Communications for Manufacturing: An Overview

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Computer Integrated Manufacturing (CIM), a term which describes the integration of corporate-wide information systems using computer and related technologies, is viewed as a vehicle through which manufacturing enterprises will maintain competitive edge in the future. Communications systems play a major role in corporate CIM strategies. In this paper, we introduce CIM and describe the communications needed to support CIM applications. The GMT400 project, a CIM experiment which is intended to investigate the applicability of MAP technology in automotive manufacturing, is described, and several other development projects in the CIM area are identified. Research and development issues in CIM are also summarized.

Manufacturing activities account for a significant portion of the world's gross national product. For example, according to Mr. T. J. O'Rourke, CEO of the Allen-Bradley Corporation, the contribution of manufacturing activities to the gross national product of the USA is estimated at over 25 percent [1]. Computer Integrated Manufacturing (CIM) comprises the integration of corporate-wide information systems using computer and related technologies. That is, CIM implies the integration of an organization's entire informational infrastructure, both within and among its functional units [2,3]. This concept is in contrast to the arbitrary application of computering and information technology which commonly results in so-called islands of automation.

Historically, computers were introduced into the manufacturing environment over thirty years ago to support inventory control. Since that time, numerous other applications of computing technology have penetrated into the manufacturing environment independently. These application areas include, but are not limited to, computer aided design (CAD), computer aided process planning (CAPP), materials requirement planning (MRP), and numerically controlled machines and robots [4]. Application dependent development efforts have resulted in systems which are incapable of intercommunicating, thus resulting in the aforementioned islands of automation [5].

Most of today's industrial automation equipment provides some level of communications capability. This can range from the most simple "terminal emulation" to the most complex local area network. Interconnecting these devices, if it can be done at all, frequently requires massive development projects and an excess of computer and communications equipment [6-9]. Many efforts are underway in both the USA and Europe to develop a common set of vendor-independent communication protocols which would be usable by all types and brands of factory equipment [10-15]. A device which properly implements these protocols should be able to fully communicate with all others. "Data plugs" on the walls should permit any equipment to be plugged in and work just as a telephone will when connected to the proper jack. Two well-known efforts are manufacturing automation protocol (MAP) and technical and office protocols (TOP) initiated by General Motors Corporation and The Boeing Company, respectively, in the early 1980s.

The CIM Environment

The major impetus for CIM comes from the current realization that the economic survival of the industrial corporations will not be achieved by simply reducing direct labor hours inputs. It will rather come from improved efficiencies within all the operations of the companies along with increased scope of the product line. A typical approach aims at reducing lead times and work-in-process inventories, increased manufacturing flexibility and improved product quality. Proper implementation of the CIM strategy calls for the integration of people, organizations, procedures, and computer systems working in concert in a dynamic and highly competitive industrial world. For instance, the needs of product support and maintenance differ greatly from the needs of manufacturing or engineering design. Product support is concerned more with the end-product functionalities or with spare parts locations while manufacturing is mainly concerned with resourse scheduling, raw material availability, and process monitoring. These differences in functional needs and priorities are also addressed and reconciled by the CIM implementation strategies.

The CIM approach refers to the process of integrating and automating the product information flow from perception through design, production, marketing, shipment, and support. While no single corporation has yet achieved a fully functional CIM environment there are major stra-

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tegic efforts in that direction. In the past, the product's flow of information was sequential in nature and had none or very few provisions for feedback and cross-application data sharing. That information flow was formerly initiated at the product perception and design phase. It was then followed by the testing, production planning, manufacturing processes, inspection, and finished goods shipments information. This sequential process resulted in lengthy product development cycle times in which time-to-market ranged from one to five years in many industries.

A more cohesive operation results from sharing the information across the various functional areas. The CIM approach supports not only information sharing but also effective management decision making. This permits a corporation to act instead of simply reacting to changes and dealing with exceptions and contingencies. Significant improvements have already been realized by various industries as a result of their CIM effort. For example, sharing product design information among the manufacturing process planners and the field support experts allows them to comment on the various design options as well as to work concurrently, thereby significantly reducing the time-to-market for new products. Other reported benefits of CIM implementations include reductions in engineering design costs, overall personnel costs, job lead times, and work in process inventories. Similarly, improvements are anticipated in product quality and in the actual utilization of capital equipment. Examples in which yields exceed 99 percent have been reported in certain operations in which specialized control devices are manufactured [1,2,16].

