THE PURDUE ENTERPRISE REFERENCE ARCHITECTURE

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Abstract. This paper presents the basic concepts which comprise the Purdue Enterprise Reference Architecture along with a description of its development and use. This architecture provides the capability for modelling the human component as well as the manufacturing or customer service component of any enterprise in addition to the information and control system component. This latter component is the major focus of most reference architectures and models available today for computer integrated manufacturing or complete enterprise study.

The paper describes a new and unique method for defining the place of the human in the computer integrated plant or enterprise. It also develops the concept of customer service which allow the architecture, which was originally developed for computer integrated manufacturing, to be extended to define the development and operation of any enterprise regardless of the industry or field of endeavor involved.

A review of important future work needed in this field is also presented.

1. INTRODUCTION

The Architecture described herein, The Purdue Enterprise Reference Architecture (PERA), has been developed from earlier work in the Purdue Laboratory for Applied Industrial Control at Purdue University including the Steel and Paper Industry Hierarchical Control System Studies [1,3,4], the Purdue Reference Model for CIM [5] and the work of the Industry-Purdue University Consortium to develop an Implementation Procedures Manual for Developing Master Plans for Computer Integrated Manufacturing [2].

Pursuit of the Implementation Procedures Manual project, however, brought the Consortium members smack up against the same problem which had faced every other originator of a model of CIM system development, that of how to treat human involvement in the CIM system. In addition they wished to also represent the elements and functions of the manufacturing system of the plant as well as the control system.

Both of these problems were solved by defining a general task representation which covered Information System Tasks (the algorithmic control tasks of the CIM Reference Model) and Manufacturing Tasks as well as Human-based Tasks. Also developed was a structural model which showed the relationship of the totality of the CIM system when all three types of these tasks were implemented as required in the manufacturing plant. The above relationship is not shown by any other Reference Architecture available to us as of this writing.

Once the above developments had been assimilated in our thinking, it was evident that the resulting structural model would apply to any Enterprise regardless of the industry involved and its applicability was far beyond that originally intended, a description of a CIM system. This document was called an Architecture to distinguish it from the already published Purdue CIM Reference Model. Either term would apply to either document with the interpretation now given the word, architecture, in the CIM literature.

2. DEVELOPMENT OF THE BASIC CONCEPTS OF THE PURDUE ENTERPRISE REFERENCE ARCHITECTURE

Figure 1 presents a simple block diagram form of the Purdue Enterprise Reference Architecture to help in its explanation. Its complete form will be shown later in this paper. Starting with the CIM Business Entity (CBE) we see that this leads first to a description of the management's mission, vision and values for the entity plus any further philosophies of operation or mandated actions concerning it such as choice of processes, vendor selection, etc. From the mission, etc. we derive the operational policies for the units for all areas of potential concern. These form the Concept Layer. See Figure 2.

In the manufacturing plant the above prescription and selection by management of possible options leads to the establishment of operational requirements for the plant. This leads to the statement of requirements for all equipments and for the methods of operation, etc., for these units. These are developed in the Definition Layer as illustrated in Figure 2.

Note that there are two, and only two kinds of requirements developed from the management pronouncements - those defining information-type tasks and those defining physical manufacturing tasks. Tasks become collected into modules or functions and these in turn can be connected into networks of information or of material and energy flow. These latter then form the Information Functional Architecture or the Manufacturing Functional Architecture respectively which are subarchitectures of the Reference Architecture itself.

Note that no consideration of implementation methods or of the place of humans in the system has yet taken place.

Once implementation is considered, the first need is to define which tasks, on either side of the overall architecture, will be fulfilled by people. By so doing, we define the place of the human in the Information Architecture and also in the Manufacturing Architecture. These together form a Human and Organizational Architecture. The remainder of the Information Architecture becomes the Information System Architecture (all the computers, software, databases, etc.). The remainder of the Manufacturing Architecture becomes the Manufacturing Equipment Architecture (all the physical plant equipment). We have therefore converted two functional architectures into three implementation architectures (Figure 2).

