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 informationgathering 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, effident 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 versa tile 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 l-l diagrams the

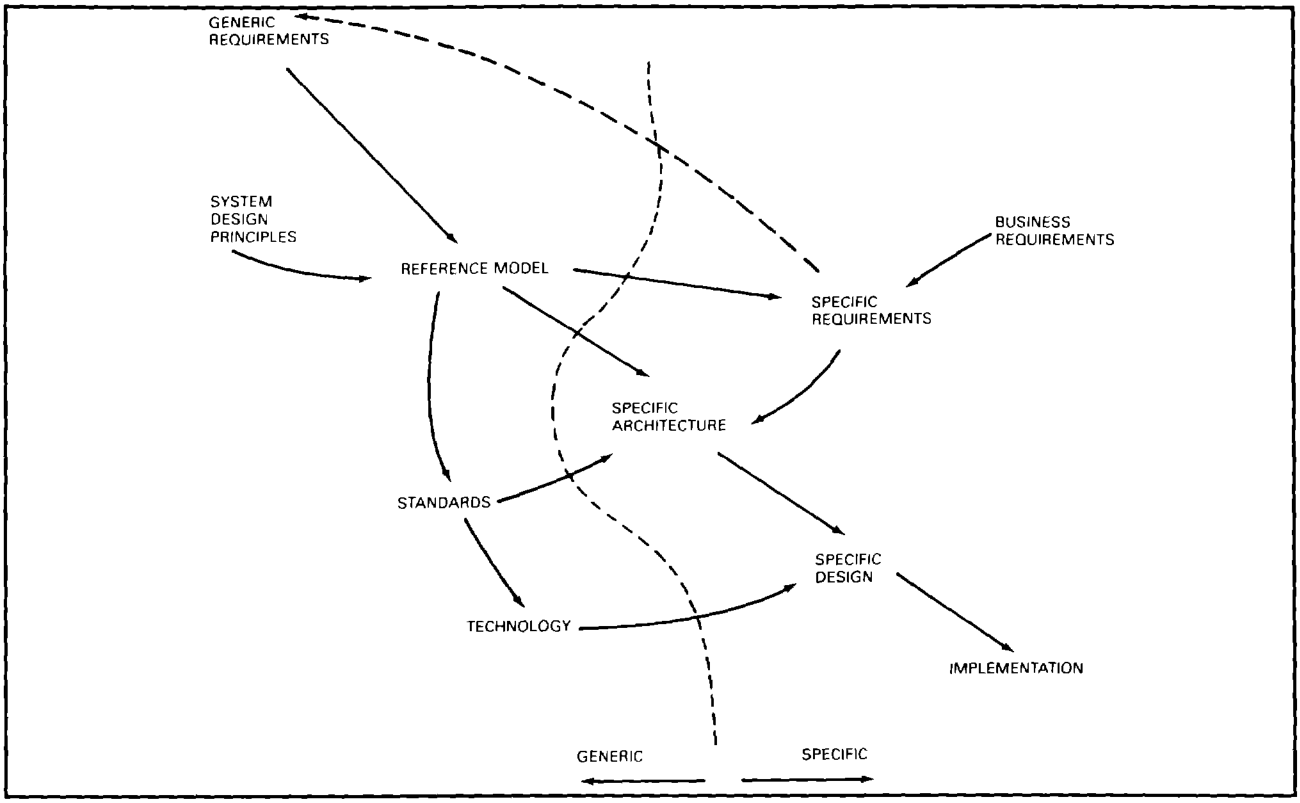

Figure 1-1 The usage context of a Reference Model.

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.

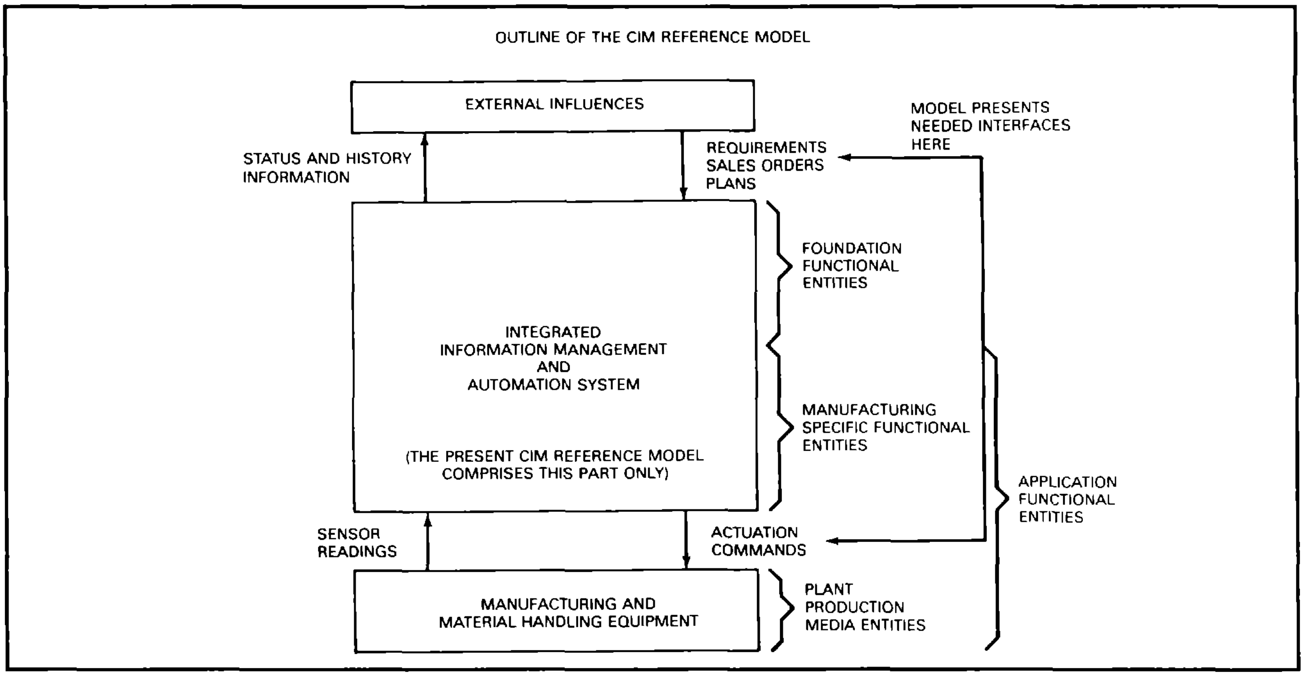

Figure 1-2 Relationship of the several classes of functional entities which comprise the CIM Reference Model and computer integrated manufacturing itself.

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).

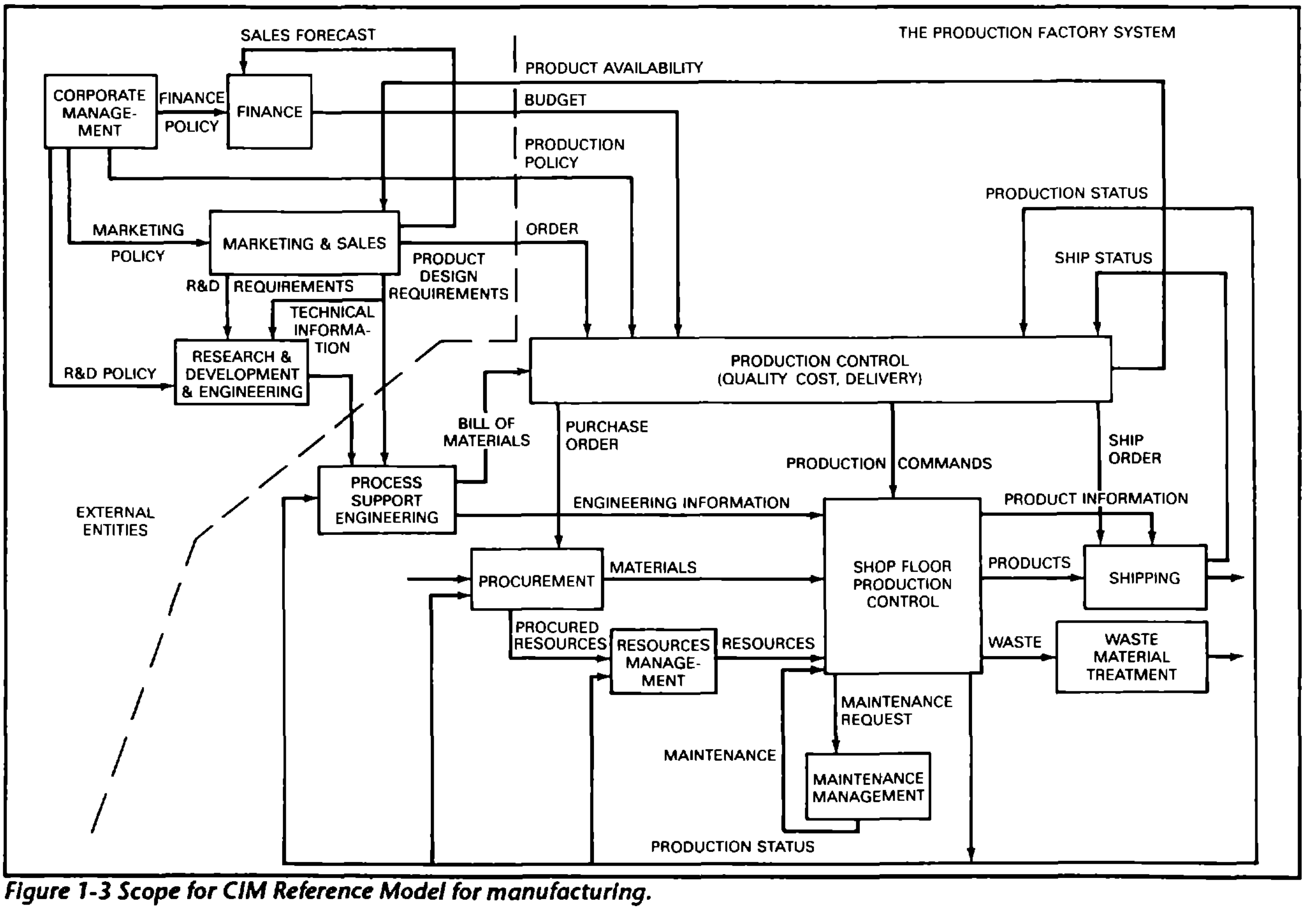

Figure 1-3 Scope for CIM Reference Model for manufacturing.

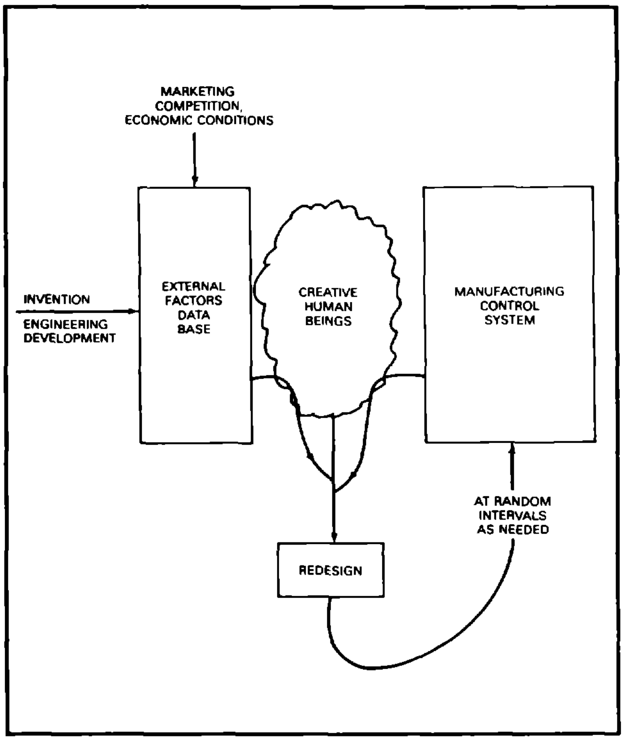

Figure 1-4 Definition of the redesign function for the CIM Information Management and Automation System Configuration which cannot be included in the Reference Model.

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-

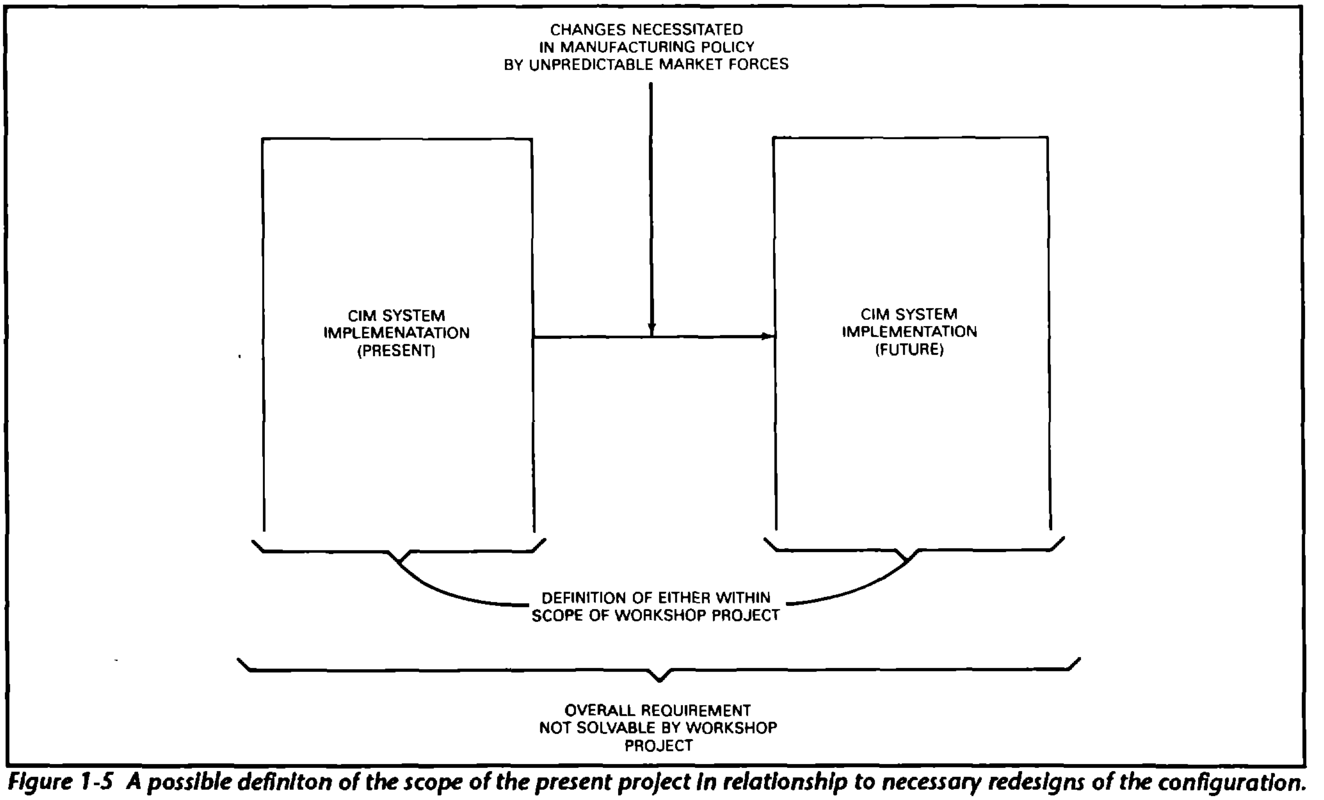

Figure 1-5 A possible definiton of the scope of the present project in relationship to necessary redesigns of the configuration.

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

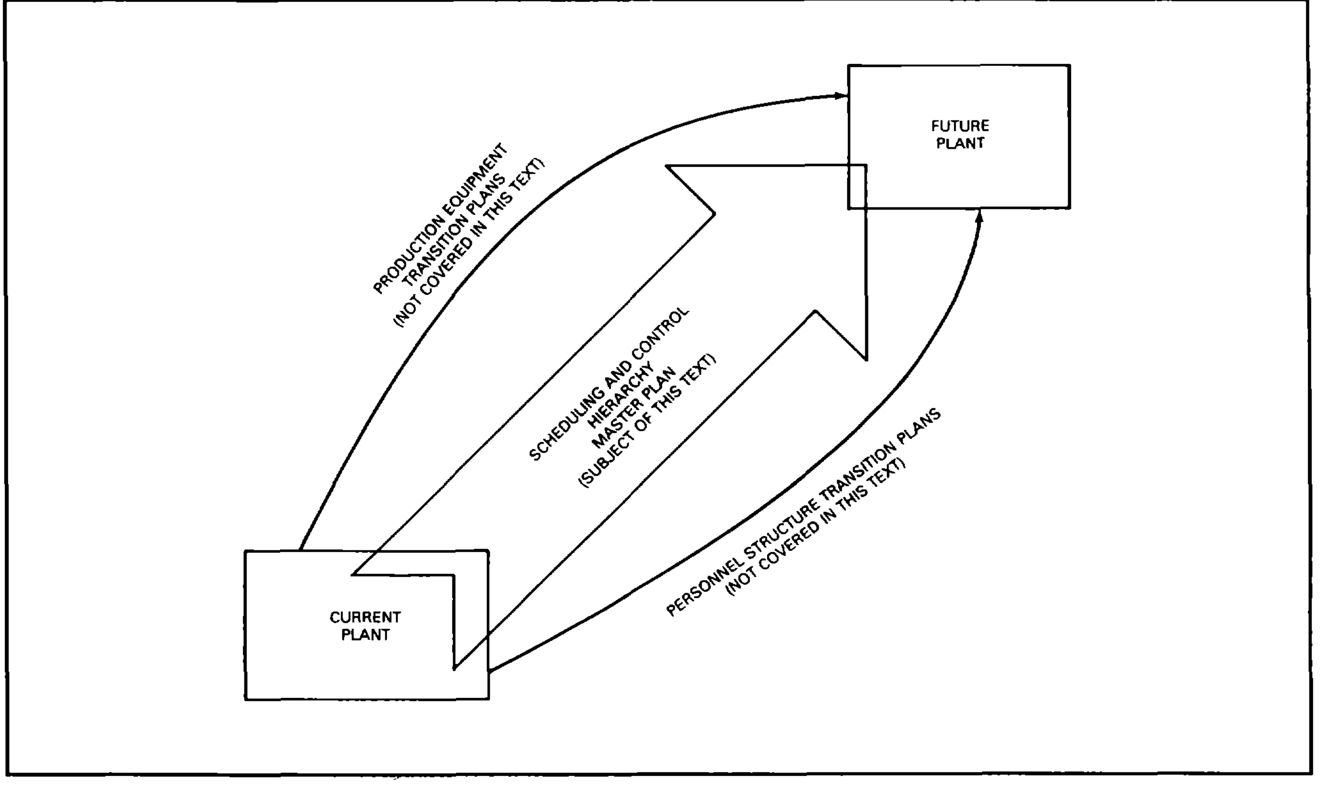

Figure 1-6 Requirements for the establishment of a Computer Integrated Manufacturing System versus the topics of this text.

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.