Today, it seems that the common hurdle to the CIM efforts is the disjointed structure of the manufacturing corporations. These corporations are generally structured in a pyramid-like form, composed of many separate entities having recognizable boundaries and tasks. Due to this organizational form, each department maintains its own procedures, data structures, and protocols. With CIM, this mode of disjointed development efforts is slowly being replaced by integrated information and control systems [17,18].

In general, the problems associated with integration today occur in three distinct settings [19]:

- application-to-application communications within the same computer.
- host-to-peripheral communications among single-vendor equipments.
- Communications among equipments of different vendors. These equipments include computers, LAN's, cell controllers, PLC's, robots, machine tools, and similar digital control devices.

The hierarchical integrated information flow model, which is considered to be the prevailing one in CIM installations is addressed below.

Hierarchical Information Models

Hierarchical CIM models show the different levels of control encountered in a CIM system ranging from the real-time control involving sensors and actuators to the system wide control applied by management executives at the highest level of manufacturing operations. In these models information flows in two directions. Process monitoring data, production status information, exception indicators, and other operational data are passed upwards through each level of the hierarchy. At each step the bulk of the data is processed and integrated for proper use. In the reverse direction, commands, set-points, and schedules are passed down. Thus, the manufacturing control functions are distributed and a logical, controlled flow of data is obtained.

There are several hierarchical control models that have been suggested in the literature. These include the Advanced Factory Management System (AFMS) developed by Computer Aided Manufacturing Inc., the Advanced Manufacturing Research Facility (AMRF) of the National Bureau of Standards (NBS) [6], and the Factory Communication Model (FCM) proposed by Suppan-Borowka [20].

In the automated manufacturing research facility (AMRF), the complex planning and control functions in an automated manufacturing facility have been broken down into a series of levels in a planning and control hierarchy. The hierarchical levels in the AMRF are *facility*, *shop*, *cell*, *workstation*, and *equipment*.

The facility level includes process planning, production management including long term schedules, and information management with links to financial and other administrative functions. Below the facility level is the shop level which manages the coordination of resources and jobs on the shop floor. The functions involved at this level include the grouping of parts belonging to certain jobs into batches using a group technology (GT) classification scheme.

The AMRF model introduces the concept of a virtual manufacturing cell. A virtual manufacturing cell consists of machines which are dynamically interconnected; that is, the configuration and number of virtual manufacturing cells varies with time. In addition to configuring job groups and virtual manufacturing cells, the functions at this level include allocating tooling, jogs/fixtures, and materials to specific workstation/job combinations. The activities at the shop level are re-evaluated based on feedback from the cell level and commands from the facility level.

Below the shop level is the cell level which contains the cell control systems for scheduling and controlling the jobs. At this point, the jobs have already been divided into groups and allocated to each cell based on job similarities. Additional functions include the scheduling of material handling and tooling within the cell.

The workstation level coordinates the activities of a workstation. Under the AMRF framework, a workstation consists of a robot, a machine tool, a material storage buffer, and a control computer. Thus, the workstation arranges the sequence of operations necessary to complete the jobs allocated to a particular cell control system. The lowest level of the planning and control hierarchy is the equipment level which consists of the controller for individual resources such as machine tools, robots, or material handling systems.

Other hierarchical information models distinguish between the following levels: corporate, plant, area manager, cell controller, and physical device. All these models assume that each function is assigned to the level whose resources best satisfy requirements. Implementation is facilitated through the introduction of hierarchical computer and communication networks. Mainframe computers are used at the highest level while the lower levels are supported by programmable logic controllers (PLCs) and cell controllers.

Cell Controller

At this point in the evolution of communications technology, not all devices can communicate via a single communications protocol. Cell controllers are used for integrating multi-vendor manufacturing devices and for coordinating all the operations within a single cell, and between cells at the same level [21]. The various functionalities of these units are discussed next.