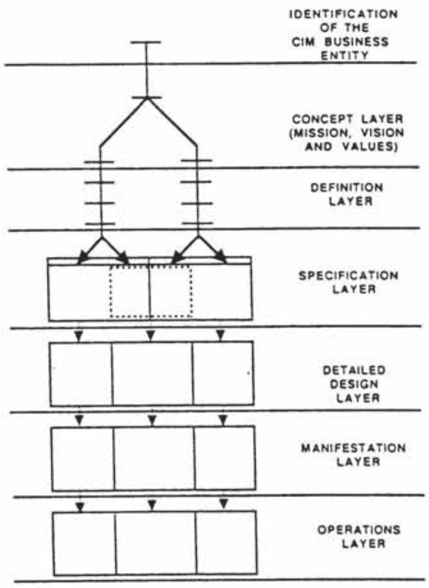

Fig. 1 A layering of the Purdue Enterprise Reference Architecture in terms of the types of tasks which are occurring within those regions on the graphical representation of the architecture

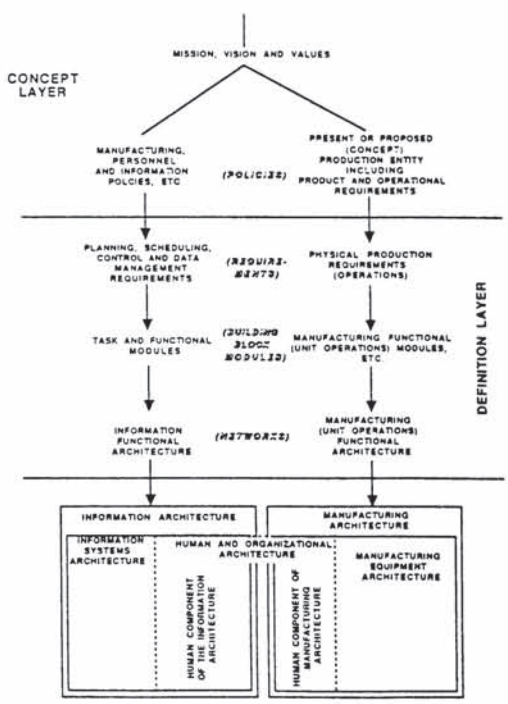

Fig. 2 Definition of the components of the definition layer

We can now follow the life history of the implementation through its four phases - functional design or specification; detailed design; construction and commissioning or manifestation; and finally operation to obsolescence. See Figure 1.

2.1 The Choice of Human Tasks

The lines separating the three implementation architectures in Figure 2 must now be defined.

There is a line which can be called the Automatability line which shows the absolute extent of technology in its capability of actually automating the tasks and functions of the CIM system of the CIM Business Entity. It is limited by the fact that many tasks and functions require human innovation, etc., and cannot be automated with presently available technology (see Figure 3).

There is another line which can be called the Humanizability line which shows the extent to which humans can be used to actually implement the tasks and functions of the CIM system of the CIM Business Entity. It is limited by human abilities in speed of response, breadth of comprehension, range of vision, physical strength, etc. Of course, prior to the industrial revolution most information functions in manufacturing were human implemented (see Figure 4).

There is still a third line which can be called the Extent of Automation line (Figure 5) which actually defines the boundary between the Human and Organizational Architecture and the Information Systems Architecture on the one hand, and between the Human and Organizational Architecture and the Manufacturing Equipment Architecture on the other. These are related to each other as shown on the next figure (Figure 6). The Extent of Automation line shows the Actual Degree of automation carried out or planned in the CIM System of the CIM Business Entity.

The location of the Extent of Automation line has:
Economic and Social, i.e., Customs, Laws & Directives, and Union Rules as well as Technological factors in its determination. This is the line actually implemented.

Table I and its associated diagrams collect the basic concepts upon which this Architecture has been developed.

