COMMUNICATIONS RESEARCH ISSUES IN CIM

by

John N. Daigle
IEOR Department
Virginia Polytechnic Institute & SU
Blacksburg, VA 24061

Robert E. Johnson
Management Science Department
Pennsylvania State University
University Park, PA 16802

Theodore S. Rappaport
Electrical Engineering Department
Virginia Polytechnic Institute & SU
Blacksburg, VA 24061

ABSTRACT

Communication systems continue to offer potential for improving the efficiency of manufacturing enterprises through Computer Integrated Manufacturing (CIM). This potential cannot, however, be realized by developments on the communications front alone. We discuss CIM issues on several fronts and endeavor to relate developments on the communications front to what we believe to be some of the major issues for CIM. We conclude that many of the issues inhibiting deployment of CIM are systems issues rather than communications issues per se.

I. INTRODUCTION

According to McIvor [1989], "CIM is the process of replacing the human physical and intellectual contribution to individual manufacturing operations, in any such sequence of operations, by machines, in a common electronic data base environment." Granting that this is only one definition of many possible, it is absolutely clear that no such environment can ever be achieved without free communications among computers and people; that is, a mature communications infrastructure both within a manufacturing enterprise and among its suppliers and customers is a necessary ingredient to achieving full CIM.

On the other hand, if we consider the goals underlying an enterprise's strategic plans, we find that survival and achieving competitive advantage, not CIM, are the real goals. CIM is a means to an end, not the end itself. Incorporating CIM aspects into an enterprise's strategic planning in order to achieve an enterprise's objectives is a difficult issue. The role advances in communications play in achieving those objectives are equally so.

Documentation of start-up difficulties for CIM abound in the literature (McIvor [1989], Jaikumar [1986]). Successes are noted as well (Avisai [1989]). An example frequently cited is an auto plant. The plant, designed to produce 60 finished vehicles per hour, but instead produces on the order of 35.

An area in which problems were encountered is painting. McIvor [1989] reports that sometimes the robots painted each other rather than the cars; sometimes their arms fatigued and developed failures. McIvor [1989] concludes that "technologies that worked in isolated pilot projects aren't easily coordinated in the real world of high volume manufacturing."

We offer a few observations along these lines. The production objective 60 cars per hour was well established. Engineering drawings detailing the physical attributes of the auto to a close approximation probably existed on some machine at some time before the plant began operation. The amount of motion that the robots would have to undergo was at least theoretically predictable. It would appear that it was possible to develop adequate stress testing in the laboratory, but for some reason this was not done.

The importance of understanding the intended application of equipment prior to release cannot be overemphasized. For example, the first named author once led a team in stress-testing the front end processor for a main frame computer. The stress-test resulted in the correction of over 300 software bugs and more than 35 hardware problems, not counting the problems which were peculiar to the particular system under test. System integration tests had already been performed at the time of stress testing; it was startling...
news to the director of engineering that integration testing did not involve real systems! The stress test, scheduled for one week, took over two months, but in the end, the product actually worked "first time every time." The point is that the system was engineered, not managed! into productivity.

In contrast to the auto plant experience mentioned above, consider Allen-Bradley's contactor plant which deploys CIM and appears to be very successful (Avashai (1989)). It is interesting to note that the contactor business in which Allen-Bradley now competes is new to Allen-Bradley; thus, we cannot conclude that a necessary ingredient in successful CIM deployment is to have a track record in the business. We can conclude, however, the Allen-Bradley experience that success requires respect for the difficulty of the task at hand, and a thorough understanding of the entire process before deployment. One of their conclusions was that in an automated environment, tolerances have to be very tight compared to a comparable manual environment.

It is tempting to place the responsibility for poor performance for some CIM deployments in an arena other than communications, but may be an oversimplification. Consider the conclusion of Allen-Bradley's in-depth risk analysis as expressed by its CEO (Avashai (1989)) "The high risk, we concluded was not in the machines. It was in designing ... The risk was in managing the software, in integrating our information system with our control system. That had never been done." To paraphrase "the risk was in the deployment of an adequate communications system."

From the above, we conclude that a serious challenge in CIM is to integrate the enterprise's data, to make information available in such a way that it can be manipulated in order to provide the desired result. One might ask, for example, was sufficient data available to allow the engineers in charge of developing the painting robots to do probabilistic modeling to determine the characteristics of the motions the robots would have to undergo on the production line under rated capacity?

All of this taken together gets us on the track of a plausible role of communications in CIM. Communications can make it possible for everyone to have access to data needed to conduct the analyses which are required to assure success throughout the project beginning with project conception and continuing through production and sales.

