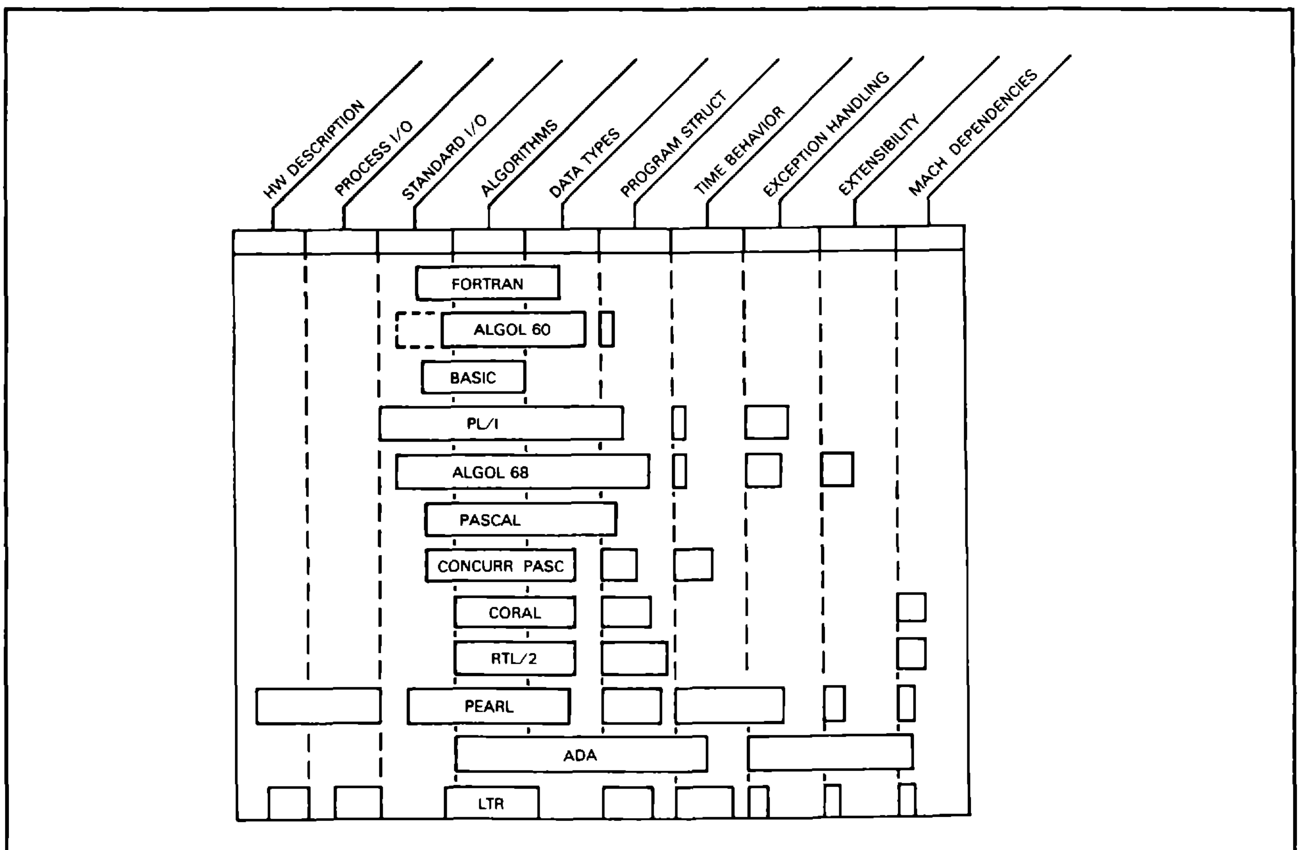


Figure 6-10 "Problem Coverage" by various programming languages [48].

ness for any given project. Two first attempts in this direction are illustrated by Figure 6-9 and Figure 6-10.

Figure 6-9 is adapted from [48] and shows regions of applicability for formal, formatted and informal software specification methods and tools.

The idea behind the scheme of Figure 6-10 is that programming languages can be regarded as formalized collections of those programming concepts which were well understood and therefore ripe for formalization at the time of the development of the respective language [48]. This view can be used by a software manager for the technical selection of the best programming language in the following way: identify the most important concepts in the application area of the project and select the language accordingly.

But in general it turns out that criteria such as the quality and stability of the compiler are economically much more important than many others for the usefulness of a particular language in a project. M. Key in [67] shows that in one particular project the forced use of an unproven language had caused an unnecessary expenditure of 200 man-years.

TEST TOOLS

The importance of test tools is in general grossly underestimated. On the one side there are not many useful tools for that purpose, on the other hand their use is almost never consciously planned. Both facts may of course be mutually interdependent. But the situation is so serious that it is necessary to break up this "vicious circle".

Figure 6-11, which is taken from [88], illustrates the reason: Experience shows that in most projects the detection of program bugs, i.e., the test coverage, follows the right curve. The explanation for this is obviously that people start out with a too optimistic view of the program error, or bug, rate in their program and test too lightly. Then, after major problems develop, they start testing in earnest and arrive at a program with 90% of the bugs out at "T90-real". If one would apply systematic testing from the beginning, one would obviously achieve a stable product much earlier ("T90-optimal") and thus save a lot of money.

The seriousness of the situation is further illustrated by the statistical evidence, that there are between 3 and 20 programming errors per 1000 lines of code before testing. Halstead [59] explains this by stating that there is a certain mental error rate which is different for each individual, but is rather constant for any one over time.

Of course it does not help much to state the seriousness of a problem if there is no solution for it. But in the case of testing there are promising methods and tools which are just not used widely enough. The available methods and tools can be roughly classified into informal and formal methods.

The *informal test methods* comprise:

1) Intuitive testing

2) Inspections

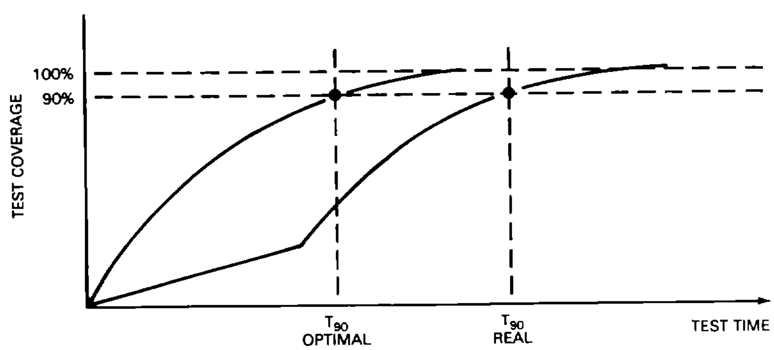


Figure 6-11 Test coverage over time.

3) "Walk throughs"

4) Test plans

5) Program controlled testing

6) Limit testing

7) Special test environments

The *formal test methods* comprise mainly what is other-wise known as *program verification*:

1) Analytic/logic verification ("program proofs")

2) Program-flow oriented verification

3) Data-flow oriented verification

For a number of languages there exist verification tools, for example, for:

FORTRAN:	ATTEST, DAVE, DISSECT, FACES, FAST, PET, RXVP, SADAT, SQLAB
PASCAL:	RXVP, SQLAB
JOVIAL:	JAVS, RXVP
PEARL:	PEARL-Analyzer

But one warning should also be given here: If used uncritically, many of these methods result in the production of enormous quantities of paper which in turn are very difficult to evaluate. Thus, a programming team should gain experience with them in pilot studies before using them in a full-sized project.

DEVELOPMENT SUPPORT HARDWARE

This is another problem area which is often not dealt with in relation to its true importance. Sufficient development support hardware is an important productivity factor and one usually needs more than is available. But it is important for the manager to know this in advance and to plan for the necessary funds in order to provide it at the right time. Figure 6-12 shows a typical curve for the support hardware needed during a major project. It has been taken from [67].

FUTURE TRENDS

It was generally agreed that the technological situation in the field of software development had improved over the past ten years and that at present there are enough tools available. The main problem today is how to use them properly. But the coverage of the software development cycle by tools is still very inhomogeneous and in some areas further developments are necessary. The following potential future developments have been identified as necessary and feasible:

1) "Intelligent" tools

2) "Contents" - or "concept"-oriented programming

3) Graphic user interface

4) Built-in-simulation

5) Integration of "rapid prototyping"

6) Language independence

7) Machine independence

8) Automatic generation of test data

9) Automatic generation of error handlers

10) Management visibility

11) Generics and macro processors

12) Guidelines for software and system development

In order to determine the priorities for these goals, the participants of the recent workshop [48] were asked to rank the proposals under two different boundary conditions:

A) Regardless of cost and only according to their technical merits and necessity.

B) With major consideration of project cost, i.e., if people had to pay for the development themselves.

This has resulted in the following order of importance in each case:

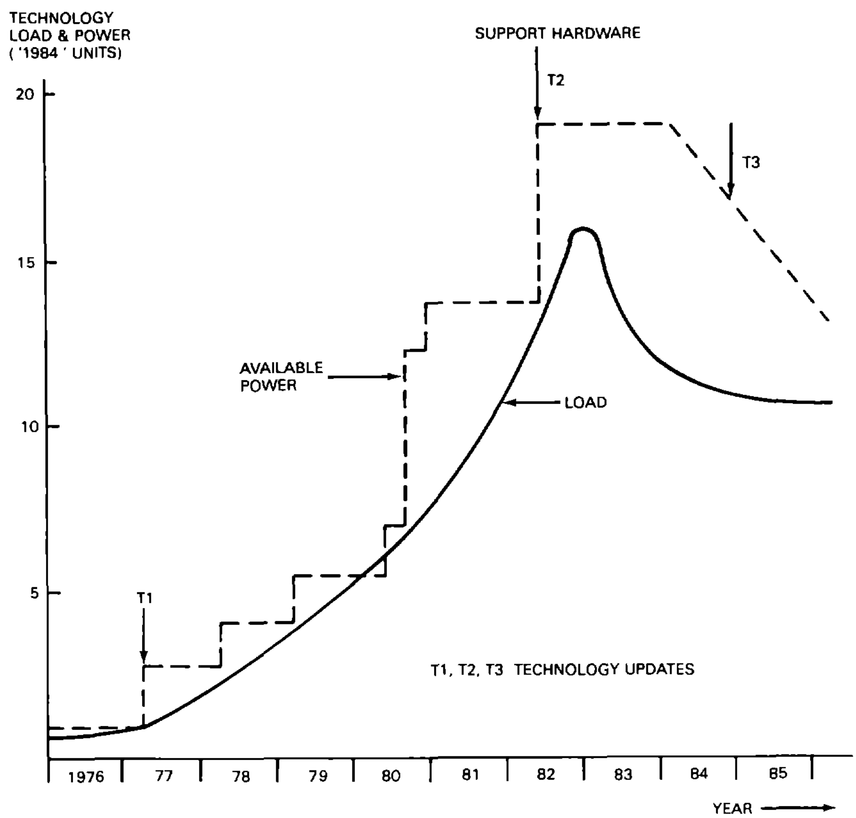


Figure 6-12 Use of support hardware over project time [48].

A)

1. "Intelligent" tools
2. Guidelines
   Integration of rapid prototyping
3. Graphic user interface
   Machine independence
   Management visibility.

B)

1. Graphic user interface
2. Integration of rapid prototyping
3. Guidelines
4. Machine independence
   Management visibility
   Concept-oriented programming

SUMMARY

The current state of the "Art of Software Management" can be summarized as follows:

1. Technically there are still problems but there are enough methods and tools around to properly support a project.
2. It is necessary to train managers better in order to enable them to:
   a. Properly use all these tools
   b. Organize their teams
   c. Motivate their people
   d. Control their resources

Management of software projects has to and can be learned and should not just be based on technological beliefs.

BLOCK DIAGRAMS OF THE PROGRAMMING REQUIREMENTS FOR THE SCHEDULING AND CONTROL HIERARCHY PROGRAM MODULARITY

As this generalized reference model readily shows, program modularity is the key to future transportability and reuse of computer programs in succeeding integrated production plant computer control systems. Modules themselves must be organized into sub-modules such that all possible commonality between comparable programs is preserved in the overall structure of the program and differences are concentrated in replaceable sub-modules which are specific to the particular applications involved. That is, program modules must be made as generic as practicable.

This is obviously not a new thought with the Committee and in fact is a well-known software engineering technique. The problem which exists is one of coordinating the design of these program modules so that their interfaces with other modules to which they interconnect are minimized. In addition, the modularized programs must themselves be written in a language which has been standardized for the real-time applications needed here.

AN EXAMPLE MODULAR PROGRAMMING SYSTEM

The first Figure (6-13) of this Section presents a diagram of the operations which are executed by programming in the process computer system. This diagram shows the overall system as carried out by a single computer containing all functions. The following figures show the corresponding diagrams for each level of a hierarchy computer system in turn. These diagrams correspond to the

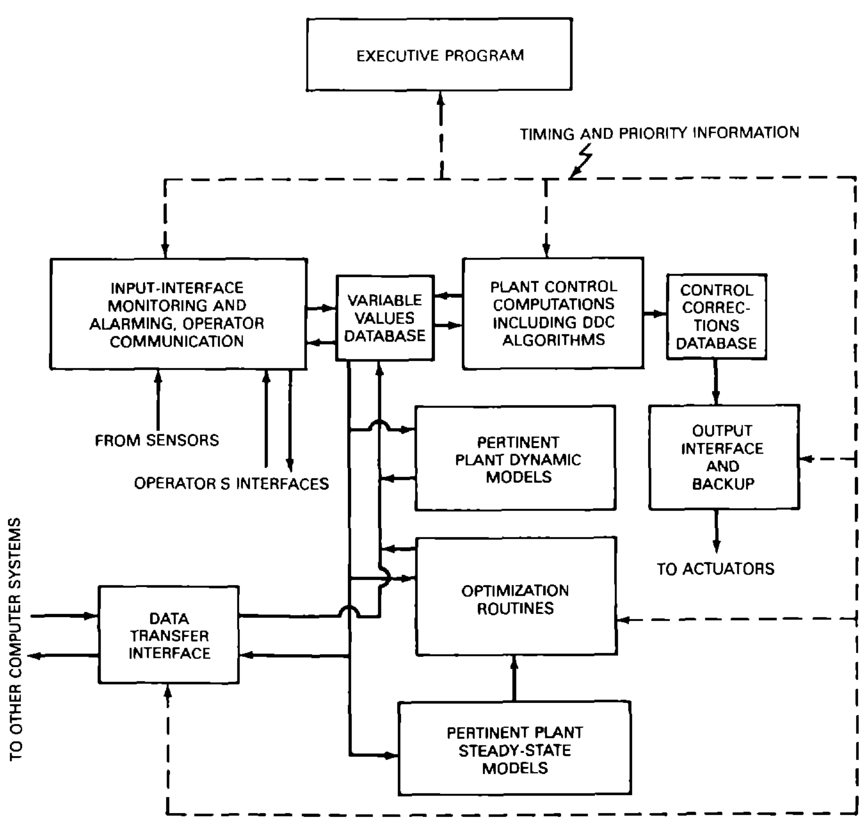


Figure 6-13 Block diagram of overall process control programming system to show desired modularity.

figures of the earlier Chapter in showing the duties carried out at each level and corresponding software modification.

Such a modular system allows any particular modules to be modified without affecting any of the other modules, thus greatly simplifying both the initial programming effort and any later required program modifications. This is made possible by the use of the database elements indicated in the diagrams. A further advantage of such a program is the fact that programs developed by others for any of the modules can be readily integrated into the overall program. The chance of finding a suitable preprogrammed module is obviously much more likely than the corresponding chance of finding the complete overall program for any particular specific application.

It should be noted that most of the differences between process control programming functions and engineering or business type programs are included in Level 1 of the hierarchy system, the second figure. Thus, the higher-level functions can probably use many programs developed for other applications. This probably will not be true for the needs for programs for the supervisors' and managers' interfaces or for any remaining time-based functions since these are the functions

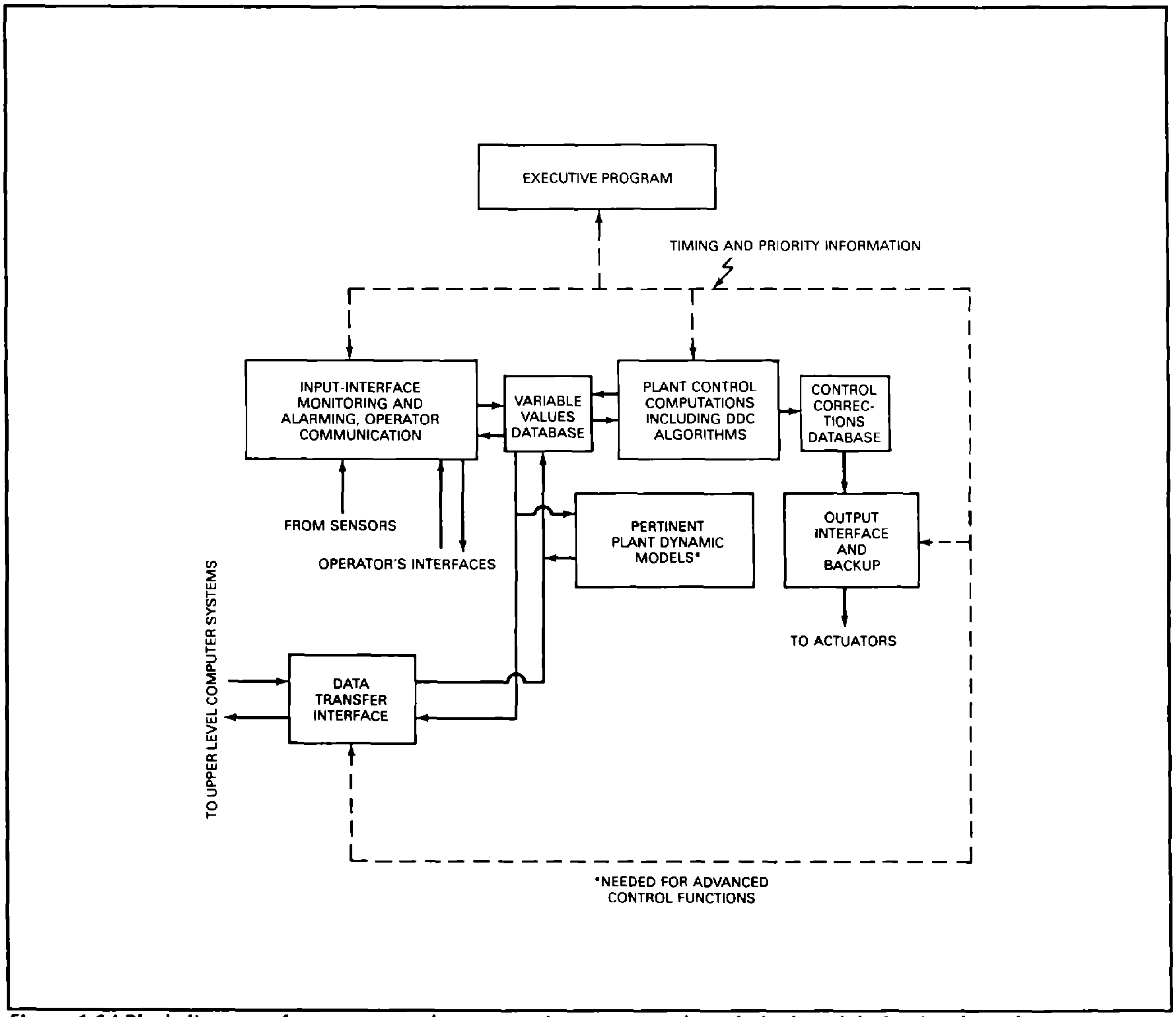


Figure 6-14 Block diagram of process control programming system to show desired modularity, Level 1 only.

which are least likely to be used for the business and scientific application fields.

While the diagrams of Figures 6-13 to 6-17 have been drawn for the main line process control, production control and production management tasks of the plant, it can readily be seen that the diagrams would apply equally well to the auxiliary tasks necessary in plant operation. These are maintenance management, raw material and energy control, product inventory control and statistical process control, among others. It can be readily seen that these functions would need access to the appropriate databases, would communicate both up and down in the hierarchy and would have the required man/machine interfaces. They would carry out the necessary task computations using the associated standard algorithms and related plant models. Most of these functions could use the standard process control sensors for any needed plant data. Thus they would probably not need any large number of special sensors.

The work involved would generally take place at levels higher than Level 1, probably at Level 2 or Level 3. Thus Figures 6-15 and 6-16, appropriately modified to include the terms common with the auxiliary tasks mentioned above, would readily apply to diagram these functions.

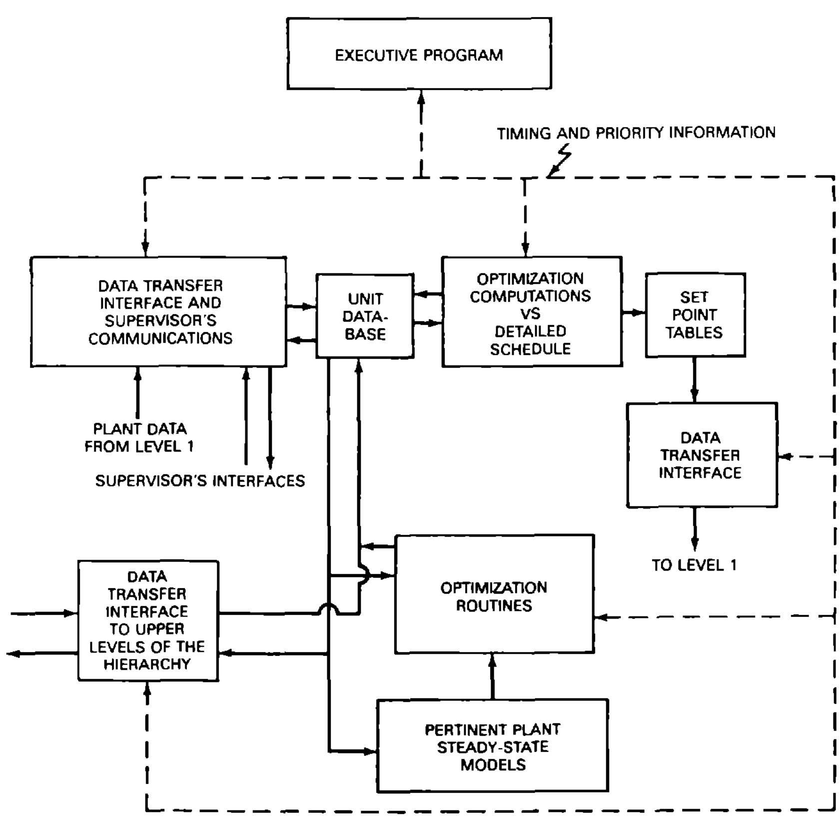


Figure 6-15 Block diagram of optimizing control programming system to show desired modularity, Level 2 only.

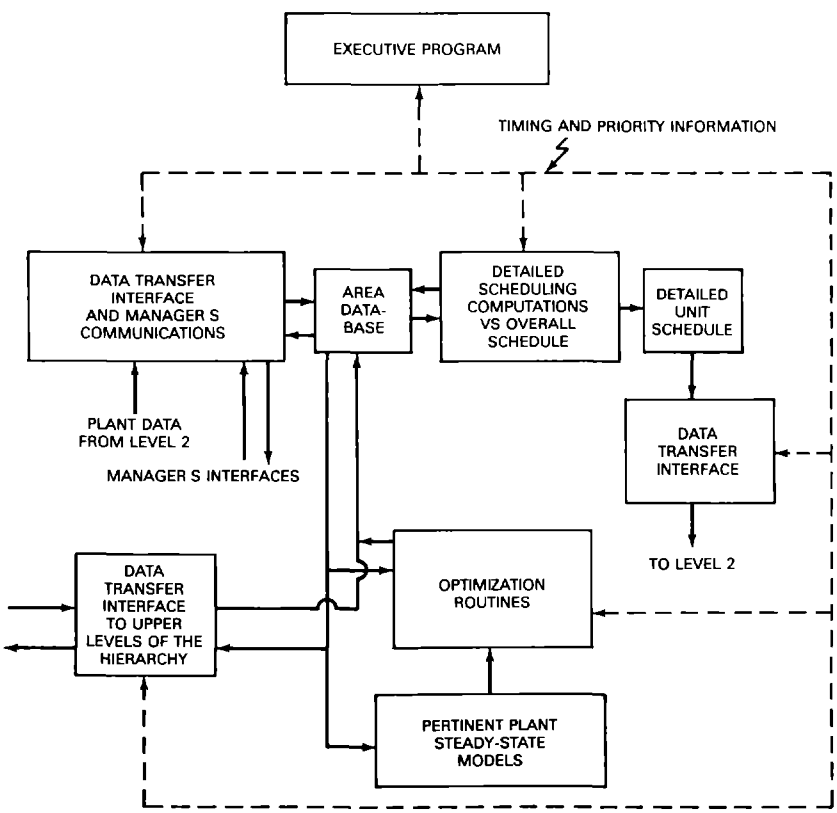


Figure 6-16 Block diagram of detailed scheduling programming system to show desired modularity, Level 3 only.

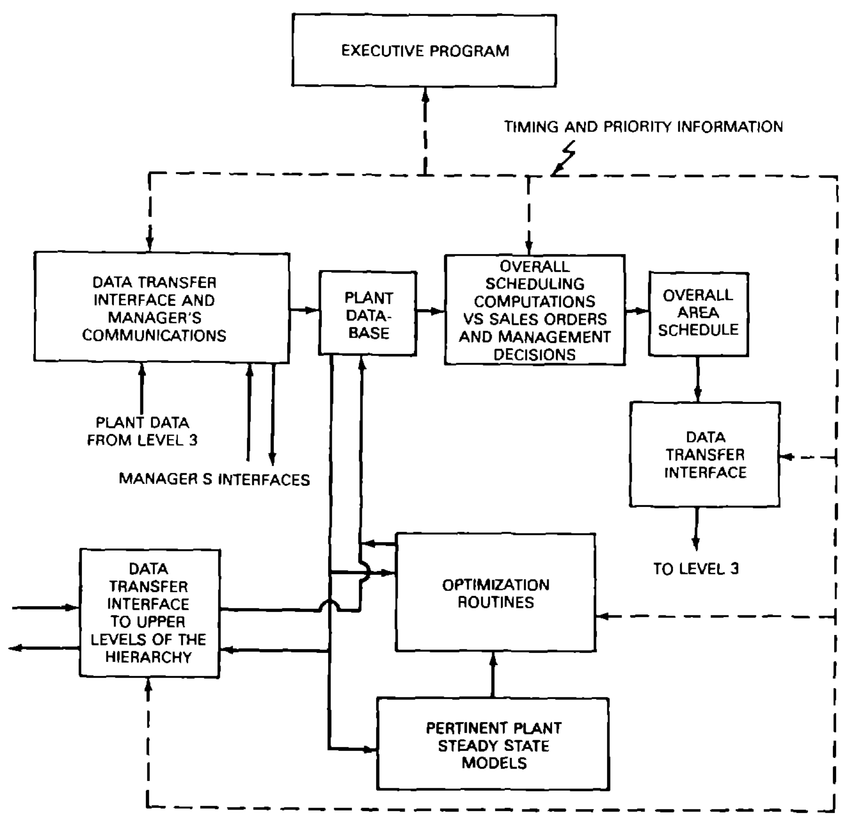


Figure 6-17 Block diagram of overall scheduling programming system to show desired modularity, Level 4 only.

7

Data Management Concepts Important in the Reference Model

INTRODUCTION

With the establishment of plant-wide data networks, as discussed in Chapter 9, the exchange of information between departments and their databases becomes the area of principal focus in the development of the Computer Integrated Manufacturing System. The need for the integration of network, hierarchical and relational databases distributed on communications networks throughout the plant must be considered. In addition, the continuance of the realtime data acquisition function for process control and management information is paramount in a plant-wide control and information system. This chapter will discuss the types and characteristics of Database Management Systems (DBMS's) before presenting an analysis of those features as they apply to real-time decision support systems.

The global database is the area where the most work is necessary to assure the needed commonality discussed here. To date there has been little standardization of the field other than for the several de facto standards developed by the several major vendors for their own products.

The database requirements for the systems discussed here are very large - up to 20 to 40 gigabytes for the steel industry systems. Both distributed and centralized databases are required in the same systems. Distributed databases, probably at each operational computer system, will contain process plans, and other control instructions, immediate future production schedule items, current plant variable data for control applications and operator interface needs, and other immediately necessary items. The centralized database is historical in nature: production results, raw material and energy usage, quality control data, sales and shipping information, maintenance data, inventory levels, etc. Much of the historical database must be relational in nature since much of its use will be for inquiries and studies of past performance in the hope of improving future operations.

Provision must be made in each case for back-up of the data because of potential computer system outages or other occurrences affecting the validity or availability of the data and information contained therein.

DATABASES NOW IN USE IN THE PROCESS INDUSTRIES [80]

Through the years, the conventional file system mechanisms have been used, typically with FORTRAN, to store and retrieve real-time data. Sequential files are used for collection and archiving. Indexed files provide random access to the data. Their simple structure provides the speed of response needed.

Ready access to data for analysis and decisions requires data to be stored in a structure that permits retrieval by content rather than location. Data tables can be structured into hierarchical or network sets in a database for later use. The Hierarchical database permits location according to a decision tree. The Network database provides more direct access to a diverse set of users, but requires the users to know the data location beforehand for efficient access to the tables. The a priori structuring of both database types limits their efficiency in ad hoc queries for analysis and optimization.

The relational database meets the needs for ad hoc queries of data for decisions in today's dynamic competitive production environment. It permits the logical independence of the data from its physical location. It also permits the use of a high level, Structured Query Language (SQL) [42] for non-procedural, set-oriented access to the data. Users need only specify what is to be done and it processes the data as sets of elements, rather than a record at a time. The hiding or transparency of the data structure to the user imposes a processing burden on each query that must be taken into account in real-time applications.

Database Management Systems currently available cover the gamut of types from the simple file manager to the SQL-driven full relational structure. Expert Systems are being developed to assist in the development of queries. DBMS's run on platforms from the Personal Computer to the large mainframe. Large databases with transactional inputs and updates as in the financial markets require large distributed processors. The PC-based systems are primarily file managers with relational query interfaces.

REQUIREMENTS FOR REAL-TIME DATABASE SYSTEMS

DATABASE ACCESS MECHANISMS

Once the data has been collected, effective use of the information requires that it be accessed for analysis and decision-making. For those applications where the needs can be identified beforehand, direct, hierarchical or network access can be provided by linking the application to the data. Some assistance is required where the amount and type of data needed varies from time to time.

A Data Dictionary is a common method of providing rapid access. The location of the data is entered into a separate database when it is stored. The search is then limited to accessing a pointer to the data. In a distributed processing system, the data dictionary can be centralized in a single master table or remain resident in the nodes owning the data. In addition to distributing the processing load, the management and control of access can remain with the data owner.

The task of manipulating data in useful sets is greatly simplified and expedited by use of a high-level query language, such as SQL, which supports the collecting and storing of fields in multiple tables in a single operation. It also permits the user, program or person, to define the data by its properties rather than by location, which need not be known by the requestor.

A simplified form of query language which is especially user-friendly is the Query-By-Example. There the user defines the data needed by its properties and relationships in a simple form like the structured query. But, the system searches for, and fills-in the blanks entered by the user. Thus, without knowing what data is available in the database, the user can seek out and retrieve data which meets his selection criteria.

Query-by-Forms is also a simple, user-friendly form of user interface. There the sets of data for input or output, or both, are defined in the field labels on a form. The DBMS handles all the data manipulation, control and cataloging needed.

REAL-TIME OPERATING CONSIDERATIONS

Perhaps the one common attribute which can characterize the process data on the shop-floor or in the plant is that of the need for real-time acquisition and processing. Real-time data can be defined as the data which needs to be manipulated, (read, written, transferred or processed) under a strict real-time constraint. Some real-time data is said to be hard real-time data while others are called soft real-time data. Hard real-time data is characterized as that data which, if not manipulated within a certain specified time, will lead to severe consequence (e.g., a major process upset). Soft real-time data on the other hand diminishes its value greatly if manipulated after the deadline but does not cause any serious catastrophe (e.g., trends on averages of the point values).

Perhaps, the single most important characteristic of a real-time data management system is its ability to provide guaranteed response for any data manipulation request for which there is a strict deadline.

The real-time database system is the determinant of guaranteed response for data manipulation requests. The database system usually provides the key functions of buffer management, multirequest switching, transaction scheduling and monitoring, recovery and consistency management and data manipulation primitives. These functions must be provided and implemented so that they are compatible with the operations of the corresponding functions in the real-time operating system; otherwise, conflicting policies executed by the operating system and the database system will lead to violation of the real-time constraints on transaction execution.

KEY CHARACTERISTICS

In considering the needs for a DBMS for integrating the control and information systems from throughout the plant, some key characteristics are suggested.

REAL-TIME COLLECTION

Data acquisition in today's process plants is primarily performed by the process-connected control, analysis and monitoring systems. Collection of these values for use by the on-process operator and advanced control processors is an inherent part of their operation. Because they operate under real-time constraints, their data conversion, manipulation and storage capabilities are limited. Conversion to engineering units as well as time-slice or snapshot collections may need to be performed by higher-level units. The DBMS must provide an easily adaptable interface to these data sources.

TIME-TAGGED RECORDS

Time is an added dimension of the data acquired from the process. Process snapshot values as well as state value changes need to be associated with a time of occurrence for later analysis of events. The closer that the tagging of the data is to the data acquisition process, the more accurate and useful the data will be. If the process-connected data acquisition control system is not prepared to provide the time-tagging of values, the DBMS will need to support the adding of time values to data sets as well as the synchronizing of its time value with the data acquisition process. It is obvious that the determinism of the DBMS will affect the consistency of the data.

ON-LINE ARCHIVING

Once the time-tagged data have been collected, the means for its storing in coherent sets in bulk media must be provided. Here the consideration is for timely storage in large volumes compared to the structuring of the data for later access. The processing of the data into an elaborately structured database could take more time than the data acquisition cycle permits. The tradeoff is against the complexity of the query processing. Data which has a high probability of need for immediate access, such as for displays of process variable trends will need to have simple access mechanisms for timely results.

MULTIPLE USER VIEWS

The need for the control and display processing at the process-connected level will be the primary determinant of the priorities and structure of the data acquisition process. Other users in the control room or throughout the plant will need the data structured into different sets, across process units, plant areas and across time. Each of these users, whether program or person, should have his own view of the data for effective analysis and decision-making. This requires a DBMS capable of supporting those types of access to the data.

STANDARD QUERY LANGUAGE

In order to gather data in useful sets for analysis, a tool is needed to describe the data set in terms of those needs. A standard language for structuring those queries such as SQL provides those tools. Providing access to the real-time data structure is a key characteristic of the language to be used.

SIMPLIFIED ARCHIVE RETRIEVAL

Because the data collected and archived by the process-connected system is normally structured according to the variable and unit to which it is connected, as well as time, subsequent retrieval for display and analysis may necessitate complex queries and extensive processing. As with the transient user views, a DBMS capable of supporting this type of access is needed.

DATA INTEGRITY

While data collection, transmission and manipulation are in process, some of its values may not be consistent with the rest of the set. For example, if one block of the set is in error during transmission and must be retransmitted, the rest of the set is out of step with it and should not be used. Likewise, during a transaction updating a data set, other users should be prevented from using the data until the transaction is completed. Also, if the transaction should fail to proceed to completion, some means of backing-out of the data must be available. A DBMS should be able to support these data integrity needs.

Of equal importance to the integrity of the data is copying between databases. In designing for rapid local access to data, large scale copying or replication of the data should be avoided. This may compromise its integrity. An application should request no more data than it can use. To do so would imply the assumption of the responsibility for its validity, which only the owner is able to do.

ACCESS CONTROL

With multiple users able to access the database distributed across the plant, the ability of those users to affect unit operations or plant operations based on that data becomes a concern. Access to the database at each level must be capable of control by the data owner. This is the lowest level at which the data can be assured to be valid. Access to lower levels, such as the data acquisition values, must be restricted to the owner of the data, even though it may provide faster and simpler access. The ability of a DBMS to control and limit the access of particular users to certain sets or views is needed.

CHARACTERISTICS OF CURRENTLY AVAILABLE SYSTEMS

There is a wide selection of database system products on the various computing platforms that can be used at the process, plant or enterprise levels. We will briefly discuss here the characteristics of some currently available DBMS's [97, 98, 19, 25, 78] that are important in the selection of a database system at any of these levels. The implications of those characteristics for control system and plant-wide system integration will be discussed in later sections.

OPERATING SYSTEM SUPPORT

Large numbers of database systems are available on various different operating systems such as VMS, UNIX, and MVS which are typically used at the plant level. These database systems are of two kinds: one kind developed by computer system vendors and the other developed by third parties. Third party DBMS's typically run on a number of different computers, thus providing greater portability and flexibility for applications. At the process level, the database systems used are typically special purpose and supplied by control systems vendor. They typically are proprietary as are their underlying operating systems. They provide short real-time response times by integrating well with the operating system environment of the control system. Therefore, the choice at this level is quite limited currently. However, as third-party database systems support more real-time features, control system vendors will consider them for use in their systems to increase compatibility and to leverage the wide database applications already available. The choice between database systems on the main-frame operating systems at the enterprise level is smaller than that at the plant level. Database machines available as back ends to some of the host main frames provide higher performance in managing the large and complex databases present at the enterprise level.

MACHINE CAPACITY REQUIRED

The computer hardware needed to support process database management is typically based on the 68000 class of processors and 1-2 megabytes of memory and optionally supports some secondary storage devices. However, as process data grows in size, which the current trend indicates to be likely, the size of memory as well as the processor power required will increase to provide both real-time access and some ad hoc access. The machine capacity required by plant level database systems is not a serious issue because they run on so many different computer systems with different capacities. However, since many database systems at this level come as bundled packages with perhaps some unnecessary utilities and features, it is useful to consider unbundled packages which allow the users to pick and choose the DBMS related tools they need.

FILE STRUCTURE

The methods of physical and logical organization of data by current database systems cover a wide range including flat files, indexed files, relational, hierarchically structured and network structured records and files, and object-oriented structures. At the process level, real-time access is more important than ad hoc access. Therefore, organization of the data either in memory or on disk using hash pointers, indices and B-trees to improve the access to data records or fields is preferred and characterizes how many process databases are structured today.

At the plant level, ad hoc access is important. Relational databases provide the flexible database organization and access required and therefore, they are the preferred DBMS's for plant management applications. At the enterprise level, the database structures and organization methods are tied to the history of the traditional financial type applications and are more evolutionary. Use of relational DBMS's at this level will increase access to enterprise databases and promote integration of plant and enterprise data.

USER INTERFACE SUPPORT

Process databases are often accessed directly by users. They are typically accessed by control system applications as well as display systems which interface to the user. As the network interconnection of systems expands, better visibility of process data to the plant will be afforded. The sophisticated user interface tools now available will make this possible. Current DBMS products provide a variety of user interface mechanisms including SQL, Forms, Query-by-example, graphics and English like natural language query mechanisms as noted above. Some DBMS's provide two or three different types of user interfaces and therefore provide better flexibility for plant level operations.

PROGRAM DEVELOPMENT

The database management systems at the process level typically provide only a set of library calls to be issued by system management applications. These generally are visible only to the control system developers.

Plant level database systems however provide different database application development support tools such as Fourth Generation languages (4GLs), host language (e.g., Fortran, C, Pascal) -embedded SQL and automatic application generators. These tools reduce the development costs and times involved in the growing number of plant level applications.

Enterprise level database systems on the other hand have traditionally come with a number of mature, screen-based application development aids, report writers and transaction development facilities. Current DBMS vendors, to distinguish themselves will continue to provide more programmer-friendly, intelligent, and graphically oriented application design tools and integrate the DBMS with a wide variety of third-party software development / engineering [CASE] tools and other tools such as spreadsheets and report writers.

Since a basic reason for moving towards the commercial DBMS's in process industries is to increase the visibility of data and thereby promote innovative applications of that data, program development facilities provided by the DBMS's will be an important criterion in selecting a plant level DBMS.

DATA DEFINITION LANGUAGE

Process databases are defined and configured generally as a part of the configuration management activity involved in the operation of a control system. The configuration tool in the control system provides menu-based mechanism for defining the structure of the process data as well as the default values associated with some of the database attributes. The data locations, names and instances of other attributes are then configured. The process data definitions can typically be only changed during reconfiguration time.

Plant databases on other hand need more flexible database definition and configuration facilities. Many of the current relational DBMS products provide such flexibility using different methods for data definition using SQL or Forms or other user interface mechanisms. Data definition using enterprise database systems however is more batch oriented, that is, database scheme definition is done once and changed only periodically at controlled re-organization points in time. Graphical-oriented database configuration mechanisms are becoming available in some DBMS products. These mechanisms will ease the configuration of control systems greatly and as a consequence will improve the use of databases. Data definition is not totally a technical issue only however; it involves the organizational issues of control, ownership and maintenance of databases as a part of the global information resource management policies. Only a few of the DBMS products currently provide any tools for dealing with such organizational policy and procedure issues.

DATA ACCESS DIRECTORY

The data definitions are stored in a data dictionary which itself is part of the database and thus can be changed and manipulated easily.

DATA MANIPULATION SUPPORT

To manipulate process data, the database systems at this level provide a limited set of primitives which read /write selected attributes of a data object. These limited primitives are not adequate to provide the variety of data manipulations that need to be performed on plant level data. A rich set of data manipulation primitives for selecting data satisfying a variety of conditions, merging the selected data, grouping the data in different ways and converting the data into various user-oriented formats is needed at the plant levels. Most plant level DBMS's currently provide a powerful SQL as the data manipulation language. SQL provides a rich set of data manipulations. Some DBMS's also provide other types of data access and manipulation capabilities, e.g., an icon-based data selection specification. Non-relational DBMS's used at the enterprise level provide more procedural data access languages leaving the more powerful data manipulation capabilities to application programming languages. Some of the current DBMS's provide extensions to SQL to provide application-environment specific features; such extensions are needed for selecting a future plant level DBMS.

CONCURRENT ACCESS MANAGEMENT

Process database systems manage the execution of concurrent requests for data by maintaining data access relationships between data owners and data users which ensure that only one user is responsible for reading /writing that data and that user is also responsible for providing the data to any requestor. This method reduces the concurrency control overhead and ensures integrity of data.

Most of the DBMS products used at the plant level are multiuser systems and, as such, they provide an elaborate concurrency control mechanism to ensure the consistency of data while executing concurrent user transactions. Many relational DBMS's use locking for controlling concurrency while only a few provide referential integrity, i.e, the ability to keep all related data updated when a single piece is updated. Referential integrity as well as the performance and flexibility of the concurrency management mechanisms will be two key factors in selecting future plant DBMS's.

Enterprise database systems provide very efficient and complex transaction processing support mechanisms which control concurrency.