Device Data Acquisition—The cell controller is the next level of automation above the factory floor devices. It is responsible for the collection of data from programmable controllers (PLC's), robots and general data acquisition devices. Sometimes, in the case of more advanced intelligent devices like the PLC, the cell controller can take advantage of capabilities of factory floor level devices, and collect summary or processed data only.

In addition, the cell controller provides a means for a factory floor or off-line operator (such as a dispatcher) to enter data manually. Data collection is generally done on two bases:

- By frequency, where points are monitored at a preset sample rate, and
- By event, where points are monitored when a certain event is signaled. The signal could be set by the front end device or by any system in the network. In the latter case, any user application, or the production manager, can set the flag and thus initiate data collection. Manual data entry naturally falls into the category of data collection by event.

Data Management.—The data collected from front end devices is stored in a real-time data area, and processed by a series of "recipes" specified by the user. There is a variety of languages used in various implementations for recipe definition. Using such recipes, a variety of functions is achieved. These include alarm handling, scaling, range checking, timing, data reduction and status checking, to mention a few. The set of recipes form the crux of monitoring and control functions within the workcell controller. They are also quite often the most computation-intensive module with the system. The real-time data is stored in an area which is accessible by most modules. In a flexible application, any user program should be able to enter data into or read data from this area.

Data Accumulation—The purpose of the cell controller is to aid in better control of manufacturing processes, and this is best achieved with an analysis of the historical data collected. Not all the data collected must be logged; in fact, the specification of points (or computed data items) to be logged and their logging frequency or condition is often left to the user. There is a general trend toward the use of standard database management systems, and specifically towards the use of the relational model. That model is the best suited for dynamic reconfigurations of the system [19].

In a heavily loaded cell controller system, where a large number of data points is being monitored, the historical database may reside on a separate computer. If the number of points being monitored is so large that multiple computers are needed, their combined historical information can be stored on a single separate computer.

Data Reporting and Analysis—The workcell controller achieves better control on the factory floor in large part because of the nature of the information it provides the supervisors and operators. Therefore, for maximum usefulness, the information must be timely, accurate and in the right amount of detail. It must also be presented in a form suitable for operational decision making. On the factory floor, the various forms of data presentation are:

- Tabular screens and reports, which consist of alpha-numeric display of values stored in the database, along with summary statistics such as totals and averages. Hard copy outputs are desirable.
- Statistical graphics, which are user-configured graphics displays of factory floor status, and are updated in real-time.
- Statistical reports and charts, such as Xbar-R charts. Printer and plotter outputs are also provided upon request.
- Editors for the databases, suitable for off-line or computer room use.
- Screen-based transaction processors, which allow an operator to proceed interactively through a series of data entry steps.

Often, the data presentation modules listed above allow for the on-line data entry from the factory floor. Among other useful characteristics of data presentation forms is the ability to configure on-line the screens that are to be displayed.

Data Communications—The workcell controller must be able to communicate with a variety of other nodes at both higher and peer levels. At the peer level, the workcell controller must be able to access point or item values from other cells. This gives it the ability to make decisions based on activities in other cells, a first step towards genuine integrated control. At the same time, the workcell controller must be able to pass data up to and respond to signals from higher level systems. Generally summary data, such as downtime totals by cause, are passed up to higher levels systems. Similarly, a higher level system may execute applications, such as labor vouchering, which signal needs, such as operator arrival data, to the cell controller.

Other Functions—Workcell controllers are built to coexist with virtually any user application. Since they are directly above floor level devices, they are also used to control the flow of other information to and from those devices. This includes job-specific data that is used in building one unit of the product. For instance, in the production of car bodies, the cell controller may be used to pass down specific information which specifies the color to paint the current car to the robots. Cell controllers are also used to develop PLC programs, which are then downloaded to the PLCs in real-time.

There are a variety of global modules which may be included in the workcell controller. For example, a user-friendly configurator for all the functions is one of the most desirable elements. A global system monitor which facilitates control of the cell modules is also a desirable module. General system utilities, such as backup and recovery systems and security modules, are also included in most systems.

Communications Requirements

The communication requirements of factory applications challenge designers to meet the needs of complex organizations in a harsh physical environment. In many cases communication takes place between quite different devices ranging from robots to graphic terminals and business computers. In addition, the systems should be able to embed already existing factory communications systems (for example, Data Highway, Pernet, or Modbus) [22]. These communication networks must cover great geographical distances while handling a large number of I/O points [23].