This is not to say that automation cannot be achieved without additional giant strides in communications systems and technology. The Japanese have operated highly mechanized production systems for over ten years with a great deal of success. But communications can help. For a review of aspects of the differences between the US experience and the Japanese experience, see Jaikumar (1986); a quote from that article which summarizes the possibilities of CIM is the following: "Their productivity was stupendous."

So, what's the difference? One of the characteristics common to the Allen-Bradley and Japanese experience is that the enterprises are both managed by small teams of engineers. Without reference to Allen-Bradley, this is what Jaikumar recommends. We note that here we have a professor of management of the Harvard business school telling us that we had better have engineers in charge if we want to be successful in CIM! Note the operative is engineers not engineers!

ROLE OF COMMUNICATIONS

Typical Uses of Communications

Factory decisions requiring support from data communications systems can be grouped into three categories: Scheduled, Real-time, and Emergency. Scheduled communications, as the name implies, can be done off-line. Information in this category includes equipment configuration change data and scheduled changes in the production schedule. In many cases, these updates can be done offline with minimal impact on the data communications system.

At the other end of the spectrum are emergency communications; these include quality control and machine breakdown interrupts. Transmission of emergency information must be done in real time, and requires quick access and minimal delays in the system for quick response to failure conditions.

The real-time category may be the most difficult (Avashai (1989)). In this set of demands are database queries that may delay production initiation; for example, the routing and tooling inquiry necessary when a pallet of material arrives at the input station of a flexible manufacturing system. At this level, the long-term information system intersects with the control system.

Factory Automation is not CIM

Many, many technological advances which have the potential for contributing to CIM have recently come about. These include giant strides in the autonomous capabilities of workstations together with the ability to intercommunicate with virtually any other computer in the enterprise. These workstations, which control actual manufacturing operations by supervising manufacturing equipment, obtain their instructions from cell controllers and higher levels as well (see Jun and McLean (1988) and the references therein).

Given the computational and communications capabilities of the cells, there is the potential to link
workstations together in an harmonious association reminiscent of the railroad construction crews of the movies; everyone knowing what everyone else is doing, when the materials are coming, communicating via telegraph, knowing when letters are coming, covering the country in railroad tracks in perfect harmony.

Other areas in which giant strides have been made are in automated network design tools and automated network management tools such as those reported in IBM [1988] and IEEE [1988c], incorporating AI features and Expert Systems to facilitate the manipulation of enormous amounts of data. Additionally, the technology for interfacing human beings with application programs, including communications packages, is beginning to reach acceptable levels as is evident to anyone who has observed a novice using certain personal computers which have graphical interfaces [see Hornbeck and Mills [1989] for convincing evidence related to communications networking).

Potential is the key here. We would be well advised to take some lessons from the "office of the future" experience. Since at least 1957 we have been looking forward to the office of the future; it is still in the future. We still have huge numbers of "islands of automation" similar to those found in the manufacturing environment. Many of these islands are capable of, and enjoy, intercommunication, but with very little contribution to competitive advantage.

Some projections on future technological aspects of communications within the factory are presented in a later section, but we will argue later that such innovations are necessary, but not sufficient ingredients in achieving CIM.

More is Not (necessarily) Better

With regard to delivering data for decision purposes, there are times when the action required is obvious; for example, a quality control interrupt requiring machine maintenance. In other cases, the correct action due to the new information may not be clear. Job shop scheduling and material requirement planning (MRP) algorithms are of necessity heuristics since the underlying problems, even in simplified form, are computationally intractable (NP-hard) problems. The history of MRP software provides an interesting example where the improvement in communications resulted, for a while, in worse decision making.

MRP systems coordinate the production of final products and all the subassemblies and components in the products, driven by a master production schedule for the finished goods. Most MRP systems were originally run in batch mode over the weekend; the run summarized all changes in orders, inventory, and factory status from the previous week. Advances in communications and software eventually allowed vendors to create a "net change" MRP system where every transaction could be reported in real time from a terminal; the system would then calculate the incremental affect of the change and adjust the instructions accordingly. The immediate result in many cases was a system that did a worse planning job than the old batch system. Subsequent investigation showed that the problem was that, over a week, many changes in demand and status cancelled each other out and that waiting a week to determine the net effect of the changes was more effective (Orlucky[1975]).

In general it is important to assess the quality of the information brought by additional data movement and the quality of the decision made from that information before considering whether to speed up the flow of information within the system. It is interesting to note that scheduling in many plants is done on a "seat-of-the-pants" basis. Scheduling aspects of software support systems are often ignored. For a review of the reasons this is so, see McKay et. al. [1988].