NETWORK ACCESSIBILITY

Process databases are naturally distributed throughout the control system (see below). To access that data, process database systems provide transparency of location by means of a symbolic name to an internal ID directory distributed across all of the nodes of the control system. Currently, most plant databases are typically centralized. However, the natural tendency occurring with the distribution of plant management operations is that of an increasingly distributed storage and management of plant data.

Some of the current plant level DBMS products support distribution and location independent management of data using the same DBMS product on the different nodes in the network. Only a few of these products currently provide the mechanisms necessary for ensuring the full integrity and recovery of the distributed data. It is important to consider if a distributed DBMS provides these recovery and integrity features that are flexible enough so as not to cause any severe performance penalties.

Since management of the operation of a distributed DBMS can lead to complex organization operational issues, it may be useful in some organizations to consider the flexible and performant distributed DBMS products becoming available recently. These products manage data on a central server but provide transparent access to that data using front ends which are distributed across the plant-wide network. They also support the use of distributed data on a flexible configuration of micros and minis on the network.

DATA FILE COMPATIBILITY

Process databases are typically in proprietary file structures and thus require custom interfacing software. Plant DBMS products typically can accept or produce data in a variety of standard formats such as ASCII and binary. Some plant DBMS products allow importing from/exporting to a standard set of application/user tools such as spreadsheets and report writers.

To transport data in a distributed DBMS, currently, standards organizations are developing SQL based presentation layer standards which will need to be considered in selecting a plant DBMS in the future. The necessity for data gateways between heterogeneous plant DBMS's also needs be considered in selecting the different systems at the plant level.

SECURITY

Security in process database systems is maintained at the user interface level. Since access to control systems is generally limited, this type of security control is adequate. However, at the plant level, more stringent security control is needed to restrict access to plant level data which is available typically on common computer platforms.

Current DBMS products at the plant level allow read/write privileges on different attributes of different data objects to certain users during certain times and under certain conditions. Only a few DBMS products provide mandatory security enforcement using such techniques as allowing users with right security level to access only the data at that security level. As more DBMS's provide such levels of security and as more users/applications access plant level data, security will become a key consideration in the selection of a plant level DBMS.

CONTROL SYSTEM INTEGRATION

In applying commercially available DBMS's to the support of real-time control systems, a balance must be struck between the ease-of-access from the point of view of all users and the time constraints of the real-time data collection system. The following are some key characteristics to be evaluated in selecting a DBMS for integration with a real-time plant control system.

DIRECT ACCESS TO FILES

The interface to the data collection nodes or system should be specified so as to provide a minimum of loading or interference to the operation of the data collector. A DBMS which supports direct access to files, requiring only a definition of fields and extents, is best suited to the broad needs of database integration in the plant-wide system.

RANGE OF DATA TYPES

The various arrays, enumerations and status words found in a process control system must be supported as well as the conventional real and integer types. The DBMS will require a multiplicity of those types in order to interface the diversity of types found in the different control systems.

DATA OWNERSHIP

The safety of the plant, as well as the efficacy of plant operations and the accuracy of accounting and the quality of the product, all depend on the validity of the data used in the control and management of the plant. The concept of the "Data Owner" as the keeper of a data element and the process which is solely responsible for the validity of the data is well established [19, 82]. In providing access to the data in the process-connected control and process management systems, this key to integrity must not be compromised. With the widespread implementation of high speed data communications networks, copying of data into other database fields and replication of data tables into user databases can no longer be justified to speed up access time. Direct access to the data owner's values provides the most timely and accurate data.

ENVIRONMENT SPACE

The overhead imposed on processing as well as the RAM and bulk memory required are significant considerations in applying a DBMS to a real-time control system. The facilities and space consumed should be minimized.

OPERATOR INTERFACE

Making effective use of the data managed by the DBMS to control the process implies the use of a user-friendly but efficient query language with ready access to all the needed information. On plant-wide systems this calls for an interface to the process database that meets those criteria.

APPLICATION DEVELOPMENT TOOLS

The simplification of decision-making procedures is an important part of optimizing the operation of the control system. High level language tools provided with the DBMS are needed to permit the development of repeatable routines for data selection and collection for use in analysis and decision-making.

HETEROGENEOUS NETWORK SUPPORT

An inherent part of integrating the plant information and control system is providing for the exchange of data between the different data acquisition, analysis and control systems provided by different vendors and operating on different hardware and software platforms. These diverse sources are selected for their optimization of their functions. Optimizing the application of the data provided by those systems is a key to the overall optimization of the operation of the process and plant.

REAL-TIME PERFORMANCE

Underlying all of the needs in process and plant control and information systems is the need for timely and accurate data. Accuracy and timeliness are interdependent. In applying a DBMS in a plant control environment, the balance between the differing needs of the users of the information and the timeliness of the result must be maintained.

Current database system products which offer relational structures with SQL capabilities continue to make advances in the performance and distributed data management features. Only limited instances of the use of these systems in real-time applications exist today. The use of these systems in soft real-time applications will grow as the performance of these systems increases to the level at which it is satisfactory for the real-time manipulation needs of centralized or distributed data.

However, for supporting the data management needs of restrictive soft real-time or hard real-time applications, these products must be redesigned with such features as:

1. Deadline-based query/transaction scheduling mechanisms;

2. Non-blocking concurrency control methods; and,

3. Main memory-based fast recovery algorithms.

Until such real-time database system products are available on the market, the choices left for automation system (process level use) or other real-time system implementors is: 1) to wait, 2) to use the best of the current DBMS products where the real-time constraints are soft and the product performance meets the worst case needs or 3) to design/implement a real-time database system dedicated for the needs of the system being built.

PLANT-WIDE INTEGRATION

Integration among process, plant and enterprise databases is quickly becoming a serious concern in many process industries. The interface which exports process data into a plant level database and vice versa is the first concern in this regard. Transformation of the structure and contents of process/plant data is an essential operation of this interface. Definition of a common interface language can improve the current ad hoc process-to-plant data interface development process.

Integration of the distributed plant data is the second concern. A data dictionary documenting the distributed data and the mappings among that data and a methodology for maintaining an active data dictionary are important in plant level distributed data integration. Also, when heterogeneous DBMS's are used at the plant level, tools which ease the development of data gateways between these different DBMS's need to be considered. Export of plant data into the enterprise database and import of enterprise data into the plant is the third concern. Simple file-based export / import mechanisms are adequate in achieving this type of data integration because plant-to-enterprise data is exchanged less frequently than process-to-plant or across-plant data.

In considering the overall functions of DBMS's to be implemented in a plant, there are several aspects which are key to the effective control of plant operation. They may be described here in relation to the access the systems provide: to the process; to the operator; from the Plant Information Network; and, from the Enterprise.

ACCESS TO THE PROCESS

Timely acquisition of data from the process and providing access to that data is the prime concern of a control system. Meeting those needs while maintaining access to other users of the data is its principal function. Support for higher level control processors with timely access to the data is implicit in this. Processing of highly structured queries is a secondary function and must be kept from compromising the primary goal.

ACCESS BY THE OPERATOR

Effective access by plant operations to the process and all that affects it is the basic objective of the control system and the database which supports it. Providing access to the process data for analysis and decisions and for control to implement plant management policies is its reason for existence. It must continue to present the needed data to the operator in a timely, accurate and comprehensible manner.

ACCESS FROM THE PLANT INFORMATION NETWORK

In today's high technology operating environment, much of the process control data manipulation has been mechanized. Data from the process is readily available at the operator's fingertips on a CRT. The data from the rest of the plant and from the business which affects his decisions is also mechanized and may also be available through CRT's. The most effective use of this latter information is to also put it at the operator's fingertips. By juxtaposing business data with affected data from the process, more timely, balanced decisions can be made in the operation of the process. This would be similar to displaying the setpoint and output values of a controller loop alongside the process variable value as has been standard practice for years.

ACCESS FROM THE ENTERPRISE

As part of the plant management structure, the results of the operators analysis and decisions must be reported up the chain-of-command. The collection, analysis and decision-making at the higher levels requires those inputs. Likewise, the passing down of operating policies based on the higher-level decisions completes the plant level control cycle. For timely and effective flow of this information to occur, the databases in each organization must be integrated.

Often the information must flow between the databases of different makers over networks with different protocols. While MAP/TOP and the ISO protocols offer a long-term solution to the network integration problem, they do not address the database integration problems. Also, the networks available for short-to-mid-term implementation do not provide complete data integration since no migration plan is included in their specifications. The integration of this data from diverse sources for use throughout the plant is the principal challenge for plant information and control system development in the next decade.

DISTRIBUTED DATABASES IN THE FACTORY

In the discussion to follow, a large number of specialized databases will be described. It must be borne in mind that these are all parts of the overall global database and must obey all rules of variable naming, data dictionary and data directory, access methods, etc., necessary for their effective utilization as such. The apparent segmentation described below is for conveniences of description, of task use or of geography and must not be allowed to invalidate any part of the global database and global access in the system [79].

THE PROCESS SENSOR DATABASE (LEVEL 1)

Today most sensor signals are analog which are then converted to digital values at the controller or data acquisition unit. With the advent of digital sensor loops, more information becomes available across the wire than simply the process value and the loop continuity status [79]. All the variable parameters of the sensor become adjustable and readable. This set of values will come to constitute the loop database. While these values have been traditionally the concern of the instrument maintenance technicians, their digital form lends itself to making them available and adjustable by people working at the higher levels of the hierarchy. Figure 7-1 presents the stages of sensor data reduction important in considering the process sensor database.

Process engineers at the process management level and operators at the process-connected level may now access sensor and actuator parameters for monitoring of scales, range and calibration. Sensor adjustments are more easily made and better record keeping of changes is practical with an on-line sensor database. Maintenance can be scheduled according to trends in the sensor parameters. This elementary data set becomes the first level database in the plant information system hierarchy.

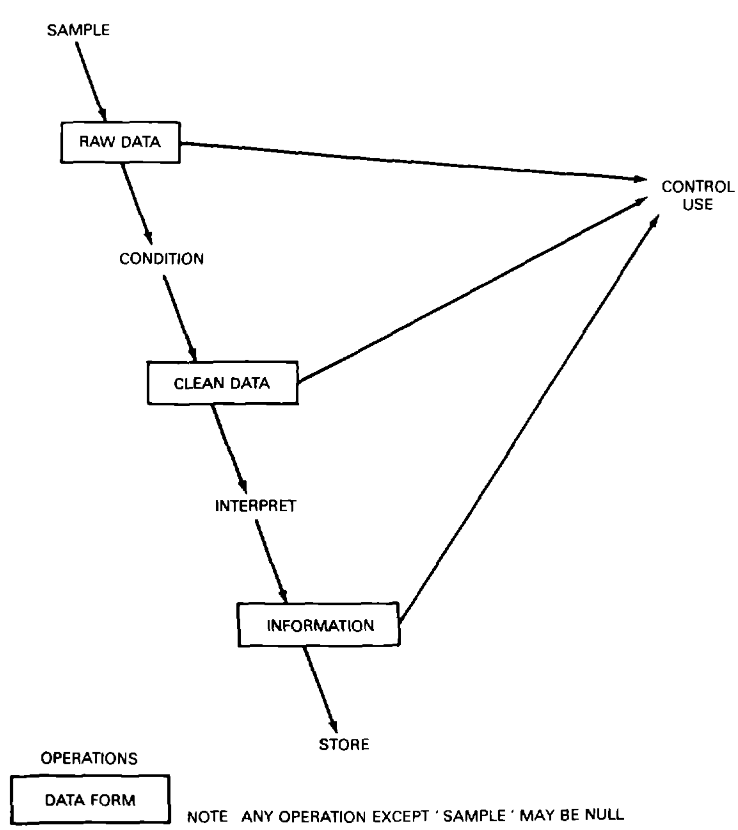


Figure 7-1 What do we do with data?

Digital control at the process-connected level has been well established over the last decade. Many functions, which formerly required a central process computer, have migrated out to controllers operated by microprocessors at this level. Batch process sequencing and control as well as sequential logic control have become integrated at this level. This database contains the loops' control and status values expressed in forms which are suitable for processing at rates in the 1 second class.

In the distributed database on the data highway, the *Loop algorithm* values support regulatory control. Sequential control as well as batch sequencing are supported by the *sequence state* database. Also, safety control depends on the *interlock logic* database. Similarly, analysis of process trends is provided by the database of *process snapshot* values. Today the database associated with process-connected devices is generally the basis for higher level databases.

THE PROCESS CONTROL DATABASE (LEVEL 2)

A process control database, called the *Unit Database* in Figure 6-15, is required for Level 2 operations in the control of each process unit of the plant. McCarthy [79] has presented the following discussion of these databases.

The distributed database at the control room must be integrated so as to meet the needs of the operations management tasks performed there. Process operation and management which occurs at this level and the higher level control strategies which are implemented here require a more sophisticated database than the lower levels. The distributed database must be partitioned and structured to meet user needs which vary across a broad range. A discussion of this partitioning and the structure to achieve it follows.

The *Process Variables and Attributes* database provides access to the values in physical (engineering) units representation. The data obtained from the process units and sensors as well as the values derived from them are accessible with greater precision for extensive calculations and transformation into control indices. These values become the "Global" Process Database where information can be accessed by Tag and Process Variable or Parameter Names independent of physical locations.

Thus the Process Control Database has a dual expression. It is on the one hand globally accessible as above and on the other hand is defined as data structures representing particular generic application functions as described below.

The *Graphics Image* database supports the display interface to the operator, simplifying interpretation of operational situations. Access to the picture elements and abstracts data enables the operator workstation to display the process information in a meaningful fashion, thus simplifying and expediting the analysis by the operator.

The *Control Algorithms* and *Computation Language* and the associated process databases permit the implementation of cross-unit and plant-wide control strategies. The language processors executing the control functions have access to a wide variety of procedures and functions in addition to the variables necessary to complete their tasks.

Alarm management is achieved with the *Event Sequence* database. The events occurring at the process as well as those interpreted from the data and calculations are organized, prioritized, and reported for use by the operator workstation and other Data Users.

Trends in process conditions and states are determined from the *Process History* database. Data collection and storage in timed snapshots and averages permits the later analysis of historical values.

Sequence-of-events analyses and reports are supported by the *Event History* database. Events occurring in the process and in the control room are time-tagged and entered into journals for later analysis.

Control system maintenance and management is sustained by the *System Event* database The system error messages are time-tagged and journalized for later diagnosis and predictive maintenance action.

The generation of logs and reports is provided for by the *Format Generation* database. Standardized reporting forms can be accessed from throughout the system, thus easing their availability and use.

As the entry level of the corporate decision-making chain, the operator requires access to the databases at all levels of the organization. The control room database is structured to simplify and expedite decisions. In addition, the needs of other organizational groups for information from this area and the relaying of operating guidelines to this area are accommodated.

DATABASES FOR HIGHER LEVEL FUNCTIONS

It is when the various department databases which were formerly required are interconnected via the data highway network that the challenge of integration becomes most apparent. These databases originally grew up in card files, file cabinets and typed and hand-written reports. When this information handling was mechanized, the database system and machine selection were guided by the inherent structure of the data (and the media). Now that a plant-wide data communications system is becoming available, the need for these diverse systems and data structures to interact with each other must be addressed. And, they vary over a considerable range.

The Quality Control laboratory and statistical functions, the production control planning and scheduling, as well as the Process Control Engineers' modeling and analysis each require their own database in addition to access to others to complete their tasks. In a like manner, Maintenance Management, Building Management, Materials Management, Order Entry and Tracking as well as Manufacturing Requirements Planning establish their own databases and require access to and from others.

The integrity of information or data values becomes a concern when databases are linked. The security of each database is part of this concern. For effective use, each user must be confident that the data received from each query is valid. The concept of Data Owner and Data User introduced in the distributed database of the Process Control Network provides this mechanism. There the process in the node which produces the information is the owner of that variable. Only that process owner can change its value. All attempts to input variables to the process Data Owner are checked for validity of access. The distributed

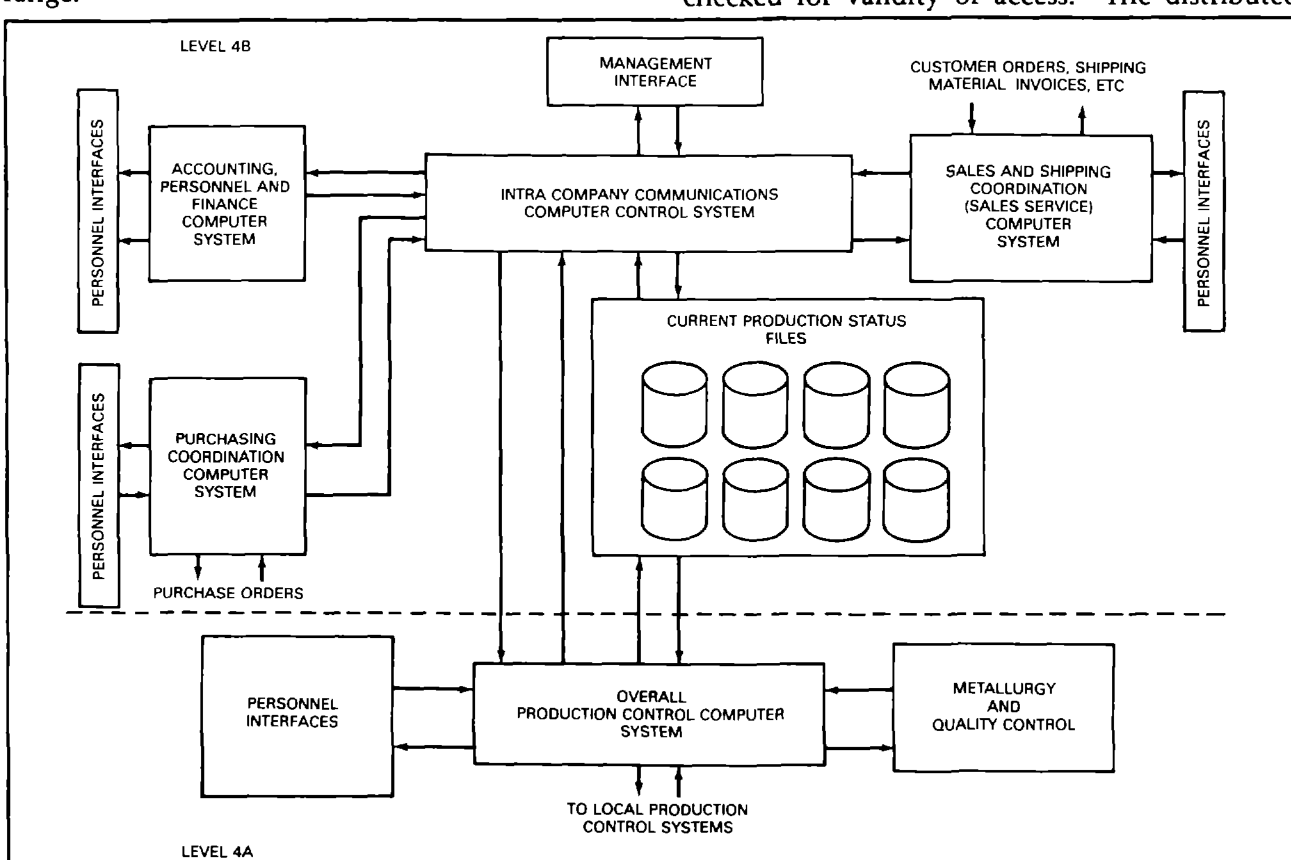


Figure 7-2 Overall plant production control system.

database manager in each node assures this in its response to data dictionary queries. The Data Owner-Data User concept can be extended to all levels. Table 7-1 presents a set of important concepts concerning Data Ownership important to the integrity of plant databases.

The need for timely and accurate data for decisions raises another concern. That is the duplication of data values across the plant-wide database. Up until now departmental database systems have routinely collected data held by other Data Owners and entered them into their structure. This was primarily done to overcome the delays in acquisition due to the latency of the slow speed networks available previously. The penalty was the loss of timeliness of the value. The high speed of today's networks removes the need to acquire the value in advance, thus removing the need for duplication. It eliminates the possible inconsistency between the actual value held by the Data Owner and the transient value held in the duplicating database.

The departmental databases located throughout the plant all come together on the network. Gateways to higher and lower levels interconnect those databases with the entire plant and corporate structure. MAP provides the tools for intercommunication. The distributed database manager coordinates the interaction.

Figure 7-2 presents several concepts concerning the centralized portion of the overall database of the plant production computer control system. Figures 7-2 and 7-3 [90] show this database labelled as the Current Production Status File. Figure 7-2 indicates that this file is maintained by the Overall Production Control Computer System of Level 4A. Management and the staff functions of the company have a READ access to this file but not a WRITE access. The latter is restricted to the Production Control System. Figure 7-3 presents a diagrammatical presentation of the proposed contents of this file and the association of each element with the staff function most likely to use this data.

TABLE 7-I

SOME DATA MANAGEMENT CONCEPTS IMPORTANT TO THE DESIGN OF THE CIM INFORMATION MANAGEMENT AND AUTOMATION SYSTEM CONFIGURATION

1. ALL PLANT COMPUTER DATA FUNCTION IMPLEMENTATIONS WILL ACT IN THE ROLE OF "HELPFUL" HUMANS IN RESPECT TO TRANSMISSION OF ESSENTIAL INFORMATION.

   DATA OWNERSHIP COMPRISES THE RESPONSIBILITY TO PROVIDE AND MAINTAIN THE INTEGRITY OF THE IMPLEMENTED SYSTEM POLICY IN RESPECT TO THE INFORMATION CONTAINED IN THAT DATA. IT *CANNOT* IMPLY ANY CHOICE OR RESTRICTION OF DISTRIBUTION OF INFORMATION ESSENTIAL TO ANOTHER ENTITY.

2. FOR EACH DATA ITEM IN THE SYSTEM, THERE IS SOME SINGLE ENTITY THAT IS RESPONSIBLE FOR THAT ITEM. ALL DATA ACCESS BETWEEN ENTITIES MUST BE EXPLICIT. DATA INTEGRITY REQUIRES EXPLICIT ACCESS FOR ALL WRITES. DATA SECURITY REQUIRES EXPLICIT ACCESS BOTH FOR

   READS AND WRITES. EXPLICIT ACCESS ALSO CONTROLS SYSTEM COMPLEXITY AND MAKES SYSTEMS EASIER TO MAINTAIN.

3. A SYSTEM-WIDE ACCESS METHOD MUST BE DEFINED. THE ACCESS METHOD WILL SUPPORT THE CONTROLLED INTERCHANGE OF DATA BETWEEN ENTITIES CONSISTENT WITH [2] ABOVE.

4. DATA PASSED BETWEEN ENTITIES IS OF THREE TYPES:

   A. RAW DATA, WHICH EMERGES DIRECTLY FROM A SENSOR,

   B. CLEAN DATA, WHICH HAS BEEN SMOOTHED, AND CONDITIONED

   C. INFORMATION, WHICH HAS BEEN ASSOCIATED WITH A SEMANTIC CONTEXT.

AS NOTED IN FIGURE 7-1.

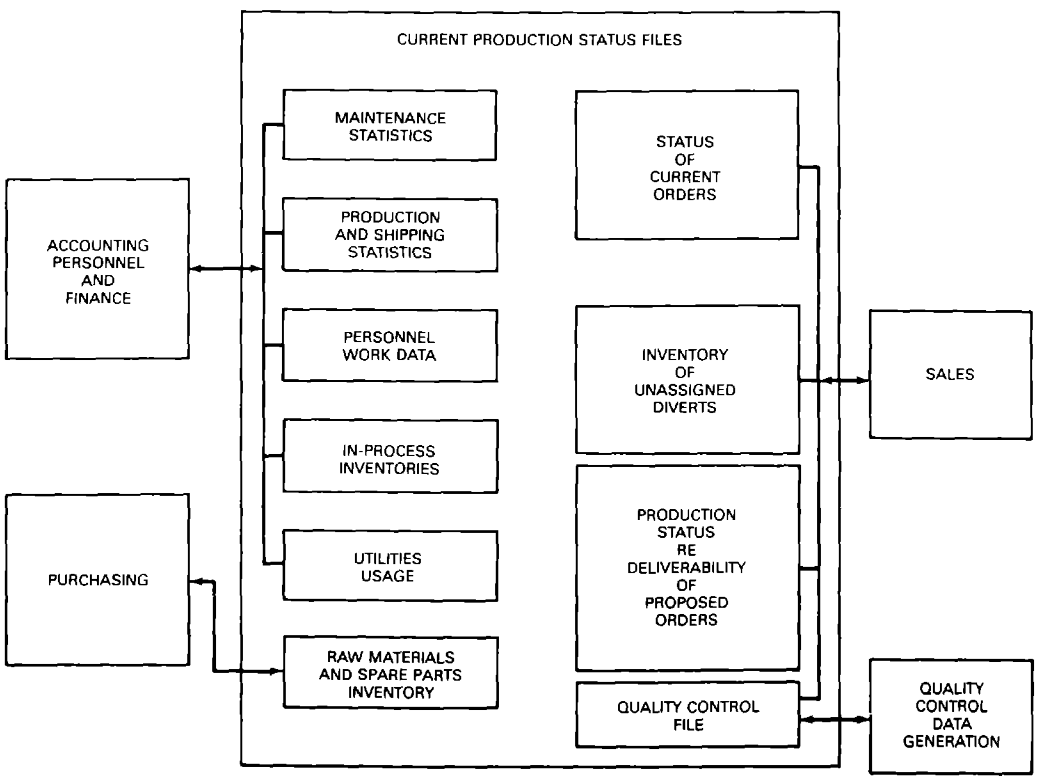


Figure 7-3 Non-operational contact with hierarchy computer control system (Level 4B), the production status file.

8

Some Scheduling Concepts and Functional Requirements for the CIM System

PRODUCTION SCHEDULING

There have been many scheduling schemes developed over the years to assist persons trying to produce desired products as requested.

For each plant a production scheduling system must be developed. The form and content of this schedule will vary depending on the type and design of the plant and the product mix produced. However, it is expected that the techniques used in determining the actual production schedule will be generic between plants in the same industry and even between industries.

It is not possible to thoroughly discuss each type of scheduling system. Three types of scheduling concepts are reviewed and the functional requirements developed. Hopefully these or combinations of these types will fit most of the production cases encountered.

1. *Typical Continuous Operation Plant Scheduling* is based on historical requirements, predicted sales forecasts modified by actual sales. Many chemical, paper and steel plants operate on this basis. Raw materials required for production runs are usually on hand. Inventory control and economic order quantity purchasing may be a part of this system.
2. *Just-In-Time Scheduling* is a newer technique and is being used for plants and processes that are designed to use this method. Since storage capacity is limited by design the initial plant costs may be reduced significantly. There are scheduling concerns to assure that all materials arrive at the proper time.
3. *Job Shop Scheduling* makes products to order. This varies from simple to complex depending on the products produced and the variety of products made within a facility. Examples might range from custom wood products to gear production to injection molding of parts.

With each of these example types of plants in turn the scheduling becomes more complicated with more interaction between plant facilities, space, materials and types of equipment required.

For any of the above cases the ability to develop a proposed schedule is usually straightforward. This calculation will remain a proposed schedule until plant feedback is provided. This will now indicate how well the plant is producing to meet the schedule. In some cases the schedule may not be met at all! Broken equipment or shortage of materials may require that other items be produced or even shutdown of the facility.

The hierarchical model through the four levels of scheduling and sequencing (Tables 3-VI to 3-X) defines the functional requirements for a typical plant schedule.

Just-in-time (JIT) scheduling adds another layer of complexity to the typical type schedule and the feedback required. A complete delivery schedule for each of the required materials must be created and constantly tracked. These must be compared against the production schedule to determine if usage is within limits to keep the plant in question at this rate. Since storage capacity is very limited each truck, car, etc., must arrive within a prescribed time window or changes must be made.

Make to order is a special case that is dependent on the number and types of products that are to be produced. In the previous examples of this type the complexity increases from an item made from wood to multitype gears to an unusual number of molded parts.

Gear production may sound easy but the molds, the metal composition, casting space, equipment availability and time required per unit make it more complex than first imagined.

Making molded parts uses all of the above but also requires special mold forms to be made, different operating conditions for each new mold and other complexities.

The hierarchical model indicates some of the following data that is required to meet production goals in a typical plant. Other data is added for other scheduling types indicating the amount of data to be handled to obtain the proper results:

1. Actual Production Rate
2. Quality of Production Product
3. Cost of Producing Product
4. Raw Material Usage
5. Energy Usage
6. Labor Required
7. Raw and Finished Goods Inventory
8. Equipment Availability
9. Storage Capacity for Raw Materials
10. Delivery Schedule for Raw Materials
11. Comparison of Rates of Consumption vs. Production Rate Required To Keep Plant Running Smoothly, Depending on Deliveries
12. Laboratory Data
13. Finished Goods Packaging (If Required)
14. Finished Goods Shipping
15. Interim Storage Availability

Figure 8-1 and Table 8-I present another way of showing the scheduling concepts involved [21]. In addition a potential production scheduling algorithm which has found acceptance in the steel industry [76, 90] is also described below.

A PRODUCTION SCHEDULING ALGORITHM

As stated in Table 3-VII, the Level 4A computer system (Figure 3-1) will be charged with maintaining the production schedule for the plant. In this part we will develop a proposal concerning the methods by which this production schedule can be initiated and maintained in this computer system.

Table 8-II presents the overall assumptions which govern the basic statement of this scheduling algorithm. With these assumptions, the procedures of Table 8-III are carried out to get the final schedule. Tables 8-IV and 8-V give the corresponding duties of associated personnel.

Figures 8-2 to 8-4 use a steel industry example to illustrate the scheduling technique outlined in the above tables and how this work interfaces with that done at the lower levels of the hierarchy.

OPTIMIZATION FROM THE MASTER SCHEDULING VIEWPOINT

The basic concept or driving force behind the installation of a master scheduling technique is the desire to obtain a coordinated flow through

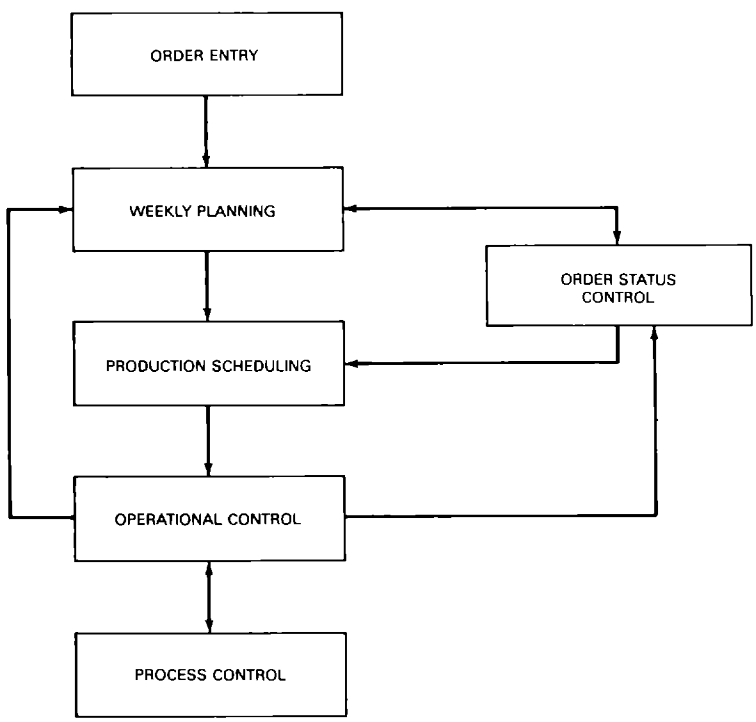


Figure 8-1 Production Management System- Functional Structure.

production in the plant. In general, master scheduling will attempt to optimize the conflicting objectives of: (1) Customer service, and, (2) Minimum inventory. It will do so in light of considerations required by equipment restrictions, handling requirements, maximum storage capabilities, general transportation operations, and overall capacity constraints.

As benefits of the master scheduling technique, the user can realistically expect to increase performance in due-date, reduce inventory and potentially increase production by utilizing a schedule that avoids production bottlenecks and/or equipment idleness. The master schedule provides a plan that can be used as an effective control to obtain these benefits.

The strategy suggested for the steel production system begins with the receipt of orders at the various sales offices. These orders are combined with forecasts to produce an order stream input to the master scheduling process. The actual orders are used for the close-in period and order history will be consulted for the long range prediction of requirements, i.e., the order stream. This stream is then ranked according to the due date accompanying each order. Since each order may have a different production time the order slack is calculated as:

$S_i = dd_i - p_i - t$

where:

S_i — slack time for order i

dd_i — due-date for order i

P_i — processing time for order i

t — current time

As long as the order slack is positive we have sufficient time to produce the item without any expediting. The problem occurs when the slack becomes negative which means that there is insufficient time to produce the order and meet the due-date required.

This order stream, now containing the characteristics of order, due-date and slack, represents a time phased requirement of finished product. The problem has then become one of somehow meeting the requirements of the stream in light of production restrictions, current inventories and other managerial objectives (i.e., smooth production level, minimize quantity of late orders, etc.)

At this point it is the function of the master scheduling system to weigh the various factors and alternatives and produce a schedule that satisfies the requirements of the order stream. The close-in schedule will be based on firm customer orders and will be used for actual production scheduling while the future schedule can be used for examinations of future resource requirements. This schedule will be optimal in the sense that a set of goal programming algorithms will have been utilized to minimize deviations from the multiple objectives of management. The master scheduling process can be viewed as Figure 8-5. The technique of goal programming appears to offer high promise in the development and solution of such a scheduling algorithm [63, 72, 76].

The concept of the job stream (Item A5, Table 8-III) can easily be input to this system. To utilize the job stream approach would require that the original order stream creation be modified by the job stream influence. The effect of the job stream would again be felt by the master schedule when it analyzed the current inventory (unapplied) mix. If a job stream approach was being utilized more matches would be anticipated and the master schedule would be adjusted accordingly. A report of the Purdue Laboratory for Applied Industrial Control (Report Number 112, *A Production Control Strategy for Hierarchical Multiobjective Scheduling with Specific Application to Steel Manufacture,* (May 1979), by Gerald T. Mackulak and Colin L. Moodie) [76] shows how many of these ideas may be implemented in the steel industry.

TABLE 8-I

PRODUCTION MANAGEMENT SYSTEM - SUBSYSTEMS

ORDER ENTRY

1. AFFECTS THE WHOLE COMPANY (IF MORE THAN ONE PLANT)
2. CHARACTERIZED BY INSTABILITY OF THE MARKET
3. CUSTOMER'S ORDERS EXPRESSED IN TECHNICAL TERMS TO ACCOUNT FOR:
   A) PLANT PRODUCTION CAPABILITY
   B) COST EFFECTIVE PRODUCTION CYCLE
   C) QUALITY/QUANTITY/DELIVERY

WEEKLY PLANNING

1. AFFECTS THE SPECIFIC PLANT
2. PERIODICALLY ISSUES ORDERS FOR PRODUCTION BASED ON:
   A) EQUIPMENT LOADING
   B) YIELD OPTIMIZATION
   C) COST OPTIMIZATION
   D) ORDERS ON FILE AND CUSTOMER'S SPECS
3. VIA MRP OR OTHER SUITABLE TECHNIQUES ASSURES AVAILABILITY OF NEEDED RAW MATERIALS ENERGY SOURCES, SPARE PARTS, ETC.

continued

Table 8-I continued

ORDER STATUS CONTROL

1. ANALYZES PRODUCTION COMPLETION DATA VERSUS ACTUAL SCHEDULES AND CUSTOMER'S ORDERS
2. RESCHEDULE IF NECESSARY

PRODUCTION SCHEDULING

1. GENERATE SHIFT/DAILY SCHEDULES BASED ON:

   A) WEEKLY PRODUCTION PLAN REQUIREMENTS

   B) MATERIAL AVAILABILITY

   C) EQUIPMENT STATUS

   D) ORDER STATUS

OPERATIONAL CONTROL (LEVEL 3)

1. EXECUTE THE PRODUCTION SCHEDULE

   A) EXPAND INTO WORK INSTRUCTIONS

   B) DISSEMINATE WORK INSTRUCTIONS

   C) COLLECT/COMPLEMENT COMPLETION DATA

   D) GENERATE AREA LEVEL REPORTS (MAINTENANCE/QUALITY/ PRODUCTION/COSTS)

   E) MAINTAIN MATERIAL INVENTORIES

   F) START FEEDBACK LOOP TO "ORDER STATUS CONTROL" SUBSYSTEM

PROCESS CONTROL (LEVELS 1 AND 2)

1. EXECUTE THE WORK INSTRUCTIONS

   A) INITIALIZE AND REGULATE THE EQUIPMENT TO MANUFACTURE THE UNIT PRODUCT(S)

      (1) CLOSED-LOOP (STAND-ALONE/ADVANCED CONTROL)

      (2) OPEN-LOOP OPERATOR GUIDE (ADVANCED CONTROL)

   B) REQUIRES SIMPLE/ENHANCED OPERATOR INTERFACE

   C) COLLECTS PRODUCTION DATA

   D) COLLECTS/ANALYZES PROCESS DATA

   E) GENERATES PRODUCTION REPORTS/ LOGS

2. FEEDBACK COMPLETION DATA

TABLE 8-II

OVERALL ASSUMPTIONS REGARDING PRODUCTION SCHEDULING

1. THERE IS NO UNIT OF THE PLANT WHOSE OPERATIONALLY IMPOSED PRODUCTION CYCLE IS AN APPRECIABLE FRACTION OF THE NORMAL PRODUCTION PERIOD OF THE PRODUCT INVOLVED IN A CUSTOMER'S ORDER.

2. THE PROBLEMS OF EQUIPMENT WEAR AND MAINTENANCE MAY DICTATE THE TIME SEQUENCES FOR PRODUCING PRODUCTS TO CUSTOMER SPECIFICATIONS OVER THE PERIOD OF AN EQUIPMENT'S USE CYCLE.

3. THERE WILL BE A STRICTLY ADHERED TO PRIORITY SYSTEM IN HANDLING CUSTOMER ORDERS AND JUDGING THEIR PLACE IN THE PLANT JOB STREAM.

4. PROVIDED BETWEEN-AREA INVENTORY LEVELS ARE MAINTAINED GREATER THAN ZERO AT ALL TIMES, EACH PRODUCTION AREA CAN BE OPTIMIZED INDEPENDENTLY OF THE OTHER AREAS PROVIDED THE PRODUCTION SCHEDULE ESTABLISHED BY THE CENTRAL PRODUCTION CONTROL SYSTEM IS CARRIED OUT.

5. TO HANDLE THE PROBLEM OF SMALL, SPECIAL ORDERS A RULE FOR ORDER ACCEPTANCE BE FORMULATED.

continued

Table 8-II continued

6. A LARGE PORTION OF THE ORDER BOOK WILL BE PREDICTABLE AT LEAST THROUGH INTERMEDIATE PRODUCTS INVENTORY. PRODUCTION OF GOODS NECESSARY TO MAINTAIN THIS INVENTORY MAY BE CARRIED OUT ON A SCHEDULE MADE OUT CONSIDERABLY IN ADVANCE. SUCH A PRODUCTION TO INVENTORY AND OPERATION FROM IT HAS BEEN CALLED THE "JOB STREAM" METHOD OF SCHEDULING.

TABLE 8-III

PRODUCTION SCHEDULING PROCEDURES

A. ITEMS CONSIDERED AT LEVEL 4A

1. EACH ORDER ITEM AS RECEIVED WILL BE ASSIGNED A PRIORITY AND AN ORDER SEQUENCE NUMBER OR PROMISED DELIVER DATE INDICATION.

2. UPON ASSIGNMENT OF THE PRIORITY AND ORDER SEQUENCE NUMBER TO THE ORDER, THE PRESENT JOB STREAM AND ALL IN-PROCESS INVENTORIES WILL BE SEARCHED TO FIND THE ITEM OF LOWEST PRIORITY WHICH CAN BE DIVERTED TO FILL THE ORDER.

3. IN MAKING THE SEARCH LISTED ABOVE, IT WILL BE CONFINED TO THOSE ITEMS IN WORKING INVENTORIES OR IN UNASSIGNED INVENTORIES. ITEMS ALREADY IN A PRODUCTION UNIT OR ALREADY LINED UP FOR SUBSEQUENT PASSAGE THROUGH SUCH A UNIT WILL NOT BE DIVERTED FROM ANOTHER ASSIGNMENT TO MEET A HIGHER PRIORITY ORDER. THIS IS NECESSARY TO AVOID A LAST MINUTE DISRUPTION TO THE OPERATION OF A UNIT TO CHANGE ITS OPERATING INSTRUCTIONS FOR A PARTICULAR ORDER.

4. AS AN ORDER MATURES, IT WILL BE ASSIGNED A CONTINUALLY HIGHER PRIORITY BASED UPON ITS PROMISE DATE TO ASSURE THAT EVEN THOSE ORDERS WHICH WERE ASSIGNED THE VERY LOWEST PRIORITY UPON RECEIPT WILL EVENTUALLY BE PRODUCED DESPITE THE ARRIVAL OF A LARGE NUMBER OF HIGHER PRIORITY ORDERS.

5. AS MUCH AS POSSIBLE A BASIC PRODUCTION STREAM, OR JOB STREAM, BASED UPON A STATISTICAL AVERAGING OF PAST ORDERS OVER A PERIOD RECOGNIZING MAJOR CYCLICAL EFFECTS, BIASED BY THE REQUIREMENTS OF PRODUCTION PROCESS EQUIPMENT, MAINTENANCE, ETC., WILL BE WORKED OUT FOR THE FORESEEABLE FUTURE. THIS SET OF DUMMY ORDERS (NOT YET CONTRACTED FOR) WILL BE USED TO ESTABLISH THE SEQUENCE OF ALL FUTURE PLANT PRODUCTION OPERATIONS AS FINALLY RECEIVED. THE STATISTICALLY ESTABLISHED PRODUCTION STREAM WILL BE DEVELOPED IN TERMS OF A SIGNIFICANTLY SIZED PRODUCTION LOT. THIS WILL BE DONE WITHOUT REFERENCE TO THE ACTUAL RATE OF PRODUCTION TO BE FINALLY SET BY CURRENT CONDITIONS. THE JOB STREAM, THUS ESTABLISHED, WOULD BE CARRIED THROUGH THE PLANT AS FAR AS THE STATISTICS SHOW THAT A REASONABLE NUMBER OF INVENTORIED ITEMS WILL SUFFICE.

6. BASED UPON THE RATE OF RECEIPT OF ORDERS AND THE CURRENT FORECAST OF MARKET CONDITIONS, THE ABOVE BASIC PRODUCTION STREAM WILL BE SCHEDULED FOR PLANT UNDERTAKING AT A RATE WHICH WILL MAINTAIN CONTINUOUS PLANT UNITS IN OPERATION AND WILL RESULT IN CUSTOMERS' ORDERS BEING PRODUCED WITHIN AN ACCEPTABLE TIME PERIOD. BASIC OBJECTIVES WILL BE TO SMOOTH OUT PLANT OPERATION WITHIN THE PRODUCTION RATE NECESSARY TO ACHIEVE MINIMUM COST OPERATION AT THAT RATE.