Observing the hierarchical information model described earlier it is clear that the information flow attributes vary along that model. The real-time requirements at the lower levels are more pronounced than those of the upper levels. The lower levels are characterized by frequent and short messages transmitted over short distances. The top level communications are more decentralized and take place over larger distances. The message types also vary with the hierarchical direction of the information flow. Top level messages include large file transfers and human interaction I/O. At the bottom, messages include shorter control statements, measurements and part programs. Other requirements include fault tolerance operability, error control mechanisms, global time structures and priority scheduling of the message traffic.

The three major design challenges in these industrial communication systems appear to be *connectivity, flexibility*, and *performance*. The challenge in connectivity is to be able to effectively communicate among all systems in a manufacturing enterprise, whether such systems are from a single vendor or multiple vendors, which is the usual case. The problems here are exacerbated by a need to interconnect and distribute processing among computers which are not even from the same generation. This problem is particularly tough in the aircraft industry in which sophisticated airplanes have a lifetime of several decades. Surely, computing methods and computing technology have advanced significantly since the introduction of, for example, the Boeing 727.

It appears that MAP is evolving as a standard for communication between systems. Many other vendor-proprietary standards, such as SNA, DECnet and TI-Way, are still widely deployed. However, most major computer vendors now offer MAP-based products. The need to interconnect software among nodes is a direct result of the need to integrate islands of automation into a coherent CIM network. At the same time, the various standards of information flow to software applications make it a difficult problem to solve [24,25].

Functional flexibility is required to cope with the wide range of needs on the factory floor. It is difficult to design a single network topology that can satisfy the needs of all applications. However, one of the most promising avenues of software development is combination of modularity and configurability. The concept allows one to decide which parts of an application resides on which machine. For example, decisions such as which computer stores the specific build-data for the production units should be left to the user. The job sequence and its management system should be detachable. Likewise, the user should be able to configure command sequences for a transaction, including routing conditions. It can be a difficult problem to validate the general user-configured transaction, but algorithms exist to help with the process.

Both the additional processing required to facilitate communication among incompatible systems and configuration flexibility negatively impact performance. However, the increased use of distributed processing systems on the factory floor is helping to improve vendor knowledge of manufacturing requirements and can potentially relieve performance bottlenecks.

Application: the GMT400 System

In this section, we discuss GMT400, a project of the Truck and Bus Group of the General Motors Corporation. There are assembly plants located in Fort Wayne and Pontiac and fabrication plants located in Oshawa, Flint, and Indianapolis which make extensive use of several computer communications networks, including one based on the MAP architecture, in the manufacturing of full-sized pick-up trucks. Some of the project goals are as follows: to achieve a near perfect quality index (142 out of 145), to improve productivity by utilizing an economic balance of direct labor and automation, and to achieve a production rate of 60 trucks per hour per plant.

The current communications system architecture is hierarchical and has five control levels which are referred to as the Information Processing Center (IPC), Plant Host, Area Manager, Cell Controller, and Plant Floor Devices. The IPC level supports functions not directly associated with the plant floor production processes. These functions are accomplished by many business systems such as order processing systems, material control systems, logistic systems, industrial engineering systems, and financial systems which comprise the IPC level. The IPC for the GMT400 project is located in Dallas, Texas.

The plant host level appears in each assembly plant. It supports plant-wide applications such as flexible scheduling, re-scheduling, and shipping control. This level provides flexible management of parts flow through the plant. For example, each vehicle may follow a production path which depends upon its customer's options or necessary repairs. The system also controls the sequence and times for vehicle movements from one area of the plant into the next in order to balance downstream work loads.

The manufacturing process is partitioned into a number of distinct functional areas. A single area manager is assigned to meet the functional requirements specific to each area such as monitoring vehicle information, managing the movement of components throughout the plant, and statistical process control. This layer includes several information systems which are categorized as fabrication support systems, cell control systems, area management systems, vehicle systems, manufacturing systems, test and control systems, and plant support systems.