3. THE TASK MODULE

In the Introduction we mentioned the need to treat human involvement in the CIM system. In addition the need also exists to represent the elements and functions of the manufacturing system of the plant as well as the control system. Both of these problems were solved by defining the general task representation as shown here in Figure 11. Information system tasks (the algorithmic control tasks of the CIM Reference Model), manufacturing tasks, and human-based tasks were then defined as shown in Figures 12 to 14. The general applicability of the task module is shown by the next figure giving our definition of an expert system in Figure 15.

TABLE I

THE CONCEPTS WHICH FORM THE PURDUE ENTERPRISE REFERENCE ARCHITECTURE

1. All tasks in the manufacturing enterprise can be classified either as informational or as physical manufacturing, i.e., involving only the moving and transformation (use) of information, or, conversely, the moving and transformation (use) of material and energy. (See Figure 2.)

2. All tasks can be defined functionally without reference to their method of implementation. It makes no difference whether they are conducted by humans or machines (or in what type of equipment or where). All of these latter considerations are implementation details. Any discussion of the place of the human can be postponed in the manufacturing system development until after all tasks and functions are defined.

3. The ultimate split of functions between humans and machines is determined as much by political and human relations-based considerations as by technical ones.

4. The split of functions for implementation between humans and machines (on both the information and manufacturing sides of the diagram of Figure 2) forms the first definition of the implementation of the resulting manufacturing system. Because of the inclusion of humans, there must be three separate elements in the implementation scheme: the Information System, Human and Organizational, and Manufacturing Equipment Architectures (Figure 2).

5. The split in assignment of these functions (ie, between humans and physical equipment) can be expressed on a diagram by an Extent of Automation line. (See Figure 5).

6. The diagrams noted above can be extended to show the whole life history of the manufacturing enterprise. (See Figures 1 and 7A and B).

7. All tasks in the Information Architecture can be considered as control in its very broadest sense, either immediately or at some future time. Likewise all data collected and information generated is ultimately to be used to effect control of the overall system being considered, either now or in the future.

   The only other use of this data and information is in the context of a historical record.

8. Likewise all operations on the manufacturing side can be considered conversions, the transformation (chemical, mechanical, positional, etc.) of some quantity of material or energy.

9. All functions and operations on the right hand (Manufacturing) side can also be shown to relate only to services for the customer, ie, operation and maintenance of the manufacturing facility to produce products for sale to customers. (See Figures 8 to 10).

10. Likewise, all functions and operations on the left hand (Informational) side relate only to the well-being of the Business Entity itself, ie, to its operational control in order to achieve the optimal operating conditions at hand.

11. Provided all timing, etc., requirements are fulfilled, it makes no difference functionally what functions are carried out by personnel versus machines, or what organizational structure or human relations requirements are used.

12. Figure 10 for the generic enterprise can be extended through the four implementation phases or levels of functional design; detailed design; construction or manifestation; and operation or use just like Figure 7A and Figure 7B.

13. Once the integration of all of the informational functions of an enterprise have been properly planned (the Master Plan), the actual implementation of such an integration may be broken up into a series of coordinated projects, any and all of which are within the financial, physical and economic capabilities of the enterprise, which can be carried out as these resources allow as long as the requirements of the Master Plan are followed. When these projects are completed the integration desired will be complete.

14. All tasks will be defined in a modular fashion along with their required interconnections such that they may be interchanged with other tasks carrying out a similar function but in a different way. Figure 16 shows the development of this modularity.

15. Likewise these tasks will be implemented in a modular fashion, again permitting their later substitution by other different methods of carrying out the same function. The choice of these implementation methods can be governed by independent design and optimization techniques as long as the task specifications are honored.