7. WHEN A PRODUCTION ERROR HAS BEEN MADE, A SEARCH WILL BE

continued

Table 8-III continued

MADE OF THE JOB STREAM TO DETERMINE THE NEXT ITEM WHICH THIS RESULTING PRODUCT MIGHT SATISFY. THE MISSED ITEM WILL BE IMMEDIATELY REORDERED. THE DIVERTED MATERIAL WILL THEN BE STORED IN THE APPROPRIATE UNAPPLIED INVENTORY AWAITING THE FULFILLMENT TIME. IT SHOULD BE NOTED THAT THE PRODUCTION SCHEDULE IS USUALLY INCREASED TO INCLUDE AN AMOUNT OF OVERPRODUCTION EQUIVALENT TO THE EXPECTED AMOUNT OF MATERIAL TO BE DIVERTED DOWNSTREAM.

8. THE FOLLOWING DECISIONS HAVE BEEN MADE CONCERNING THE OPERATION OF THE PRODUCTION PLANNING AND CONTROL SYSTEM TO BE IMPLEMENTED BY THE COMPUTER HIERARCHY DESCRIBED HEREIN.

   a. A SEARCH WILL BE MADE OF THE DIVERTED INVENTORY FIRST IN AN ATTEMPT TO FILL ORDERS FROM MATERIAL ON HAND.

   b. UNASSIGNED STOCK AT ALL INVENTORY POINTS MUST BE SEARCHED TO DETERMINE WHETHER EXISTING PRODUCT MAY BE USED TO FILL A GIVEN ORDER OR WHETHER NEW PRODUCT MUST BE MADE ESPECIALLY FOR IT.

   c. ALL MATERIAL IN PROGRESS ASSIGNED TO A PARTICULAR ORDER, WHICH IS OF A LOWER PRIORITY THAN THAT ASSIGNED TO THE CURRENT ORDER, WILL BE SEARCHED TO FILL THE PRESENT ORDER AND TO REWORK THE MATERIALS FOR THE DIVERTED ORDER.

9. INVENTORY TIME LIMIT FOR FINISHED STOCK MUST BE HONORED TO PREVENT DETERIORATION AND RESULTING QUALITY LOSS.

B ITEMS CONSIDERED AT LEVEL 3

1. STOCK INVENTORIES RESERVED TO COVER FLUCTUATIONS IN DEMAND WILL NORMALLY BE CONSIDERED AS ONE STANDARD DEVIATION OF THE ORDER RATE PER CATEGORY OVER THE REPETITIVE PERIOD OF THE ORDER BOOK PLUS A SAFETY STOCK FOR ACCIDENT.

2. ASSUME THAT TRANSPORTATION REQUIREMENTS BETWEEN AREAS DO NOT IMPOSE DELAYS IN PLANT OPERATION WHICH MUST BE CONSIDERED IN THE SCHEDULING PROCESS.

TABLE 8-IV

DUTIES ASSIGNED TO PERSONNEL AT THE OVERALL PRODUCTION CONTROL LEVEL (LEVEL 4A)

1. DETERMINATION OF, MAINTENANCE OF AND MODIFICATION OF CURRENT PRIORITY OBJECTIVES USED IN THE GOAL PROGRAMMING CALCULATION OF THE MASTER SCHEDULE.

2. OVERRIDE AND MODIFY THE PROPOSED MASTER SCHEDULE IN LIGHT OF ANY CONSIDERATIONS NOT APPARENT TO THE OPTIMAL SCHEDULING ALGORITHM.

3. VERIFICATION AND AUTHORIZATION OF THE MASTER SCHEDULE BEFORE RELEASING IT TO THE LOWER LEVELS FOR DETAILED SCHEDULING.

4. MODIFICATION OF PRIORITIES FROM THOSE DETERMINED BY THE SYSTEM TO HANDLE ANY RUSH JOB CUSTOMER.

5. ALTERATION OF LOT SIZE RESTRICTIONS TO HANDLE ANY SPECIAL SMALL ORDERS.

6. CAUSE THE INITIATION OF AN UPDATED MASTER SCHEDULE AT ANY TIME DUE TO RECEIPT OF INFORMATION REGARDING PROBLEMS WHICH MAY EXIST ANYWHERE IN THE SYSTEM.

TABLE 8-V

PRODUCTION SCHEDULING DUTIES ASSIGNED TO PERSONNEL AT THE AREA SUPERVISORY LEVEL (LEVEL 3)

1. MANUAL OVERRIDE ON CUSTOMER PRIORITIES DEPENDING ON THE PRODUCTION SITUATION ENCOUNTERED.
2. DETAILED EXCEPTION PRODUCTION SMOOTHING NECESSARY TO ACHIEVE MINIMUM COST OPERATION.
3. DETERMINATION OF ADDITIONAL PRODUCTION ALLOWANCES TO COMPENSATE FOR PRODUCTION PROCESS BREAKDOWNS OR OTHER DIFFICULTIES.
4. INPUT ANY KNOWN TRANSPORTATION DELAYS RESULTING FROM SPECIAL ITEM HANDLING.
5. ALTERATION OF EXPECTED DIRECT PERCENTAGES FROM THOSE SELECTED AS INITIAL STANDARDS.
6. EXCEPTIONS TO INITIAL MANPOWER BALANCING RULES TO HANDLE UNFORESEEN PEAK LOADS, UNFORECASTED PROBLEMS, OR CHANGES IN UNION RULES, SICKNESS, ETC.

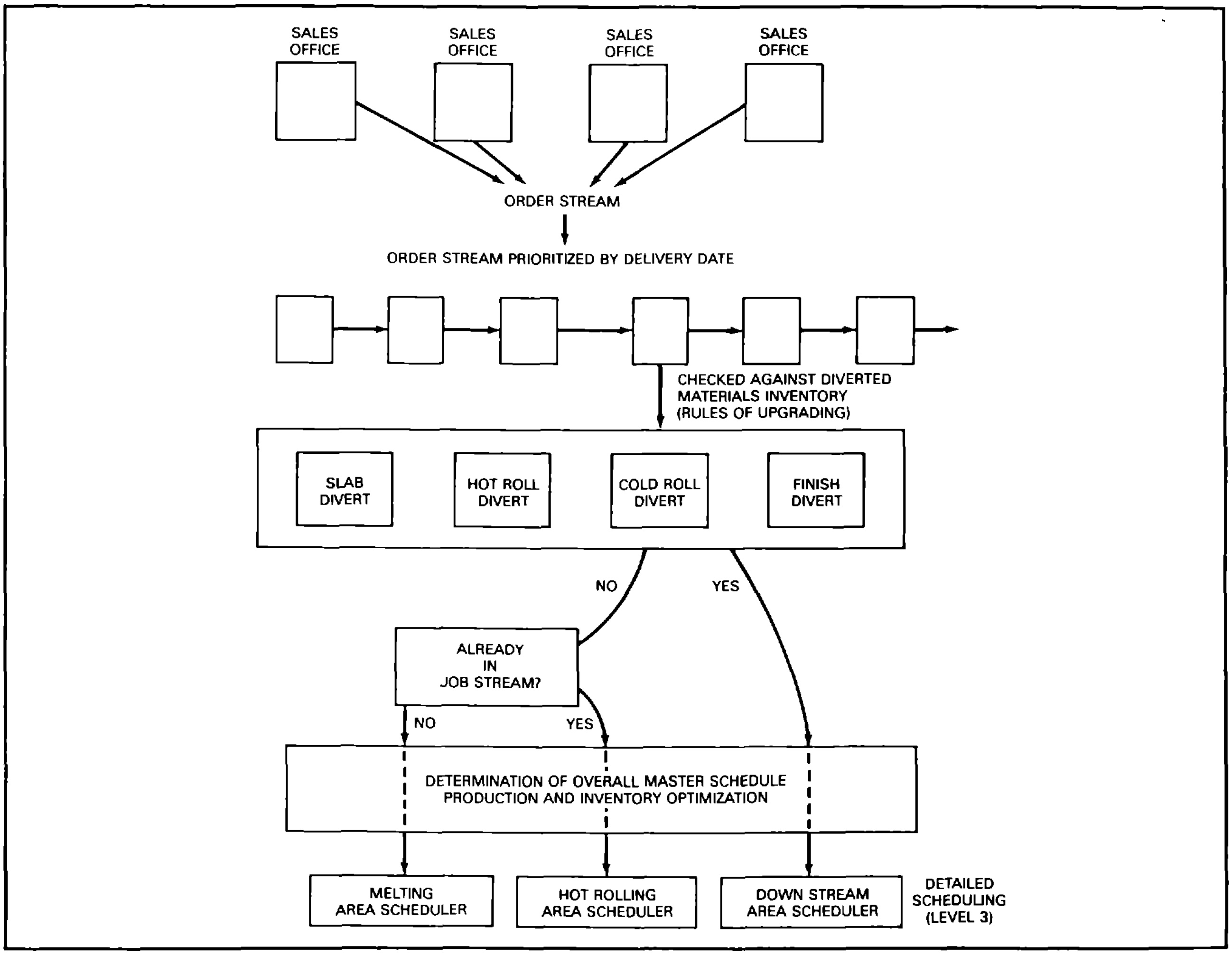


Figure 8-2 An Illustrative example of the Plant Scheduling Procedure at the Overall Production Scheduling Level (Level 4A).

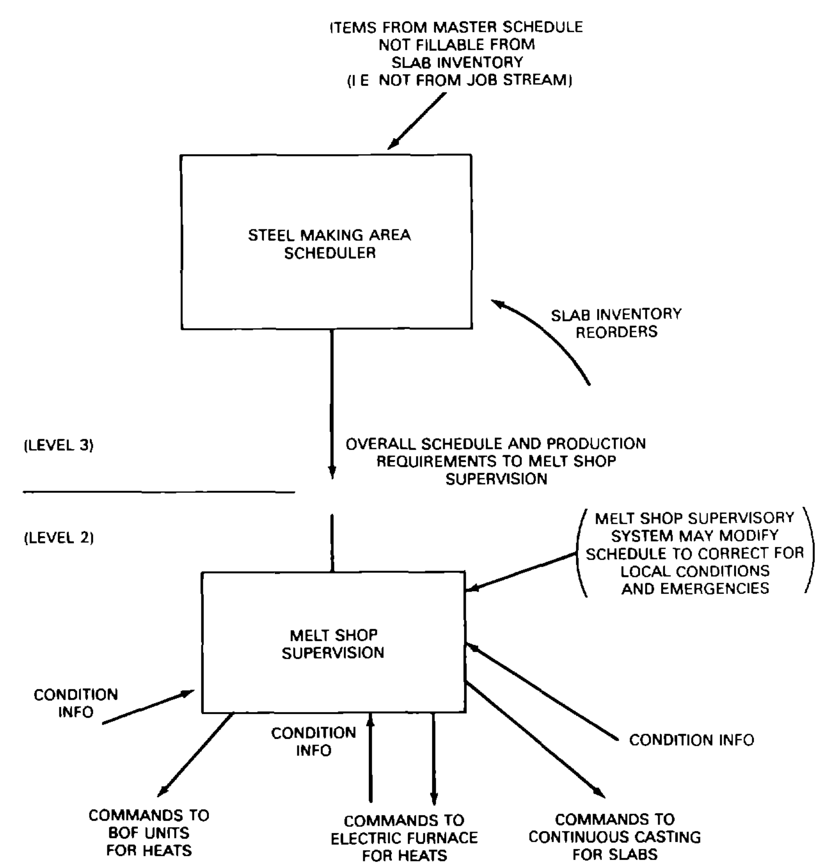


Figure 8-3 Intermediate Level Scheduling Functions as illustrated by the Steel Making Area System.

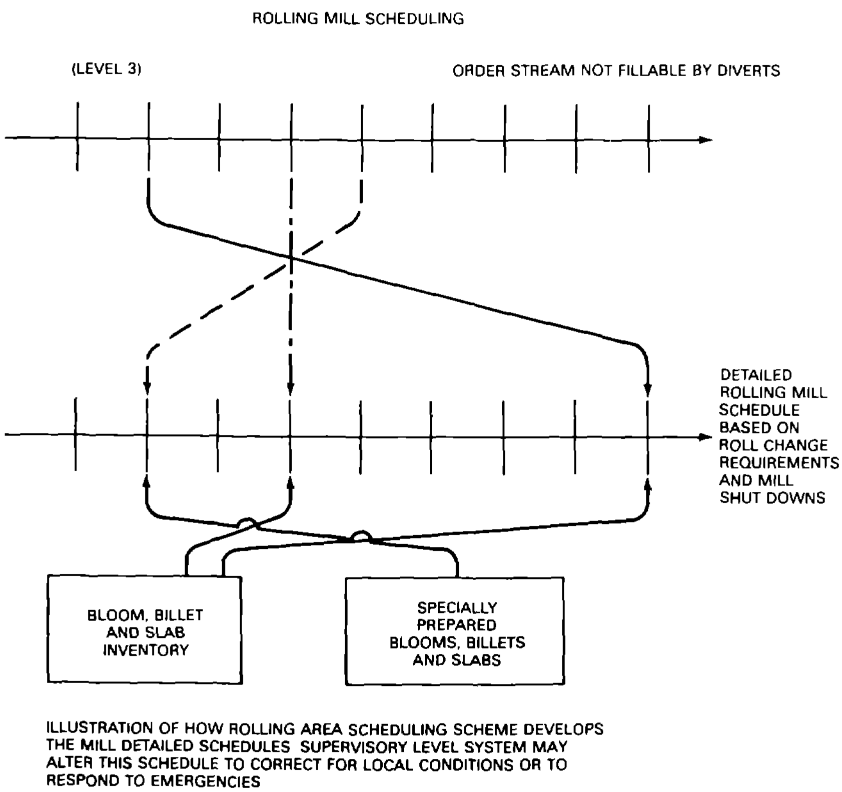


Figure 8-4 Intermediate Level Scheduling Functions as Illustrated by the Hot Rolling Area System.

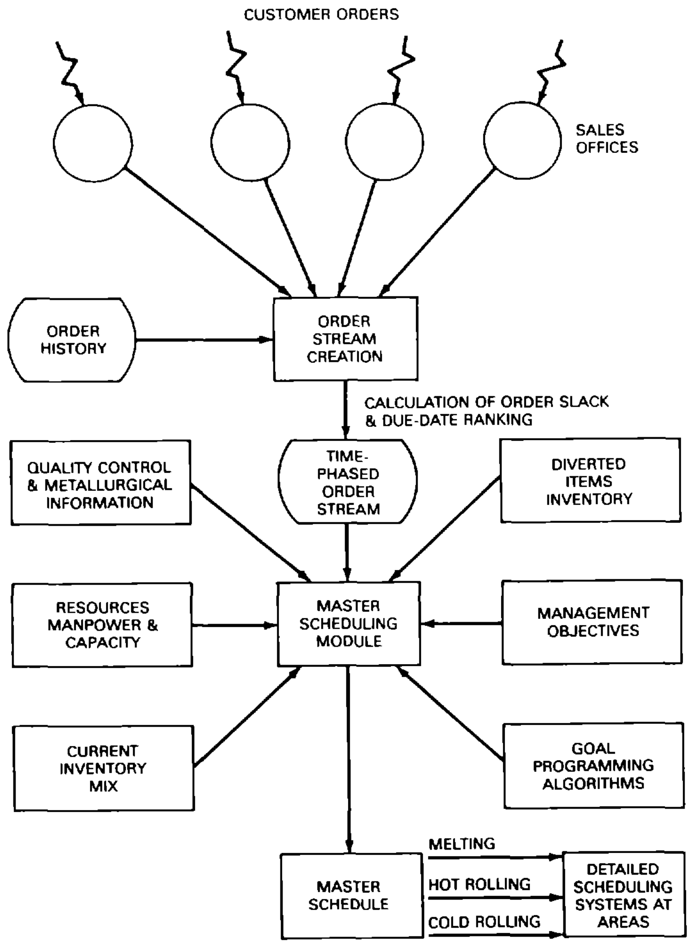


Figure 8-5 Master Scheduling Process at Overall Production Scheduling (Level 4A).

9

Communications Concepts and Considerations Important in the Reference Model

COMMUNICATIONS IN COMPUTER CONTROL SYSTEMS

In addition to communicating with the outside world in terms of reading the process variables and sending out control actuator adjustments, each control computer must also communicate with the other computers in the hierarchy, and with its associated peripheral equipment, operators consoles, etc. This chapter will cover this topic.

THE PROCESS/DATA SYSTEM INTERFACE AS A BEGINNING FOR COMPUTER SYSTEMS COMMUNICATIONS

In the earliest plant computer control system situations the plant wiring system could be effectively sketched as in Figure 9-1. Here the line connecting the sensor or actuator symbol to the computer represents a single pair of data wires. However, when the number of sensors and actuators becomes very large and the distances between them and the computer become long, the overall cost of such a wiring system becomes quite high and it is necessary to seek another, less expensive solution than that of having a separate pair of leads for each individual sensor or actuator running from their location to the computer's location.

Consolidation of all of the variables in one area of the plant into a remote multiplexer with its own analog-to-digital and digital-to-analog conversion equipment and transmission of the resulting consolidated data to the computer in digital form should greatly reduce the above costs as illustrated in Figure 9-2. The next stage is to put all of the remote multiplexers onto one data cable or data highway as shown in Figure 9-3. While not immediately obvious in this figure this method will further greatly reduce the total length of wiring and hence the overall wiring costs. However, by using this latter type of configuration, we immediately impose several conditions on the communications system which were not previously present.

1. The transmission speed must be at least three times faster than before in order to give the same effective rate of service as the three previously separate lines of Figure 9-2.

2. A permanent or temporary "line master" must be established to decide who obtains control of the common line in order to transmit messages at any one time. Otherwise, several of the potential senders may try to send a message at the same time resulting in a "contention" situation existing on the line.

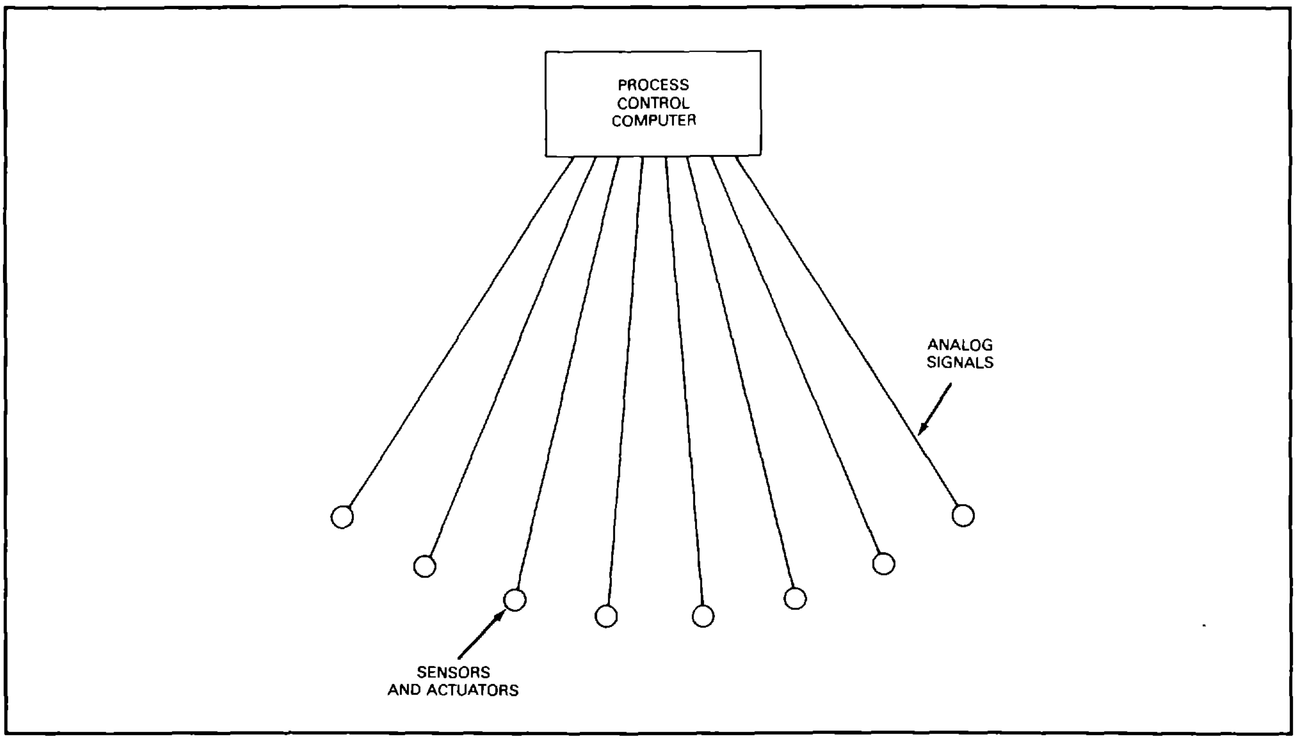


Figure 9-1 Star or tree structure Plant Data System communications layout.

3. A code or "protocol" system for use in the message must be established to indicate which of the multiplexers or the main computer is sending the message and to whom it is addressed. Otherwise, the remote multiplexers must be "polled" by the computer one by one in order to identify who is sending what message at any particular time. Note, that in the data highway system the remote multiplexers can theoretically talk with each other directly without going through the control computer provided one of the three has mastership of the line at that moment. This complicates the protocol or addressing requirement.

4. Reliability of the line is now more important than before since a failed line will now disable several remote multiplexers and not just one.

A generalization of the system of Figure 9-3 is given in Figure 9-4 where mastership resides permanently in the Highway Traffic Director and all units on the line including the computer are "polled" in turn as in Item 3 above. This is the system used by most of the distributed, microprocessor-based, digital control systems today.

It should be noted that each of the situations diagramed in Figures 9-3 and 9-4 could also exist as well between groups of computers and a central computer as between a single computer and a group of multiplexers.

An additional form of the data highway of Figure 9-3 is that of Figure 9-5 which shows a ring or loop structure. Its advantage is that a single break will not disable any part of the system provided two-way transmission of signals is possible on the remaining cable fragments [14].

THE OPEN SYSTEM INTERCONNECTION MODEL OR DIAGRAM

In order to properly describe any system more complex than those just mentioned, a model is necessary to be sure that each of the discussors can always properly identify those aspects of the data system about which the other is speaking. In order to accomplish this, the International Standards Organization (ISO) has defined its Open System

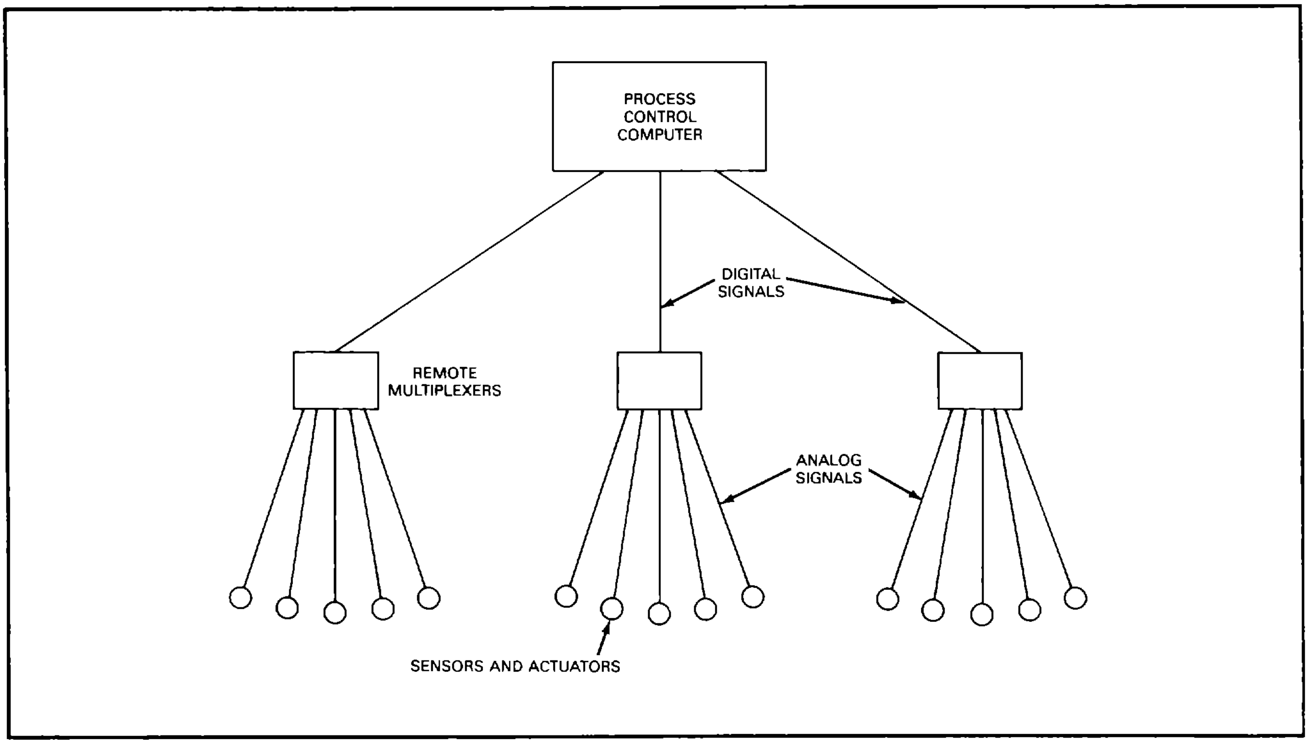


Figure 9-2 Use of remote multiplexers to reduce wiring costs in large data and control systems.

Interconnection Model (Figure 9-6) [8]. This divides the interconnection into seven layers as described below. It should be noted in passing that Figure 9-6 is the best example available of an Implementation Hierarchy View. It is described below.

Layering is a good approach to device interfacing because it divides the problem into smaller, more manageable segments. In performing its task, each layer communicates via the established protocols with its peer in another device as indicated in Figure 9-6 which shows communication between two transport layers. Within a device, each layer wraps the lower layers and isolates them from the higher ones. Each adds value to services provided by the lower set of layers, building them up until the highest level can perform distributed applications [46].

Layers 1-4 are called the transfer service since they are the ones responsible for moving messages from one point to another. Layers 5-7 are known as user layers, because they give the user access to data on the network. At present, formal standards have only been developed for the first three layers. The functions of all seven protocol levels are:

Layer 1 (Physical Layer) specifies the electrical, mechanical and functional characteristics for the interface, enabling it to exchange ones and zeroes. The layer defines voltages, signal control sequences, and the physical form of the cable and connector. The right hand side of Figure 9-6 further indicates the tasks assigned to Level 1 and to the media-access unit of the device. Standards include Electronic Industries Association's (EIA) RS-232C, RS-422A, RS-423 and RS-440 plus the IEEE 802 Standards (see below).

Layer 2 (Data Link Layer) describes the passage of data frames at the interface. It can address a frame or decode an address. The Link Layer defines the data format. It also performs error detection and error recovery. Standards for this layer include HDLC, ADCCP, DEC's DDCMP, and IBM's SDLC and BISYNC (described below).

Layer 3 (Network Layer) looks beyond the DTE-DCE (Data Terminal Equipment - Data Connection Equipment, i.e., between Levels 1 and 2) interface to control data frames between stations on a network. It establishes an end-to-end connection for transparent data delivery. This layer controls the actual switching and routing of mes-

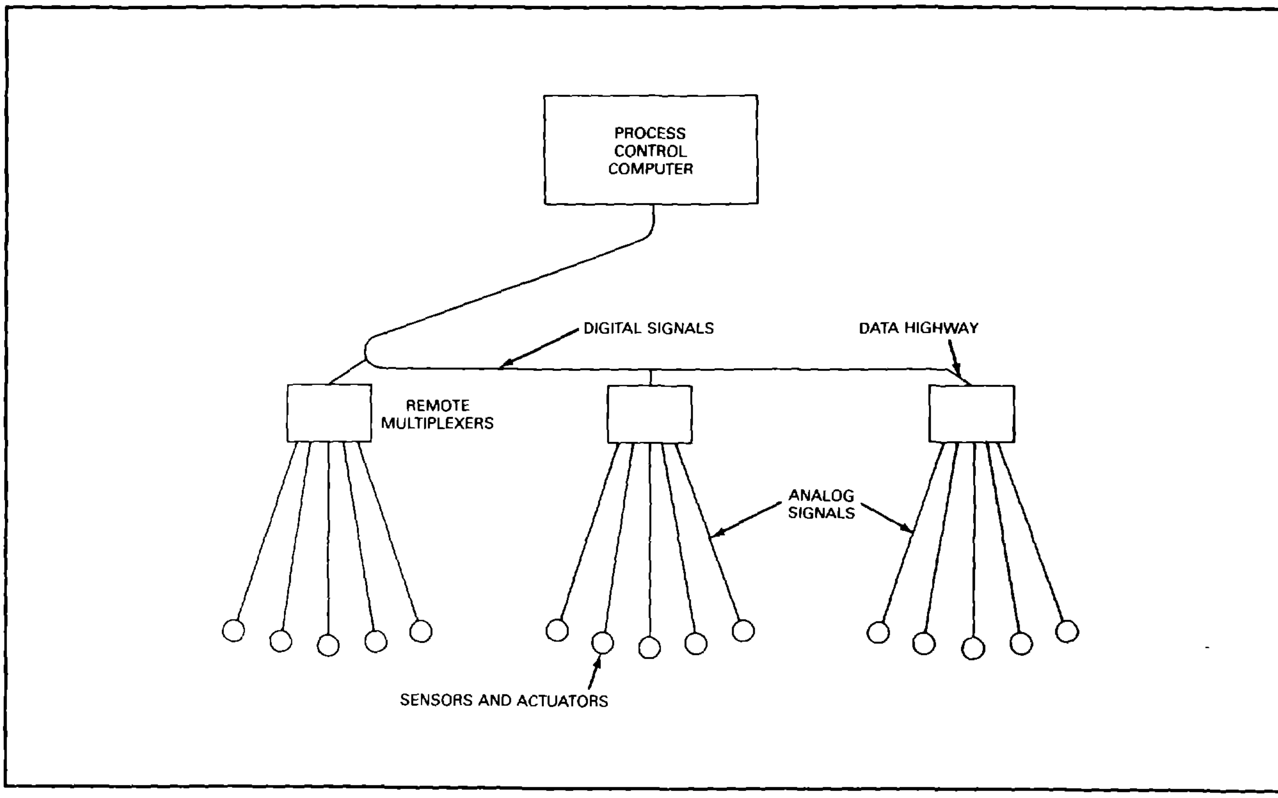


Figure 9-3 Use of the Data Highway to further reduce wiring costs in large data and control systems (branch or bus configuration).

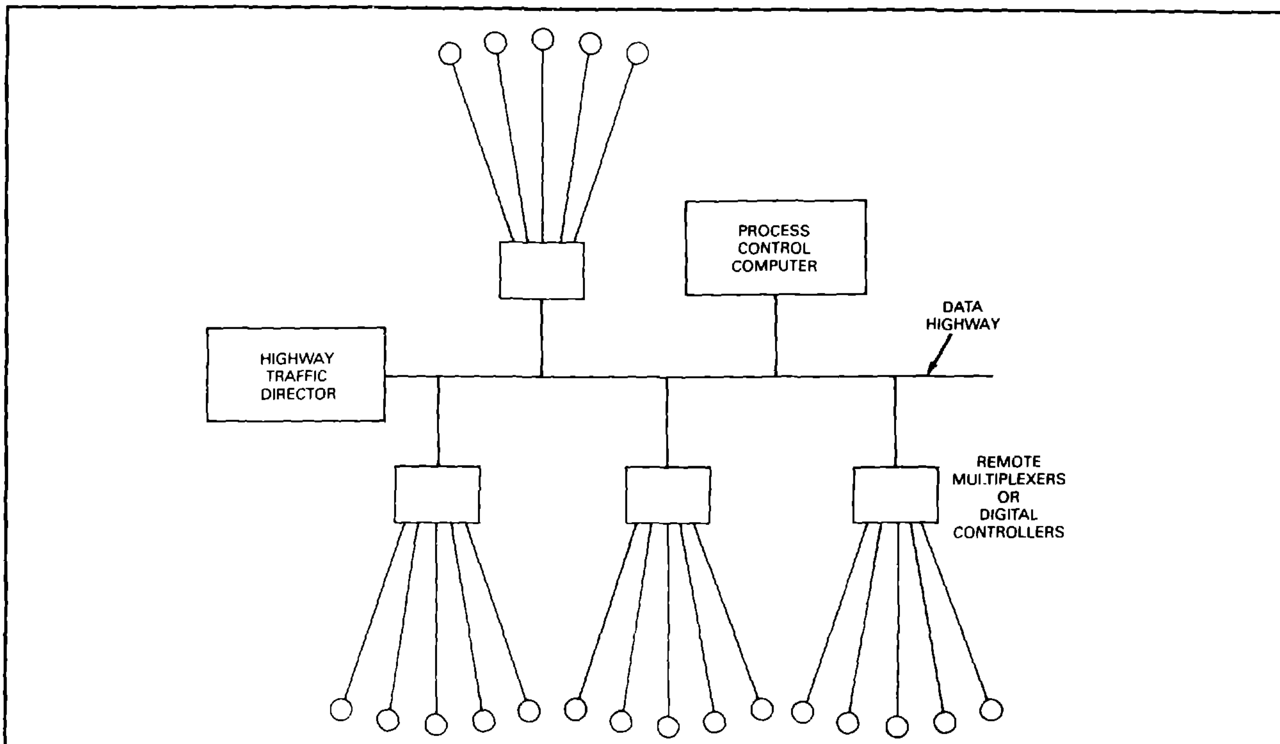


Figure 9-4 The common form of the data highway with distributed, microprocessor-based digital control systems.

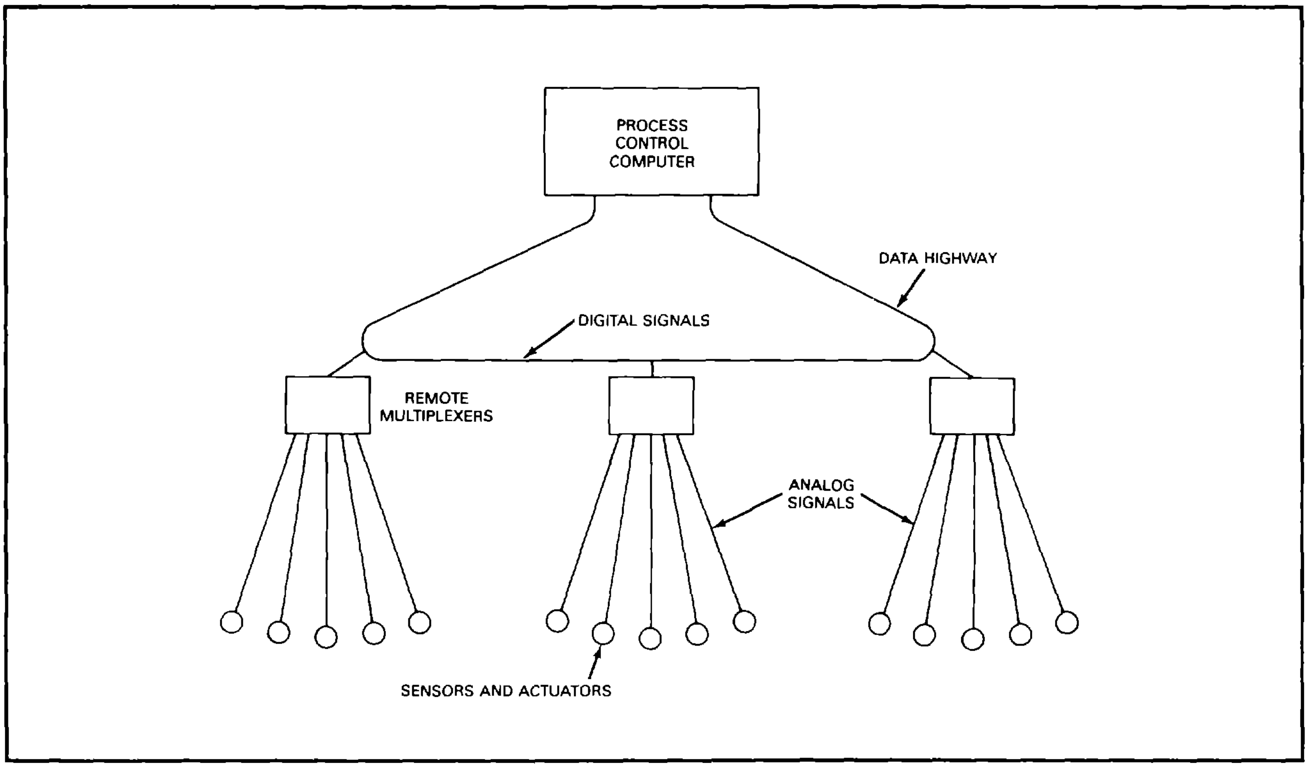


Figure 9-5 Use of the data highway to furter reduce wiring costs in large data and control system (loop configuration).

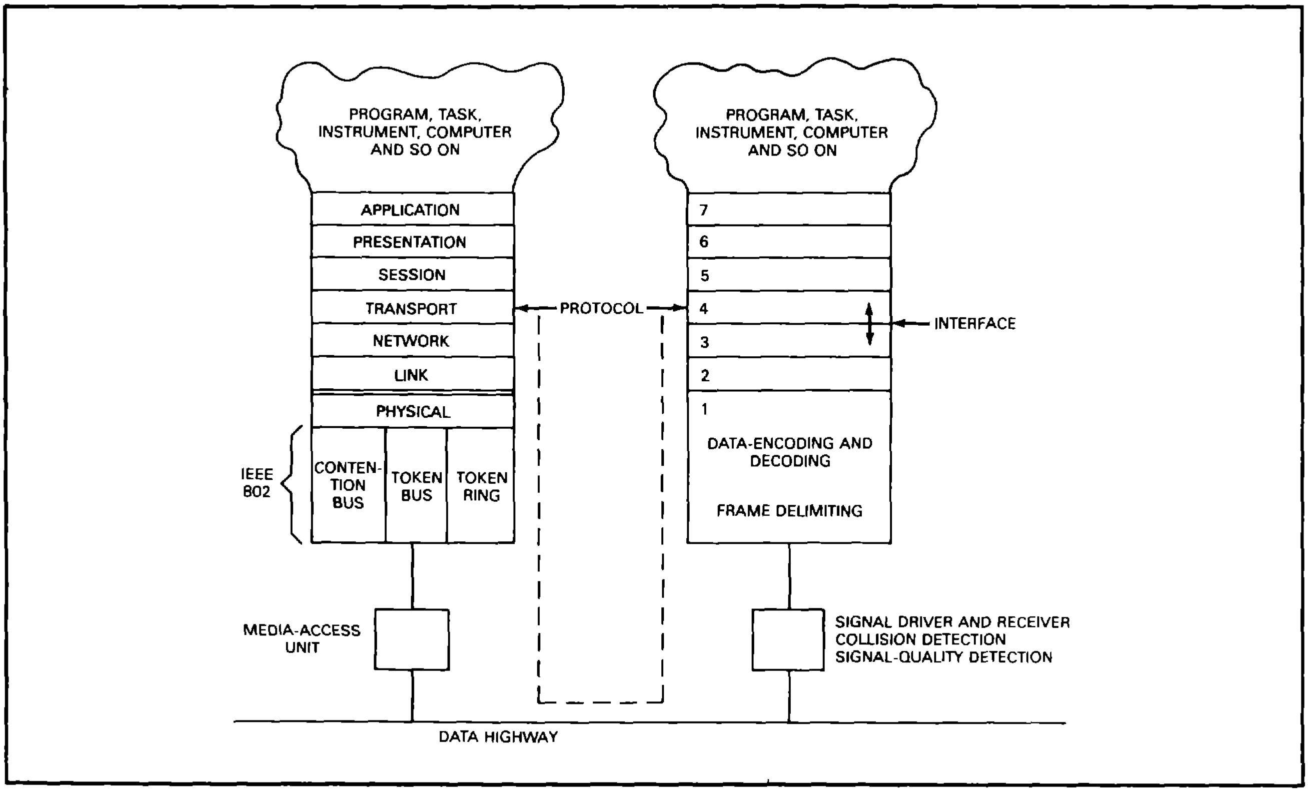


Figure 9-6 The Open System Interconnect Diagram of the International Standards Organization.

sages. CCITT's X.20, X.21, or X.25 may apply for this layer.

Layer 4 (Transport Layer) provides the user with a network-independent interface. It serves as an error check on the lower layers, and ensures a reliable connection between network devices.

Layer 5 (Session Layer) allows for a structured, logical exchange of messages between points on the network. For example, if many terminals are communicating with a central computer simultaneously, the Session Layer tracks and maintains each individual "conversation."

Layer 6 (Presentation Layer) presents the Application Layer (Layer 7) with a set of services, including management, display and control of structured data. It handles the transformation of messages between various computer, data terminal and database formats.

Layer 7 (Application Layer) is the highest DSI (data systems interface) layer. It applies end-user data to the network (e.g., through remote job entry or a virtual terminal). This layer also directly serves the end-user by providing data appropriate to a real application. The other six layers exist only to support this one.

Figure 9-7 presents another view of the ISO Open Systems Interconnection Model showing some existing standards at each of the first three layers of the diagram [46].

SOME COMMERCIALLY AVAILABLE PLANT DATA COMMUNICATIONS SYSTEMS (LAYER 1)

If the equipments of more than one vendor are to be connectable to each other in the systems just discussed then some standard method of plant communications must be established through agreement between vendors (local standards), between major segments of the industry (national standards), or between the industries of many nations (international standards).

The earliest such standard for digital data transmission was the twenty milliampere current loop sometimes called the teletype standard because of the wide use of teletypes in early computer systems. This is an asynchronous transmission of digital data over a twisted pair of wires by turning a 20 mA current on and off. Start and stop bits are used to isolate data frames and to identify zeroes and spaces. A major drawback is that it cannot be used for complex networks. There are just not enough wires to carry the necessary control signals.