The plant floor level is responsible for the monitoring, control, and dynamic configuration of automated equipment on a real time basis. Major features of this layer which are of interest from a communication level include decentralized databases and robust integration of test systems.

The programmable device level incorporates robots, programmable logic controllers, automated guided vehicle systems (AGVS) automated storage and retrieval systems (ASRS) automated vehicle identification (AVI) systems and the weld controllers involved in the automotive production process.

A table which shows some statistics regarding intelligent devices involved in the GMT400 automation project at the device level is given below.

Level Interconnection

The single Information Processing Center located in Dallas, Texas supports all assembly and fabrication plants. There is one Plant Host per assembly plant, and the IPC and the Plant Host are interconnected by a long haul network through dialed service. IBM's System Network Architecture (SNA) provides logical communication between these levels.

	Assembly Plants		**Fabrication Plants**		
	Fort Wayne	**Pontiac**	**Oshawa**	**Flint**	**Indianapolis**
Robots	135	136	127	5	0
PLC	199	208	278	63	156
AGV	100	—	424	—	—
AVI/Scanners	54	117	63	N/A	167
Weld Timers	134	153	124	226	251
Terminals	475	475	475	21	39
Printers	175	175	175	13	11
Storage/Retrival	—	—	—	2	—
Monitor Points	5000	5000	8000	2000	2000

Area Managers are interconnected by DECNET, and Ethernet based local area network. The area manager level and the Plant Host level are interconnected via an SNA gateway on a point-to-point basis.

Backbone

The GMT400 project requires that each plant support communications between a multitude of vendor-supplied devices. The devices must communicate over a variety of dynamic logical connections involving simplex, half-duplex, and full-duplex modes. The type of information which may be transferred between devices is mixed, consisting of video, data, and audio. The communications backbone must be expandable and reliable, having no single point of failure. A broadband coaxial cable system (that is, multiple channels) is used to meet these requirements. Some channels are used for video, others for data, and still others for audio. Each logical channel provides a transparent path between devices and exists independently of the other channels on the cable. The logical channels are independent of these physical locations. Reliability is achieved through facility duplication, real-time monitoring, and failure prediction.

Terminal Access

A major requirement for communications below the Area Manager level involves the use of terminals for providing access to applications in the control hierarchy. Each device on the plant floor can be accessed by any application at any layer since they are all interconnected via a LAN. The GMT400 implementation uses a CSMA/CD based broadband network which interconnects asynchronous I/O devices. These include plant floor devices which can only communicate through proprietary protocols, IBM 3270 type devices, and personal computers requiring files and printer sharing and multiple connections.

Communications among the area manager, the cell controllers, and certain robot controllers is supported by a 10 Mbps MAP 2.1 broadband network. The system uses board level products wherever possible and MAP standard protocols for layers 1 through 7. ISO's CASE (Common Application Service Elements) and MMFS (Manufacturing Message File Standards) are implemented on MAP stations, as is network management including directory services.

In addition to the CSMA/CD and MAP networks, some devices (such as, test systems) are interconnected using several channels of the broadband coaxial cable in a point-to-point configuration using the DDCMP protocol. Thus, through the use of frequency division multiplexing, the coaxial cable supports three networks: CSMA/CD, MAP 2.1 and a DDCMP based network.

Communications between the Plant Floor level and the programmable device level is provided by a variety of networks. Currently, cell controllers support Allen Bradley's Data Highway, Pertron's Pertnet, and other proprietary networks. Robots and programmable logic controllers are connected to these proprietary networks. In addition, networks based on CSMA/CD, DDCMP, and MAP are also used for the communications between the Plant Floor and Programmable Device layers. Communications between the programmable devices and their sensor and actuators is provided by the specific vendors consisting typically of hardwire interconnections.

Summary

In the brief introduction to the GMT400 project, we have attempted to give an example of the range of communication systems needed to operate a reasonably modern manufacturing system. While the project may not use the latest technology throughout, it is hoped that this example, in which a complete plant is dependent on MAP for floor level automation, serves to illustrate a major advance in the area of factory communications. This example, which includes only a subset of the manufacturing enterprise, also serves to illustrate the need for a comprehensive understanding of networks and their behavior in the manufacturing environment. We now turn to a discussion of some of the issues which appear to be of importance in pushing the frontier in factory communication.