Engineering is the Answer

A most desirable attribute of CIM is its potential for flexibility. That is, we want CIM because we hope to gain competitive advantage by satisfying customer demand on a more personal basis, be the product an automobile or a fruit jar. We project demand for automobile customized to an individual customer's preferences, the automobile to be delivered on a timely basis (that is, while the customer still really wants the specified set of features being purchased).

The big question is, "what types of demand does a particular firm want to meet?" The answer, of course, lies in whether or not the enterprise sees the product line in its strategic plans together with whether or not the enterprise can compete effectively in the product area. This question must be answered in the context of increasing customer demand for quality. With regard to automation, it is not sufficient to be able to meet current standards but to meet the standards of the future.

The answer to the big question appears to lie in engineering. That is, the product from raw materials to delivery should be completely understood before large capital outlays occur. We have to develop a vision on how the raw materials, and parts will be converted into the product in very realistic terms, how the completed product will be stored, how the product will be marketed and delivered, and how the product may evolve. This would appear possible only through completely engineering the entire production and delivery system on paper prior to committing to the product.
The key to achieving sensible answers to the big question is data integration. This means that data must be available and in a usable form to all who need it in order to get the job done. In addition, it must somehow be made known that the data is available. Progress at the application and presentation layers of the communication protocol stacks are of paramount importance in obtaining this knowledge.

Judging from the relative experiences of the Allen-Bradley contactor plant and the auto plant, it does not appear that experience in a particular product line is as significant factor as it might appear at first glance. The auto maker had an incredible amount of experience building little contactors. Judging from the relative experiences of the Allen-Bradley contactor plant and the auto plant, it does not appear that experience in a particular product line is as significant factor as it might appear at first glance. The auto maker had an incredible amount of experience building little contactors. Only an extremely skilled observer could determine which of the undertakings was the more ambitious in terms of available resources, and it is tempting to conclude that the contactor plant succeeded because it was so simple. But, on the other hand, the contactor plant produces hundreds of different products, carries no inventory, has incredibly short turn around time, high machine utilization, and very few rejects. Although the automobile production facility may be extremely complicated compared to the contactor plant, one would not expect that to be the case in the painting subsystem.

INFORMATION RELATED TASKS

information flow

Multi-stage manufacturing systems generally contain most or all of the hierarchy of stages as defined in the Automated Manufacturing Research Facility at the National Bureau of Standards: Facility, Shop, Cell, and Workstation or Machine levels (IEEE, 1988b). At each level, data is transmitted and received from the levels above and below that stage; before designing the hardware for data communications to operate in this environment, it is necessary to understand what data is needed and how often it is needed to support the decision process at that stage.

At the Facility level, corporate management data is combined with forecasted demand to create a Master Production Schedule (MPS) which is passed down to the Shop level. This stage is almost always done by humans in an interactive planning process. The MPS is created on a scheduled basis.

The Shop level converts the MPS into specific instructions for the Cell level; this is often done with an MRP and shop scheduling system. Data from the Cell level is required here to reflect the status of the shop and work-in-process inventory levels in the current production schedule. As noted above, the frequency with which the MPS/MRP schedule can be redone is a significant issue here; whenever the production schedule is revised, it must be transmitted to the Cells.

At the Cell level, the demands imposed by the Shop schedule are resolved by scheduling the intra-cell routing, transportation and production plans. The Cell scheduler receives information from the Workstations on job status; it also must monitor emergency information such as quality control and machine failure interrupts for transmission to the Shop level.

The Workstations receive directions from the Cell as to the sequence of parts and job tasks to perform; they report job and machine information back to the Cell controller.

Communications Problems

The preceding section briefly describes some of the communications channels and required information handling necessary to support CIM. The principal problem in estimating the communications requirements is the mixture of planned and unplanned communication necessary to support the system. It is clear that ignoring the state of the shop when planning a schedule is incorrect, since such schedules in general will be infeasible. It is equally clear that every tool failure should not propagate up the hierarchy to require a revision of the master production schedule. What is not clear is to what degree the system should respond to changed information. How many tool failures should be tolerated before we incur the cost of reloading this week’s schedule? How many changes in sales forecast should be accumulated before the production schedule is recalculated? These issues are not new; what forces their consideration is the formality of the planning and control process that CIM requires. When most of the planning process is done by humans, a network of informal decision rules grows out of experience in operating the system. If one is to achieve the goal of an integrated factory that operates without regular human intervention, these rules must be made explicit. Making certain decision rules explicit will also determine the requirements for some of the data communications channels. For example, shop schedule revisions can either be a real-time issue or be confined to predetermined intervals; the communications requirements differ drastically.