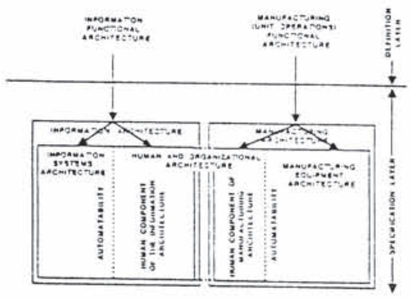

Fig. 3 Development of the three implementation architectures and definition of the human and organizational architecture showing the automatability line

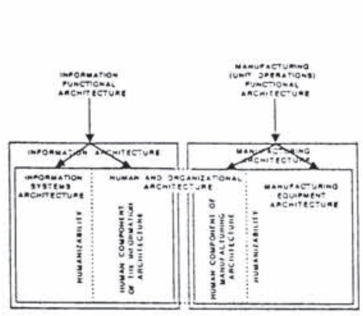

Fig. 4 Definition of the human and organizational architecture showing the humanizability line

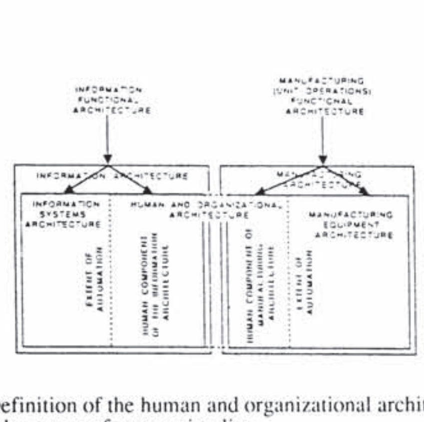

Fig. 5 Definition of the human and organizational architecture showing the extent of automation line

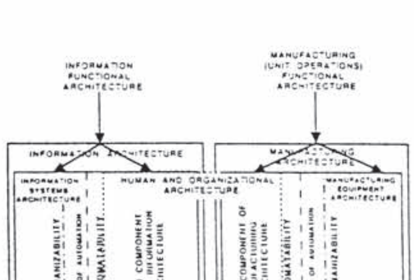

Fig. 6 Relations of the automatability, humanizability and extent of automation lines in defining the human and organizational architecture

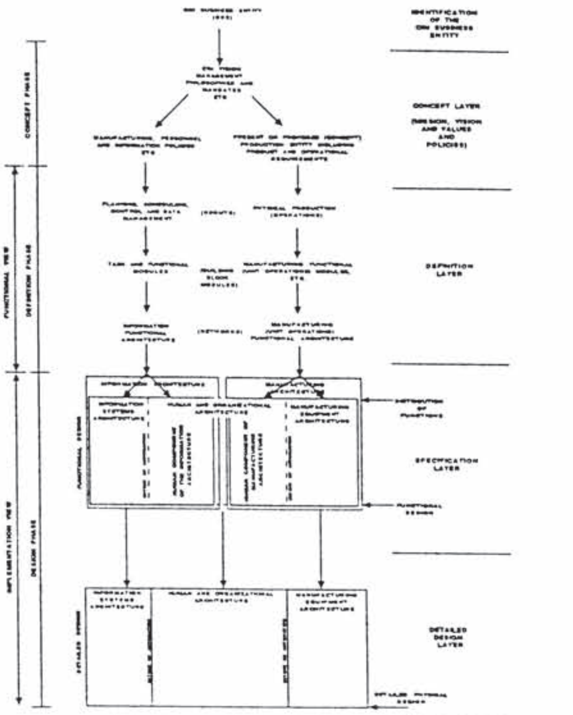

Fig. 7a Development of a CIM program as shown by the Purdue Enterprise Reference Architecture (phases of the program)