Development Projects

Manufacturing networks are still in their infancy, thus there exists plenty of room for development work. Several major projects in the area of networks for manufacturing are being developed in the United States and in Europe. Of course one of the first networks specifically developed for manufacturing is MAP. In the United States, further developments are undertaken privately by individual companies or in a public forum through workshops and conferences sponsored by universities [26], industrial companies, the National Science Foundation (NSF) [25] and the National Bureau of Standards (NBS) [24]. For example, a standard network for interconnecting sensors, actuators, and machine controllers referred to as field bus is currently being developed by ISA (the Instrument Society of America) [27]. Other current developments include the use of optical fibers and wireless communications [28,29], design and implementation of efficient protocols for meeting cost and performance requirements of automation applications, manufacturing languages [30,31], and network interfaces to processes and machines [32,33]. In-house industrial prototype applications were recently presented by Deer's and Company Harvester Works [34], Motorolla and Intel [35], Proctor and Gamble Co. [36], and by Fanuc [37].

In Europe, the European Strategic Program for Research in Information Technology (ESPRIT) [13-15] consists of the following five major efforts: advanced microelectronics, software technology, advanced information processing, office systems, and CIM. The CIM effort contains two projects: CNMA (Communications Network for Manufacturing Applications) and OSA (Open System Architecture). CNMA is the CIM oriented initiative in Europe to define protocol profiles for communication services supporting CIM and to demonstrate internetworking of multi-vendor equipment. It is designed to support the smaller companies by providing them with the choice of specifying the control equipment at the cell level. These companies are looking for low-cost multi-vendor MAP communication capabilities down to the device level.

The ESPRIT project is administered by the Information Technology and Telecommunications Task Force for the Commission of the European Communities (CEC). It is the most ambitious, cooperative research program ever embarked upon in Europe, enabling the cooperation of several hundred large and small industrial companies and research institutions in 12 European countries. The CNMA project which started at the beginning of 1986 had its first demonstration at the Hannover Fair in April of 1987. The demonstration included running several manufacturing applications on three interconnected networks: a token bus broadband network at 10 Mbps, a CSMA/CD network running at 10 Mbps, and a token bus carrierband network running at 5 Mbps. Pilot tests of CNMA implementations were scheduled for the end of 1987 at British Aerospace, and for the end of 1988 at BMW and Aeritalia.

Research and Development Issues

Great strides have been made in bringing about an integrated communications system in the manufacturing environment over the last few years. In particular, the MAP and TOP efforts have resulted in protocol stacks which allow diverse equipments to intercommunicate, thus allowing for the interchange of information amongst the various functional units of a manufacturing company. Over the same time period, proprietary systems have continued to evolve. The potential for effective communications has been demonstrated, but much remains to be done [38]. In the highly competitive manufacturing environment, efficiencies must continue to be improved and costs reduced. Advances in communications can help to bring about such continued improvement. Both development issues, which relate to the application of currently available technology, and research issues which relate to the solution of fundamental problems in designing communication networks, bear heavily on the potential for continued improvement.

One can begin to appreciate the complexity of a manufacturing communication system by realizing that a manufacturing system is essentially a complicated distributed processing system. Since even the most simple distributed processing systems are very difficult to understand, it is easy to see that understanding a complex distributed processing system in an [8]. A possible key to advancing the state of the art might be the formulation of a language having sufficient descriptive power to describe the manufacturing environment. In essence, what this means is that the tools should be able to describe parallelism, correlation, and coordination in both real-time control and non time-critical environments, and in addition, should allow for multiple levels of abstraction. Further, the language should be able to describe the impact of exceptions on operation of the system. Once the environment can be described symbolically in a language commonly understood by researchers and developers, there would be an increased likelihood that key issues could be identified. This might lead to improved problem formulation which would certainly lead to progress. The key point here is that the fragmented research which is going on in the factory communications areas will likely lead to a thorough understanding of system components, but it is unlikely that such efforts would lead to an understanding of the relevance of those results to manufacturing enterprises.