The RS 232C standard corrects many of the problems listed above for transmission over relatively short distances (up to 50 ft.). It uses voltage rather than current signals and provides both synchronous and asynchronous transmission over single or double twisted pairs of wires. The standard defines the physical characteristics of the connectors to be used and the electrical characteristics of the signals themselves. This standard was developed by the EIA (Electronic Industries As-

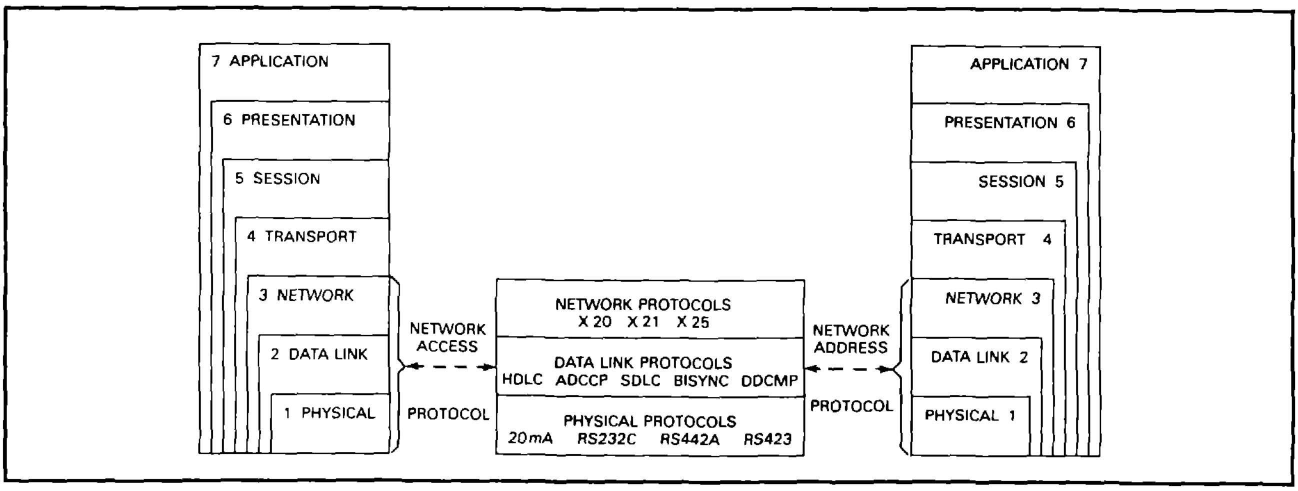


Figure 9-7 Another sketch of the Open System Interconnection Model showing some existing standards to Layer 3.

sociation). There are international standards also for this method.

The RS 422A standard (also by EIA) was developed for distances greater than 50 feet. It thus permits a daisy-chain or multi-drop network for devices to be assembled into a system. This standard specifies the use of a balanced voltage interface circuit, i.e., a differential transmitter is connected by a twisted pair cable to a differential receiver. It will support data rates up to 10 megabits per second and has far greater noise immunity than RS 232C. It is also far less susceptible to signal noise. RS 449 specifies the physical characteristics of the connectors for RS 422A. Again there are equivalent international standards for both.

The CAMAC Modular Instrumentation System for Data Handling [6] was an early conceived data system as shown in Figure 9-8. CAMAC means Computer Automated Measurement and Control. It was originally developed by the nuclear organizations of Europe and the United States for standardizing nuclear laboratory instrumentation. It has been widely accepted for this use and has had some industrial process control acceptance. This

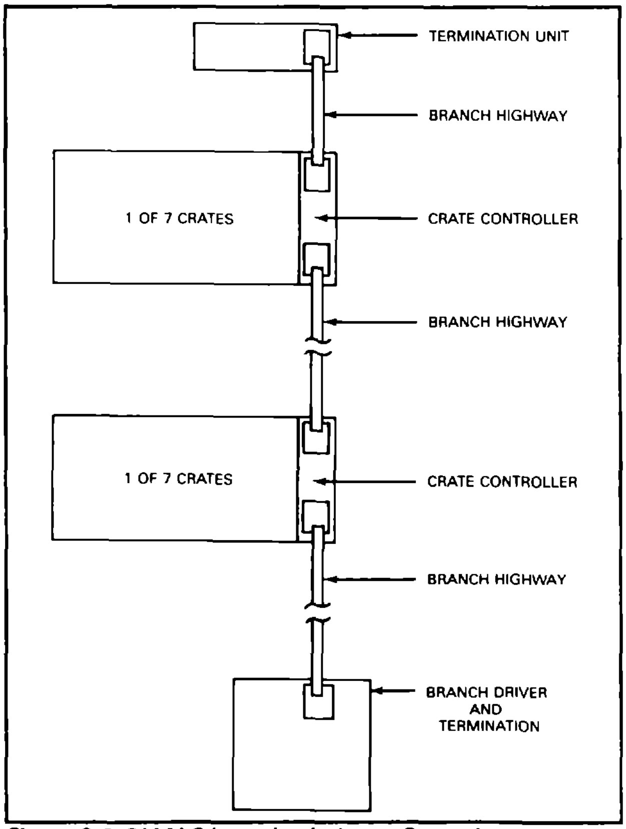


Figure 9-8 CAMAC branch: chain configuration.

equipment calls for a 132-wire cable or Branch Highway to connect up to seven crate units as shown in Figure 9-8. These could include a central computer and up to six remote multiplexers if so desired since a minicomputer or a remote multiplexer and their associated electronics can readily be included in any one crate. The Branch Highway has provision for the parallel transmission of 24-bit data in either direction on separate sets of wires. The desire for inexpensive data communications systems as mentioned earlier led to the subsequent development of the CAMAC Serial Highway which reduced the 132-wire cable of the Branch Highway system to two pairs of twisted wire as originally specified [6] or to a single coaxial cable in a revised implementation (Figure 9-9). However, its present specification calls for a unidirectional transfer of data and a requirement to pass through each module in turn. Both of these greatly increase its vulnerability to cable breaks and failed modules. This requirement for the system is called "store and forward" and is in direct contrast to the indications of Figures 9-3 and 9-4 where the elements are considered as "drops" and their individual failures would not necessarily cause total line failures.

The Hewlett-Packard Bus Interface System [7] (IEEE Standard 488) is a 15-wire cable which transmits data in "byte serial" form, i.e., eight bits parallel. Figure 9-10 diagrams a typical laboratory instrument application of this concept and the use of each of the 15 lines. The Hewlett-Packard scheme is primarily intended for laboratory-type systems and is very popular for such use. As presently conceived it has the following limitations [7]:

1. Number of connected devices or multiplexers - 15.

2. Data rate - 1 Megabyte per second maximum.

3. Transmission path length - 50 feet total accumulated cable length.

4. Data transfer is bidirectional.

These limitations if maintained would, of course, make it unsuitable for industrial systems of any convenient size.

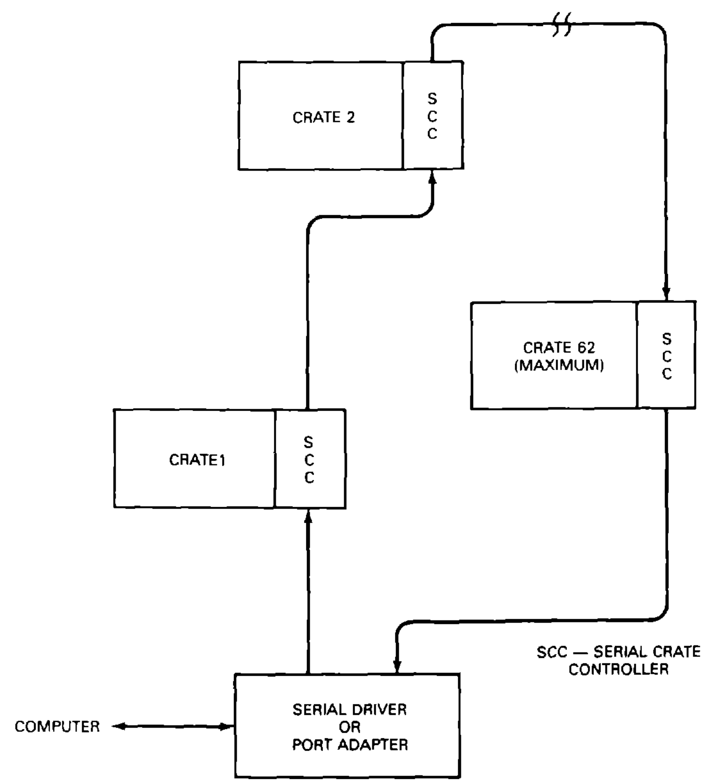


Figure 9-9 CAMAC Serial Highway.

SOME PRESENT DAY MESSAGE CODING SCHEMES (LAYER 2) [46])

Message coding schemes or data link control protocols form the second layer in the communications architecture. They act as a kind of grammar for data communications, establishing rules for setting up a link between network stations and for accurately moving data across the link. They set up and terminate connections, ensure software synchronization, and perform error detection. Data link protocols come in two basic types: character- and bit-oriented.

Character-oriented protocols have been in use the longer of the two. They rely on a series of control characters within each frame to maintain accurate data transmission. (See Figures 9-11 and 9-12.) This makes code transparency, which is essential to any efficient protocol, a much more complex task. Another drawback to this type of protocol is its relatively slow speed; each frame must be acknowledged before the next is transmitted. Examples of character-oriented protocols are BISYNC of the International Business Machines Corporation (IBM) and DDCMP of the Digital Equipment Corporation (DEC).

IBM BISYNC - IBM's Binary Synchronous Communications Protocol (BSC) describes a byte-serial method of transmission that is limited to half-duplex. Even so, BISYNC is comparably fast, with a variable message format (Figure 9-11). But extensive software is needed for control. BISYNC uses a byte-stuffing method to ensure data transparency. But it can only perform error checking on data, not control characters.

DEC DDCMP - DEC's Digital Data Communications Message Protocol also relies on control characters, though not as many as BISYNC. DDCMP can operate in both half and full-duplex and has a

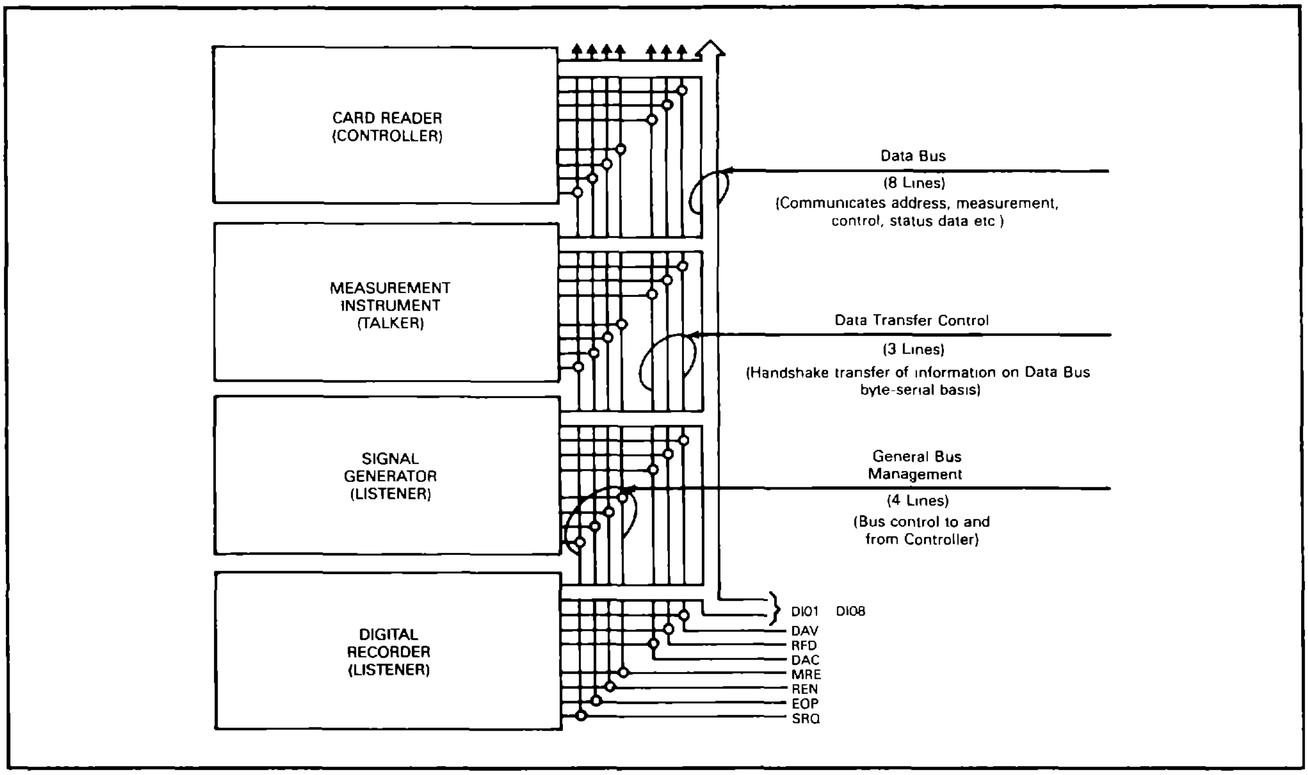


Figure 9-10 The Hewlett-Packard Interface System. IEEE Standard 488. Information flow is bi-directional. Because of parallel connection, any device is potentially able to communicate directly with any other [7].

IBM BINARY SYNCHRONOUS COMMUNICATIONS (BISYNC)

SYN	SYN	SOH	HEADER	STX	TEXT	ETX	BCC LRC-8 CRC-12 or CRC-16

DIGITAL DATA COMMUNICATIONS MESSAGE PROTOCOL (DDCMP)

			HEADER							
SYN	SYN	SOH	COUNT (14 BITS)	FLAGS (2 BITS)	RESPONSE (8 BITS)	SEQUENCE (8 BITS)	ADDRESS (8 BITS)	CRC-16 (16 BITS)	INFO (8-BIT CHARAC-TERS)	CRC-16 (16 BITS)

LEGEND

SYN	SYNCHRONOUS IDLE	BCC	BLOCK CHECK CHARACTER
SOH	START OF HEADING	LRC	LONG REDUNDANCY CHECK
STX	START OF TEXT	CRC	CYCLIC REDUNDANCY CHECK
ETX	END OF TEXT		

Figure 9-11 Examples of message coding schemes (frame structure) character-oriented protocols.

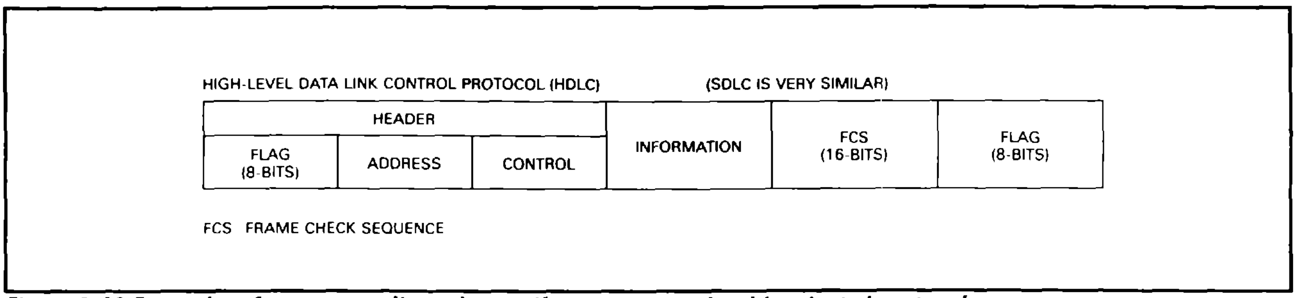


Figure 9-12 Examples of message coding schemes (frame structures), a bit-oriented protocol.

fixed message format (Figure 9-11). Error detection is done on both data and control characters via a 16-bit cyclic redundancy check. Half or full-duplex refers to whether one or two directional transmission is possible on the line at any one time.

Bit-oriented protocols need only two or three control characters to identify individual data frames (Figure 9-12). Because frames do not have to be acknowledged when they are received, this type of protocol can offer higher transmission speeds, at least twice the rate of character-oriented protocols. Part of this gain comes from the ability to transmit in full as well as half-duplex. Specialized ICs have been developed to implement such bit-oriented standards as HDLC, ADCCP, and IBM's proprietary protocol, SDLC.

HDLC (ISO) - High Level Data Link Control (HDLC) (Figure 9-12) is a protocol that has become a *de facto* industrial standard. The federal government, in its equivalent FED STD 1003, has made HDLC mandatory in all computer network procurements.

HDLC controls the flow of data between two or more stations. It does not specify the kind or amount of data, but the method by which remote stations are addressed. It defines two types of network stations: a primary, which issues commands and receives expected responses, and a secondary, which receives commands and sends out the required data. The primary station could be a computer operating system, a PC acting as a network master, or some other processing device. Because of this setup, HDLC is better suited than other data link protocols for multistation networks.

ADCCP (ANSI) - ANSI's Advanced Data Communication Control Procedures form a standard that is essentially identical to HDLC. It too sets up primary-secondary stations, uses a fixed message format, and operates in both half and full duplex. ANSI is the American National Standards Institute.

Another area in which the two standards agree is that of code transparency, for which both use a bit-insertion or "bit-stuffing" technique. This means that a device is able to communicate with a network while being completely ignorant of the network's data link procedure. The device does not have to dedicate any part of its message for data link control purposes. This is important because it allows devices to be connected to a network quickly and easily, and without re-programming.

IBM SDLC - The Synchronous Data Link Control protocol follows along the same lines as HDLC and ADCCP. Since this is IBM's standard, it has a large following in the data processing industry for computer-computer network uses. SDLC protocol is code-independent, requiring only that the transmitted data be eight bits or less. It should be noted that the other standards listed above are slight modifications of SDLC to make it more acceptable to IBM's competitor companies.

Note the FLAGS which initiate and end each bit-oriented message. These must be completely distinguishable from any codes used internally in the message to avoid truncating a true message and thus causing serious errors.

MESSAGE TRANSMISSION METHODS (LAYER 3) [46]

Message transmission selection methods, often called network protocols, form the third layer in the communications architecture of Figure 9-6. Where data link protocols handle data at either end of the line, network protocols handle what goes on in between. They route messages from source to destination, but do not provide broader network control functions. They become important whenever there are several or many different paths by which the message could be sent between the two devices in question. This would occur, for example, when sending data some distance over the public telephone network. They are not important within a relatively limited plant data communications system. Network protocols come in two basic types: circuit-switching and packet-switching.

In circuit-switching, a device is given a discrete bit rate at which to transmit data (or a discrete bandwidth in the case of analog networks). Within this restriction the user is free to specify any mode of communication, including protocol, data format, speed, and error control methods. The only restriction placed on the user is that both transmitter and receiver operate under the same communication mode. CCITT protocols X.20 and X.21 are examples of circuit-switching protocols. CCITT is the International Telegraph and Telephone Consultative Committee.

X.20 (CCITT) - The X.20 standard establishes a network interface for asynchronous transmission. Electrical characteristics are compatible with standards RS-232C, 422A, and 423. There are two applicable bit rates for X.20 transmission: Class 1 specifies 300 bits/s, while Class 2 specifies a range from 40-200 bits/s. All control signaling between the station and the network must be done in ASCII code (CCITT equivalent V.3). ASCII is the American Standard Code for Information Interchange.

X.21 (CCITT) - This interface is a general purpose standard for synchronous operation, covering the first three layers of network architecture. It is applicable at 600, 2400, 4800, 9600, and 48,000 bits/s, and is completely transparent to data and procedures. The connection setup for the protocol is based on electrical signaling, rather than control messages, which is a major shortcoming. Japan, Germany and the Scandinavian countries have adopted the X.21 standard.

In packet-switching, network data from many users is formed into discrete packets, which travel over shared lines to their various destinations. The transmitter and receiver do not form a physical link in a packet-switching network. They communicate over a "virtual circuit," many of which can be maintained across a single physical link provided its bandwidth is sufficient.

Once data is on the network, it is sent to its destination by whatever route is fastest at that moment; this means higher data rates than those afforded by circuit-switching protocols. All of this routing, which is handled by the network protocol, is transparent to both devices. Another advantage of this type of protocol is speed transformation; the transmitter and receiver do not have to be running at the same speed to communicate.

X.25 (CCITT) - This protocol sets procedures for gaining access to a packet-switched network. It defines characteristics for the first three network layers, and is almost identical to HDLC at Layer 2. At Layer 3, it provides a virtual circuit service between devices connected to the network. X.25 permits up to 4096 such virtual circuits to be multiplexed on a single access link. It is a local rather than an end-to-end protocol. This means that the network can wrap X.25 packets in some other, more complex protocol, send them over the line, and have them unwrapped at the other end. This standard is most effective in multi-station networks that demand real-time monitoring of devices and rely on the integrity of network data.

THE MASTERSHIP PROBLEM AND MODERN COMMUNICATIONS NETWORKS

As discussed in the first part of this section, the use of a common transmission system or data highway requires the establishment of mastership or the determination as to which unit has control of the transmission lines at any one time in terms of assigning the right to transmit messages. One obvious solution is to assign a permanent master such as the control computer in a relatively small data network (Figure 9-4). However, this imposes a rigid discipline on the system and may not allow sufficient system flexibility. Therefore a multiple-mastership system needs to be worked out for the larger systems. Two basic forms are currently popular - they are: contention and token passing.

Contention. In this method a link layer needing to transmit listens first to hear if any other device is transmitting. If the transmission line is busy, the device waits; if the line is not busy, the device transmits. Because of signal-propagation delays on the transmission line, two or more devices can start transmitting simultaneously or nearly simultaneously. If they do, the data on the transmission line will "collide." The protocol then is for each device to detect the collision and stop transmitting for a random amount of time, so the devices' messages do not collide again when they retry. If a collision does recur, each device refrains from transmitting for a random time twice as long as before. This method is called Carrier Sense Multiple Access with Collision Detection, or CSMA/CD. It forms the basis for the IEEE 802.3 Standard. While once considered for only office and laboratory communication schemes, CSMA/CD systems have proven themselves in the plant environment [1].

Token passing. In a network of devices there can be a line-access protocol that lets only one device at a time hold a "token," or access rights. When that device is through using the transmission line, it passes the token to another device via a special data unit. The token can be passed around from device to device, giving each access rights to the transmission line in turn. It forms the basis for the IEEE 802.4 and 802.5 Standards.

CSMA/CD is very simple to implement. However, access to the line is statistical rather than deterministic, so that it is possible (but highly unlikely) that a device's transmission could repeatedly collide with others and never be sent.

Token passing is more complex. For example, protocols must be established for how a new device just added to the network will get the token, what happens if the device then holding the token loses power, what happens if two devices pick up a token, and so on. These are not insurmountable problems, but they do make the token line-access method more involved.

Besides the data-unit structure and the line-access method, another consideration for the link layer (Layer 2) is the type of service it will give the network layer (Layer 3). The simplest service is called a datagram. Here a source can send one data unit and no more to a destination. The transmitting link layer takes no further responsibility for ensuring that the data have been transmitted correctly or for retransmitting the data if there were errors. With datagram service, the higher-layer protocols, typically the transport layer (Layer 4), must make sure the data are getting through correctly. In other situations, very complete services must be performed at the link level.

Connection service ensures that data are being correctly transmitted at the link level. This service involves numbering the frames to make sure they are received in proper sequence and that duplicate frames are not received. To do this, any particular source-destination pair must exchange information about their connections, such as the synchronizing of source and destination frame counters and the acknowledging of received data. The control field is used for this purpose, and it also indicates if a datagram or connection service is used.

Former long-distance networks relied exclusively on connection link-level service, and much communications software uses that service. The newer networks rely on datagrams only.

Local networks can be configured in several ways, with the basic configurations being buses, rings and stars. In a star network (Figures 9-1 and 9-2), the central hub is responsible for switching messages between the communicating points at the periphery, and though this has been a common topology in time-shared computer applications, it does not fulfill the requirement that failure of a single node should not affect the rest of the system.

The bus configuration (Figures 9-3 and 9-4) can be used for both token passing and collision sensing. The ring topology (Figure 9-5) can be used for token-passing, though not for CSMA/CD [14].

THE DEVELOPING INTERNATIONAL STANDARDS IN INDUSTRIAL CONTROL COMMUNICATIONS SYSTEMS
THE MAP/TOP SYSTEM

With the appearance of the IEEE 802 set of standards, the ever growing need of industry for a viable set of communications standards promises to be fulfilled. The General Motors Company in 1980 took the lead in defining MAP (the Manufacturing Automation Protocol) based on the token passing protocol of IEEE 802.4. This action by such a large and economically important company found a ready response with other companies. It quickly led to the formation of a nationwide MAP Users Group with several hundred user companies as members. This has since been expanded world wide in a World Federation (see definition below). In a welcomed spirit of cooperation, the vendor companies responded with a companion organization (the Corporation for Open Systems (COS)) pledged to work with the MAP group to bring about the needed standards.

As noted earlier the organizational structure was completed with the proposal for TOP (Technical and Office Protocol) by the Boeing Computer Services company and combined with the MAP group as the MAP/TOP Users Group.

These groups make proposals for additions and corrections to the existing standards through the technical societies (IEEE, ISA, etc.) and the national and international standards certifying bodies (ANSI, ISO, EIC, etc.) (see definitions below). A major part of their work is to propose or select suitable standards for the upper levels of the ISO/OSI model to interface with the IEEE 802 standards already specified at Layers 1 and 2.

Because of the worldwide interest and massive support for this effort, work has proceeded rapidly although the large number of players sometimes slows the development of the needed consensus on the technical details of the developing standards.

Figures 9-13 and 9-14 use the ISO/OSI model structure to show the recommended protocols and equipment standards at each layer of the model as of the time of writing of this report. As noted continued development is still necessary although final agreement seems assured.

The reader is referred to Appendix IV for the definitions of the major set of acronyms used in this field and appearing in this section.

The OSI Reference Model divides communication functionality into seven layers. The MAP 3.0 specification (issued in September 1987) [22] is a suite of ISO standard protocols that are most appropriate for manufacturing automation. Thus MAP and TOP support an open, multivendor environment within the arena of enterprise automation and integration.

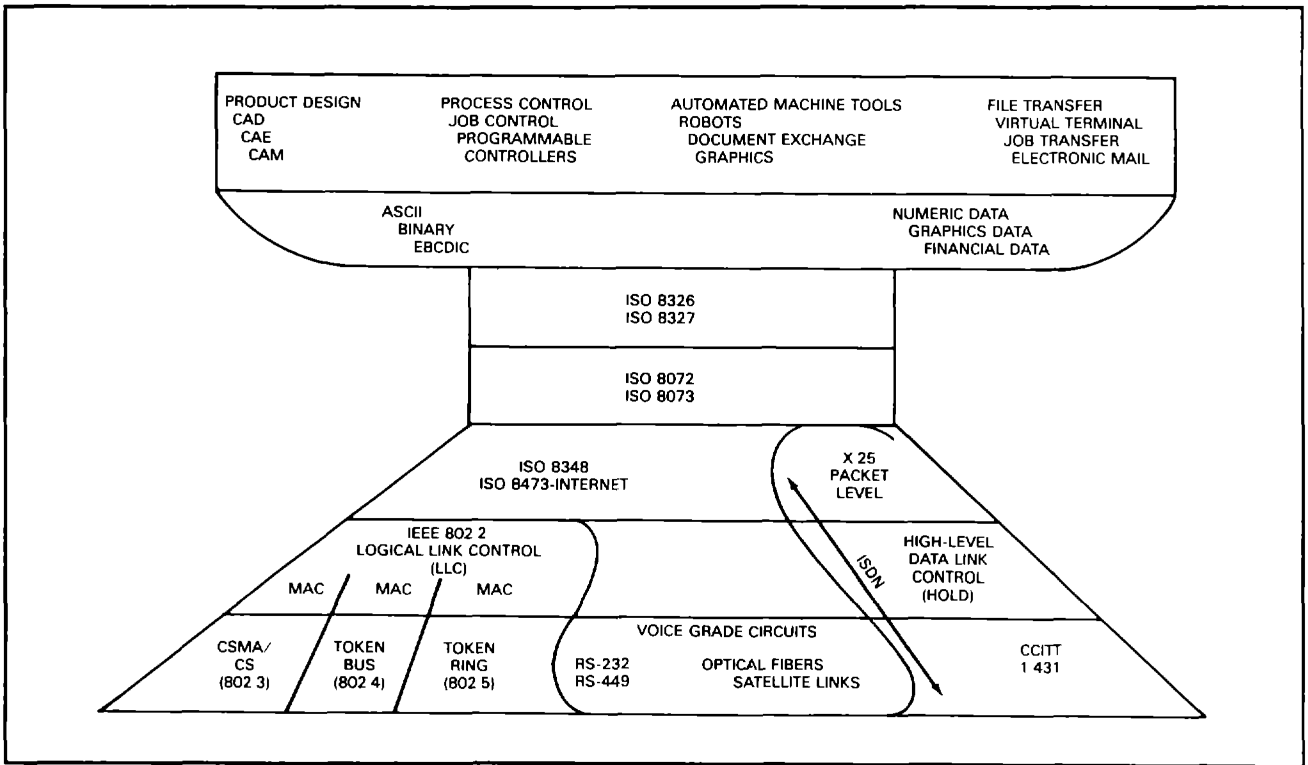


Figure 9-13 Present-day suite of standards for application at the several layers of the ISO/OSI model (compare to Figure 9-7) [51].

LAYER	TOP VERSION 1 0 PROTOCOLS	MAP VERSION 3 0 PROTOCOLS
7	ISO FTAM (ISO 8571/1 4) FILE TRANSFER X 400 ELECTRONIC MAIL	FILE TRANSFER ACCESS AND MANAGEMENT (FTAM) (ISO 8571/1-4) MANUFACTURING MESSAGE SERVICE (MMS) (ISO 9506) ASOCIATION CONTROL SERVICE ELEMENT (ACSE) (ISO 8650/2-8649/2)
6	ISO PRESENTATION (ISO 8822/8823) CONNECTION ORIENTED PRESENTATION	
5	ISO SESSION (ISO 8327/8326) BASIC CONNECTION-ORIENTED SERVICE	
4	ISO TRANSPORT (ISO 8073/8072) CLASS 4	
3	ISO INTERNET (ISO 8473/8348) CONNECTIONLESS MODE NETWORK END SYSTEM/INTERMEDIATE SYSTEM PROTOCOL (ES-IE)	
2	ISO LOGICAL LINK CONTROL (ISO 8802/2) (IEEE 802 2) LOGICAL LINK CONTROL CLASS 1, CLASS 3 (LLC) MEDIA ACCESS CONTROL (MAC)	
1	ISO CSMA/CD (ISO 8802/3) (IEEE 802 3) CSMA/CD	ISO TOKEN-PASSING BUS (ISO 8802/4) (IEEE 802 4) TOKEN-PASSING-BUS

Figure 9-14 Top and Map network architectures.

MAP IN THE PROCESS INDUSTRIES [27]

Until recently, the process and process control industries had not recognized the need for, or had input into, the MAP/TOP specification to the same extent as the discrete parts industries. However, as competition from off-shore intensifies, the press for true integration of continuous and batch processes will accelerate. This trend will limit the viability of the current generation of single-vendor Distributed Control Systems (DCS). An equally important trend is the growing recognition of the need for a Multivendor Field Bus to connect sensors and actuators to DCS controllers and SCADA systems. Work on the Field Bus is underway in ISA SP 50 and IEC SC65A-WG6.

The MAP in the Process Industries white paper, developed by the MAP in the Process Industries Initiative (MPII) of the U.S. MAP/TOP Users Group with support from ISA, addresses many of the issues listed above, as well as new issues, that are important to the process industries. Process related issues cited by the white paper include:

1. Environmental concerns, including Intrinsic Safety (IS) and Electro-Magnetic Interference (EMI), which are addressed by Fiber Optics.

2. A MAP Compatible Field Bus for connecting sensors and valves to controllers and consoles.

3. Real-time Performance, i.e., Transactions, including user program functions, completed in a "few" milliseconds (msec).

4. Reliability and redundancy of networks and media.

5. Availability, i.e., network component MTBF of many years.

6. Security, i.e., preventing unauthorized access to and disclosure/change of sensitive information.

7. Network support and management.

8. Support for multivendor DCS using a common process control language.

What started out as the "MAP Process Industries Initiative" is now a legitimate Special Interest Group of the MAP Users' Group. The European MAP/TOP Users Group (EMUG) is interested in many of the same issues. They will play a leading role in the process control and fiber optics arenas.

STRUCTURE OF MAP AND THE CELL ARCHITECTURE

The MAP Cell architecture adds a 5 Megabit per second Carrier Band (CB) physical signaling option to MAP. CB is applicable to small networks, such as Cells, which are limited to roughly 500 meters and 20 nodes. This is defined in the IEEE 802.4 Phase Coherent CB standard. A very high speed Fiber Optic standard is also being developed in the IEEE 802.4G committee. This proposed standard is applicable both to complete plants and to smaller cells and in typical process environments. Thus there is strong user interest in its inclusion in MAP.

The Cell architecture also allows use of the Confirmed Data Link services, originally standardized by ISA-S72.01 1985 and IEC 955:PROWAY, Send Data with Acknowledge (SDA) and Request Data with Reply (RDR), which were later combined in the IEEE 802.2 Type 3 Link Control service. The PROWAY standard makes restrictions on IEEE 802.2 and 802.4 protocols that are needed in industrial networks. The Cell architecture provides performance improvements of 300 to 500 percent or more over the Backbone architecture, as well as offering significant cost advantages.

MINI-MAP AND PROCESS CONTROL ARCHITECTURE [104]

The reliable data link service allows the cell architecture to contain "MiniMAP", which uses only three of the seven layers of the OSI reference model. ("Full MAP", which is based entirely on seven layers, is also contained in the cell architecture.) The layers present in Mini MAP are the Physical layer, the Data Link layer, and the Application layer. MiniMAP promises to provide real-time capabilities not found in Full MAP, as well as cost savings. MiniMAP does not support all of the capabilities of Full MAP, however. Some of the Full MAP facilities not present in MiniMAP are the ability to send arbitrarily long application messages, route messages transparently to a destination node almost anywhere in the world, and use ISO application protocols other than MMS. MAP Enhanced Performance Architecture (EPA) combines MiniMAP and Full MAP in the same station to obtain both the real-time capabilities of MiniMAP and the flexibility of Full MAP.

The Instrument Society of America (ISA) Working Group SP72 is currently completing a standard known as the Process Communication Architecture (PCA). A working draft of this standard is referenced by MAP 3.0 as the definition of the MiniMAP part of EPA.

Figure 9-15 (copied from the latest draft of the PCA standard) shows the relationship between the protocol layers of both a pure PCA node as well as an OSI/PCA node which is a MAP EPA node (containing both MiniMap and Full MAP). Table 9-I lists the functions of each of the seven OSI layers found in Full Map and also explains why the layers not found in PCA are not needed, either because the function is not needed, or because the function is better done in a different layer.

COMPARING PERFORMANCE OF FULL MAP AND PCA

Table 9-II compares the performance of Full MAP and the Process Control Architectures. All times are given in msec (milliseconds) and assume no access to the Name/Address Directory is required.

The 30 msec Status Read on a PCA Cell closely approaches the goal for Real-time Performance (Transactions completed in a "few", perhaps 20, msec, including User program functions) stated in

TABLE 9-I

TASK RELATIONSHIPS OF FULL MAP AND MINIMAP

Full MAP	Mini MAP
Physical Layer	
Ph1) Transparent Transmission of bit streams.	Ph1) Same as Full MAP.
Data Link Layer	
L1) Message delimiting.	L1) Same as Full MAP.
L2) Identification of endpoints.	L2) Same as Full MAP.
L3) Error detection.	L3) Same as Full MAP.
L4) Detection and recovery from lost or duplicated information not performed in the Data Link Layer.	L4) Detection and recovery from lost or duplicated information is performed by the Type 3 Data Link service.
L5) Flow control is not performed in the Data Link layer.	L5) Flow control is performed by the Type 3 Data Link service with assistance by the user.
Network Layer	
N1) Routing frames between nodes on different subnetworks.	N1) Routing between subnets not directly performed by PCA. Network Adapter provides access to OSI including OSI Network Layer routing.
N2) Addressing to a "real" DL address.	N2) DL address is directly carried in all PCA frames.
N3) Reporting routing statistics.	N3) Routing statistics are not significant on one Subnet.
Transport Layer-Class 4	
T1) Maintaining a Connection-Oriented environment.	T1) A-Associations are maintained by use of Confirmed Data Transfers and management of MMS Invoke IDs.
T2) Coordination (negotiation) of Transport resources and capabilities.	T2) Transport specific actions are not required.
	T2-1) The ALP can prevent excessive usage of Data Link resources by use of Management services. Also the MMS ALP is inherently Request/Response oriented and can provide a measure of flow control using the DLP indication of a lack a resources to the ALP. Negotiation of DATA Link capabilities is not required since the Conformance Profiles define a specific set of capabilities shared by all conforming nodes.

continued

Table 9-1 continued

T3) Guaranteeing reliable insequence non-duplicated data delivery.	T3) On a single subnetwork, reliable non-duplicated delivery is guaranteed by the DLP. In addition, when delivery is not possible the User is notified. In-sequence delivery is not required for Request/Response ALPs which allows limiting the data in a request or response.
	T3-1) Over a network composed of multiple subnetworks, reliable non-duplicated delivery is guaranteed by the ALP and by the Network Adapter.
T4) Flow control.	T4) See T2-1
T5) Multiplexing AP-Associations (P-,S-Connections) over one T-Connection.	T5) Multiple Users and AEs are supported over individual LSAPs.
T6) Notification of loss of underlying N-service (& possibly of A-Association).	T6) Loss of communication with an addressed peer node is detected by the DLP confirmation.
	T6-1) When using the Token Bus DLP and the Alive List, the status of all Token Holding nodes is also available from Station Mgmt.
Session Layer	
S1) Coordination (negotiation) of Session resources and capabilities.	S1) Session specific actions are not required.
S2) Full duplex data transfers.	S2) Full duplex data transfers are provided. This is adequate for the Request/Response ALP.
S3) Graceful close of A-Associations (P-Connections) without loss of data.	S3) Graceful close is not necessary since there is no connection and segmentation is not used. A-Abort is provided.
S4) Allow unlimited User data.	S4) See T2-1, T3-1
Presentation Layer	
P1) Coordination (negotiation) of presentation resources and capabilities.	P1) Presentation specific actions are not required.
P2) Conveying A-Protocol (P-Context) identification.	P2) The A-Protocol (Companion Standard) is identified in the ALP Initiate.Request PDU.
Application Layer	
A1) Identification of communication partners and setup of their association using ACSE.	A1) ACSE no present, identification is determined by the Link Service access point. The application state machine keeps track of associations.
A2) Communication of semantics specific to the task to be performed.	A2) Same specific application protocol as in Full MAP.

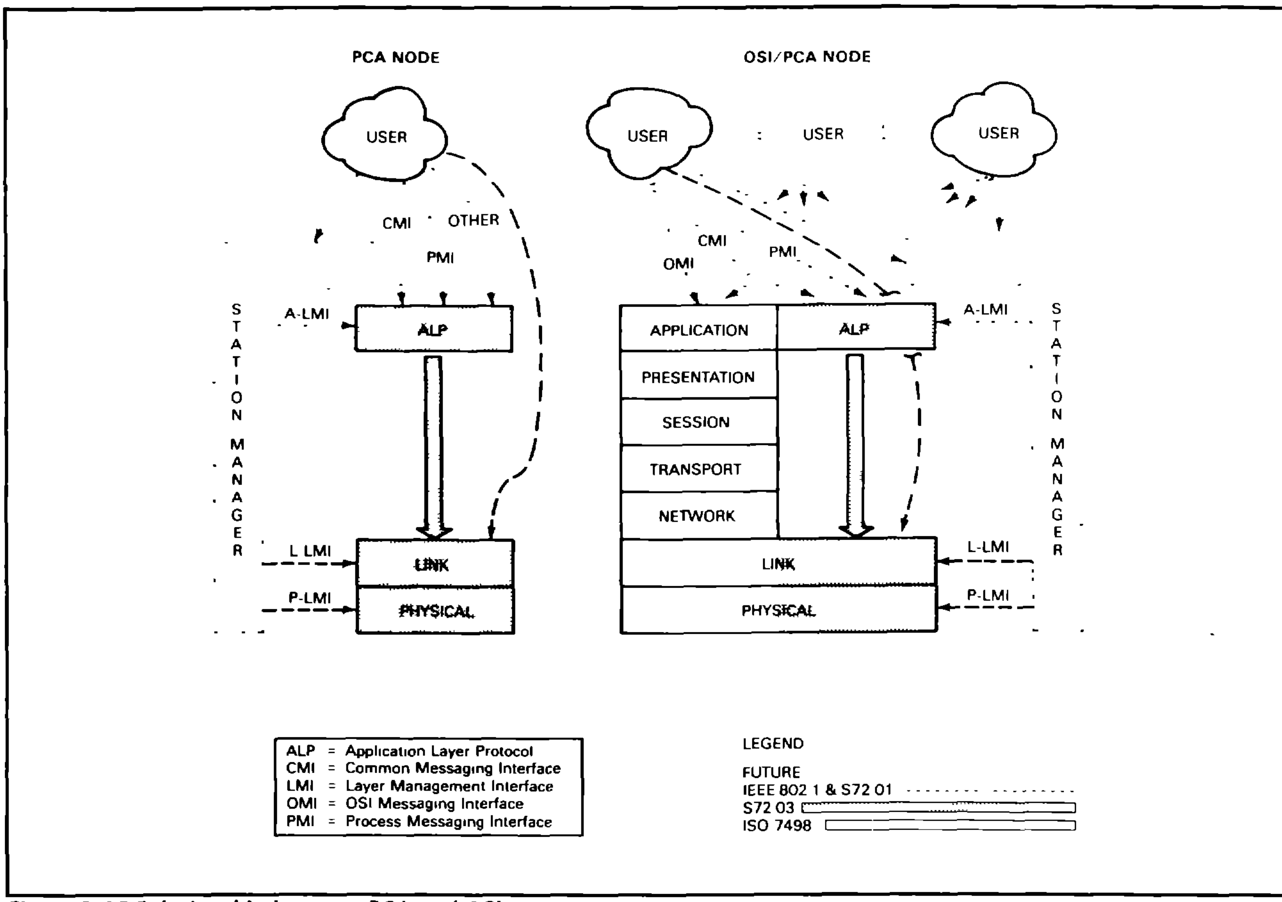


Figure 9-15 Relationship between PCA and OSI.

"The MAP in the Process Industries," white paper. Even more encouraging is the 65 msec activation of Alarms over PCA, which yields a 5X improvement over Full MAP.

From this analysis we conclude that the Process Control Architecture's real-time performance yields a 3X to 5X improvement over Full MAP. This performance is achieved without making the assumptions about Cell Controller capabilities or Cell size that are needed to achieve maximum performance over Full MAP.

ACHIEVING LOWER COST

The process control industry has cost requirements that are more severe than those of much of the automotive industry, where the cost of a $5,000 Full MAP communication board may be allocated to a $30,000 robot. In the process control industry this same board might be needed in a $1,500 single-loop controller or Programmable Logic Controller.

The PCA is one answer to these cost requirements. It is able to communicate with any OSI/PCA node or other PCA nodes. Thus Real-Time PCA Performance is achieved. Very simple PCA nodes can be constructed using the RDR service. These nodes need not pass the token. This improves performance by decreasing token latency. It also allows use of much simpler token bus chips, which will significantly reduce cost. PCA/RDR nodes are appropriate for sensors, bar code readers and other simple devices.

Because four protocols are eliminated and management is simplified in PCA nodes, these nodes will always be less expensive than both Full MAP and OSI/PCA nodes. OSI/PCA nodes will be the most expensive, since they must support a dual communications architecture. We can expect PCA/SDA connect cost to show a 2X to 3X improvement over Full MAP connect cost in 1988. PCA/RDR nodes will be significantly lower cost than PCA/SDA nodes when reduced Token Bus chips are available.