TECHNOLOGY FOR THE FUTURE

Some present day communications problems Capabilities for factory communications continue to evolve at a rapid pace. In a little over 6 years since its inception, the Manufacturing Automation Protocol (MAP) has been installed in numerous plants, and
many networking strategies are being adopted for factory communication networks; see Fong and Reinstedler [1989] for an up-to-date application description and Chapin [1989] for a status report on ISO and related standards.

While these are important uses, the potential is not being realized because the time delay involved in the end user-to-computer interface is often very great. Sometimes, it is the relatively low data rate communications among personnel in manufacturing that hampers productivity.

In order to stay competitive, manufacturers are finding it necessary to tighten the communications loop between the production line, quality control, and the design staff. Many times, in small batch production runs, daily (or hourly) revisions to the manufacturing process are required based upon the dynamic needs of the customers. This is particularly the case, for example, in the custom metal working industries, the heavy truck industry, and the electronics industry. As an example, in the heavy truck industry, a customer may wish to purchase a few (less than 10) trucks which have a customized steering mechanism. The customization may involve a new part, or may simply require a new retrofit using existing inventory. Such an order often results in confusion and delay, because the shop floor personnel are unfamiliar with the proper installation procedures. Communication with the design engineer or another on-site specialist is needed before the order can be filled. The delays encountered by the shop floor result in large monetary losses as the custom product sits in the factory or in storage. Networking for factory floor personnel is discussed in Anderson [1989], which appears later in this Proceedings.

We see these technologies as being classifiable in four groups: expert systems, wireless networks, radio frequency (RF) tags, and others. Expert systems have been previously mentioned. Wireless communications is and RF tags are covered elsewhere in this proceedings by Rappaport and Schettler, respectively. We mention these only briefly.

Wireless Information Networks (WINs)

The need to establish communication links on a timely basis is vital for more efficient manufacturing. Daily voice communications between managers, engineers, and customers must be made without regard to the location of each party. A wireless, mobile communications system can accommodate voice traffic within a building easily, and some systems are becoming commercially available today. For an more in-depth discussion, see Rappaport [1989] and the references therein.

RF Tags for Manufacturing

In present day assembly, a paper card is often attached to parts-in-process to store the bill of materials, inspection results, and rework history. The paper can now be replaced by a small integrated circuit known as an RF tag (Schettler [1988]). The tag is a passive device which contains static and dynamic memory. When passed through a radio field having the appropriate frequency and modulation, the tag is powered (through rectification of the received radio energy) and becomes a tiny transceiver, capable of reading data from, and transmitting data to, a radio scanning unit. The scanning unit is connected to a computer, thus the tag becomes another peripheral storage device for the computer. In future factories, the radio scanning unit (or the RF tag itself) will be directly addressable by the Wireless Information Network, so that inventory databases and expert systems may be updated in real time.

The RF tag lends itself readily to automated warehouses. Just as barcode readers are being used today in shelving and inventory, RF tags will permit automated shelving and parts retrieval, but with greater distances between the transmitting device and the receiving device, and without the need of a line-of-sight path between the two. For a more in-depth discussion, see Schettler [1989] and the references therein.

Other Future Communication Capabilities

Two other communications capabilities that will aid manufacturing include improved vendor communication links and improved techniques for transferring high bandwidth material such as drawings and associated graphic arts. In order to implement true just-in-time (JIT) manufacturing, vendor co-operation is key, and the factory and vendor must mutually be able to quickly adjust their delivery schedules. A recent trend in the trucking industry is the use of satellite navigation and communication to permit instant mobile communications between individual trucks and the dispatcher McKnight [1989]. This capability offers great potential for U.S. manufacturing, as it is now possible for the first time to have flexibility in trucking. If a particular plant is in need of raw materials, vendors can now ask trucking companies to make unscheduled pickups and know the exact times at which such pickups occur.

Very small aperture terminals (VSATs), which are small satellite transceiver stations operating in the microwave radio spectrum [10], offer instant communications with other plants and vendors. Such links are useful for transmitting high speed data, such as text, video information, and graphics, between two places
without incurring the delays of mailed material or the expense of leased wire lines. Many times, transponder air time can be rented at rates which are more economical than telephone lines. From the telephone side, the application of the Integrated Digital System Network (ISDN) may support large bandwidth file transfers economically over long distances.

REFERENCES


BIOGRAPHICAL SKETCHES

John N. Daigle is Associate Professor of Industrial Engineering and Operations Research at Virginia Polytechnic Institute and State University, Blacksburg, