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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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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.