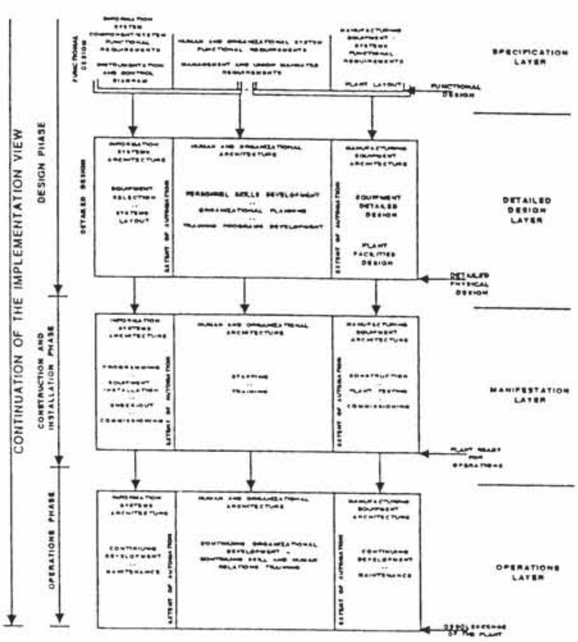

Fig. 7b The later phases in CIM system evolution and their tasks in relation to the Purdue Enterprise Reference Architecture

16. Provided the modular implementation just noted is used, the interconnection between these modules can be considered interfaces. If these interfaces are specified and implemented using company, industry, national and/or internationally agreed upon standards, the interchange and substitution noted in Items 14 and 15 above will be greatly facilitated.

Parameters (coefficients in algorithms or dynamic models) may be:

1. Tables of Constants.
2. Operational Variable Value Dependent Selections from Tables of Constants (Precomputed Adaptive Control).
3. Results of Active On-Line or Periodic Recalculation by Adaptive Tuning, Etc., Algorithms.

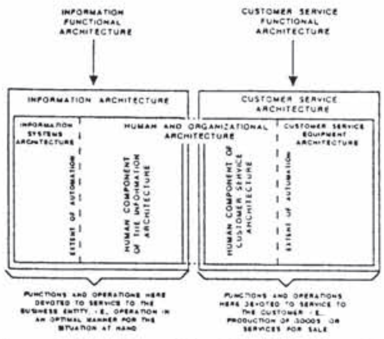

Fig. 8 Further explanation of the definition of the Generic Enterprise by the Purdue Enterprise Reference Architecture

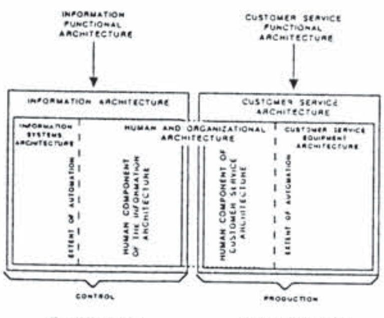

Fig. 9 Further explanation of the definition of the Generic Enterprise by the Purdue Enterprise Reference Architecture

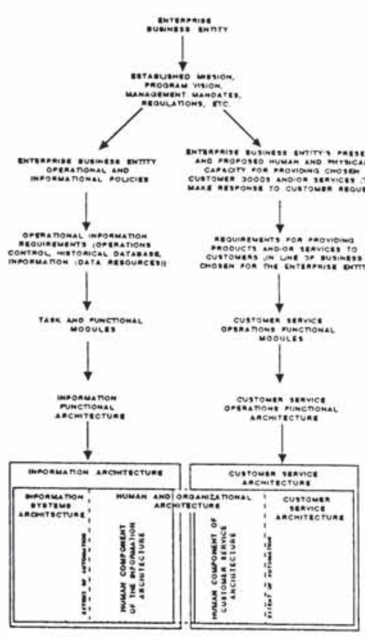

Fig. 10 The overall diagram for the Generic Enterprise

4. Expert Systems Outputs.
5. Neural Nets Outputs.
6. Etc.

(End of Table I)

It should be noted that the modules represented here and their connectivity into networks comprises a type of data-flow mechanism.

Timing, repetition rates, speed of response and other time-based requirements on information task execution are established by the plant, area, and unit operating schedule and are based on the operating characteristics of the manufacturing equipment and the need for meeting the business objectives and practices of the CIM Business Entity. Implementation methods of each task or function must support all such time-based requirements.

4. NEEDED FUTURE WORK

It has been less than three years since the initial concept of the Purdue Enterprise Reference Architecture. Thus studies of its true ramifications and the total extent of its applications are only at a beginning stage. However, even at this time an extensive list of topics of further study of these points can be generated:

1. One can readily develop a long list of work aids and computer-based tools which could be used under the aegis of the Architecture to help facilitate the concept, development and implementation of CIM programs and Enterprise studies. Such lists should be pursued and kept up-to-date. An evaluation of the relative usefulness of these techniques as they were placed on the list would be extremely helpful to the user of the resulting list.