Experimental work in realistic factory environments is likely to be a strong contributer to advances in communications for manufacturing. We have given a thumb-nail description of the GMT400 truck plant. The results of such experimental efforts can be of great value to advancing the state of the art. In particular, researchers might work with developers in defining the types of measurements which are appropriate, and may help to design statistical test and measurement programs which might yield useful data for analysis purposes. It seems unlikely that equally useful results could be obtained in a pure laboratory environment without direct input from an experimental system such as the GMT400 project. What is needed is a cooperative effort between the experimenters and the analysts, both within corporations and throughout the research communities. More frequent use of nondisclosure agreements, which protect the property rights of corporations while providing valuable data to researchers, could go a long way towards improving the quality of both research and development in this area. Such models of cooperative work are not new, but there do not seem to be many such cooperative efforts in the factory communications area.

A serious impediment to the implementation of CIM is the lack of adequate tools to support cost justification. The lack of tools results primarily from the difficulty of assessing the strategic value of modernization expenditure and the integration they bring about. Management expectation for short term return on investment impose economic barriers to improvement of productivity through CIM. In essence, the current accounting practices are oriented toward capital improvements which will be obsolete in a period of less than five years, having essentially no value by the end of that time [2]. Such tactical underpinnings of accounting and the resulting investment practices do not appear to be the appropriate framework for evaluating investments relative to CIM.

Industrial systems integration includes everything from the interfaces to the individual devices at the lowest level through the highest level financial systems of the corporation. Such an integration aims at providing the end user with application solutions, while hiding the means through which that integration is achieved. Binding of major technological advances in two areas, communication technology and data management, is required to achieve these objectives. While the OSI MAP/TOP reference models have extensively addressed the communication technology issues, minimal progress has been made in the development of standards and specifications for the application to application communication logic.

Another important missing element beyond current standardization effort is a global database scheme for creating data communication applications and data management models. What is needed is a conceptual solution to the problem of effective storage, retrieval, manipulation, and management of large quantities of text, graphical, audio, and video data in a distributed, multi-application and multi-vendor environment. Such a system will result in uniform data dictionaries, data structures, storage modes and display procedures.

Summary

Faced with the challenges of today's global market place, corporate management is turning to computer integrated manufacturing, CIM, to obtain the quality level, productivity, and flexibility improvements necessary to compete. The fundamental building block of CIM is data communications. We have presented a brief overview of the data communications role in the CIM context and contemporary functional design requirements along with a number of research and development issues. An industrial MAP application is described, and several domestic and international development projects are cited. We hope that this overview will help to put the various communications for manufacturing issues in perspective and to illustrate the vitality and viability of current efforts at the design, implementation, and research frontiers.

References

[1] T. J. O'Rourke, "A case for computer integrated manufacturing," Keynote Address, *NSF Workshop on Factory Communications*, Pennsylvania State University, State College, PA, Nov. 4-6, 1987.

[2] R. S. Kaplan, "Must CIM be justified by faith alone," *Harvard Business Review*, March-April 1986.

[3] A. Kochan, and D. Cowan, *Implementing CIM*, IFS Publications, London, 1986.

[4] Y. Koren, *Computer Control of Manufacturing Systems*, McGraw-Hill International, Tokyo, 1983.

[5] R. P. Sadowski, "History of computer use in manufacturing shows major need now for integration," *Industrial Engineering*, March 1984.

[6] C. Rembold, C. Blume, and R. Dillman, *Computer Integrated Manufacturing: Technology and Systems*, Marcel Dekker, New York, 1985.

[7] P. G. Ranky, *The Design and Operation of FMS*, North Holland, New York, 1983.

[8] J. L. Hammond, and P. J. P. O'Reilly, *Performance Analysis of Local Computer Networks*, Addison-Wesley, Reading, MA, 1986.

[9] M. Schwartz, *Telecommunications Networks: Protocols, Modeling and Analysis*, Addison-Wesley, Reading, MA, 1987.

[10] *MAP 3.0 Implementation Release*, Available through the MAP/TOP Users Group, One SME Drive, P.O. Box 930, Dearborn, MI 48121.

[11] *TOP 3.0 Implementation Release*, Available through the MAP/TOP Users Group, One SME Drive, P.O. Box 930, Dearborn, MI 48121.