TABLE 9-II

RESPONSE TIMING CAPABILITIES OF FULLMAP AND PROCESS CONTROL ARCHITECTURE

BACKBONE to CELL using	Full MAP	PCA
Status Read/ Temporary Associations	800	n/a
Status Read/ Permanent Associations	160	n/a
Alarm Activate/ Temporary Associations	800	n/a
File Transfer	?	n/a
CELL to CELL using	**Full MAP**	**PCA**
Status Read/ Temporary Associations	330	65
Status Read/ Permanent Associations	85	30
Alarm Activate/ Temporary Associations	330	65

MMS AND MMS COMPANION STANDARDS BACKGROUND

MMS (*M*anufacturing *M*essage *S*pecification) is an Application Layer protocol intended to standardize communication services required to control and monitor factory and plant floor devices in a vendor-independent fashion. Being in the Application Layer of the ISO Open System Interconnection (OSI) reference model, MMS specifies the abstract semantics for factory communication, but does not specify the mechanism for moving information from one device to another. The other standard protocols specified by full MAP or MiniMAP to be used in conjunction with MMS handle the actual movement of the information.

The MMS family of standards is composed of two primary parts, base documents and companion documents. It was recognized that all plant floor devices provide a certain set of common services. Hence, a core commonality could be maintained between plant floor devices. On the other hand, most devices provide some functionality specific to their device class. Base documents are generic, in the sense that they provide a large number of services for a wide variety of devices. Services are described in a generic sense, with further specifications for devices having certain classes of functionality provided by companion standards.

One main reason why MMS will affect the LAN marketplace for factory floor LANs is that the services offered to the applications programmers are greatly enhanced from those provided in most proprietary LANs today. MMS services are loosely categorized into clauses for ease of description and understanding. These clauses are MMS context management, VMD support, domain management, program invocation management, variable access, semaphore management, operator communication, event management, journal management, and file management. It is possible for a device to support some of the services in a clause without supporting all capabilities.

During the development of MMS, it became obvious that the development group lacked the necessary expertise in each of the separate application areas to specify all that is necessary to standardize communications in those areas. Thus, the group created the concept of "MMS companion standards" as good as possible for communication to "generic" factory-plant floor devices. The concept of the MMS companion standard is that standards bodies, expert in their own fields, are encouraged to write standards which specify how MMS is used in their field. Currently, MMS companion standards are being written by various standards bodies (one of which is the ISA for process control applications). An MMS companion standard gives additional requirements for a particular class of device or application. The effect of a companion standard is to extend the scope of standardization beyond the "generic" device, to standardized aspects of devices within particular device or application classes.

Each companion standard specifies, for a particular type of plant floor device or application, the set of services and protocols that must be supported, the options and selections required, and, in some cases, the format of fields for a particular industry. For example, several levels of MMS support for process control are being developed, and the format of the process control status fields will be defined in the ISA Process Messaging Service standard, which is the MMS companion standard for process control.

Companion standards may also prescribe the existence of "predefined" (preexistent) objects, which exist in a device without explicit creation of these objects using MMS services. As an example of a predefined object, the process control draft companion standard specifies predefined variables representing the attributes of a particular control loop, such as the process variable, the set point, the control output, and the various tuning parameters.

While companion standards are developed for each of the plant floor device types by groups of experts independently, commonality is ensured via the use of a common base document and by the efforts of the MMS development group to monitor and coordinate the development of companion standards. Hence, a degree of interoperability between devices of different classes is provided by MMS.

THE ISA PROCESS MESSAGING SERVICE

As mentioned previously, the ISA S72.02 Process Messaging Service (PMS) standard (being developed by the ISA SP72 Working Group) is the process control companion standard to MMS. The standard is too large to completely describe in this section, but an overview along with some samples of specific detail is worthwhile. Figure 9-16 shows the relationship between the PMS and the other standards required to complete the communication requirements.

The PMS standard begins with the usual scope, definitions, references, and such. Then an architectural model is presented to specify the intended kinds of applications and to indicate how the communications in those applications are structured. Communications using the Process Messaging Service takes place between entities known as "Communications Agents". Communications agents are essentially logical in nature.

Typical functions performed by Communications Agents are the provision of a means to direct communications to a single process control server device (such as a loop controller), the representation and the making available of all process control objects, by name, on the entire process control system, and the provision of a method to uniquely control the sequencing and management of process batch manufacturing operations. Not all process control systems will contain agents

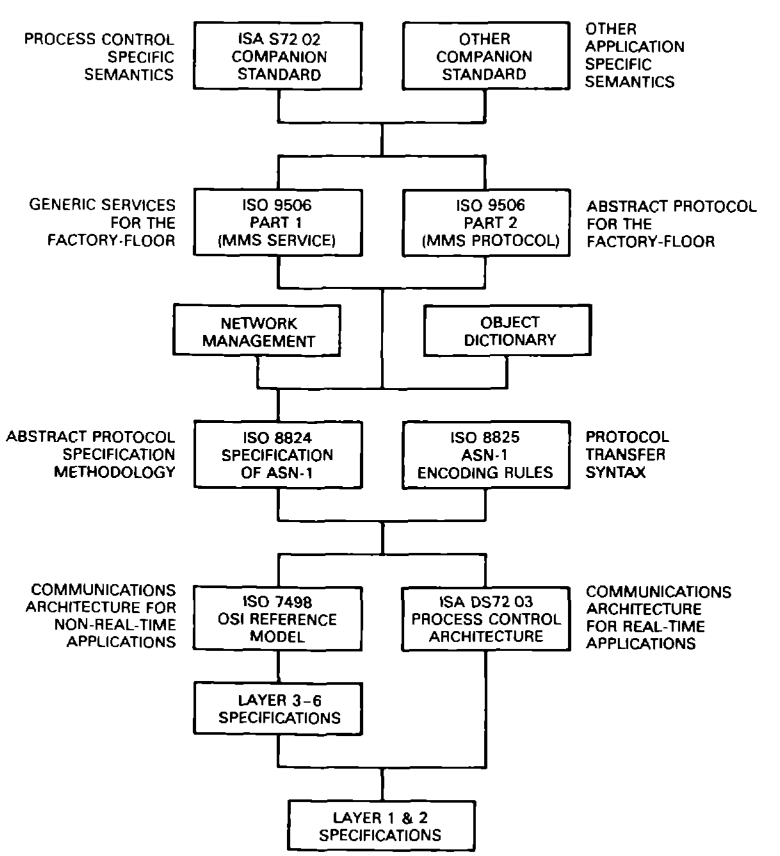
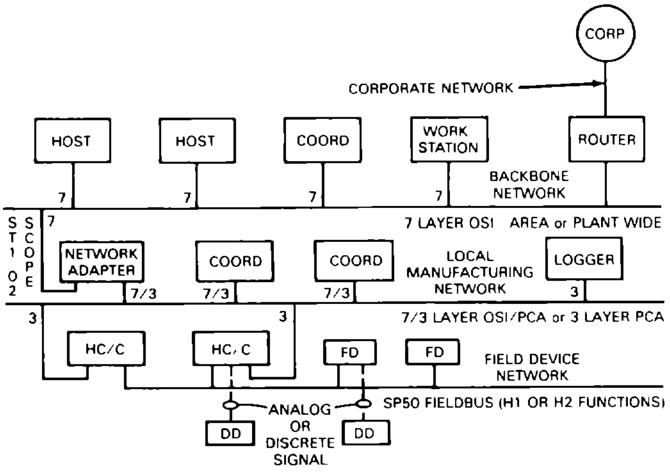


Figure 9-16 Relationship between ISA S72.02 and other standards.



EXAMPLES OF DEVICES

COORDINATOR
- Operator Console
- Supervisory Console
- Cell Controller

FIELD DEVICE (FD)
- Smart Transmitter
- Analyzer (e g GC)
- Scanner
- Smart Actuator
- Field Multiplexer
- Field Data Concentrator
- Field Single Loop Controller
- Field PL Controller

WORKSTATION
- Process Window

DUMB DEVICE (DD)
- Thermocouple
- Valve
- Pressure Sensor
- Tachometer

HIERARCHICAL CONCENTRATOR/CONTROLLER (HC/C)
- Multiplexer
- Data Concentrator
- Single Loop Controller
- Multi Loop Controller
- Batch Controller
- PL Controller

LOGGER
- Data Logger
- Historian

HOST
- File Server
- Plant Data Base Manager (Process Std Recipes)
- Area Controller
- Optimizer
- Quality Control
- Batch Scheduler
- Material Requirements Planning

NETWORK ADAPTER
- Transparent communication at Layers 3 or 7

Figure 9-17 Example set of interconnected process plant equipment.

to perform all of the listed functions, and agents may also exist to perform other functions. Each individual Communications Agent performs one specific function. Physical implementation of each agent, and the relative positioning of each agent within the process control system hardware architecture, are issues left to the implementator.

Figure 9-17 (out of the PCA document) shows an example of a set of process plant devices interconnected by communications links. The exact organization of the devices and the communications links as shown in the figure is only an example of an interconnection plan.

A set of process control specific communication functions is described in the PMS standard. Some of the items included in this set are initiating and concluding communications, reading and writing the attributes of process control objects (such as loop control structures), defining events, specification of communications to be performed on an event, passing alarm information, communicating with an operator, hardware status and control, controlling a program or recipe, sending unsolicited information, identifying a device, setting up and performing the logging of events, reading the log of event occurrences, and downloading or uploading of information. For each process control specific function, the required MMS service is specified and details for the use of that service are given.

Another chapter of the PMS standard defines standard attribute names for process control objects. A sample of such names are the process control object type (which may be input, output, calculation, control server, analog, discrete, accumulation, counter, or timer), the process variable, the quality of the process variable information (e.g., ok, out of range, manually entered, hardware error, etc.), the set point, the output of the process control object, the mode of the object (manual, auto, cascade, remote cascade, or remote manual), the process variable high and low trip points, the rate of change trip points, the alarm status of a process control object, the controller gain, and the controller rate time.

There is also a set of names for specific events such as the reaching of the various trip points or the occurrence of various kinds of hardware failures. In addition to names, the PMS standard defines a set of extra fields which are attached to the generic MMS messages when MMS is used in a process control environment. These fields provide process control specific information on such things as the status of specific devices and the nature of events and alarms.

A further important area covered by the PMS standard is the subject of conformance to the standard. The base MMS standard is very weak on conformance. The problem is that the MMS standard is so all-encompassing, that it is unlikely that any device will support the entire standard. MMS does provide a means to specify exactly what subset of services is supported by a device, and what level of support is provided for types of data, but very little is said about what combination of services should be supported to perform a specific job. The PMS standard, like the other companion standards, defines a set of conformance classes based on the application area of the standard. For each class, PMS specifies the intended functions to be performed and the set of MMS services which must be supported. Classes are based on types of process equipment, types of application within the process control and monitoring area, and on levels of performance.

Finally, the PMS standard provides much needed examples. The base MMS standard does not have examples, because it was felt that the best examples are those based on actual applications, and the base standard is supposed to be generic.

MAP OR TOP? [103]

By providing a standard communications language and a shared medium, Manufacturing Automation Protocol (MAP) networks allow dissimilar computers and devices in factories to communicate with each other. With computers and devices able to communicate, manufacturing efficiency and flexibility is increased, helping companies reap higher returns from their investments in CIM systems.

MAP specifies a 10 megabits-per-second (Mbps) token-passing bus network operating on broadband cable. Its origins date back to 1980, when General Motors (GM) began investigating alternatives after determining that its point-to-point wiring system was expensive, inflexible and inefficient relative to performance. GM determined that linking all devices with a single, contiguous cable and allowing them to communicate with a common set of protocols was the best solution.

MAP on broadband satisfies a manufacturers' most important factory communications needs; multivendor connectivity, predictable network access and response time, wide area coverage and multiple data channels.

Why MAP? The answer lies in the multivendor nature of most factories. Unlike proprietary networks, which interconnect devices from a single manufacturer, MAP's standards-based architecture allows a diversity of computers and production devices to communicate through a common set of protocols over a single cable.

With the worldwide, standards-based protocol system provided by MAP, and TOP (10 megabits-per-second CSMA/CD system operating on either baseband or broadband cable) manufacturers are free to select the best computer or tool for each production task, and not compromise the choice by having to accept whatever will run on the proprietary system.

Why not use TOP as a factory floor network? Except for task-dependent, time-critical applications found in production areas where CSMA/CD is not appropriate, TOP provides an acceptable network solution. In those cases where a deterministic solution is required MAP is recommended.

MAP's token-passing method provides predictable network access and response times because the token is passed in turn to all workstations. Because only the station with the token can send data, the possibility of collisions is eliminated.

Predictable access and assured response times help satisfy the wide area coverage requirement of factory networks. Many plants are hundreds of thousands, and sometimes millions, of square feet, and have hundreds of networked workstations. The performance of such a large system would be severely limited without assured access and response times.

Why broadband? With multiple channels, broadband is suitable for use as an enterprise-wide cable because it can support multiple types of transmissions, such as data, voice, video and utility. A typical configuration is to run MAP in factory areas over several of the broadband channels, Ethernet and token ring in offices and laboratories, and video and utilities throughout the company.

ETHERNET may also be found in the factory either as an existing system or in application areas not requiring the time-critical, predictability of MAP. These ETHERNET plus TOP segments can be linked to the MAP network via bridges.

MODULAR STRUCTURE OF THE COMMUNICATIONS INTERFACE (HARDWARE AND SOFTWARE)

GENERAL

This section describes the communications requirements of each level of the CIM Reference Model in more detail; see Figures 9-18 to 9-21. The purpose here is to define the architecture, module boundaries, connections, interface points, communication needs, and areas for future standards.

The small arrows denote connections with tight coupling and free access between modules. The large arrows represent a yet-to-be-determined structure that imposes a strict, standardized paradigm for communications. The scheme should be powerful, flexible, and easily configurable. The relatively new discipline of object-oriented programming may provide some insight into a workable solution, but solutions are not the purpose here. The goal is to accommodate interchangeable applications modules in a standardized way.

DESCRIPTION OF MODULES

Translators (Levels 1, 2, 3, and 4)

Translators (rope-bordered boxes) are functions intended to indicate points for the focus of standardization. They are interfacing functions that accept requests or data from applications and hand them to device-dependent drivers and perhaps work in the other direction as well. The function is most likely to be handled by the executive and could be as simple as a shared data base. Another solution could involve named variables and commands (e.g., read, write, initialize, and I/O control codes) handled by a data base manager. It is not the purpose here to prescribe the solution; only the intended function. In any event, the idea is to insure that different device drivers do not adversely influence the applications code and vice versa.

Data Communications (Levels 1, 2, 3, and 4)

To move from one level to another in a hierarchy a service is needed that provides the paths for the communications. The committee has agreed that direct communications should not be prohibited. In the interest of simplicity and efficiency these functions should be provided by the same service. In this model the following is proposed: The communications paths could be configured hierarchically as discussed earlier. In this case the direct-communications messages might follow the same paths through the network passing through appropriate nodes but only being read by the destination node. Earlier nodes would only provide the routing functions.

Human Operator (Level 1)

The human operator is the person or persons responsible for the operation of the manufacturing process; the user of Level 1 (Figure 9-18) of the process control system.

Process (Level 1)

The process is the focus of the entire system. It receives energy and material from the world, control from the operator and the control system, and generates a product.

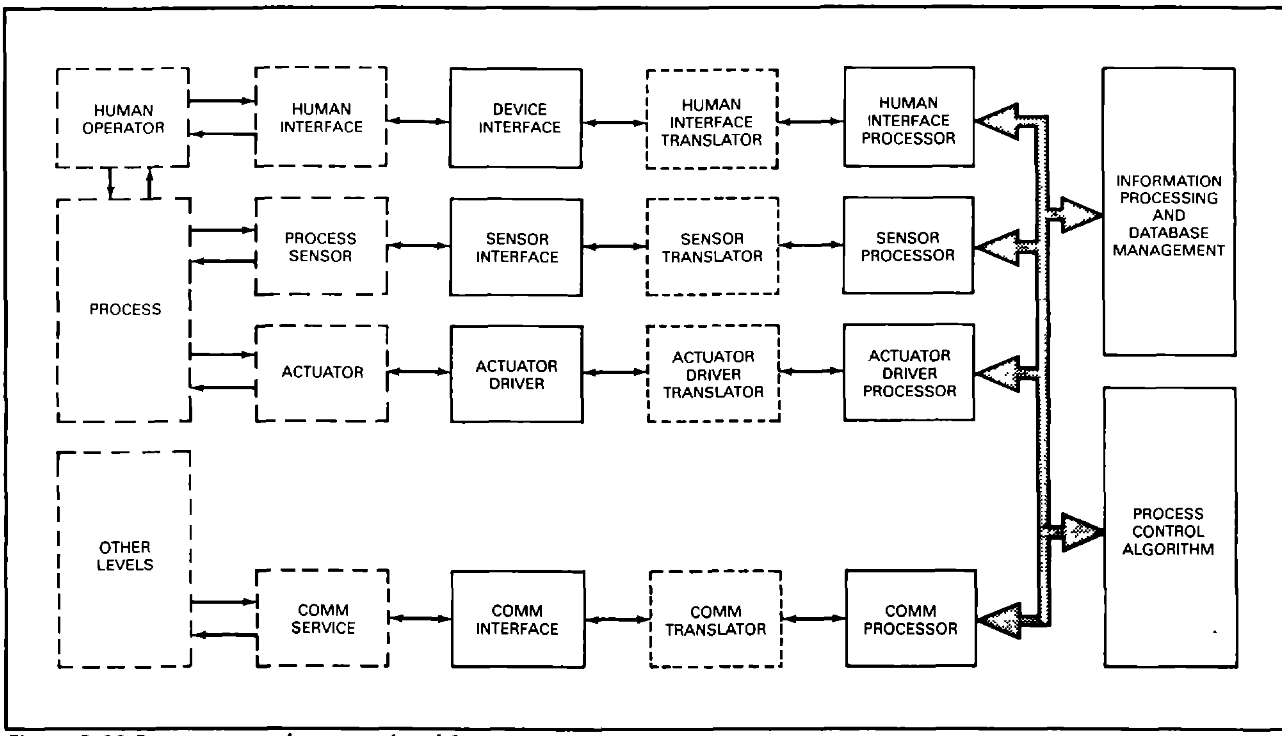


Figure 9-18 Process control system - Level 1.

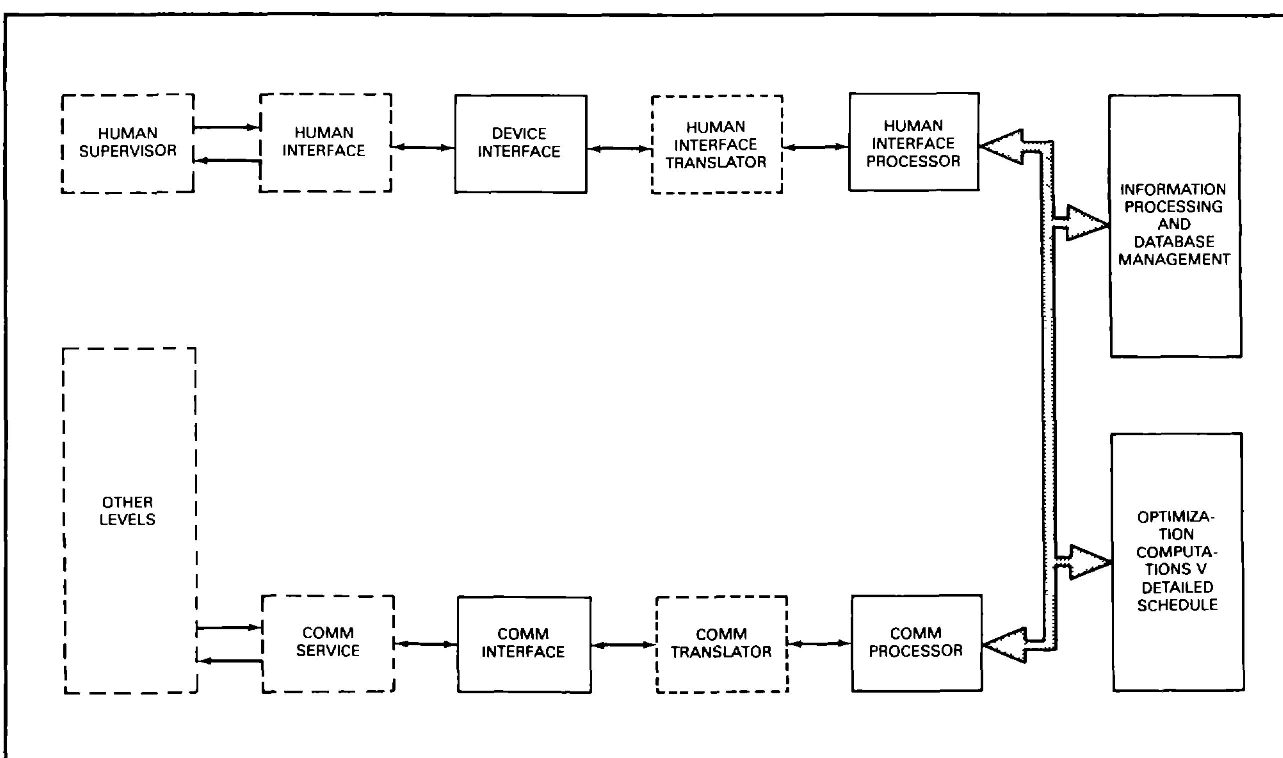


Figure 9-19 Process control system - Level 2.

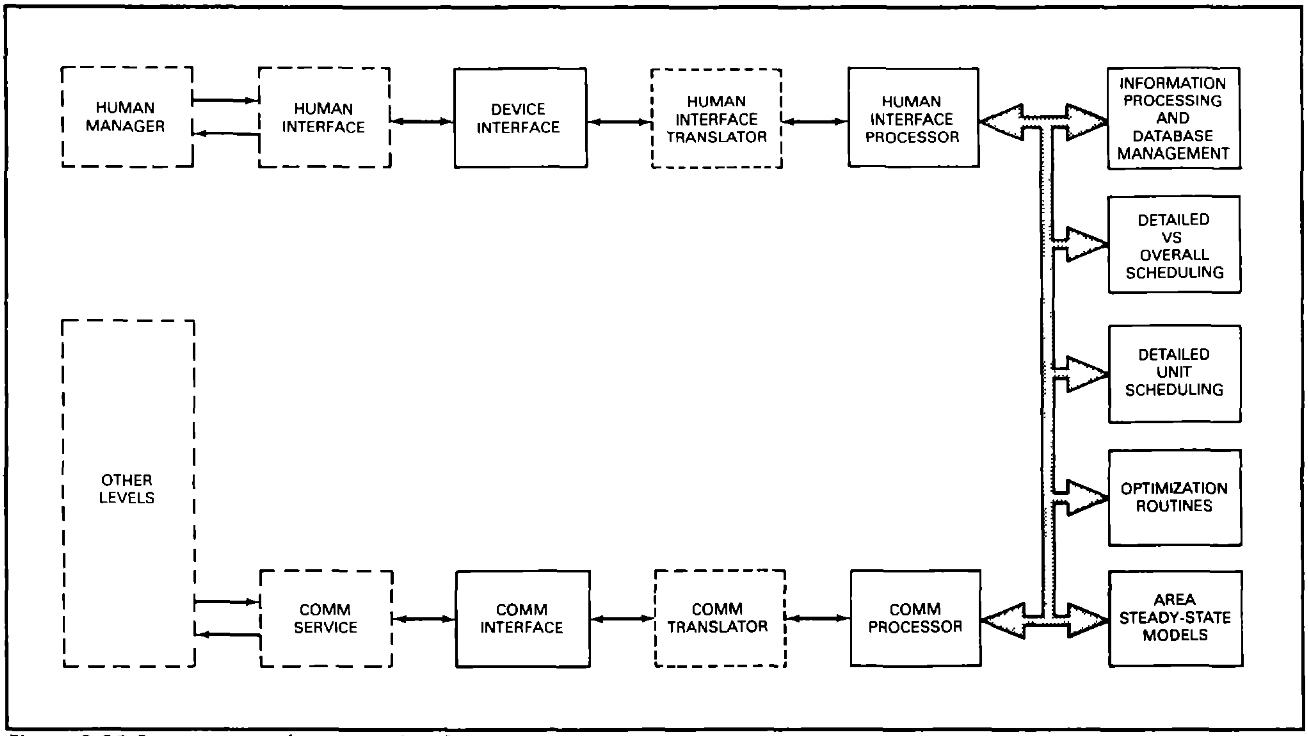


Figure 9-20 Process control system - Level 3.

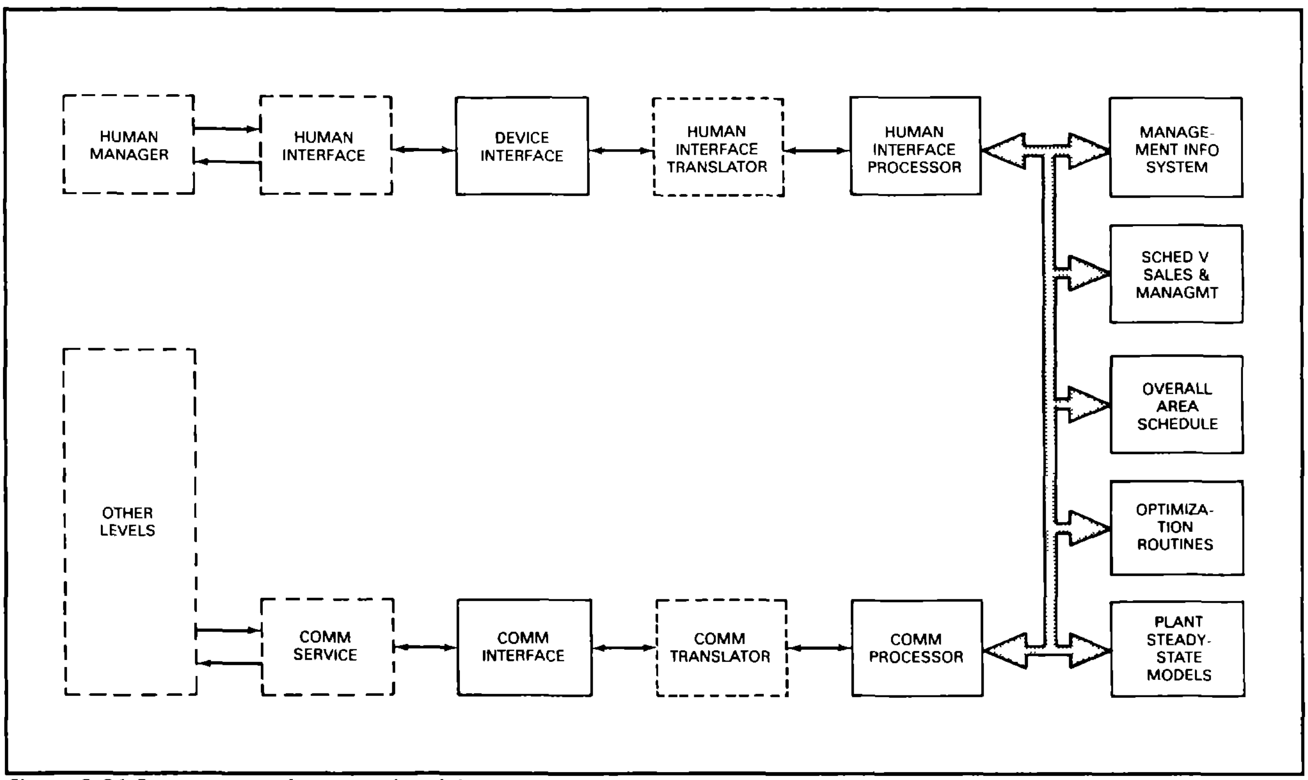


Figure 9-21 Process control system - Level 4.

Other Levels (Levels 1, 2, 3, and 4)

This box represents the conduit through which messages pass to and from other levels.

Human Interface (Levels 1, 2, 3, and 4)

The human interface is the entity that physically transfers information to and from the human operator. It communicates with the device interface.

Device Interface (Levels 1, 2, 3, and 4)

The device interface is dependent upon the human interface device (hardware and software) and interfaces with it idiosyncratically. At its other end it interfaces in a yet-to-be-standardized way with the human interface translator.

Human Interface Translator (Levels 1, 2, 3, and 4)

The human interface translator is a yet-to-be-standardized mechanism that mediates between the device interface and the human interface processor. It provides device independence to the human interface processor. See Translators, above.

Human Interface Processor (Levels 1, 2, 3, and 4)

The human interface processor provides the residence for the human interface applications logic. It provides the tightly coupled relationships with the process values, e.g., measurements and setpoint-entry feedback. It also communicates with the other local (this level) applications modules via the local communications service shown by the large arrows.

Process Sensor (Level 1)

A process sensor is a data-gathering device connected to the process. It provides information about the process through the sensor interface.

Sensor Interface (Level 1)

The sensor interface is dependent upon the sensor device (hardware and software) and interfaces with it idiosyncratically. At its other end it interfaces in a yet-to-be-standardized way with the sensor translator.

Sensor Translator (Level 1)

The sensor translator is a yet-to-be-standardized mechanism that mediates between the sensor interface and the sensor processor. It provides device independence to the sensor processor. See Translators, above.

Sensor Processor (Level 1)

The sensor processor provides the residence for the sensor applications logic. It provides the tightly coupled relationships with the human interface. It also communicates with the other local (this level) applications modules via the local communications service shown by the large arrows.

Actuator (Level 1)

A process actuator is a transducing device connected to the process. It provides physical adjustments to the process as dictated by the actuator driver.

Actuator Driver (Level 1)

The actuator driver is dependent upon the actuator device (hardware and software) and interfaces with it idiosyncratically. At its other end it interfaces in a yet-to-be-standardized way with the actuator driver translator.

Actuator Driver Translator (Level 1)

The actuator driver translator is a yet-to-be-standardized mechanism that mediates between the actuator driver and the actuator driver processor. It provides device independence to the actuator driver processor. See Translators, above.

Actuator Driver Processor (Level 1)

The actuator driver processor provides the residence for the actuator applications logic, e.g., direct digital control. It also communicates with the other local (this level) applications modules, primarily the process-control system, via the local communications service shown by the large arrows.

Comm Service (Levels 1, 2, 3, and 4)

The communications service is the entity that physically transfers information to and from the other levels of the hierarchy. It communicates with the communications interface.

Comm Interface (Levels 1, 2, 3, and 4)

The communications interface is dependent upon the communications service (hardware and software) and interfaces with it idiosyncratically. At its other end it interfaces in a yet-to-be-standardized way with the communications translator.

Comm Translator (Levels 1, 2, 3, 4)

The communications translator is a yet-to-be-standardized mechanism that mediates between the communications interface and the communications processor. It provides device independence to the communications processor. See Translators, above.

Comm Processor (Levels 1, 2, 3, and 4)

The communications processor provides the residence for the communications applications logic. It also communicates with the other local (this level) applications modules via the local communications service shown by the large arrows.

Information Processing System (Levels 1, 2, and 3)

The information processing system is the residence of all the data processing applications code (MIS) required at its level. It communicates with the other local applications modules at its level via the local communications shown by the large arrow.

Process Control System (Level 1)

The process control system is the residence of all the process control applications code at this level. It communicates with the other local applications modules at this level via the local communications service shown by the large arrows.

Human Supervisor (Level 2)

The human supervisor is the person or persons responsible for the supervision of the manufacturing process -- the user of Level 2 (Figure 9-19) of the process control system.

Optimization Computations vs. Detailed Schedule (Level 2)

The optimization computations vs. detailed schedule module is the residence of the applications logic that optimally assigns the detailed production schedule to the production facilities under its control. It communicates with the other local applications modules at this level via the local communications service shown by the large arrows.

Human Manager (Levels 3 and 4)

The human managers are the persons responsible for the management of the manufacturing process; the users of levels 3, and 4 (Figures 9-20 and 9-21) of the plant control system. The managers of Level 4 also have contact with the outside world, for example, sales and marketing.

Detailed vs. Overall Scheduling (Level 3)

The detailed vs. overall scheduling module is the residence of the applications logic that sends optimal assignments from the overall schedule to the detailed unit scheduling module connected to it. It communicates with additional applications modules at this level via the local communications service shown by the large arrows.

Detailed Unit Scheduling (Level 3)

The detailed unit scheduling module is the residence of the applications logic that optimally assigns the detailed schedule from the detailed vs. overall scheduling module to the units under its control. It communicates with the other local applications modules at this level via the local communications service shown by the large arrows.

Optimization Routines (Levels 3 and 4)

The optimization routines interact with the plant steady-state models to provide high-level control of the production facilities. They communicate with the other local applications modules at their level via the local communications service shown by the large arrows.

Plant Steady-State Models (Levels 3 and 4)

The plant steady-state models provide the steady-state response predictions needed by the other applications modules at their level to perform their prescribed functions. They communicate directly with the optimization routines and with the other local applications modules at their level via the local communications service shown by the large arrows.

Management Information System (Level 4)

The management information system is the residence of all the data processing and management information system applications code required at this level. It communicates with the other local applications modules at this level via the local communications service shown by the large arrows.

Scheduling vs. Sales and Management (Level 4)

The scheduling vs. sales and management module is the residence of the applications logic that sends optimal assignments from sales and management to the overall area scheduling module connected to it. It communicates with additional applications modules at this level via the local communications service shown by the large arrows.

Overall Scheduling (Level 4)

The overall scheduling module is the residence of the applications logic that optimally assigns the overall schedule from the scheduling vs. sales and management module to the units under its control. It communicates with the other local applications modules at this level via the local communications service shown by the large arrows.

10

The Place of the Human Worker in the Manufacturing Plant of the Future

PERSONNEL IN THE PLANT OF THE FUTURE

CIM often is considered in a technical context (computers, networks data and software). However, these are only tools. Unless an enterprise is organized, trained and has the mindset to use these tools, they will not generate the anticipated results. If nothing else, early experience has taught us that the human and organizational side of CIM is extremely important.

The place of the human plant operator, the supervisor, and the engineer in a future plant controlled by such a computer system as is being discussed here is a vital part of the study of any such system. We will now present one view of how the human might best be integrated with such a system to achieve the best synergism of the capabilities of each.

In discussing the probable place of operational personnel in the industrial plant of the future one must bear in mind that there are two major considerations at work here. The first of these is that of the "quality of working life" of plant production personnel. They must be relieved of dirty, undesirable, and monotonous tasks; their health and safety must be strenuously protected; and the salary awarded must be high enough to assure a certain standard of living. The second or counter factor to this is, of course, the economic one, that of the capital and operating cost of a mechanical and/or electronic device capable of carrying out those functions now assigned to these personnel. At the plant floor level these decisions can be made "ad hoc" for each situation as it arises since the proposed control system described here can operate regardless of its actual plant production interface provided the necessary communications is established and maintained. That is, a process can either be manually operated or it can be completely computer controlled in the broadest sense, provided the necessary reporting is assured.

At the upper levels of the hierarchy there is a natural allocation of tasks among plant and company supervisory personnel as noted in Figure 10-1. The distribution of tasks almost exactly corresponds to that assigned within the hierarchical computer system as amply shown by Figure 10-2 [44]. Thus a one-to-one relationship must exist between the tasks of the plant production supervisory personnel and the functions of the computer integrated manufacturing system operating the plant in order to obtain the potential synergism that exists.

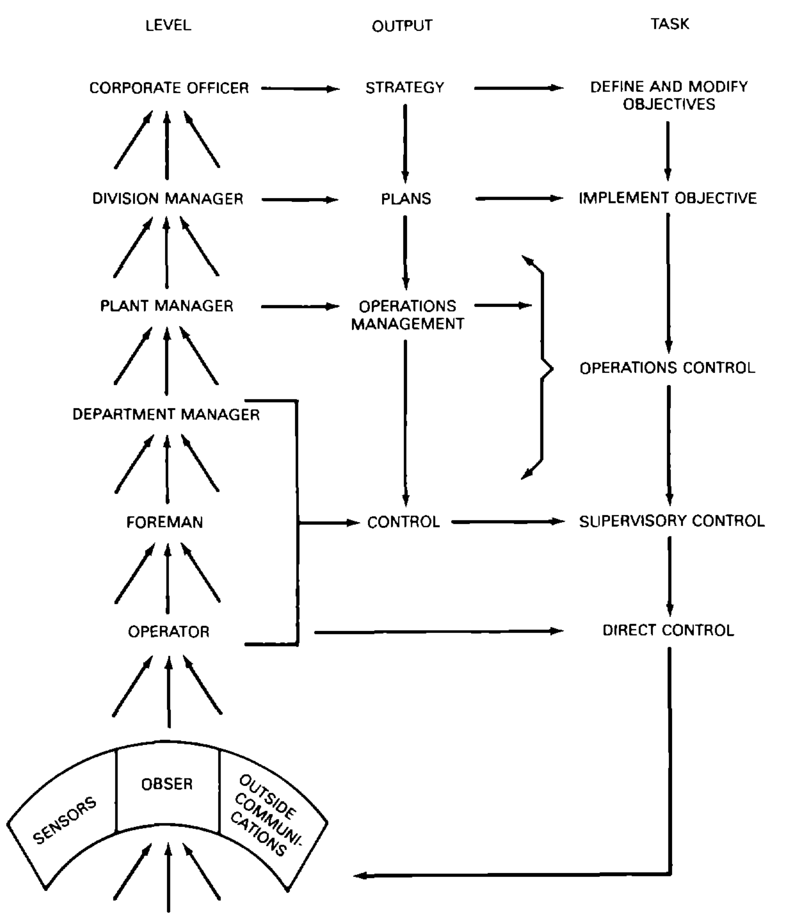


Figure 10-1 Personnel task hierarchy in a large manufacturing plant.

MILL CULTURES AND HUMAN RESOURCES

A committee of the Manufacturing Studies Board of the National Research Council [39] found that certain basic characteristics of this new technology (CIM) are fundamental to identifying human resource practices that are effective in implementing it. When compared with the technologies the CIM replaced, the applications were characterized by:

1. Greater interdependence among work activities;
2. Fewer employees in a group responsible for each product, part or process;
3. Higher capital investment per employee;
4. More immediate consequences of the failure of part of the system on the whole production system;
5. More costly consequences of malfunctions in the system; and,

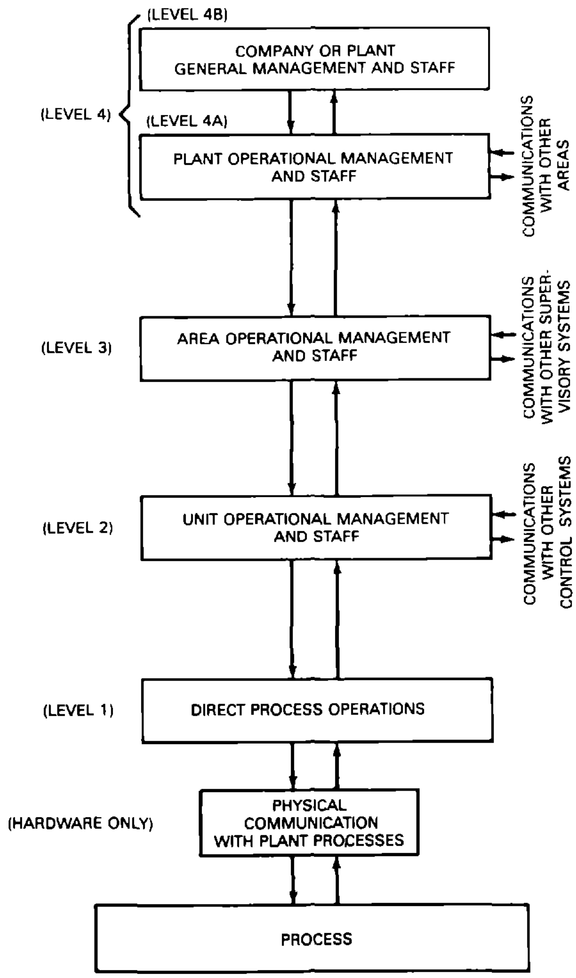


Figure 10-2 Plant operational management hierarchical structure to match the computer hierarchy.

6. More sensitivity of process or plant output to variations in human skills, knowledge, and attitude, and to mental rather than physical effort.

These characteristics of CIM have caused many manufacturers involved with implementing it to initiate or expedite pursuit of the following interrelated organizational objectives:

1. A highly flexible, problem-solving, interacting and committed work force to permit the optimum use of the automation tools;

2. A flexible human and innovative management organization with fewer levels and job classifications to accommodate the employees needs to relate to cultural aspects of the system;

3. A high retention rate of well-trained workers to maintain in the work force; and,

4. A strong partnership between management and the work force representatives (unions, where they represent the work force) to ease the adjustments to changes brought on by the new technology.

Thus, the human resource aspects of plant modernization are a significant dimension of the overall implementation task.

MAN-MACHINE INTERFACES

The operator's and supervisor's consoles in the distributed computer system are almost always of a common basic design. Likewise, they are of a standard pixel addressable color CRT variety which is also usable in a wide range of other computer system applications in order to keep their costs as competitive as possible. They are, of course, customized to a particular process control application by the programming applied by the vendor to each unit. As with the basic set up of the unit for control operations, implementations of the CRT based, operator's or supervisor's console by the user is readily done by means of a "configuration" method rather than by general programming - again greatly easing the task involved. The vendor had previously provided the programmed menu which made the set-up by configuration noted above possible. Here, the industrial control vendors have admirably answered an obvious need, adapting the same CRT interface design by menu programming to satisfy a set of widely varying needs among a large variety of processes and industries [84,114,117].

In fact, if future man-machine duties work out as just described they may have done an even better job than expected. Because, as indicated in Figure 10-3, the new console systems, when properly coordinated with the distributed microprocessor control systems of Levels 1 and 2, really have the potential of moving the plant operator's task from Level 1 to Level 2 or 3. That is, the present day process control operator can easily become a true process supervisor and thus make a much more effective use of the capabilities of the human in the process control hierarchy structure as a monitor and overseer rather than a machine-paced participant. A whole new order of magnitude of reliability is necessary for the above to become established practice. However, as discussed above, these new systems have the potential (not yet completely exploited by most vendors) to indeed achieve these required reliabilities or better availabilities.

Situated as it is at Level 1 of the hierarchy, the microprocessor-based, distributed digital control system thus becomes the "control enforcement" medium for the plant.

INNOVATION IN THE WORKPLACE

As noted in Appendix IV under the definition of [policy implementors] the primary task assigned to most manufacturing plant personnel is that of a policy implementor, i.e., to carry out in the most expeditious manner possible the task or instruction assigned them by other plant entities, usually higher in the hierarchy. Personnel are usually assigned to such tasks because the actions involved are: (1) too complex in terms of dexterity, sensory information or intelligence required for machine implementation, or (2) humans are more cost effective in carrying out the task, or (3) the necessary machines are economically and technically feasible but have not yet been developed or procured for social or political reasons.

As noted under the above definition, the substitution of a human worker for a machine, and vice versa, in no way subverts the definition of the CIM Reference Model for the resulting factory, provided only that the required information concerning the implementation of the task involved as needed by adjacent and upper level entities is provided in a timely and accurate manner by either.