2. Along with the task structure (Architecture) presented here, there is a corresponding "structure" to define the format of and the requirements for all of the data (information) used in the execution of these tasks. This would involve database structure, distribution, method of access, etc. It would also include topics such as data length, labels, determination of and recording of accuracy and reproducibility, etc.

3. There are many CIM and Enterprise models and architectures available in the literature today. It would be important to attempt to map several of these against each other to show their relationship to each other as well as the range of applicability of each.

4. The mapping exercise of Item 3 above might provide the information necessary to meld several of the most widely applicable architectures into one "best" proposal. Another possibility would be the development of several candidates, each optimized for a particular class of applications. If our history with the present architecture is any indication, such a single best example, or even a stable of best examples optimized for specific applications, would be of invaluable help in promoting the integrated operation of all types of enterprises.

5. The Entity Relationship Diagram describes databases and their use in the Information Architecture. A similar diagram for the Manufacturing Architecture would describe inventories and their contents. Is there a similar diagram possible for the Human and Organizational Architecture?

6. Several of the existing architectures strive for mathematical and logical proofs of their concepts. It would be important to try to fit such proofs to this architecture as well.

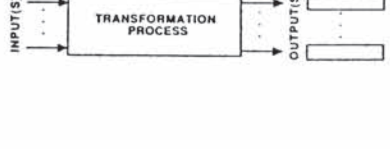

Fig. 11

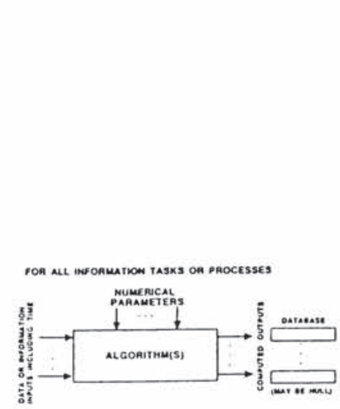

Fig. 12 Information functional module

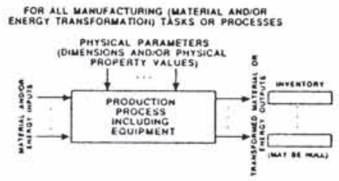

Fig. 13 Manufacturing functional module

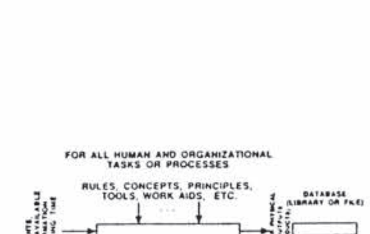

Fig. 14 Human and organizational functional module (the non-automated or non-mechanised task)

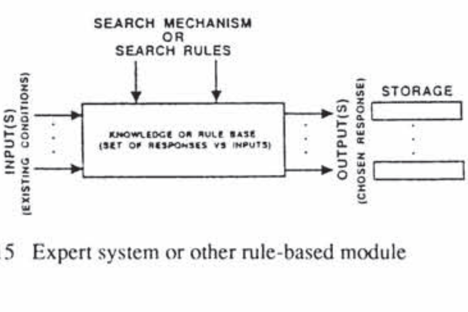

Fig. 15 Expert system or other rule-based module

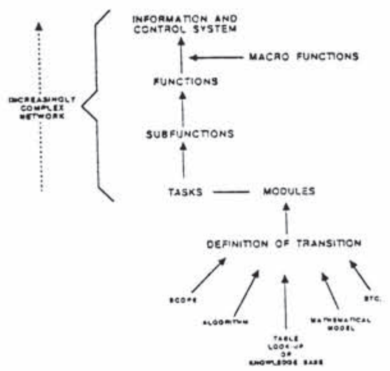

Fig. 16 Development of the functional network (functional architecture)

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