[12] ISO/DP 9506, "Manufacturing message specification (MMS)," Part 1, Service Definition, June 1987. Available through the MAP/TOP Users Group, One SME Drive, P.O. Box 930, Dearborn, MI 48121.

[13] *ESPRIT '85*, Commission of the European Communities, Status Report, Elsevier Science Publishers, North Holland, Amsterdam, 1986.

[14] J. Booth and B. Girard, "CNMA—putting standards to work," *Proc. of ESPRIT Technical Week*, Brussels, Belgium, Sept. 1987.

[15] P. Ghooh, "Crossroads for the MAP bandwagon," *Electronic Review*, vol. 219, no. 11, pp. 28-29, 1986.

[16] P. R. Warndorf, and M. E. Merchant, "Development and future trends in CIM in the USA," *International Journal of Technology Management*, vol. 1, no. 1-2, pp. 161-178, 1986.

[17] D. Appleton, "Current status of CIM," *Datamation*, Dec. 15, 1984.

[18] J. M. Martin, "CIM: What the Future Holds," *Manufacturing Engineering*, pp. 36-42, Jan. 1988.

[19] Special Report, "Database management: gateway to CIM," *American Machinist*, pp. 81-88, Oct. 1987.

[20] J. Suppan-Borowka, "Analyzing the performance of the MAP backbone," *MAP Application Review*, pp. 87-100, SME Publications, Dearborn, MI, 1986.

[21] A. K. Agrawal, "A distributed control system for flexible manufacturing cells," *SME Technical Paper*, MS 86-342, SME Publications, Dearborn, MI, 1986.

[22] G. A. Pelton, "An application architecture and application interface for manufacturing floor environments," *MAP Application Review*, SME Publication, Dearborn, MI, pp. 119-128, 1986.

[23] G. F. Campbell, and J. R. Pimentel, "Topological aspects of MAP network design," *11th Conf. Local Comp. Networks*, Minneapolis, MN, pp. 34-43, Oct. 1986.

[24] *Proc. of NBS Workshop on Factory Communications*, Gaithersburg, MD, March 1987.

[25] NSF Workshop on Factory Communications, Pennsylvania State University, State College, PA, Nov. 4-6, 1987.

[26] P. Ranky, *Computer Integrated Manufacturing*, Prentice-Hall International, London, 1986.

[27] "Field instrument bus standard," SP50, 2nd version, Instrument Society of America, Pittsburgh, PA, Sept. 1986.

[28] M. R. Finley, Jr, "Optical fibers in local area networks," *IEEE Communications Magazine*, pp. 22-35, Aug. 1984.

[29] E. E. Bergmann, "Fiber optics as a physical network layer for MAP," *Proc. of IEEE INFOCOM '87*, San Francisco, CA, April 1987.

[30] H. Gomaa, "Programming of multiple robot systems," *Wang Institute Technical Report TR-86-15*, Nov. 1986.

[31] H. U. Steusloff, "Realzeit-programmiersprachen," *Informatik-Spektrum*, pp. 81-93, Springer-Verlag, Berlin, 1984.

[32] G. Faerber, M. Polke, and H. Steusloff, "Mensch-prozess-kommunikation," *Chem.-Ing.-Tech.*, Nr. 4, pp. 307-317, 1985.

[33] SECS: SEMI STANDARDS (Equipment), Semiconductor Equipment and Material Institute Inc., Mt. View, CA, 1985.

[34] D. C. Sott, "Making MAP a reality—a user's view," *MAP*

Applications Review, pp. 129-135, *SME Publications,* Dearborn, MI, 1986.

[35] B. Vellieux, "Local industrial networks: applications, constraints, and solutions," *Toute Electronic,* no. 522, pp. 70-77, March 1987.

[36] R. P. Ruckman, "When I can talk to the outside world, what will I say (CIM)," *Proc. of the Sixth Annual Control Engineering Conference,* Rosemount, IL, 1987.

[37] K. Toyoda, "Setting up factory automation with MAP," *Robot,* no. 57, pp. 75-81, April 1987.

[38] G. Schaffer, "MAP climate: clouds but clearing," *American Machinist,* pp. 75-78, 1987.

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