The difficulty in defining the role of the human worker in the manufacturing plant arises when they have been assigned both an implementor and a policy role in the same task, i.e., some of the decisions assigned to them are pro forma and can be described by an algorithm and can potentially be carried out by a computer or other device, but others do require true innovation that must be captured in terms of a new policy (i.e., they become [policy makers]) or the resulting innovation will be lost.

Again, where the requirement for such actions on the part of the human worker are known, such a

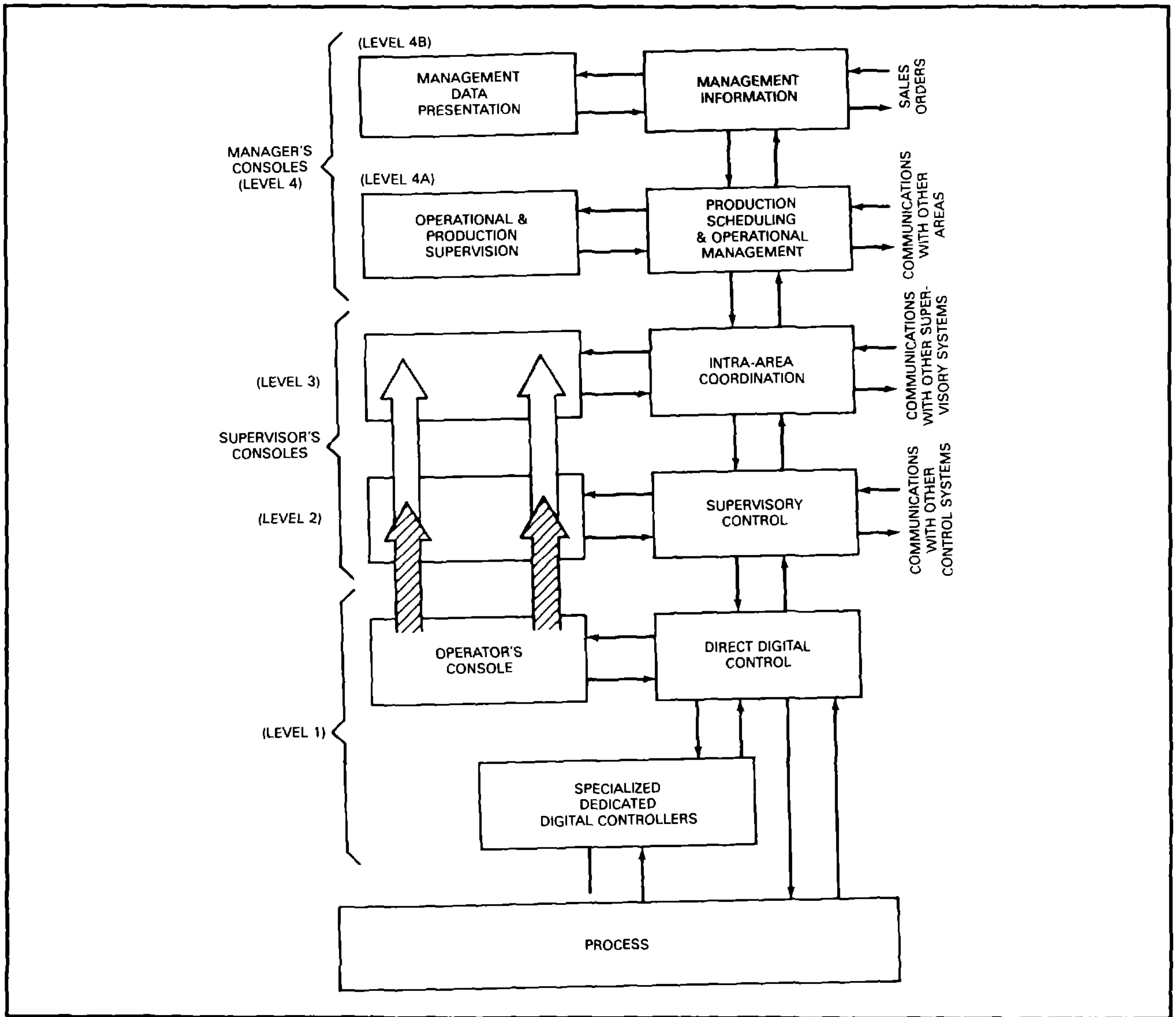


Figure 10-3 Potential future use of the plant operator as a process supervisor rather than a control manipulator.

dichotomy can be readily provided for by defining the workers' assigned job as two tasks: one (the policy implementation part) will be within the plant's information and control hierarchy as described herein and will be so treated; the other, the part requiring innovation will be treated as an external entity and will be considered as part of engineering, marketing, etc., where it best fits.

The major requirement here is to provide the necessary information gathering and transmission facilities so that the resulting innovative decision and its corresponding actions are recorded and made available to all those plant entities which are affected by or need information concerning that decision or action.

SOME NOTES ON HUMAN ORGANIZATION IN THE FACTORY

It is noted that there is a definite movement in some social quarters to proscribe a one-level or minimum number of levels of management organization on the factory. This is carried out by one or more of the following methods:

1. By limiting the usual perquisites of management (status symbols, dress code, etc.) without really decreasing the levels of authority, i.e., a policy of personnel eqalité. This does not affect the CIM Reference Model representation or the resulting organization.

2. By truly distributing innovation demanding decision-making as low in the organization as possible, or,

3. Assigning the necessary innovative decision-making to committees composed of both management and worker personnel. It must be noted that this stratagem merely substitutes the committees for the usual individual assigned the task in question and does not invalidate the normal CIM Reference Model allowance for the resulting decision.

Thus Items 1 and 3 above represent no real change of the CIM Reference Model presented here even though the cosmetic appearance to the personnel involved is considerably different. Item 2 is a fundamentally different organization unless it is handled as discussed in the previous section by defining each worker so involved as having two separate tasks - one innovative and one algorithmic.

Again the key to an effective CIM architecture is the provision and use of the requisite communications facilities for all tasks within the CIM structure.

AN EXAMPLE OF PARTICIPATIVE MANAGEMENT

Like all American manufacturing companies the Monsanto Chemical Company [71] has been impacted by a global economy that has seen faster technological change and obsolescence in products. This led Monsanto's corporate management to a fundamental reexamination of the various businesses that comprised the corporation. The result was a clear decision that if corporate growth was to come from the biological sciences of agriculture, nutrition and health-care, the traditional parts of the corporation must be able to provide the cash to fund the future growth. It was imperative that the cash generator be capable of performing its mission. Therefore, traditional businesses were examined with a very critical eye and those that were weak or marginal were divested as were those that did not fit the strategic direction.

The Fibers Division of Monsanto produces products at four manufacturing sites with approximately 6500 people. It comprises about 40% of the Chemical Company in people, sales and assets. The Division has existed in one form or another since the mid 50's. Its newest manufacturing site began operations in the early 1960's.

The Fibers Division's business was such that if they were to fulfill their role, they had to reexamine the way they would operate in the future. Indeed, if they could not meet their financial targets, then their survival over the long term was questionable.

Since they were so heavily leveraged by manufacturing, it was obvious that they had to focus efforts on establishing a strategy characterized by quality of product and service, flexibility, action and low cost. In essence, they were talking about an organization renewal in their manufacturing function.

Organization renewal can occur in a number of ways. It is unusual for it to occur other than be imposed from above. Of course when this happens, the organization seldom renews itself in the sense that its people do not become truly committed to its goals, and the new leadership needed to guide the organization according to the new and different precepts of action seldom develops.

The organizational renewal now being experienced in fibers manufacturing may well turn out to be different because it was begun with a simple directive from the general manager of manufacturing—improve productivity by 50% in three years as measured by very specific indices, or the Company would seriously investigate selling the Division.

The challenge to improve productivity by 50% required a new way of thinking. The organization had to examine old paradigms and question the way it did everything. A step change was required, not an incremental change. The Division named this consolidated effort the *Plant of the 90's.*

The manufacturing staff developed a broad framework over a nine month period in 1985 in which to accomplish the directive. Originally, the framework focused on application of technology such as computer integrated manufacturing, just in time (JIT) inventory systems, electronic linkages to our customers, distributed process control, artificial intelligence and robotics. This technology, *CIM*, became the first cornerstone of the plan. However, two additional opportunities soon emerged as having significant impact.

A process to be called *Total Quality* quickly established itself as a second cornerstone for our Plant of the 90's.

Total quality within the Monsanto Chemical Company is a defined process and key concept by which constant improvement is sought in every aspect of the Company's business. It is heavily dependent on developing and sharing information and on employee involvement and thus is a natural fit in the Plant of the 90's effort.

It was during the discussion of the generic CIM model that it was realized that the application of this technology would have significant human resources impact. One issue that quickly emerged, for instance, was the question of where various types of work would be performed. How much lab work would be pushed out to the production units? Would the plant maintain a centralized cadre of engineering talent? Would maintenance be integrated under the production umbrella? Etc. etc. This issue was prompted by the approach to information systems which was selected.

Prior to the CIM approach, information systems were developed in the plants—one area at a time. Where it was necessary to link systems, specific programs were written to provide the bridge.

Should the Company continue to automate in this fashion, it would forego many of the organizational benefits from integration within manufacturing and find it very difficult to link manufacturing with other parts of the business, to their suppliers and to their customers. It became clear that unless an integrated organization was used, having integrated information made little sense.

It was at this point that the Division decided to engage in a parallel *Human Resources Planning* effort.

Thus while the effort initially focused on computer integrated manufacturing, it was now only one of three cornerstones in the vision of the Plant of the 90's.

The human resources study opened new vistas about employee involvement, job responsibility and organization design as well as challenging the established power bases in the plant's traditional organizations. An integrated information database cuts across functions so that new and or different players can fulfill the same functional role now claimed by someone in accounting, in quality control, in engineering or in personnel, for example.

The human resources function, therefore, was given the charter to examine the plant culture—that is, how tasks were accomplished—and to suggest changes that made sense in light of the implications of the technology being discussed. It was believed that through careful integration of the three cornerstones (CIM, Total Quality, Human Resources Planning) a plant would gain maximum benefit from the renewal effort and would thus drive the organization beyond the financial targets set.

The following is a brief description of the Human Resources Planning that occurred as part of the Plant of the 90's process.

Seven key questions were used (Table 10-I) to guide this planning effort—the same questions used by the manufacturing management staff when they developed their vision for the application of computer technology. The idea was to take a blinders-off approach to creating a vision of what the Division wanted its plants to look like in the 90's and in particular, to identify the step changes needed in policies and practices that had to occur to achieve the established productivity goals. These questions provided the framework for examining where we were, where we wanted to go and how to get there.

The Human Resources Planning effort was organized as a mirror image to the manufacturing staff effort. Representative of each site was given the responsibility to put in place a team to do their individual work to implement the vision.

The result of examining those questions was a strategy to support manufacturing's mission. There was little doubt that the Division had to

TABLE 10-I

QUESTIONS USED IN THE HUMAN RESOURCES STUDY

1. WHERE ARE WE? (TODAY)
2. WHERE DO WE WANT TO GO BY 1990?
3. HOW ARE WE GOING TO GET THERE? (ORGANIZATION AND TECHNOLOGY)
4. WHEN WILL IT BE DONE? (SEQUENCING AND EVENTS)
5. WHO IS RESPONSIBLE FOR WHAT?
6. HOW MUCH WILL IT COST AND WHAT ARE THE FINANCIAL BENEFITS?
7. HOW WILL WE KNOW WHEN WE ARE THERE?

TABLE 10-II

KEY POINTS IN THE HUMAN RESOURCES STRATEGY

1. ORGANIZATION
2. WORK ENVIRONMENT
3. COMPENSATION/RECOGNITION
4. COMMUNICATIONS
5. MANAGEMENT STYLE
6. TRAINING

push the organization faster to engage all employees in the attainment of the organization goals.

The motivating force to get everyone's attention was continued economic viability—survival.

The strategy developed includes the following major points (Table 10-II):

Strategies/organizaton—It was desired to place responsibility, authority and decision making lower in the organization. The vehicle to accomplish this was self-managed teams of employees. To create self-managed teams required a significant change in organization structure and job responsibilities.

Strategies/work environment—A highly flexible work environment that provided employees the ability to change their own work practices to better accomplish goals was needed. Restrictive work practices and functional barriers were to be eroded.

Strategies/compensation—Elements of performance and knowledge were to become part of the compensation equation as well as ability to pay and competition. In addition, it was necessary to minimize differences in compensation and benefit practices between wage and salary employees to foster team behavior.

Strategies/communications—The whole purpose of Total Quality and CIM is to provide and use information to achieve improved results and less hassle. Therefore, it was imperative that employees at all levels be dealt into the information loop to promote employee involvement. Because survival was paramount, business direction and results information was important. But, information about what the customer said and wanted was also important to maintain any momentum established. Employees do not get involved just because it is decreed that they should. Something must convince them that it is in their own best interest. Economic survival can get things going, but something else must keep the ball rolling. The only thing that makes sense is what the customer says and wants. Thus direct customer interfaces with employees at every level of the organization is a key element of the communications strategy.

Strategies/management style—In order to accelerate employee involvement, it was necessary to replace the traditional boss/subordinate relationship with a facilitator/ employee relationship. Some individuals adapt very easily to this role. Others, however, find it very difficult, and some find it impossible. Therefore, training was the last key point.

Strategies/training—To shift the organization would require unprecedented levels of training. Management and employees had to define and adopt new roles as well as learn new organization and job skills. In addition, training the organization in the concepts of total quality and making employees computer literate would be massive undertakings.

To sum up, the Division had to achieve an employee involvement as a process and on a scale beyond anything previously known.

To implement the human resources strategies, the Division personnel staff became part of the Plant of the 90's organization structures at each site working to implement the vision.

At each plant site a steering committee was named which was generally the same group that developed each plant's model of the vision. Its responsibilities include, direction setting, project prioritizing, resourcing and capital, and benefits approval.

A Plant of the 90's coordinator was designated who reported to the Site Steering Committee. This individual coordinated the three efforts of CIM, Total Quality and Human Resources, monitored results, reported on project status and coordinated with other sites.

These duties for the Plant of the 90's effort are in addition to the normal job duties of these individuals.

Thus the human resources strategy of employment involvement was integrated into the Plant of the 90's effort.

TABLE 10-III

THE EMPLOYEE INVOLVEMENT PROCESS

1. RECOGNIZE THE NEED TO CHANGE
2. SHARE INFORMATION
3. CREATE THE EMPLOYMENT INVOLVEMENT STRUCTURES
4. SKILLS IMPROVEMENT
5. TEAM BUILDING (INCLUDING MANAGEMENT ACCEPTANCE)
6. REFINE STRATEGY AND STRUCTURE
7. REWARD/RECOGNITION

Strategies and plans are great, but one must translate them into action. There is a process to follow to accomplish employee involvement, and the staff carefully set about making it happen in each of the plants. The process is shown in Table 10-III.

It should emphasize that this is not a quick fix program. It is a process that must be managed almost in a sequential mode.

A brief scenario will show what is happening at one plant to show the application of the above process.

This is a plant that is going through a complete transformation in its management style. It was previously a very traditionally managed organization with what we call a "mill culture", as it is known in the textile industry. Employees were very much task oriented and a we/they attitude prevailed. Today it is 90% team based. This change did not occur overnight. Indeed, it is not yet complete. The change that is occurring began in earnest in 1979.

The viability of the plant was in question all throughout this period. Thus a need to change (survival) was clearly recognized. The effort to begin employee involvement began with the sharing of information, not only negative information but also positive information about plant performance.

Most companies are good at using negative information as a springboard to get action, but they seldom share hard data about how well the plant or business is doing or other information employees could use to do their jobs better. Direct communication with customers was unheard of below the second level of supervision.

In addition to simply providing information, the plant management communicated why they felt a change in style was needed. Each employee participated in an eight hour training program on the need to increase productivity, improve product quality and how the plant could address the quality of work life, almost a small business economics course.

It was during this period of time that the quality circle concept was adopted throughout the division. Quality circles provided a structure that allowed the plant to further experiment with the mechanics and techniques of employee involvement.

From there, the plant evolved to special issue resolution teams—groups of employees that come together to address special problems and then disband once the problem is solved. These teams still function and have been the real forerunners of the plant's current team based management style. They emphasized statistical process control training and the developing of closed loop computer technology to control their processes.

Planning for team based management began in January 1985. It was prompted again by the perceived need to accelerate employee involvement as one of the major strategies to insure economic survival. It seemed to be the natural way of doing business, particularly when two voluntary termination programs (one for the Fibers Division and one a corporate restructuring program) resulted in the loss of about 60% of the plant's first line supervision.

The planning addressed the subjects or organization structure, job tasks, communication issues and the types of training necessary to implement this approach. It was accomplished by design teams for each function made up of a cross section of employees with input from others as needed.

Such planning is not easy to accomplish because it covers changes to the basic structure of the organization and threatens the current jobs of many of the remaining employees rather than just allocating the work to be done. Organizations will either get tacit agreement or real commitment depending on how they approach questions of this kind.

The team based management concept was implemented as follows: Design team members attended three days of training and discussions with the plant manager and staff in which the vision for the plant was presented and issues were discussed and concerns vented. Part of the time spent was to identify and assess the culture that existed in the plant.

The issue of culture is important because one has to know whether the current culture is conducive to carrying out the vision. There must be a critical mass that believes and trusts in the vision. If not it will be doomed to failure.

Culture as used here simply refers to the way employees perceive things to be that result in behaviors. A more practical definition is simply that it is what employees talk about in the cafeteria or at the bowling alley.

Employees identified the various subcultures and management styles in the plant and what was needed for change. Some of the subcultures identified were—good ole boy—Rip Van Winkle—hippopotamus. The last referred to the behavior of the hippopotamus when threatened by the approach of strangers or outsiders. They sink to the bottom of the river and only rise after the disturbance has passed.

Some of the management styles identified included Sherman tanks, hand wringers and exploders. There probably is no need to explain those.

The purpose of identifying the cultures and styles is to identify new skills and roles that have to be performed in the team based environment.

For supervision, the old role was to maintain the status quo and control everything. The new role is to take a greater leadership approach, control things and gain a commitment from people. It requires different skills. Supervisors must expand their database for decision making by involving more expertise. They must lead change and project ideas for teams to implement.

Other team members must expand their accountability and responsibility and become more proactive.

Following the discussion of the vision and employee concerns, the design teams went to work to look at how the work could be restructured. The teams were given considerable freedom.

The design teams eliminated the job of first line supervisor, restructured the work in the department and developed new communication roles and requirements. Coordinators were created to handle paperwork and administrative duties—make assignments, schedule vacations, schedule overtime, coordinate major maintenance, get and dispense supplies and communicate between shifts. The coordinator role is rotated among the operators.

The first line supervisor became a resource person to help the coordinator and other team members perform their jobs.

The first attempt at team design centered around employees doing a common job. This quickly evolved to teams that follow the product line, from raw material to finished product and shipment—the concept of a plant within a plant. Much of this becomes possible, of course, as you apply computer technology to consolidate control rooms, etc.

This plant is expanding its views of integration and moving forward to fully integrated, multifunction/ multiskilled teams, the members of which now perform production, maintenance and quality control duties. Integration of support services into the production line organizations is the key to moving responsibilities lower in the organization and broadening the scope of responsibilities of Fibers Division employees. The plant will soon have a team based environment that is structured like a natural work group with all functional areas folded under a product team umbrella and small core groups to provide plant-wide assistance. The goal is to have these natural work groups take the responsibility for running their own business by giving them control for such areas as quality assurance, maintenance planning and execution, safety, customer/supplier relationships, training, cost control, etc.

Figures 10-4 and 10-5 illustrate what is wanted in the way of behaviors associated with each shift in organization toward the multiskill, multifunction teams. As people gain more confidence in their abilities and in the motives of management, they begin to question other aspects of the organization and what can be done to achieve additional improvement. It is this process that causes new leaders to develop and emerge. It happens at all levels of the organization. For instance, the real leaders of the CIM effort are people who prior to 1985 were good solid folks but who did not receive the recognition they get today and who did not have the impact on the organization they have today.

Of course all of this creates issues that must be addressed. How will we pay employees, what about job security, what policies and procedures will become incompatible with the team environment, what happens to employees that cannot adapt to the team environment, etc., etc.?

One of the most important aspects of moving to a team based environment that must be addressed is that of eliminating differences in the way groups of people are treated. An equity mentality must be established otherwise the team environment will be weakened. Several items have been identified that signal the existence of different classes of people and steps are being taken to eliminate those differences. Those differences include such things as the terms hourly and salary employees; different

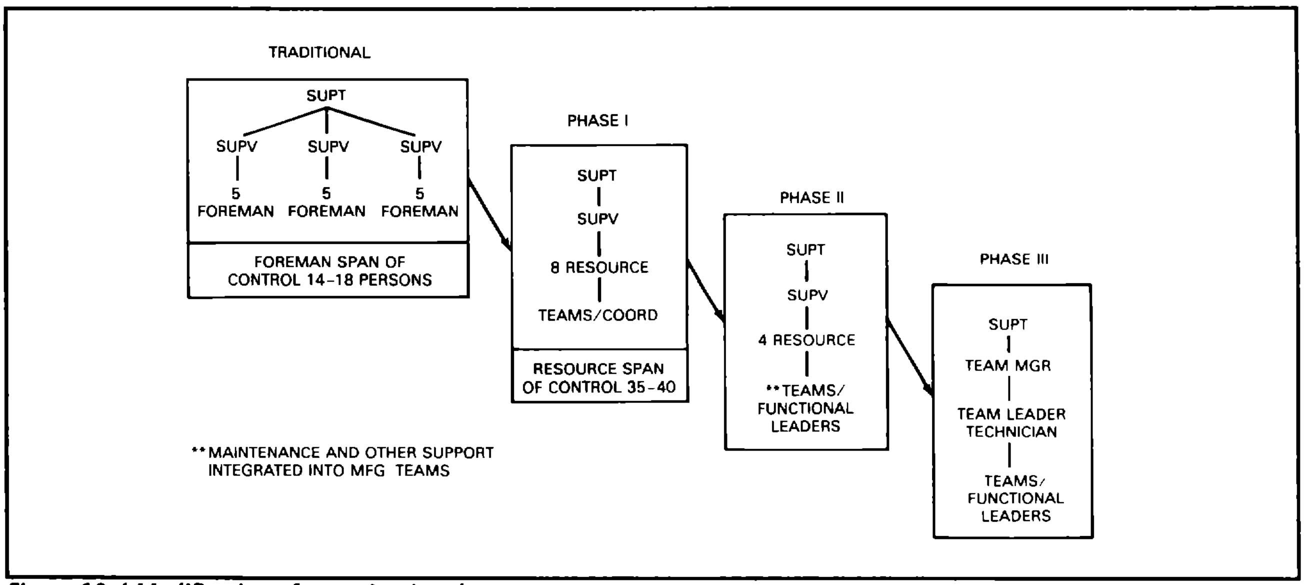


Figure 10-4 Modification of organizational structures.

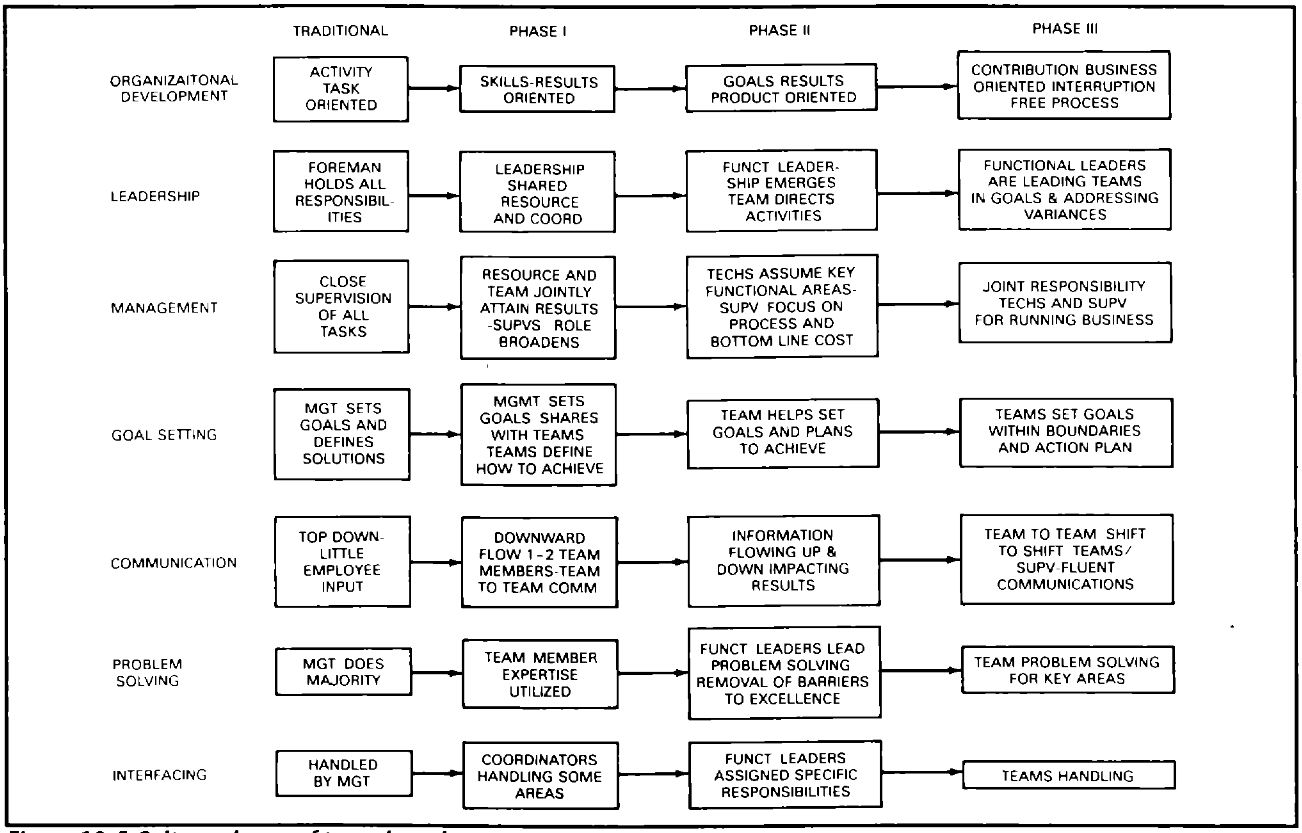


Figure 10-5 Culture phases of team-based management.

treatment in benefit items, such as waiting days for accident and sickness pay; delivery of paychecks in an envelope vs no envelope; training classes held off site vs on site; and the list goes on and on. One plant identified some 40 differences.

Many of these elements are easy to correct and really don't cost anything to change. On the other hand, there is cost, and potentially substantial cost associated with others. In one case, there were different pension plans for salary employees and hourly employees. The Division is seriously considering moving to an all salary workforce and will face significant short term increases in pension costs because of the different funding assumptions involved.

Another issue is that of job security. Obviously anticipating that and implementing a fully integrated, multiskill, multifunction team environment will allow us to reduce headcount substantially. The Division has committed to reduce headcount through attrition and believes that it is possible. However, if attrition does not occur as anticipated they may have to consider other means of reducing headcount either through fewer contract employees or by the use of creative voluntary termination programs. They are committed not to lay off just because employee involvement allowed them to eliminate jobs.

Next is the issue of reward and recognition. Most pay systems to not reinforce a team environment. It must change to incorporate an element of variable compensation based on performance against goals. Gainsharing is a term often used. It is the Division's belief, based on their own research, that the gainsharing plan to be used must be homegrown. It will, however, be the last major element to be implemented as part of the team based environment.

Too often money is used to help achieve gains that one could otherwise achieve through the application of good management practices. Therefore, it is intended to have a good experience base in the Plant of the 90's concepts before turning to gainsharing to drive the business for the last bit of improvement. The estimate is that the project is about two years away from considering any type of gainsharing plan.

In the meantime, issues of "What will I be paid for all this effort?" must be addressed. An approach to be used is called *learn and earn* (see Figure 10-6).

For completion of Module I, there will be a one-time payment of $400, for completion of Module II, a one-time payment of $800, and when requirements are satisfied for the product line technician, movement to the salary workforce with a merit and progression compensation system.

The overall results from the Plant of the 90's efforts includes the ability to operate with fewer people. From January 1985 until now the salary workforce has been reduced 23%, with a much more substantial reduction in first line supervision. The wage workforce has been reduced 11%. These reductions have occurred in light of a 30% increase in volumes and they are in addition to the cutbacks that resulted from discontinued businesses.

The cost of goods has been pushed down an experience curve comparable to that of a growth industry even though the plant manufactures very mature products.

The process has influenced allocation of capital investments that allow them to implement computer-based technologies.

The Total Quality Index has seen significant improvement. This index measures how well our fiber performs on customer equipment.

The Division will be very close to accomplishing their required 50% increase in productivity by the end of 1988. The labor portion of that index will be at 150%.

Given all the foregoing, is there anything which should have been done differently?

In general, everyone is quite pleased with the results. People in the manufacturing function are turned on. They receive a lot of attention. Some have broadened their careers finding new interest and recognition as leaders of the effort.

From the macro Division standpoint a better position for the future would have been possible if the entire Division had engaged in a visioning process before any one function began its effort. It might eliminate some of the confusion and retrofitting that will be faced later. On the other hand, fibers manufacturing has acted as a change agent. The results achieved and the recognition gained has had a significant impact on the other functions of the Division. Sales is now beginning to do similar conceptual thinking as a result of examining EDI concepts to help build customer partnerships.

From the plant standpoint, it might have speeded results if the visioning process had been conducted for each plant as a whole rather than by approaching a vision for each department/function in the plant and then trying to integrate those visions into one for the plant. They could have moved to the broader concept of natural work groups faster.

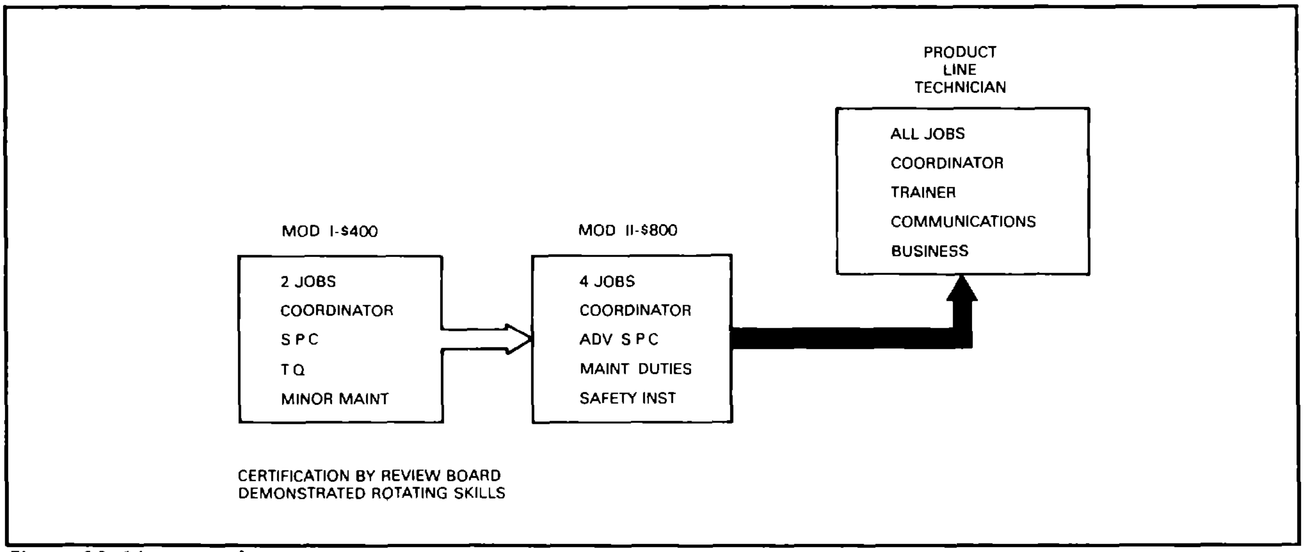


Figure 10-6 Learn and earn program.

However, as one plant coordinator put it, "We could not achieve a vision of a team on a plant-wide concept." They were content to let that evolve. The results have been quite satisfactory.

The heavy training load that accompanies this kind of style should have been anticipated. Line management has now agreed that a commitment of what amounts to 25% of overall payroll costs is a worthwhile expenditure to implement and maintain employee involvement. The results have been worth it, but it has been a major burden to accomplish the needed training as well as to meet production commitments and occasionally the temptation is present to slip back into the old style of management.

Each of the Division's four plants has a slightly different approach to the Plant of the 90's, and some are farther along than others. All are committed to the team approach and the use of natural work groups, and all are rapidly employing the technology associated with computer integrated manufacturing.

They continue to expand their horizons as they consider the impact of integrated computer technology and information. While the team efforts have begun at the lowest levels in the plants, it will not be long before a blurring of job distinctions and functions at the middle and higher levels will be seen. Already design teams are at work to identify how teams will impact the next level up. It doesn't take much imagination to realize that if one gets teams fully operational and functioning smoothly in the plants, that the role of the plant manager and his staff can change substantially.

What is happening in manufacturing will also happen in every function of the Division. In fact, as a result of the Plant of the 90's effort, the Division is now adopting a *Business of the 90's* effort for the Division to determine what will be needed and how they will operate in the future considering the possibilities that arise from application of computer technology and information integration.

(Editor's Note: In view of the previous section of this Chapter entitled, "Some Notes in Human Organization in the Factory," it is interesting to discuss the Monsanto development in this light. It is easy to see that the Monsanto plan comprises implementation of Items 1 and 3 of the list in the noted section, i.e., the policy of personnel equality in terms of perquisites and the substitution of committees or task groups for individual managers or supervisors as is well shown by Figure 10-4. Note that this does not affect the hierarchical management structure (as noted in Figure 10-4) except for the substitution of committee or task group for the individual manager. The workers are responding because of the attention they are getting, almost a Hawthorne effect [93].

The major accomplishment of the Monsanto project and related developments is its restoration of teamwork in the workplace to replace the autocracy of previous management practices and the adversarial relationship between management and unionized workers. This is effectively a return to the cooperativeness that existed in the industry before the Industrial Revolution separated management and the worker).

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Appendix I

Notes Concerning the Hierarchy Structure For CIM Systems

It can be noted that in all of the installations made to date the chosen mode of implementation of the plant-wide system has been a hierarchy of separate computers.

Hierarchy systems have been favored as the implementation media to-date since they have the following characteristics important to their designers:

1. They follow the usual human management structure of the plant (see Table AI-I below).
2. They promote the Principle of Autonomy (i.e., responsibility can be delegated as low in the hierarchy as possible).
3. They promote the Principle of Locality (i.e., since plant units are usually widely distributed, but also usually comprise relatively self-contained units, distributed control can be readily applied).
4. They readily permit the distribution of plant-wide computing tasks to a multicomputer system due to the natural layering of control functions in the hierarchy [90,119].
5. The distribution just noted reduces the span of control responsibility of each control computer thus reducing its work load and the tasks of its implementation.

TABLE AI-I

DESIGN OF HIERARCHICAL CONTROL SYSTEMS

I. ALL CONTROL SYSTEMS REQUIRE MORE THAN ONE LEVEL, I.E., ALL ARE HIERARCHIES TO SOME DEGREE. THE DESIGN QUESTION IS: WHAT AND HOW MANY ARE THE LEVELS AND WHAT ARE THEIR ASSIGNED DUTIES?

II. ORGANIZATIONS AND COMPUTER ARCHITECTURES ARE HIERARCHICAL:

1. IN ORDER TO REDUCE THE EXCESSIVE INFORMATION LOADS WHICH IMPEDE THE DECISION MAKING PROCESS IN FLATTER ORGANIZATIONS.

continued

Table AI-I continued

2. TO KEEP THE SPAN OF CONTROL WITHIN HUMAN DECISION MAKING CAPABILITIES.

III. A FLATTER ORGANIZATION OR ARCHITECTURE IS FAVORED BECAUSE IT:

1. REDUCES THE "HUMAN" COMMUNICATION ERROR (NOT COMMUNICATING, MISUNDERSTANDING, FALSE INFORMATION).
2. SHORTENS THE RESPONSE TIME OF THE MANAGEMENT SYSTEM.

IV. WITH THE CIM ENVIRONMENT THE CAPABILITY OF RAPIDLY AND ACCURATELY TRANSFERRING DATA TO ALL FUNCTIONS FOR DECISION MAKING REDUCES THE NEED FOR EXCESSIVE SUPERVISORY LAYERS. IT DOES THIS BY:

1. PROVIDING TIMELY AND ACCURATE DATA AT CRITICAL LOCATIONS.
2. SOLVING DECISION LOGIC PROBLEMS, SUCH AS SCHEDULING PRODUCTION, EQUIPMENT DOWNTIME, ETC., THAT DO NOT NEED THE SUPER CAPABILITIES OF THE HUMAN BRAIN.
3. REDUCING RESPONSE TIME FOR LAN AND WAN CAPABILITIES. (LOCAL AND WIDE AREA NETWORKS.)
4. ELIMINATING HUMAN COMMUNICATION PROBLEMS (NOT COMMUNICATING, MISUNDERSTANDING OR FALSE INFORMATION).
5. MANIPULATING AND CONTROLLING VOLUMINOUS AMOUNTS OF DATA FORMERLY CONTROLLED BY INDIVIDUALS.

V. THERE ARE SEVERAL FACTORS WHICH TEND TO INCREASE THE NUMBER OF LEVELS IN THE HIERARCHICAL STRUCTURE FOR THE CIM INFORMATION MANAGEMENT AND AUTOMATION CONFIGURATION. THESE ARE:

1. MODULARITY:

   A. SCOPE

   B. LOCALITY (PRINCIPLE OF LOCALITY)

2. THE NEED TO LIMIT THE COMPLEXITY OF INDIVIDUAL ENTITIES TO FACILITATE HUMAN COMPREHENSION AND COMPUTATIONAL TRACTABILITY.
3. PRINCIPLE OF AUTONOMY FOR THE APPLICATION FUNCTIONAL ENTITIES.
4. FLEXIBILITY TO PROMOTE THE INTRODUCTION OF NEW TECHNOLOGIES.
5. PHYSICAL LIMITATIONS OF FAN-IN AND FAN-OUT

   A. PROCESSING CAPACITY

   B. RESPONSE TIME

6. HIGHER HIERARCHICAL FUNCTIONS TEND TO FOCUS ON PLANNING (I.E., SCHEDULING), LOWER LEVELS ON EXECUTION.

Appendix II

Development Considerations for the CIM Reference Model

STATEMENT OF OBJECTIVES FOR THE CIM REFERENCE MODEL

The reference model in conjunction with specific manufacturing requirements, objectives and design methodologies provides a framework for the architecture and design of the CIM system that implements a particular established plant manufacturing policy.

The resulting architecture will include the following*:

1. Definition of entities and related tasks.

2. Relationship between entities.

3. Required data flow between entities.

4. Definition of the data management structure and the data dictionary needs.

5. Interfaces to external influences.

One may consider the plant in many different ways when developing a model of its operation. The next section discusses the six different views that have been identified in the Committee's studies [120]. Views are converted into designs for a specific system through the system architecture. The architecture's considerations which must be included are defined below as: platform, communications, database management, scheduling and control, and human organization.

When developing a CIM Reference Model one may go from the specific to the generic, i.e., review several different specific plants from various industries and develop the generic commonality among them as shown in Figure AII-1. Note that the reverse path can be followed in developing a specific model (i.e., an automobile manufacturing plant or a paper mill) from the generic model. Another method is to list the generic functions directly as outlined in Table AII-I.

Table AII-II lists a group of basic principles involved in the model and which provide examination points to judge the generic qualities of the model. Table AII-III shows the interrelationship of the several views as described in this document.

VIEWS OF THE CIM REFERENCE MODEL

Six different (views) or dimensions along which one can review the factory have been identified [85]. They are listed below. They may not be truly orthogonal (i.e., distinctly different). In addition, available models in the literature are generally combinations of different views.

* The discrete industry model may also include physical material flow.

1. Scheduling and Control Hierarchy
   Exemplified by the model developed in the Purdue University steel plant hierarchical computer control project [90] and used in Chapter 3 of this document.

2. Implementation Hierarchy
   Exemplified by the ISO/OSI Communications Model. See Chapter 9, Figure 9-6 and associated discussion. This view highlights the application/support distinction. See Chapter 5 for a more general Implementation Hierarchy.

3. Functional Network
   Exemplified by the data-flow diagram. (This diagram may be a derivative of Nos. 1, 2 and 4). See Chapter 4.

4. Physics View
   Exemplified by the model of ISO/TC 184/SC 5/WG 1. See Appendix III.

5. Sequential View
   Exemplified by the flow chart, such as that of the ESPRIT project of the European Economic Community [120]. Not used in this text.

6. Metrics or performance views
   Exemplified by the models developed by the Digital Equipment Corporation (DEC) [45, 53] and ESPRIT. Not used in this text.

NOTE:
Further research may prove that the Sequential and Metric views are superfluous to the other four. Only the first four are discussed in this document.

DEVELOPMENT OF THE SYSTEM ARCHITECTURES

There are five architectures which can be defined in designing a particular configuration for a CIM information management and automation system [85]. Architectures define the interconnection of the elements of the systems. When combined with the specifications of these elements they comprise the design of the system. They are:

1. Platform:
   A. Hardware (computer and machines)
   B. Support software
2. Communications
3. Data management database, management of process data
4. Scheduling and control
5. Human organization (policy implementor management), human interface

TABLE AII-I

METHODOLOGIES FOR THE DEVELOPMENT OF THE CIM FUNCTIONAL REFERENCE MODEL

I. LIST THE FOLLOWING FOR CIM SYSTEMS IN GENERAL:

   1. GENERIC FUNCTIONAL ENTITIES OF THE FACTORY

      A. TASKS OF THE ENTITIES

      B. INPUTS NEEDED FOR EACH TASK (INFORMATION AND MATERIAL)

         1) SOURCE

         2) CHARACTERISTICS (ACCURACY, RATE, PRIVATE, PUBLIC, ETC.)

      C. OUTPUT OF EACH TASK (INFORMATION AND PHYSICAL OBJECTS)

         1) RECEPTOR

         2) CHARACTERISTICS

   2. GENERIC INTEGRATED DATABASE NEEDS OF THE FUNCTIONAL ENTITIES

   3. GENERIC COMMUNICATIONS NEEDS OF FUNCTIONAL ENTITIES

   4. GENERIC INFORMATION PROCESSING NEEDS OF THE FUNCTIONAL ENTITIES

continued

Table AII-I continued

II. MAKE AN EMPIRICAL COMPARISON OF THE OVERALL REQUIREMENTS DERIVED FROM SEVERAL DIFFERENT INDUSTRIES.

TABLE AII-II

BASIC PRINCIPLES USED FOR DEVELOPMENT OF THECIM REFERENCE MODEL

1. PRINCIPLE OF [AUTONOMY] LEADING TO A MODULAR SYSTEM WITH HIGH *COHESION* AND LOW *COUPLING*. AUTONOMY MEANS THAT INDIVIDUAL UNITS ARE AS INDEPENDENT IN ACTION AS OVERALL INTEGRATION CAN PERMIT.

2. PRINCIPLE OF [LOCALITY] LEADING TO DISTRIBUTED PROCESSING AND *TIME-PHASED DECOMPOSITION*. LOCALITY MEANS THAT UNITS IN THE SAME GEOGRAPHICAL REGION TEND TO WORK CLOSELY TOGETHER. A UNIT WORKS MORE CLOSELY WITH ITS NEIGHBORS THAN WITH THOSE MORE DISTANT.

   NOTE: ITEMS 1 AND 2 REFER TO THE APPLICATION FUNCTIONAL ENTITIES OF THE SYSTEM IN QUESTION.

3. THERE WILL BE NO APPLICATION BIAS.

4. THE OVERALL SYSTEM SHOULD BE STRUCTURED TO LIMIT THE COMPLEXITY OF EACH ENTITY. THE RESULTING SIMPLICITY FACILITATES:

   A) HUMAN COMPREHENSION

   B) COMPUTATIONAL LOAD

   C) PHYSICAL STRUCTURE

5. THE SYSTEM SHOULD EXHIBIT ARCHITECTURAL FLEXIBILITY TO PROMOTE THE INTRODUCTION OF NEW TECHNOLOGIES.

6. THE REFERENCE MODEL SHOULD SUPPORT MULTIPLE *VIEWS* TO EXPRESS DIFFERENT DIMENSIONS OF THE PROBLEM.

7. EACH *VIEW* HAS ITS OWN NATURAL STRUCTURE WHICH MAY OR MAY NOT BE HIERARCHICAL.

TABLE AII-III

RELATIONSHIP OF THE SEVERAL VIEWS AND ARCHITECTURES TO THE FUNCTIONAL ENTITIES

1. EACH OF THE ARCHITECTURES RELATES TO THE SCHEDULING AND CONTROL HIERARCHY VIEW WHICH DEFINES THE HIERARCHY LEVELS AND THEIR SPECIFIC TASKS AND FUNCTIONAL REQUIREMENTS. (SEE CHAPTER 3 AND FIGURES 3-1 AND 3-2). THE ARCHITECTURES THEN SPECIFY THEIR CORRESPONDING EQUIPMENT, PERSONNEL, SOFTWARE, ETC., REQUIRED TO FULFILL THE STATED NEEDS. THE FOUNDATION AND MANUFACTURING SPECIFIC FUNCTIONAL ENTITIES ARE COMPRISED IN THE RESULTING ARCHITECTURES.

2. THE IMPLEMENTATION HIERARCHY VIEW SHOWS HOW THE REQUIRED FOUNDATION FUNCTIONAL ENTITIES INTERFACE TO PRODUCE EACH MANUFACTURING SPECIFIC FUNCTIONAL ENTITY. SEE CHAPTER 5 AND FIGURE 5-1.

3. THE FUNCTIONAL NETWORK VIEW (ALSO CALLED THE DATA-FLOW OR INFORMATION-FLOW GRAPH) SHOWS THE INTERACTION OF THE MANUFACTURING SPECIFIC FUNCTIONAL ENTITIES AND THE EXTERNAL INFLUENCE ENTITIES COMPRISING THE INFORMATION MANAGEMENT AND AUTOMATION SYSTEM INCLUDING THE INFORMATION FLOW BETWEEN THEM. SEE CHAPTER 4 AND FIGURES 4-1 TO 4-15.

4. THE PHYSICS VIEW RELATES MATERIAL AND INFORMATION TRANSPORT AND TRANSFORMATION IN THE CIM SYSTEM WITH THE REQUIRED CONTROL FUNCTIONS. SEE APPENDIX III.

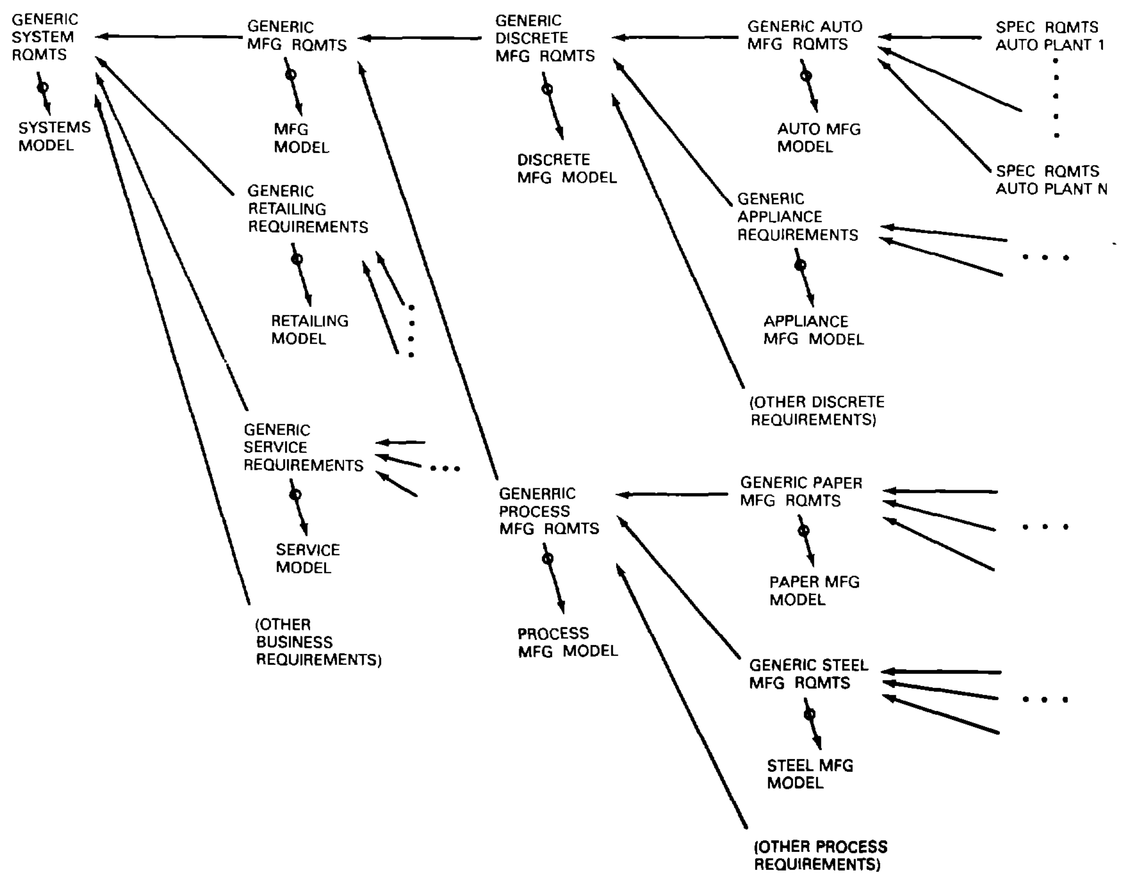


Figure AII-I Empirical development of the CIM Reference Model from the requirements of different industries.

Appendix III

An Example of the Physics View The Generic Production Activity Model (GPAM) [38]

Working Group 1 (ISO/TC184/SC5/WG1 - Reference Model) has approached the modelling of those characteristics relevant to systems integration within the Factory Automation Model (FAM) through the concept of an *activity*. An activity can be considered an abstraction which performs defined *actions* within the set of constraints imposed by the activity's *subjects*. The action and subject of an activity are each subdivided into a number of parts which are considered generic across all levels of the FAM.

They have represented this whole assemblage in a Generic Production Activity Model (GPAM), which is illustrated in Figure AIII-1. It is generic in the sense that it can be applied to each level of the Factory Automation Model to depict the basic entities of that level related to standards. The internals of the GPAM represent an interrelated set of four actions, four activities, and four subjects (flows). The actions, subjects and activities are defined below:

FOUR ACTIONS

(1) *Transform:* The act of changing information, material, or resources from one form to another form. This includes encoding or parsing information, decomposing commands, and cutting, forming, or assembling material.

(2) *Transport:* The act of moving information, material or resources from one point in the enterprise to another.

(3) *Verify:* The act of certifying the compliance of all transformed or transported information, material and resources to determine its conformance to a specification.

(4) *Store:* The act of retaining information, material or resources at a specified location within the enterprise until it is required to be transported.

FOUR SUBJECTS (FLOWS)

(1) *Information in/out:* The technological data (together with the meaning within the given context) required for, or resulting from, the performance of an activity.

(2) *Material in/out:* The raw material and work-in-process or finished parts used by an activity and passed on for further use by other activities.

(3) *Resources in/out:* The equipment, human, utility, etc., required by an activity to perform its functions.

(4) *Command/Status*: The commands direct the performance of an activity, and the status indicates the evolution of an activity.

FOUR ACTIVITIES

(1) *Processing* is an activity performed on material, information, or resources to achieve the stated objectives given by commands and status.

(2) *Execution* is an activity on material (handling or processing) which produces desired parts and scrap.

(3) *Support* is an activity provided by resources to assist manufacturing.

(4) *Control* is the activity which coordinates the Transport, Transform, Verify and Store actions and the Processing, Execution and Support activities.

The dependency of material/resources (M/R) flow and related operations on the equivalent information flow emphasizes the key role of information in the integration process. Both information and material/resources enter (and leave) an activity. The M/R are transformed according to the appropriate information, and the information is itself transformed. Likewise, the modified M/R are then transported (and perhaps transformed several times), verified and stored while certain aspects of the accompanying information undergo analogous processing. The Control activity continually monitors the information and issues commands and status as appropriate.

REMARKS

This concept of a Generic Production Activity Model provides a simple, but versatile, means of representing the activities of a typical shop floor production facility. And it enables the Working Group to identify and classify standards suitable for systems integration.

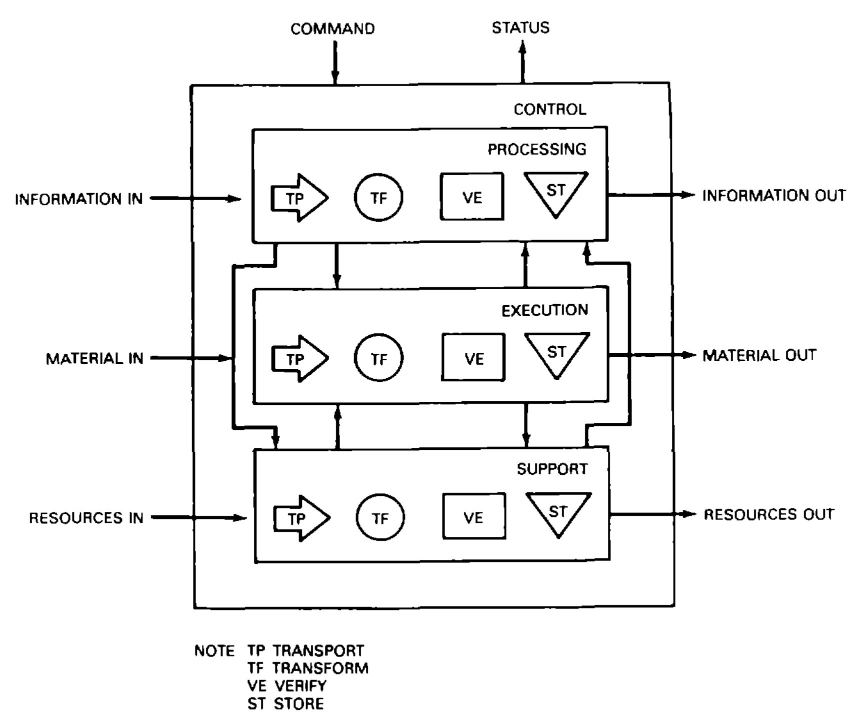


Figure AIII-1 Generic production activity model.

COMMENTS

Despite its importance as a source of information concerning needed standards, etc., the Physics View, as outlined here, is a broad generalization of the process to be addressed but appears to say nothing about the nature of the Control and Information System involved. Since this latter is our main task in developing this CIM Reference Model, the Physics View will not be used further here.

Appendix IV

Definitions of the Field of CIM Reference Models

COMPUTER INTEGRATED MANUFACTURING

Computer Integrated Manufacturing is defined in the present context as follows: Computer Integrated Manufacturing (CIM) is manufacturing supported by information and automation intended to create an overall system, (1) which is responsive to the human and economic environment interpreted on all levels and, (2) which improves the management of the industrial facility.

Computer Integrated Manufacturing (CIM) is the use of computers to streamline the flow of materials and information within a manufacturing organization. The goal of CIM is to increase productivity, product quality and manufacturing flexibility while decreasing cost and time-to-market. It's important to keep in mind that CIM itself isn't the goal, but instead a strategy to ensure the long-term survivability of the manufacturing organization.

CIM is the strategy by which manufacturers organize the various hardware and software components, such as robotics, machine vision, CAD, CAM and Manufacturing Resource Planning (MRP-II), into a unified system working toward the same goals. There is, however, no hard and fast scientific formula for CIM.

Each organization must build its own CIM system to fit its personality and organizational requirements. CIM implies more than getting the various pieces of hardware in the manufacturing process communicating with each other. Organizational and procedural flexibility is necessary in the CIM implementation process. Just as a CIM program is molded to the organization, the organization must be willing to change in order to realize the full benefit of a CIM implementation [5].

Computer Integrated Manufacturing involves the development and implementation of a computer-based information management and automation system for the enterprise which allows the establishment of a business process to:

1. Automate the information flow of the plant

2. Deploy appropriate automation and information technologies wherever they are needed in the plant

3. Make optimal use of the capabilities of plant personnel

4. Maximize information access at all levels of the system

5. Provide timely, accurate and complete information on plant operations wherever and whenever needed with the object of obtaining a competitive advantage for the company.

An effective CIM implementation will *improve* the industrial facility's systems':

1. Manageability
2. Product quality
3. Cost effectiveness
4. Accountability
5. Productivity
6. Predictability
7. Flexibility, and
8. Quality of working life of the people involved.

As a result the company is:

1. More responsive to its customers' needs and changing market conditions,
2. Able to improve product quality and lower product costs by:
    a) Improved utilization of resources,
    b) Reduced operational complexity,
    c) Improved ability to respond to disturbances,
    d) Improved predictability/consistency,
3. Able to assist plant personnel in making frequent, routine decisions,
4. Able to improve the availability of timely, accurate and complete plant information,
5. Able to provide better operational tools for improved:
    a) Monitoring,
    b) Control,
    c) Performance,
    d) Costs.

DEFINITIONS OF THE TERMS RELATED TO THE ESTABLISHED MANUFACTURING POLICY

1. The established manufacturing policy is the set of rules (i.e., previously established) for operating the example manufacturing plant to achieve the goals of management. It can be articulated and delegated in a general way (e.g., a set of algorithms rather than required human innovation, etc.). The term policy is understood to extend to individual measurements and tolerances prescribed to implement production.

2. Policy makers are *external influences* that formulate the established manufacturing policy. Because of the innovation necessary, they will be human beings for the foreseeable future.

3. Policy implementors execute the established manufacturing policy. They may be humans, computer systems or other devices depending upon the capabilities needed. Policy implementors comprise the information management and automation system configuration. Policy implementors comprise those [agents whose decisions are effectively computable].

EXPLANATORY NOTE

Because of the current inability of computer systems to innovate in the way commonly attributed to personnel, we cannot expect the planning and policy-making functions of a company to be incorporated into computer systems for the foreseeable future.

Since we are here defining an "automatable" function the above functions must be kept external to the Integrated Information Management and Automation System discussed herein. Thus although they are integral parts of the business enterprise, upper management personnel and their planning function must be considered as external influences driving the computer-based system.

On the other hand, policy implementors (including all proforma decision making) whether machines or people are considered to be integral parts of the Integrated Information Management and Automation System since their decisions can in principle be expressed in algorithmic form. Whether people or machines are used are economic and political not technological decisions.

IMPLICATION OF THE TERMS RELATED TO THE ESTABLISHED MANUFACTURING POLICY

1. The established manufacturing policy determines the system configuration. If this configuration becomes inadequate (i.e., can no longer be implemented to satisfy the existing policy) because that policy has been changed (beyond allowable limits) then a system redesign (i.e., configuration change) must occur. See Appendix AV.

2. There may be more than one functionally equivalent configuration to implement a particular established manufacturing policy.

3. The major goal of the configuration is to make the plant as controllable as possible within the established manufacturing policy.

4. Conversely, the charge to the policy makers is to define the widest implementable set of manufacturing polices for the plant, i.e., maximum flexibility.

FUNCTIONAL ENTITY

A functional entity is that cohesive collection of elements (humans, machines, computers, control devices, computer programs (any or all)) required to carry out one or more closely related tasks or transformations which comprise a recognized function of the manufacturing plant in fulfilling the established manufacturing policy of the company, e.g., production units or staff departments, etc.

A functional entity may contain other functional entities.

APPLICATION FUNCTIONAL ENTITY

An application functional entity is involved in carrying out the primary mission of the manufacturing plant in question as outlined by the established manufacturing policy of the company. It is directly concerned with the handling and control of raw materials, intermediates and products of the company. The *principles* of *autonomy* and *locality* apply to these entities

Application functional entities serve as sources and/or sinks of process operational data in the problem domain. They are made up of *manufacturing specific functional entities* and the physical means of production or *plant production media*.

FOUNDATION FUNCTIONAL ENTITY

A foundation functional entity is a cohesive collection of elements (possibly shared) that carry out a generic supporting function. It does not necessarily obey the *principles of autonomy* and *locality* in its operations. Examples of foundation functional entities are:

Communications	Man-Machine Interfaces
Control Library	Operating Systems
DataBases	Sensor Management
Graphics Packages	Statistical Quality Control Systems Hardware Etc.

CHARACTERISTICS OF FOUNDATION FUNCTIONAL ENTITIES

Foundation Functional Entities share the following characteristics:

1. Totally shared by all application functional entities or other support functions as needed.

2. Aid in the technical integration of the application functional entities.

3. Problem domain independent.

4. Not a source or sink of process operational data in the problem domain.

5. Are amenable to standardization.

APPLICATION FUNCTIONAL ENTITIES VS. FOUNDATION FUNCTIONAL ENTITIES

APPLICATION FUNCTIONAL ENTITIES

1. Derive context from the problem domain.
2. Cohesive collection of elements performing some recognizable function in the problem (mfg.) domain.
3. Include *manufacturing specific functional entities* and *plant production media.*

FOUNDATION FUNCTIONAL ENTITIES

1. Exist as common support utilities generally applicable to some or all of the application entities.
2. Aid in the technical integration of application entities.
3. Carried out by support elements (specific computers, hardware, and software elements).

MANUFACTURING SPECIFIC FUNCTIONAL ENTITIES

Manufacturing specific functional entities are commonly elements of larger applications functional entities but may be listed as separate entities in their own right. They form the parts of the application functional entities which are included in the plant's integrated information and automation system in contrast to the *plant production media* which carry out the physical production steps and material handling functions of the plant. Manufacturing specific functional entities will commonly include foundation functional entities within their make-up. Examples of manufacturing specific functional entities are:

Computer System Configurations	Product Shipping Administration
Cost Accounting	Product and Process Planning
Inventory Management	Purchasing (Raw Material and Spares)
Maintenance Planning	Quality Control
Order Entry	Resource Management Scheduling

PLANT PRODUCTION MEDIA FUNCTIONAL ENTITIES

Plant production media functional entities comprise those physical production machines, equipments and devices including material handling, which move, position, and transform raw materials into the desired products of the manufacturing enterprise.

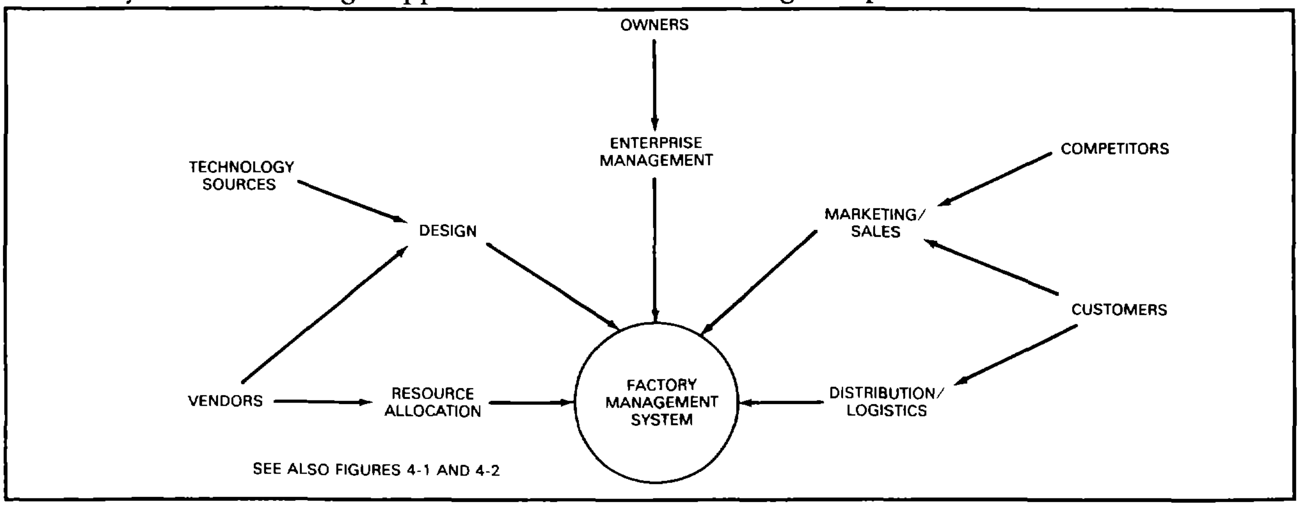


Figure AIV-1 The functional context of external influences.

EXTERNAL INFLUENCES

An external influence is a functional entity (external entity) that is separate from the production plant and does not take part in its internal ongoing operations but whose actions can have an effect upon the future operation of the plant. They may be part of the company in question or may be units of a separate company working with the functional entities of the production plant. See Figures AIV-1 to AIV-4 and Table AIV-I for examples of the various types of functional entities and their interrelationships.

TASKS

A task is a recognized action or set of actions comprising a specific part of the operations of a functional entity of the production plant in fulfilling the established manufacturing policy of the company. It is the lowest level of functional decomposition of an enterprise that corresponds to the function of a single person or machine at a point in time.

A task corresponds to an information transformation in the CIM system.

FUNCTIONAL REQUIREMENT

A functional requirement is a specification constraining the way in which a given task is to be performed, the results to be obtained (speed, accuracy, etc.) as well as the elements of the functional entities involved (initiator, source, receptor, etc.).

CRITERIA FOR CHOICE OF SYSTEM FUNCTIONAL ENTITIES

1. They should provide the most meaningful model (i.e., that lasting through subsequent model development).

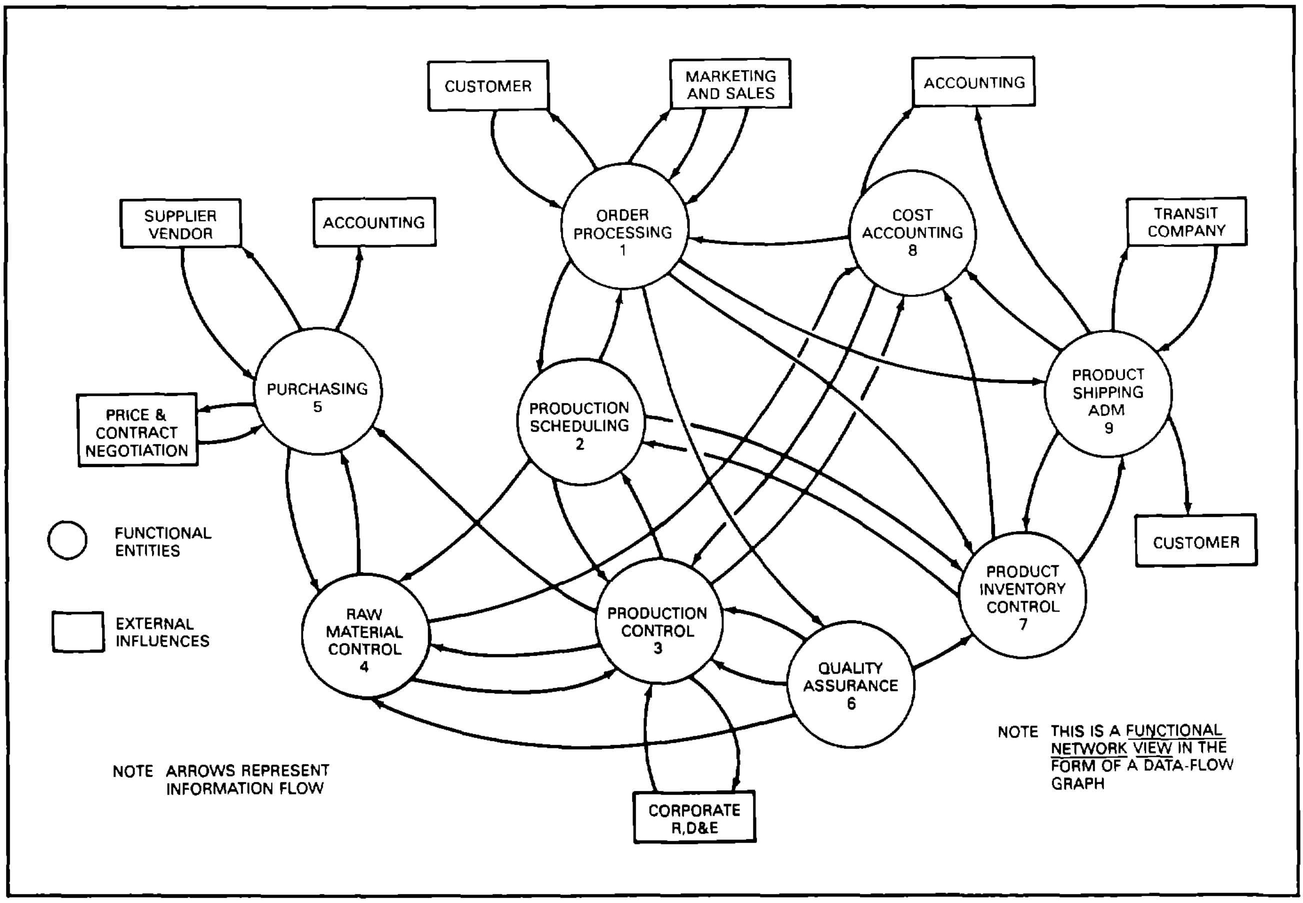


Figure AIV-2 A potential set of manufacturing specific functional entities and external influences for a manufacturing plant.

2. They should provide a distinctive logical node (e.g., an information storage and decision point).

3. All tasks within the functional entity are clearly related.

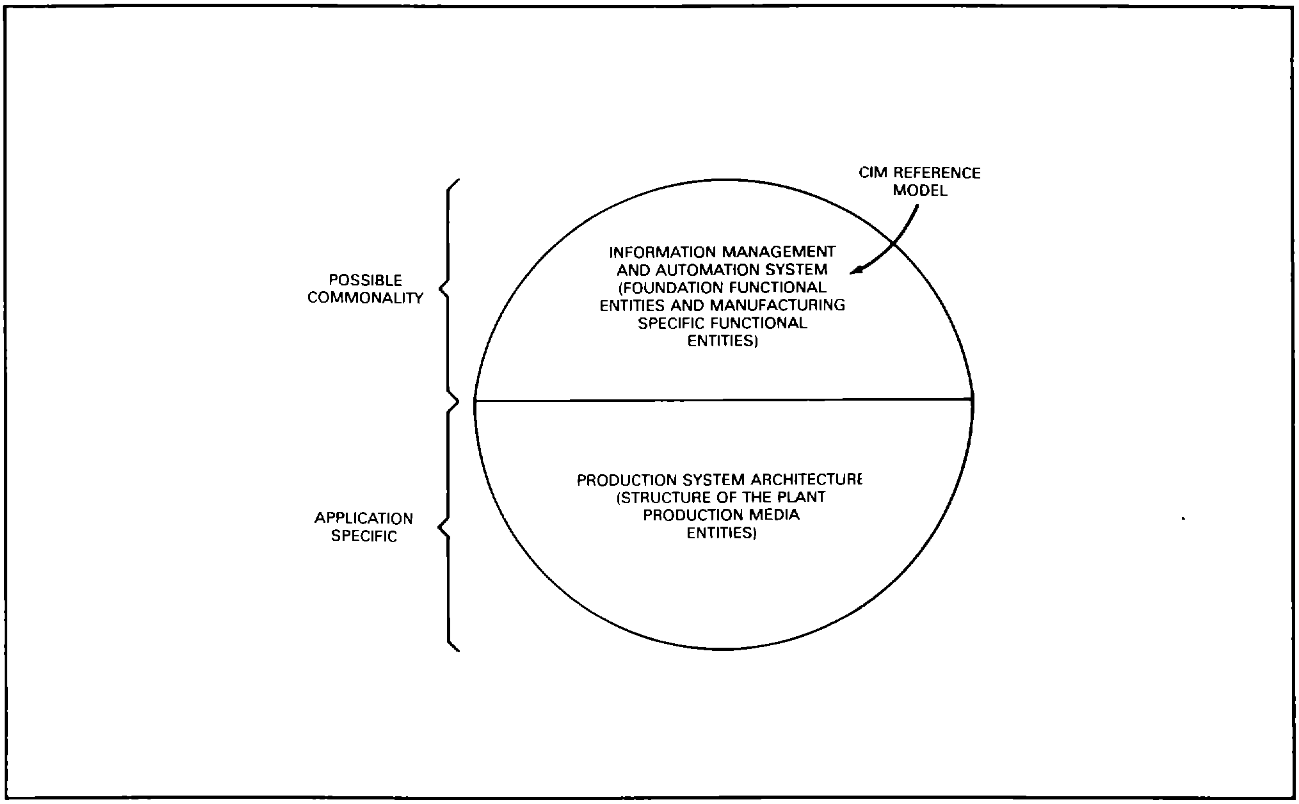


Figure AIV-3 Distinctions between those functional entities exhibiting generic application and commonality versus Plant Production Media entities which are Plant and Application specific.

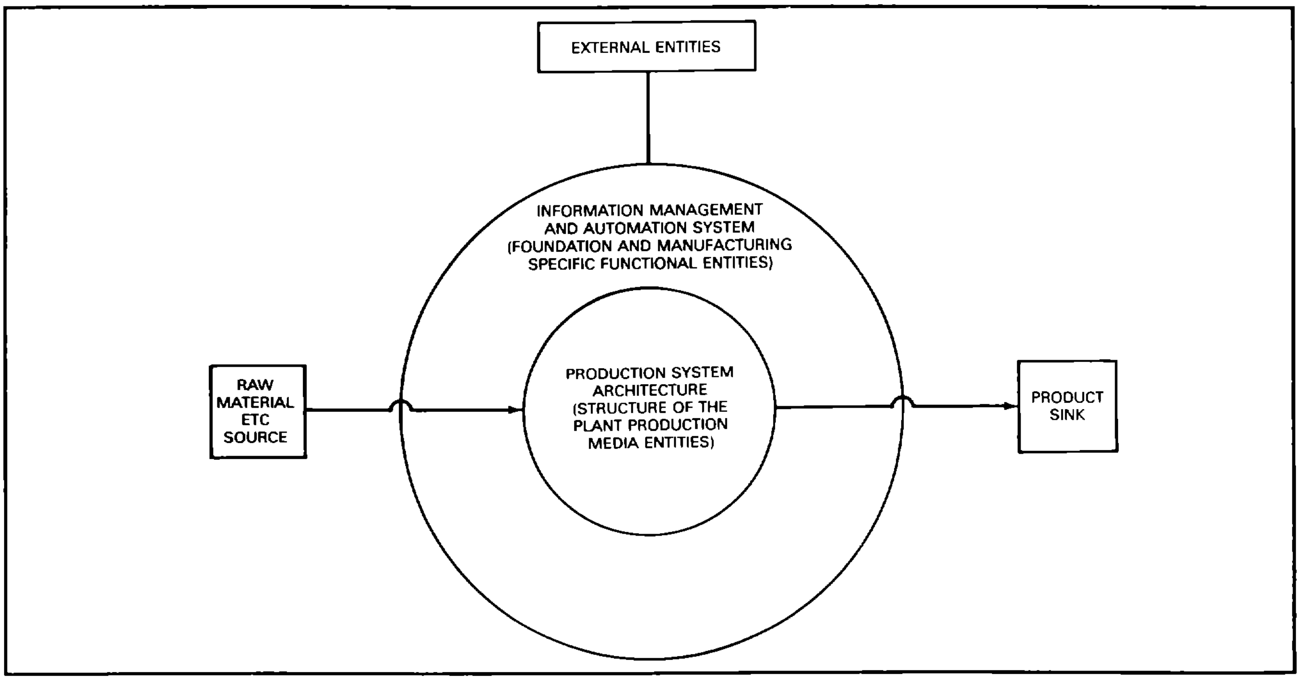


Figure AIV-4 Another diagram showing the relationship of the several classes of entities as regards the CIM Reference Model.

TABLE AIV-1

THE RELATIONSHIP OF FOUNDATION AND APPLICATION ELEMENTS AND FUNCTIONAL ENTITIES IN CARRYING OUT THE TASKS OF THE MANUFACTURING PLANT

	FOUNDATION	**APPLICATION** (MANUFACTURING SPECIFIC AND PLANT PRODUCTION MEDIA)
ELEMENTS	COMPUTERS PROGRAMS (DB) CABLE PLANT	NC PROGRAMS MACHINE TOOLS
FUNC. ENTS.	DB SYSTEM HUMAN INTERFACE SYSTEM SCHEDULER QA SYSTEM	QC SYSTEM MATERIAL TRANS
TASKS	DATABASE HUMAN INTERFACE COMMUNICATIONS SCHEDULING QA	QC

A GLOSSARY OF THE FIELD OF CIM REFERENCE MODELS*

ACSE

- Association Control Service Element. ACSE is one of the application protocols specified by MAP

Actual Cost

- An acceptable approximation of the true cost of producing a part, product, or group of parts or products, including all labor and material costs and a reasonable allocation of overhead charges.

Algorithm

- A prescribed set of well defined rules or processes for the solution of a problem in a finite number of steps, e.g , a full statement of an arithmetic procedure for evaluating sin x to a stated precision.

AMIG

- Australian MAP Interest Group (see World Federation).

ANSI

- American National Standards Institute (see Standards Organizations).

Application

- A user or machine oriented function supported by automation technology.

Application Process

- An element within a system that performs the information/data processing for a particular application.

Architectural Resources

- The integrating elements used to build a CIM system. Resources can be categorized as interfaces, protocols or handlers and management tools.

Architecture

- A set of principles, rules and standards and other supporting data, classified and presented in a form to illustrate the arrangement and connectivity of parts of a system.

ASC

- Accredited Standard Committee. A standards committee accredited to ANSI.

ASN.1

- Abstract Syntax Notation One. An ISO standard (DIS 8824 and DIS 8825) that specifies a canonical method of data encoding. This standard is an extension of CCITT standard X.409.

Automated Assembly

- Assembly by means of operations performed automatically by machines. A computer system may monitor the production and quality levels of the assembly operations.

Automation

- The implementation of processes by automatic means; the theory, art or technique of making a process more automatic; the investigation, design, development and application of methods for rendering processes automatic, self-moving or self-controlling; the conversion of a procedure, a process or equipment to automatic operation.

Backbone

- The trunk media of a multimedia LAN separated into sections by bridges, routers, or gateways.

Bandwidth

- The number of user data bytes (i.e., exclusive of communications overhead) that can be sent across the network per second.

Bar Code

- Array of rectangular marks and spaces in a predetermined pattern depicting machine performance; can be numeric, alphanumeric or combinations thereof.

Baseband

- A single channel signaling technique in which the digital signal is encoded and impressed on the physical medium.

Batch Process

- An industrial manufacturing method in which one of several units are produced at a time, in contrast to Continuous Process (q.v.).

Baud

- Unit of signalling speed. Baud is the same as bits per second *only* when every signal event represents exactly one bit.

BER

- Bit Error Rate. The ratio of bits received in error to total bits received.

Bit - 1.

An abbreviation of Binary Digit. 2. A single character is a binary number. 3. A single pulse in a group of pulses. 4. A smallest code element which may possess information in either of two states. 5. An acronym for Binary Digit; the smallest unit of information in the binary numbering system. Represented by the digits 0 and 1. 6. The smallest division of PC word.

Blending

- The process of physically mixing two or more lots of material to produce a homogeneous lot. Blends normally receive new identification and require retesting.

Bottleneck

- A facility, function, department, etc., that impedes production.

Bridge

- A network device that interconnects two local area networks that use the same LLC but may use different MACs. A bridge requires only OSI Level 1 and 2 protocols (Also see *Gateway* and *Router*).

Broadband

- A medium based on CATV technology where multiple simultaneous signals may be frequency division multiplexed.

Broadcast

- A message addressed to all stations connected to a LAN.

Bus

- A broadcast topology where all data stations are connected in parallel to the medium (see Topology).

Business Plan

- A statement of income projections, costs and profits usually accompanied by the budgets and a projected balance sheet as well as a cash flow (source and application of funds) statement. It is usually stated in terms of dollars only. The business plan and the production plan, although frequently stated in different terms, should be in agreement with each other. (*cf*, manufacturing resource planning).

Byte

- A small unit of data bits that are treated as a single unit. The number of bits in a byte is hardware specific, but is most commonly eight (see Octet).

CAM

- Computer Aided Manufacturing.

Capacity

- The highest, sustainable output rate which can be achieved with the current product specifications, product mix, worker effort, plant, and equipment.

Carrier Band

- A single channel signalling technique in which the digital signal is modulated on a carrier and transmitted (also see Baseband).

CASA/SME

- The Computer and Automated Systems Association of the Society of Manufacturing Engineers. CASA/SME is a professional engineering association dedicated to the advancement of engineering technology. CASA/SME sponsors both the MAP and TOP Users Groups.

CASE

- *C*ommon *A*pplications *S*ervice *E*lements. CASE is one of the applications protocols specified by MAP. Largely superseded by ACSE (op. cit.).

CATV

- Community Antenna Television (see Broadband).

CBEMA

- Computer and Business Equipment Manufacturers Association (see Standards Organization).

CCITT

- International Consulting Committee on Telephone and Telegraph (see Standards Organizations).

Cell Model

- A graphic representation of a human- or machine-directed function, which has elements of input, activity and output.

Centralization - 1.

The process of consolidating authority and decision making within a single office or person. 2. The act of bringing together physically or geographically operations or organizational units related by nature of function to form a central grouping.

Changeover Time

- The time required to modify or replace an existing facility of workplace, usually including both teardown time for the existing condition and setup for the new condition.

CIM

- Computer Integrated Manufacturing.

CIM Architecture

- A set of principles and rules for selecting and developing products and standards that can participate in a CIM system.

CIM System

- Refers to an implementation of the CIM architecture to integrate an enterprise.

Closed Loop System

- Refers to a feedback control system involving one or more feedback control loops, which combine functions of controlled signals and of commands, in order to keep relationships between the two stable.

CMIG

- Canadian MAP Interest Group (see World Federation).

Cohesion

- Requires that each module is designed to perform a single-well-defined function, and the function is completely contained in the module.

Communication

- The transfer of information and understanding from one point or person to another person. The basic elements in the process of communication are an information source, encoding, transmission, reception, and decoding.

Component

- An inclusive term used to identify a raw material, ingredient, part or subassembly that goes into a higher level assembly, compound or other item. May also include packaging materials for finished items.

Computer

- An electronic device which uses programmed instructions to monitor and control various types of data in order to solve mathematical problems or control industrial applications. Its instructions are executed in various sequences, as required.

Computer Graphics

- A man-oriented system which uses the capabilities of a computer to create, transform, and display pictorial and symbolic data.

Conceptual Model

- An abstract representation of an object or phenomenon that provides a common understanding.

Control

- Measurement of performance or actions and comparison with established standards in order to maintain performance and actions within permissible limits of variance from the standard. May involve taking corrective action to bring performance into line with the plan or standards.

Control Action

- Is the institution of the necessary activity to cause a process, device or system to carry out the tasks assigned to that particular process, device or system.

COS

- Corporation for Open Systems. An organization of vendors formed in 1985 to coordinate member company efforts in the selection of standards and protocols, conformance testing, and the establishment of certification.

Coupling

- Refers to the number of informational and control linkages between two modules. It is desirable to minimize these linkages and make them explicit.

Data

- A representative of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation, or processing by humans or automatic means.

Database Management

- A set of rules about file organization and processing, generally contained in complex software, which controls the definition and access of complex, interrelated files which are shared by numerous application systems.

DCS

- Distributed Control System.

Decision-Making

- The response to a need or stimulus by means of acquiring and organizing information, processing this information to yield alternative courses of action, and selecting one course of action from among the alternatives.

Delivery Schedule

- The required or agreed upon time or rate of delivery of goods or services purchased for a future period.

Direct Digital Control (DDC)

- The use of a digital computer to establish commands to the final control elements of multiple regulatory loops.

Directory Service

- The network management function that provides all addressing information required to access an application process (see PSAP Address).

DIS

- Draft International Standard. The second stage of an ISO STandard (see IS).

Distributed Computing

- Computing performed within a network of distributed computing facilities. The processors for this type of system usually function with control distributed in time and space throughout the network. Associated with the distributed process are distributed storage facilities.

DP

- Draft Proposal. The first stage of an ISO Standard (see IS).

ECSA

- Exchange Carriers Standard Association (see Standards Organizations).

EIA

- Electrical Industries Association (see Standards Organizations).

Electronic Data Processing (EDP) - 1.

Data processing largely performed by electronic devices. 2. Pertaining to data processing equipment that is predominantly electronic, such as an electronic digital computer.

EMUG

- European MAP Users Group (see World Federation).

Enterprise

- Is a set of functions that carry a product through its entire life span from concept through manufacture, distribution, sales and service.

Entity

- An active element within an OSI layer (e.g. Token Bus MAC is an entity in OSI Layer 2).

EPA

- Enhanced Performance Architecture. An extension to MAP that provides for low delay communication between nodes on a single segment (see MAP/EPA and MINI-MAP).

Feedback

- Is the determination of the degree or manner of accomplishment of the control action and the use of the information to assure that the control action is accomplished.

Feedback Control

- A type of system control obtained when a portion of the output signal is operated upon and fed back to the input in order to obtain a desired effect.

Fiber

- See Fiber Optics.

Fiber Optics

- A medium that uses light conducted through glass or plastic fibers for data transmission.

Field Bus

- A standard under development in ISA SP50 for a bus to interconnect process control sensors, actuators, and control devices.

FIPS

- Federal Information Processing Standards (see NBS).

FMS

- Flexible Manufacturing Systems.

FTAM

- *F*ile *T*ransfer *A*ccess and *M*anagement Protocol (ISO DP 8571). FTAM is one of the application protocols specified by MAP and TOP. (DP - Draft Proposal)

Function

- A group of tasks that can be classified as having a common objective within a company.

Gateway

- A network device that interconnects two networks that may have different protocols (see Bridge and Router).

Hardware

- Physical equipment, as opposed to the computer program or method of use; e.g., mechanical, magnetic, electrical or electronic devices. Contrast with software.

Hierarchy

- A data structure consisting of sets and subsets such that every subset of a set is a lower rank than the data of the set. Any structure consisting of units and subunits where the subunits are of lower rank than the units involved.

Human Factors

- The field of effort and body of knowledge devoted to the adaptation and design of equipment for efficient and advantageous use by people considering physiological, psychological and training factors.

Human Interface

- A tool able to intercept, interpret and guide the interaction of the end user with the system.

IEEE

- Institute of Electrical and Electronic Engineers (see Standards Organizations).

IEEE 802

- One of the standards committees working on LAN standards. IEEE 802 has produced standards for CSMA/CD, Token Bus, Token Ring, and Logical Link Control. Activity continues in all of the above areas and in the area of Metropolitan Area Networks. IEEE 802 is composed following WGs (working groups) and TAGs (technical assistance groups):
IEEE 802.0 - Executive Committee
IEEE 802.1 - Higher Layer Interface
IEEE 802.2 - Logical Link Control
IEEE 802.3 - CSMA/CD
IEEE 802.4 - Token Bus
IEEE 802.5 - Token Ring
IEEE 802.6 - Metropolitan Area Network
IEEE 802.7 - Broadband TAG
IEEE 802.8 - Fiber Optics TAG

IEEE P1118

- A standards committee working on the development of a "Microcontroller Serial Control Bus". This standard is to be a technology-based, not application-based and is intended to be suitable for many different application types, including (but not limited to) instrumentation, process control, and RS232-type peripherals.

Information

- The knowledge of facts, measurements and requirements necessary for accomplishing useful work.

In-Process Inventory

- Product in various stages of completion throughout the factory, including raw material that has been released for initial processing and completely processed material awaiting final inspection and acceptance as finished product or shipment to a customer.

Interface

- A shared boundary; e.g., a hardware component to link two devices, a portion of storage or registers accessed by two or more programs.

Integrated System

- A system in which separate programs perform separate functions with communication and data-passing between functional programs performing standardized I/O routines and a common database. Such systems allow flexibility in addition/revision/deletion of various processing functions without disrupting the entire system.

Inventory

- Parts and material on hand.

Inventory Management

- Management of the inventories, with the primary objectives of determining: 1. Items that should be ordered, and in what quantity. 2. The timing of order release and order due dates. 3. Changes in the quantity called for and the rescheduling of orders already planned. Its two broad areas are inventory accounting, which is the administrative aspect, and inventory planning and control, which consists of planning procedures and techniques that lead to inventory order action.

IS

- International Standard. The third (and highest) stage of an ISO Standard. Prospective ISO standards are balloted three times The first stage is as a Draft Proposal (DP). After a Draft Proposal has been in use a period of time (typically 6 months to a year) the standard, frequently with corrections and changes, is re-balloted as Draft International Standard. After the Draft International Standard (DIS) has been in use for a period of time (typically 1 to 2 years) it is re-balloted as an International Standard (IS).

ISA

- Instrument Society of America (see Standards Organizations).

ISA SP50

- A standards committee working on a standard of a communications bus for interconnecting control device to sensors and actuators (Field Bus).

ISA SP72

- A standards committee working on a standards for use in process control. These standards include PROWAY, Process Control Architecture, and Process Messaging.

ISO

- International Standards Organization (see Standards Organizations).

ISDN

- *I*ntegrated *S*ystems *D*igital *N*etwork. ISDN is a suite of protocols being defined by CCITT to provide voice and data services over wide area networks (WANs).

ITI

- *I*ndustrial *T*echnology *I*nstitute. A nonprofit organization founded by the University of Michigan and sponsored by the State of Michigan dedicated to computer integrated manufacturing. ITI offers MAP conformance testing and certification.

JMUG

- Japanese MAP Users Group (see World Federation).

LAN

- Local Area Network. Local area networks are a communications mechanism by which computers and peripherals in a limited geographical area can be connected. They provide a physical channel of moderate to high data rate (1-20 Mbit) which has a consistently low error rate (typically 10^{-9}).

Layer

- A subdivision of the OSI architecture (See OSI Reference Model).

Line Driver

- A circuit specifically designed to transmit digital information over long lines, that is extended distances.

LLC

- *L*ogical *L*ink *C*ontrol. The upper sublayer of the data link layer (Layer 2) used by all types of IEEE 802 LANs. LLC provides a common set of services and interfaces to higher layer protocols. Three types of services are specified:
Type 1: Connectionless. A set of services that permit peer entities to transmit data to each other without the establishment of connections. Type 1 service is used by both MAP and TOP.
Type 2: Connection oriented. A set of services that permit peer entities to establish, use, and terminate connections with each other in order to transmit data.
Type 3: Acknowledged connectionless. A set of services that permit a peer entity to send messages requiring immediate response to another peer entity. This class of services can also be used for polled (master-slave) operation.

LSAP

- Link Service Access Point (see SAP).

MAC

- Media Access Control. The lower sublayer of the Data Link Layer (Layer 2) unique to each type of IEEE 802 Local Area Networks. MAC provides mechanism by which users access (share) the network. The MACs defined by IEEE 802 are IEEE 802.3 CSMA/CD, IEEE 802.4 Token Bus, IEEE 802.5 Token Ring, and IEEE 802.6 Metropolitan Area Network (still under study).

Maintenance

- Any activity intended to eliminate faults or to keep hardware or programs in satisfactory working condition, including tests, measurements, replacements, adjustments and repairs.

Management

- 1. The process of utilizing material and human resources to accomplish designated objectives. It involves the activities of planning, organizing, directing, coordinating and controlling. 2. That group of people who perform the functions described above.

Manufacturing Planning

- The function of setting the limits or levels of manufacturing operations in the future, consideration being given to sales forecasts and the requirements and availability of personnel, machines, materials and finances. The manufacturing plan is usually in fairly broad terms and does not specify in detail each of the individual products to be made but usually specifies the amount of capacity that will be required.

Manufacturing Resource Planning

- A method for the effective planning of all the resources of a manufacturing company. Ideally it addresses operational planning in units, financial planning in dollars, and has a simulation capability to answer "what if" questions. It is made up of a variety of functions, each linked together: Business Planning, Production Planning, Master Production Scheduling, Material Requirements Planning, Capacity Requirements Planning and the execution systems for capacity and priority. Outputs from these systems would be integrated with financial reports such as the business plan, purchase commitment report, shipping budget, inventory projections in dollars, etc. Manufacturing resource planning is a direct outgrowth and extension of MRP. Often referred to as MRP II. (*cf*, closed-loop MRP).

MAP

- *M*anufacturing *A*utomation *P*rotocol. A specification for a suite of communications standards for use in manufacturing automation developed under the auspices of the General Motors Corporation. The development of this specification is being taken over by the *MAP/TOP* Users Group under the auspices of *CASA/SME* (The Computer and Automated Systems Association of the Society of Manufacturing Engineers).

MAP/EPA

- Part of the EPA architecture, a MAP/EPA node contains both the MAP protocols and the protocols required for communication to Mini-MAP. It can communicate with both Mini-MAP nodes on the same segment and full MAP nodes anywhere in the network.

MAP/TOP Users Group

- The United States and Canada's MAP/TOP Users Group (see CASA/SME and World Federation).

Market Demand

- The total need for a product or line of product.

Master-Slave

- A mode of operation where one data station (the master) control the network access of one or more data stations (the slaves).

Material

- Any commodity used directly or indirectly in producing a product, e.g., raw materials, component parts, subassemblies, and supplies.

Material Control

- The function of maintaining a constantly available supply of raw materials, purchased parts and supplies that are required for the production of products.

Material Flow

- The progressive movement of material, parts or products toward the completion of a production process between work stations, storage areas, machines, departments and the like.

Materials Planning

- The planning of requirements for components based upon requirements for higher level assemblies. The production schedule is exploded or extended through the use of the bills of materials and the results are netted against inventory.

Mathematical Model

- A mathematical representation of a process, device, or concept.

Mbit

- Million Bits Per Second.

Media

- The physical interconnection between devices attached to the LAN. Typical LAN media are Twisted Pair, Baseband Coax, Broadband Coax, and Fiber Optics.

Message

- A collection of one or more sentences and/or command statements to be used as an information exchange between applications or users.

MINI-MAP

- A subset of MAP protocols extended to provide higher performance for applications whose communications are limited to a single LAN. A Mini-MAP node contains only the lower two layers Pphysical and Link) of the MAP protocols. It can only communicate directly with MAP/EPA or MINI-MAP nodes on the same segment.

MMFS

- Manufacturing Messaging Format Standard. The application protocol specified by older versions of MAP to do manufacturing messaging. This protocol has been replaced by MMS.

MMS

- Manufacturing Messaging Specification. MMS is one of the application protocols specified by MAP.

Model

- A synthetic abstraction of reality.

Modem

- Modulator -Demodulator. A device that provides both combining (modulation) and separation (demodulation) of data and carrier, and a physical medium interface. Typically used to connect a node to a broadband network (see Transceiver).

Multiplexing

- The time-shared scanning of a number of data lines into a single channel. Only one data line is enabled at any instant.

NBS

- National Bureau of Standards (see Standards Organizations).

Network Management

- The facility by which network communication and devices are monitored and controlled.

Objective

- A desired end result, condition or goal which forms a basis for managerial decision-making.

Octet

- A group of eight bits treated as a unit (see Byte).

Open Loop System

- A control system which has no means of comparing the output with the input; i e., there is no feedback.

Open System

- A system that obeys public standards in its communication with other systems and/or between layers.

Operating System - 1.

Software which controls the execution of computer programs and which may provide scheduling, debugging, input/output control, accounting compilation, storage assignment, data management and related services. 2. The master control program of a computer which controls all hardware activity.

Operator - 1.

In the description of a process, that which indicates the action to be performed on operands. 2. A person who operates a machine.

Opportunity Cost

- The return on capital that could have resulted had the capital been used for some purpose other than its present use. Sometimes refers to the best alternative use of the capital; at other times to the average return from feasible alternative.

Optimization

- A method by which a process is continually adjusted to the best obtainable set of operating conditions.

Organization

- 1. The classification or groupings of the activities of an enterprise for the purpose of administrating them. Division of work to be done into defined tasks along with the assignment of these tasks to individuals or groups of individuals qualified for their efficient accomplishment. 2. Determining the necessary activities and positions within an enterprise, department or group, arranging them into the best functional relationships, clearly defining the authority, responsibilities and duties of each and assigning them to individuals so that the available effort can be effectively and systematically applied and coordinated.

OSI

- Open System Interconnect.

OSI Reference Model

- A seven layered model of communications networks defined by ISO. The seven layers are:
Layer 7 - Application: provides the interface for the application to access the OSI environment.
Layer 6 - Presentation: provides for data conversion to preserve the meaning of the data.
Layer 5 - Session: provides user-to-user connections.
Layer 4 - Transport: provides end-to-end reliability.
Layer 3 - Network: provides routing of data through the network.
Layer 2 - Data Link: provides link access control and reliability.
Layer 1 - Physical: provides an interface to the physical medium.

Parameter - 1.

A variable that is given a constant value for a specified application. 2. A variable that controls the effect and usage of a command. 3. Alterable values that control the effect and usage of a graphics command. 4. A constant whose values determine the operation or characteristics of a system. In $y = ax^2 - bx + c$; a, b, and c are the parameters of a family of parabolas. 5. A variable, t, such that each variable of a related system of variables may be expressed as a function of t.

PCA

- Process Communications Architecture. An architecture for a three layer (Physical, Data Link, and Application) open communications system being developed by ISA SP72. It can provide communications functions that are needed in control and automations applications. PCA uses OSI protocols and provides a transparent application interface to 7-layer MAP networks.

PDU

- Protocol Data Unit. Each of the seven OSI layers accepts data SDUs (SubData Unit) from the layer above, adds its own header PCI (Protocol Control Information) and passes the data to the layer below as a PDU. Conversely, each of the layers also accepts data from the layer below, strips off its header, and passes it up to the layer above.

Planning

- The procedure for determining a course of action intended to accomplish a desired result.

PMS

- Process Messaging Service (see ISA SP72).

Preventive Maintenance

- Maintenance specifically intended to prevent faults from occurring during subsequent operation.

Process Control

- Pertaining to systems whose purpose is to provide automation of continuous operations. This is contrasted with numerical control, which provides automation of discrete operations.

Production - 1.

The manufacturing of goods. 2. The act of changing the shape, composition, or combination of materials, parts, or subassemblies to increase their value. 3. The quantity of goods produced.

Production Capacity

- The highest, sustainable output rate which can be achieved with the current product specifications, product mix, worker effort, plant, and equipment.

Production Planning - 1.

The systematic scheduling of men, materials, and machines by using lead times, time standards, delivery dates, work loads, and similar data for the purpose of producing products efficiently and economically and meeting desired deliver dates. 2. Routing and scheduling.

Production Schedule

- A plan which authorizes the factory to manufacture a certain quantity of a specific item. Usually initiated by the production planning department. (*cf*, shop order, work order, manufacturing order, job order).

Protocol

- A formal definition that describes how data is to be formatted for communication between a data source and a data sink.

PROWAY

- A standard for a process control highway based on *IEEE 802.4* token bus immediate acknowledged MAC (Media Access Control), a physical layer utilizing a phase-contiguous signaling technique. Developed by ISA SP72.

Quality Control

- The procedure of establishing acceptable limits of variation in size, weight, finish, and so forth for products or services and of maintaining the resulting goods or services within these limits.

Real Time

- 1. Pertaining to the actual time during which a physical process transpires. 2. Pertaining to computation performed while the related physical process is taking place so that results of the computation can be used in guiding the physical process.

Repeater

- A device that amplifies or regenerates data signals in order to extend the distance between data stations.

Response Time

- The total time necessary to send a message and receive a response back at the sender exclusive of application processing time.

Rework - 1.

The process of correcting a defect or deficiency in a product or part. 2. Units of product requiring correction.

Router

- A network device that interconnects two computer networks that have the same network architecture. A router requires OSI Level 1, 2 and 3 protocols (see Bridge and Gateway).

RS511

- A messaging standard, also known as MMS, under development in EIA for communication between factory floor devices. It uses ASN.1 for data encoding (see ASN.1 and MMS).

SAP

- Service Access Point. The connection point between a protocol in one OSI layer and a protocol in the layer above. SAPs provide a mechanism by which a message can be routed through the appropriate protocol as it is passed up through the OSI layers.

SC

- Standing Committee.

Scheduling

- The process of setting operation start dates for jobs to allow them to be completed by their due date.

Simulation

- The representation of certain features of the behavior of a physical or abstract system by the behavior of another system.

SME

- Society of Manufacturing Engineers (see CASA/SME).

SNAP

- Sub-Network Access Protocol. SNAP provides a mechanism to uniquely identify private protocols above LLC.

Source Address

- The physical (hardware) address of the node that transmitted the frame (see Frame).

Standards Organizations

- Many different national and international organizations are involved in the task of MAP, TOP and LAN standards. Some of the key organizations are:

ANSI - American National Standards Institute. ANSI X3T9.5 is working on high speed (50 to 100 Mbit/second) LAN standards.

CBEMA - Computer and Business Equipment Manufacturers Association. CBEMA committee X3T9.5 is working on high speed (50-100 Mbit) LAN standards.

CCITT - International Consulting Committee on Telephone and Telegraph. CCITT standards important to MAP and TOP are the X.25 family of standards that are used to gateway MAP or TOP to wide area networks (WANs) and X.409 which provided the basis of ASN.1.

ECMA - European Computer Manufacturers Association. ECMA is also working on LAN standards in cooperation with IEEE 802.

ESCA - Exchange Carriers Standard Association.

EIA - Electrical Industries Association. Work is currently in progress in EIA on RS511, a messaging standard for use between factory floor applications.

IEC - International Electrical Technical Commission. An IEC standards committee (IEC TC97/WG6) has defined a LAN for use in process control environments (PROWAY) in cooperation with IEEE 802.4 and is working on a Field Bus standard. Also known as EIC.

IEEE - Institute of Electrical and Electronic Engineers. An IEEE standards committee (IEEE 802) is chartered to work on LAN standards for data rates of to 10 Mbit/second and had produced the standard for CSMA/CD (IEEE 802.3) used by TOP and the standard for Token Bus (IEEE 802.4) used by MAP. These standards have also been approved by ISO (DIS 8802/3 and DIS 8802/4).

ISA - Instrument Society of America. The ISA is responsible for the PROWAY standard in the United States. ISA SP50 is working on a field bus standard. ISA is the American cognizant organization for EIC-developed standards.

ISO - International Organization for Standardization. ISO takes standards submitted by its member national standards bodies, ballots the standards internationally, and approves international standards. The major ISO standards used by MAP are ISO FTAM (DP 8571), ISO Session (IS 8327), ISO Transport (IS 8073) and ISO Internet (DIS 8473).

NBS - National Bureau of Standards. An organization of the United States government that is responsible for the standards used by other government agencies (e.g., FIPS, Federal Information Processing Standards). NBS also provides compliance testing services, and hosts standard development workshops.

SME - Society of Manufacturing Engineers (see CASA/SME).

Station Management

- The portion of Network Management that applies to the lowest two OSI layers.

Statistical Quality Control

- A means of controlling the quality of a product or process by the application of the laws of probability and statistical techniques to the observed characteristics of such product or process.

Sublayer

- A subdivision of an OSI layer (e.g., the IEEE 802 Standard divides the link layer into the LLC and MAC sublayers)

Subsystem

- A collection of logically connected functions that implement a particular function in the system.

System

- An organized collection of personnel, machines, and methods required to accomplish a set of specific functions.

System Development

- A formal, phased approach to producing a significant new system or major changes to an existing system. It stresses teamwork among users and technical personnel, a series of major milestones, and through documentation to assure compliance with performance and schedule goals.

System Engineering

- The process of selecting and integrating functionally distinct devices, mechanism, and subsystems necessary for optimum performance of the operation.

System Requirements Definition Phase

- The portion of system development whose purpose is to investigate a company, or part of a company, in sufficient depth to develop a firm business proposition involving a changed method of operation. It results in a statement of the functional requirements of new systems.

TAGS

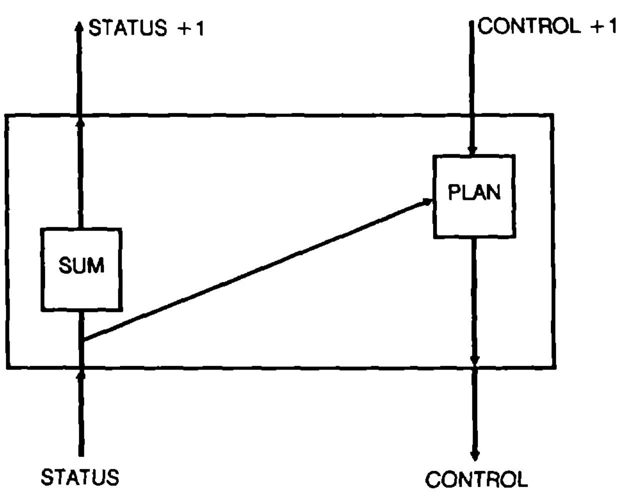
- Technical Assistance Groups. (See IEEE 802).

TC

- Technical Committee.

Time-Phased Decomposition

- Involves reducing the complexity of a system by decomposing the solution into a number of hierarchically arranged modules. Each level of the hierarchy represents:
A. A shift in the time domain (lower-level layers are closer to real-time).
B. A corresponding narrowing of the "scope-of-control" in lower levels.
C. Each level provides planning (control) input to lower layers and accepts process status from lower layers. For Example:



Token Bus

- An access procedure where the right to transmit is passed from device to device via a logical ring on a physical bus.

TOP

- Technical and Office Protocol. A development of the CSMA/CD (Carrier Sense Multiple Access with Collision Detection) protocol (also IEEE 802.3) under the auspices of Boeing Computer Services for office and laboratory automation use. This has been combined with MAP and further development will be under the auspices of the MAP/TOP Users Group.

TTP

- Telephone Twisted Pair. A network medium that uses existing telephone wiring. Standards work is in process on a TTP standard for IEEE 802.3 STANDLAN and IEEE 802.5 token ring.

WG

- Working Group.

Wiring Closet

- The room or location where the telecommunication wiring for a building, or section of building, comes together to be interconnected.

Workstation

- The assigned location where a worker performs his job. A man-machine interface system for carrying out computer related functions.

World Federation

- The joining together of the three international regions related to MAP and its promotion and standardization: (1) The Americas (Canadian MAP interest group and U.S. MAP/TOP Users Group) and Western Pacific (Australian MAP Interest Group), (2) Asia (Japan MAP users Group), and (3) Europe (European MAP Users Groups).

*Please also see Table 4-II for definitions of the terms used in Chapter 4 of this work.

Appendix V

A Proposed Model of the Enterprise

A JAPANESE REFERENCE MODEL INCLUDING THE EXTERNAL INFLUENCES

The following material is an adaptation of a recent Japanese Industrial automation System Model (dated June 11, 1987, Anonymous) [20] used here to further define what is included and what is excluded from the present CIM Reference Model as described in this text.

Item A, Corporate Management and Staff Functions; Item B, Marketing and Sales; and Item C, Research, Development and Engineering of Table AIV-I all satisfy the definitions of External Influences as given above. Item D, Production management, Operations, Quality Assurance, Logistics and Cost Management Functions, are all items included in the Manufacturing Facility's task list (Tables 3-VI - 3-X, pp 31-34). Thus the present tables become another way to express the material of the later list.

Table AIV-II presents the source and sink locations and the function names of the tasks represented by a data-flow diagram whose communications links are described by the lines so enumerated. Note that these communication links connect the External Influences (Table AV-I, Items A, B, and C) with each other and with the factory itself (Item D of Table AV-I). This resulting data-flow diagram is thus much different from that described in Chapter 4. Figure AV-3 converts Table AV-II into a data-flow graph to show the interconnections involved.

Note that this model can only be descriptive and not mathematical because of the inclusions of the innovative functions. (See also Chapter 10 to see the description of the innovative function in the personnel staffing of a plant). The reader should further note that it has not been possible for the Committee to completely coordinate the descriptions and titles in the Japanese model with those of Chapters 3, 4, and 5 of the CIM Reference Model described in this text.

TABLE AV-I

TASKS OF THE SEVERAL ORGANIZATIONAL ENTITIES IN THE JAPANESE INDUSTRIAL AUTOMATION SYSTEM DESCRIPTIVE MODEL

A. Corporate Management and Staff (an external influence)

0 CORPORATE GOVERNANCE & MANAGEMENT

0.1 DIRECTION
0.2 STRATEGIC PLANNING
- 0.2.1 BUSINESS AREA STRATEGIC PLANNING
- 0.2.2 MANUFACTURING STRATEGIC PLANNING

0.3 FEASIBILITY STUDIES
- 0.3.1 JUSTIFICATION OF CAPITAL INVESTMENT (FINANCIAL)
- 0.3.2 R & D MANAGEMENT
- 0.3.3 COST-BENEFIT ANALYSES (COST-EFFECTIVENESS ANALYSES)

0.4 RISK MANAGEMENT

1 CORPORATE STAFF FUNCTIONS

1.1 PURCHASING (PROCUREMENT CONTRACTS)
1.2 PERSONNEL (HUMAN RESOURCE MANAGEMENT)
1.3 TRANSPORTATION SERVICES (SHIPPING CONTRACTS)
1.4 ACCOUNTING

B. Marketing and Sales (an external influence)

2 MARKETING AND SALES

2.1 MARKET RESEARCH
2.2 ADVERTISING
2.3 SALES FORECASTS
2.4 MASTER SALES SCHEDULE
2.5 PRICING
2.6 SALES
2.7 WARRANTY SERVICE
2.8 PRODUCT LIABILITY

C. Research, Development and Engineering (an external influence)

3 R & D

3.0 R & D PLANNING
3.1 BASIC RESEARCH
3.2 APPLIED RESEARCH
3 3 PRODUCT DEVELOPMENT
- 3 3.1 PRODUCT DEVELOPMENT
- 3.3.2 DESIGN
- 3.3.3 TRIAL PRODUCTION
- 3.3.4 EXPERIMENT

3.4 MANUFACTURING DEVELOPMENT

4 PRODUCT DESIGN AND ENGINEERING

4.1 DEFINE PRODUCT SPECIFICATIONS
4.2 PRELIMINARY DESIGN & TESTING
4.3 DETAILED DESIGNS
4.4 DESIGN ANALYSES, TEST, EVALUATION
4.5 REVISE DESIGNS
4.6 RELEASE DESIGNS FOR PRODUCTION PLANNING

5 PREPRODUCTION PLANNING & ENGINEERING

5.1 PROJECT MANAGEMENT
- 5.1.1 NEEDED TIME (FOR PRODUCTION)
  - 5.1.1.1 STANDARD NEEDED TIME
  - 5.1.1.2 NEEDED TIME IN EMERGENCY CASE
- 5.1.2 CRITICAL PATH
- 5.1.3 DEVELOP SCHEDULE CONTROL METHODS
- 5.1.4 DEVELOP COST CONTROL METHODS (IN EXECUTION)

continued

Table V-1 continued

5.1.5 SET TARGET COSTS

5.2 ANALYSIS

5.2.1 PRODUCTIVITY

5.2.2 CAPACITY

5.2.3 MAKE/BUY

5.2.4 COST

5.2.5 PROCESS

5.2.5.1 CONTROL OF CAPACITY AVAILABLE

5.2.5.2 TOLERANCE CHARTING

5.3 PROCESS PLANNING

5.3.1 PROCESS SELECTION

5.3.2 DEVELOP PROCESS ROUTING

5.3.3 PROCESS PARAMETERS

5.3.4 SELECT MACHINE TOOLS

5.3.5 PURCHASE MACHINE TOOLS

5.4 TOOLING

5.4.1 TOOLING REQMTS

5.4.2 TOOLING DESIGN

5.5 LABOR STANDARDS

5.6 PLANT ENGINEERING

5.6.1 PLANT LAYOUT

5.6.2 PLANT REARRANGEMENT AND CONSTRUCTION

5.6.3 INSTALLATION

5.7 BILL OF MATERIALS

5.8 QUALITY ASSURANCE PLANNING OF PRODUCTION

5.8.1 VENDOR QUALIFICATION

5.8.2 RAW MTL. SPEC.

5.8.3 IN-PROCESS Q/C PLAN

5.8.3.1 WIP GAGING/TESTING

5.8.3.2 WIP AUDIT

5.8.4 PRODUCT AUDIT PROCEDURES

6 SOFTWARE DEVELOPMENT FOR PRODUCTION

6.1 CAM (NC PROGRAMMING)

6.1.1 SCULPTURED SURFACES PROGRAMMING

6.1.2 LATHE PROGRAMMING

6.1.3 TWO DIMENSIONAL PROGRAMMING

6.1.4 PROGRAMMING FOR MACHINE CONTROLS (INCLUDE ROBOTS)

6.1.5 PROGRAM MAINTENANCE

6.2 CAT (PROGRAMMING FOR TEST & INSPECTION)

6.2.1 PROGRAMMING FOR INSPECTION CONTROLLER

6.2.2 CALCULATION OF RESULTS AND FEEDBACK

6.3 PROCESS CONTROL PROGRAMMING

6.3.1 PROGRAMMING FOR MATERIAL HANDLING (ROBOTS, AGV, WAREHOUSE)

6.3.2 PROCESS CONTROL SIMULATION

6.3.3 OFF-LINE PROGRAMMING (FOR SUCH AS CHIP MANAGEMENT AND COMMUNICATION MANAGEMENT)

7 INFORMATION SYSTEM AND MANAGEMENT

7.1 SYSTEM SOFTWARE

7.2 DATABASE MANAGEMENT SYSTEM (DBMS)

7.3 LAN (LOCAL AREA NETWORK)

7.4 WAN (WIDE AREA NETWORK)

7.5 SYSTEM AUDIT

D. Production Management, Operations, Quality Assurance, and Support, Logistics, and Cost Management (part of the Purdue CIM Reference Model)

8 PRODUCTION MANAGEMENT

8.1 MASTER PRODUCTION SCHEDULE

8.2 PRODUCTION & INVENTORY CONTROL

8.3 PROGRAM STORAGE & DISTRIBUTION

8.4 PRODUCTION MONITORING

8.5 MAINTENANCE

continued

Table V-1 continued

8.5.1 SCHEDULED MAINTENANCE

8.5.2 CORRECTIVE MAINTENANCE

8.5.3 SPARES SUPPLY

8.6 QUALITY CONTROL

8.7 COST CONTROL

9 PERFORM PRODUCTION OPERATIONS

9.1 MATERIAL (RAW & WORK IN PROCESS) STORES

9 2 TRANSPORT MATERIAL

9.3 TRANSFORMATION

9.4 INCOMING INSPECTION

9.5 VENDOR PERFORMANCE

9.6 IN PROCESS GAGING/TESTING

9.7 IN PROCESS AUDIT

9.8 PRODUCT AUDIT

10 PRODUCTION SUPPORT

10.1 PROCUREMENT

10.2 GENERAL STORES

10.3 TOOL CONTROL

10.4 MAINTENANCE

10.4.1 SCHEDULE MAINTENANCE

10.4.2 CORRECTIVE MAINTENANCE

10.5 PLANT SECURITY

10.5.1 FIRE & WATCH

10.6 ENERGY MANAGEMENT

10.7 TIME & ATTENDANCE

10.8 ENVIRONMENT CONTROL

10.9 HEALTH & SAFETY

10.10 WASTE MATERIAL TREATMENT

11 LOGISTICS

11.1 RECEIVING

11.2 WAREHOUSING AND SHIPPING

12 COST MANAGEMENT

12.1 PROFITABILITY ANALYSES

12.2 MANAGEMENT TO TARGET COSTS

12.3 COST ESTIMATING

12.4 SYSTEM PERFORMANCE TRACKING

TABLE AV-II

INTERCONNECTIONS IN THE INDUSTRIAL AUTOMATION SYSTEM (IAS)

Part A: Information Flow Included in the Data Flow Diagram - Figure 2-3

FROM	TO	TYPE OF DATA	Information Content of Data
0.2.1	2.X	SD	MARKETING POLICY
0.3	2.1	S	PROJECT PLANNING
0.3.3	12.X	S	COST BENEFITS ANALYSIS
0.3.2	3.X	S	R & D POLICY
2.1	0.X	SD	MARKETING POLICY
2.6	11.2	S	DELIVERY ORDER
2.6	8.2	S	CUSTOMER ORDERS
2.4	8.1	S	MASTER SALES SCHEDULE
2.1	4.X	S	MARKET RESEARCH (NEEDS)
2.3	5.1	S	SALES PROJECTIONS
2.7	4.2	S	QUALITY REQUIREMENTS
2.8	5.8	SD	QA PLANNING
3.X	4.X	S	NEW TECHNOLOGY
4.4	2.5	SD	EST. PRODUCT COST
4.6	2.2	SD	PRODUCT DESCRIPTION
4.6	5.X	SD	PRODUCT DESCRIPTION
4.6	11.X	SD	PRODUCT DESCRIPTION
4.6	7.2	SD	PRODUCT DESCRIPTION
4.6	6.X	SD	PRODUCT DESCRIPTION
4.6	5.3	SD	PRODUCT DESCRIPTION
4.6	12.3	SD	PRODUCT DESCRIPTION
4.6	9.4	SD	PRODUCT DESCRIPTIONA
5.1	11.2	S	PRODUCTS DELIVERY
5.7	11.1	S	PROCUREMENT DEMAND
5.2.4	2.6	SD	EST. PRODUCT COST
5.7	8.2	SD	BILL OF MATERIALS
5.7	8.1	SD	BILL OF MATERIALS
5.7	8.5	SD	BILL OF MATERIALS
5.3	8.2	SD	DETAILED PROCESS PLAN
5.3	8.4	SD	DETAILED PROCESS PLAN
5.3	6.3	SD	PROCESS PLANNING
5.4	6.X	S	TOOLING

continued

Table V-2 continued

FROM	TO	TYPE OF DATA	Information Content of Data
5.2.2	6.X	S	DETAIL ROUTING
5.8	6.2	SD	QA PLANNING
5.1.4	12.X	S	COST CONTROL
5.2.1	4.3	S	PRODUCIBILITY REQUIREMENTS
5.2.4	4.4	S	PRODUCTION COST
5.X	7.6	S	SYSTEM AUDIT
6.1	8.3	S	NC MACHINE PROGRAM
6.2	8.3	S	TEST & INSPECTION PROGRAM
6.3	8.3	S	PROCESS CONT. PROGRAM
6.X	8.3	SD	M/C CONTROL DATA
6.1	9.4	S	NC INSPECTION PROGRAM
7.2	5.X	S	DATABASE MANAGEMENT
8.2	10.1	S	PURCHASING ORDER
8.5	10.4	S	MAINTENANCE REQUESTS
8.2	9.3	S	WORK ORDERS
8.2	9.2	S	MOVE ORDERS
8.3	9.3	SD	M/C CONTROL DATA
8.1	5.2	SD	CAPACITY CONSTRAINTS
8.6	5.8	S	QUALITY PERFORMANCE
8.1.4	2.4	SD	CAPACITY CONSTRAINTS
8.2	2.6	S	DELIVERY DATES
9.3	10.3	S	TOOLING REQUISITIONS
9.3	10.2	S	STORES REQUISITIONS
9.X	8.X	S	STATUS
12.2	4.4	S	COST REQUIREMENTS

In the context above the symbols S and SD have the following meanings:

S Data used locally by only one activity, module or function.

SD Data used by two or more activities, modules or functions.

Part B: Some Important Data Flows Not Included in Figure 2-3

FROM	TO	TYPE OF DATA	Information Content of Data
5.8	8.6	S	QUALITY CONTROL STANDARDS
7.X	9.X	S	INFORMATION SYSTEM OPERATIONAL CAPABILITIES
8.7	12.4	S	COST DATA
8.5	10.4	S	MAINTENANCE REQUIREMENTS
9.1	8.2	SD	INVENTORY STATUS
9.2	8.3	SD	MATERIAL MOVEMENT DATA
9.3	8.3	SD	PRODUCTION DATA
9.4	8.6	S	QUALITY CONTROL DATA - RAW MATERIALS
9.6	8.6	SD	QUALITY CONTROL DATA - IN PROCESS
9.7	8.6	SD	QUALITY CONTROL DATA - IN PROCESS
9.8	8.6	SD	QUALITY CONTROL DATA - PRODUCTS
10.2	8.2	SD	INVENTORY STATUS
10.4	8.5	S	MAINTENANCE RESULTS
10.1	8.2	S	CONFIRMATION OF PROCUREMENT
12.3	8.7	S	PRODUCTION COST GOALS

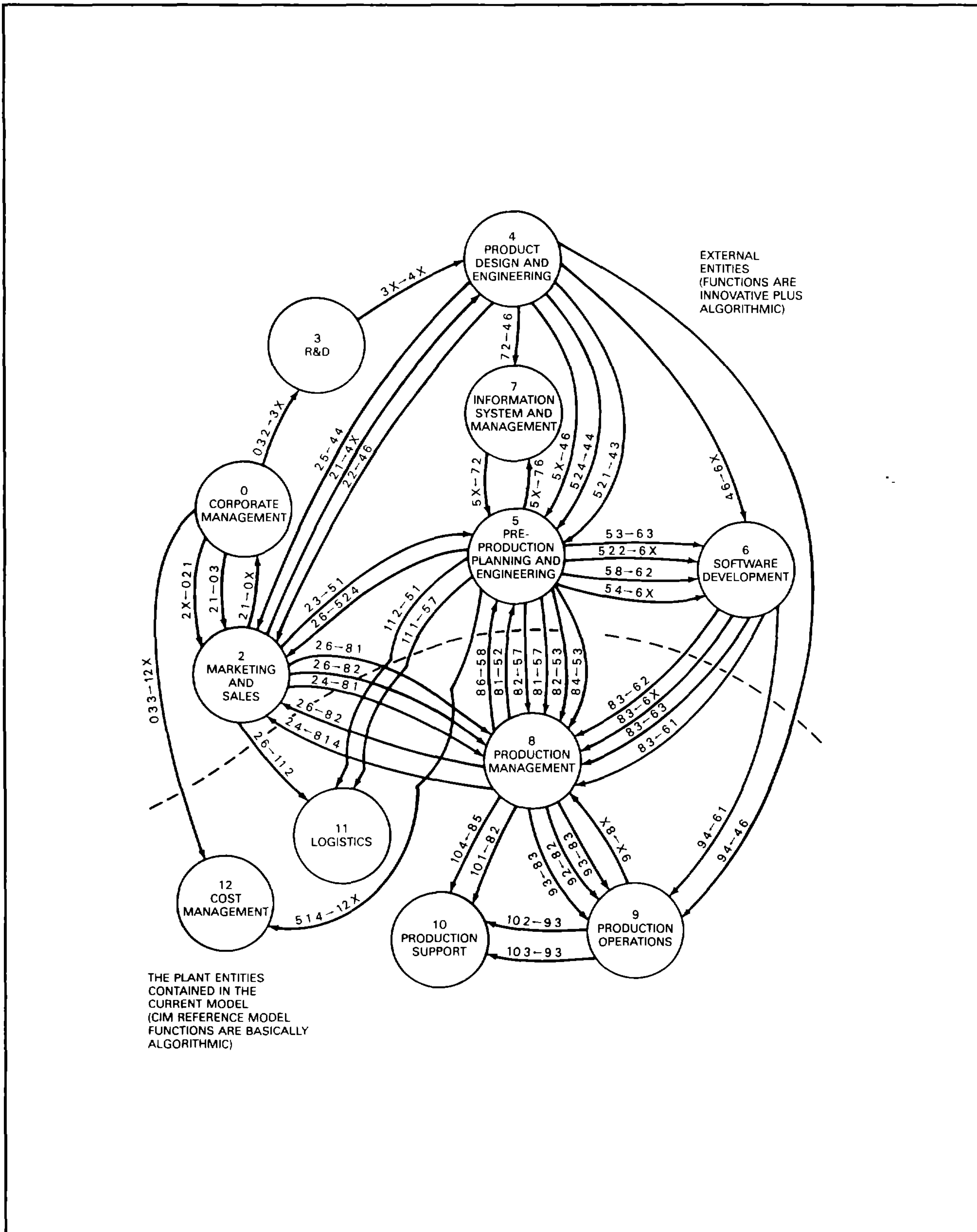


Figure AV-1 Data Flow Diagram Japanese Model of the Enterprise.

Appendix VI

List of Members CIM Reference Model Committee

Mr. Spiros Arethas
Scientific Systems Services, Inc.
17213 West Continental Drive
Lansing, IL 60438

Mr. Terry BeCraft, Mgr.
Manufacturing & Quality Systems
ARMCO, Inc.
Corporate Information Res. Mgmt.
621 Curtis Street
Middletown, OH 45043

Mr. Kornel Berta
Mobil Research and Dev. Corp.
P. O. Box 1026
Princeton, NJ 08540

Mr. Edgar H. Bristol
Senior Research Engineer
The Foxboro Company
Neponset Avenue
Foxboro, MA 02035

Dr. Mark E. Brown
Senior Researcher
Industrial Technology Institute
Advanced Manufacturing Technologies Laboratory
P. O. Box 1485
Ann Arbor, MI 48106

Mr. Robert F. Carroll
Consultant, Matrix
Technologies, Inc.
685 Wellington Way
Lexington, KY 40503

Dr. Asoke Chatterjee
Polymer Products Development
Building 353
Experiment Station
E. I. duPont de Nemours
and Company, Inc.
Wilmington, DE 19898

Ms. Carol V. Derringer,
Manager
Applied Technical Computing
Group
Columbus Division
BATTELLE
505 King Avenue
Columbus, OH 43201-2693

Mr. Bill Embleton
Marketing Manager
Industrial Systems Group
Measurex Systems, Inc.
One Results Way
Cupertino, CA 95014

Mr. Richard Esker
E. I. duPont de Nemours
and Company, Inc.
Wilmington, DE 19898

Mr. Steve Gabel
Honeywell, Inc.
1000 Boone Ave., N
Golden Valley, MN 55427

Mr. Robert A. Gier
Associate
Austin Consulting,
A Division of the Austin Company
9801 W. Higgins Road
Rosemont, IL 60018

Mr. Charles E. Half
Senior Sales Manager
Metals and Manufacturing
258 Kappa Drive
Pittsburgh, PA 15238

Dr. Albert T. Jones
Deputy Manager, AMRF
National Bureau of Standards
Building 220
Room A127
Gaithersburg, MD 20899

Mr. James J. McCarthy
Honeywell, Inc.
16404 N. Black Canyon Hwy.
Phoenix, AZ 95023

Mr. James A. McDonald
Great Lakes Steel
#1 Quality Drive
Ecorse, MI 48229

Mr. Henry M. Morris
Technology Editor
Control Engineering
1350 East Touhy Avenue
Des Plains, IL 60018

Dr. Gyung-Jin Park
Assistant Professor 10/87
CAD/CAM Center
School of Engineering and Technology
Purdue University at Indianapolis
799 W. Michigan Street
Indianapolis, IN 46202

Dr. H. Van Dyke Parunak
Industrial Technology Institute
P. O. Box 1485
Ann Arbor, MI 48106

Dr. Thomas M. Perkins, Jr.
CIM Marketing Manager
Process Industry Marketing
Digital Equipment Corporation
40 Old Bolton Road OGO1-1/S06
Stow, MA 01775

Mr. R. P. Ruckman
Digital Systems Group Leader
The Procter & Gamble Company
Winton Hill Technical Center
6300 Center Hill Road
Cincinnati, OH 45224

Mr. Raymond D. Sawyer
The Foxboro Company
38 Neponset Avenue
Foxboro, MA 20235

Mr. Bailey Squier
CAM-I International
611 Ryan Plaza Drive
Suite 1107
Arlington, TX 76011

Mr. William P. Sykes
Manufacturing Systems Services
2802 Lexington Road
Louisville, KY 40206

Mr. Clyde Van Haren
James River Corporation
916 Willard Drive
P. O. Box 19090
Green Bay, WI 54307

Mr. W. C. M. Vaughan
Senior Principal Software Engr.
Process Management Systems Div.
Honeywell, Inc.
16404 N. Black Canyon Hwy.
Phoenix, AZ 85023

Mr. James Ventresca
SynGenics
72 East Granville Road
Worthington, OH 43085

Mr. Gerald R. White
Principal Consultant
The Foxboro Company
10707 Haddington Drive
Houston, TX 77043-3295

Mr. John F. White
Industrial Technology
Institute
P. O. Box 1485
Ann Arbor, MI 48106

Prof. Theodore J. Williams
Purdue Laboratory for
Applied Industrial Control
Purdue University
334 Potter Building
West Lafayette, IN 47907

Mr. Roy W. Yunker
Director, Process Control
Glass Division
PPG Industries, Inc.
P. O. Box 11472
Pittsburgh, PA 15238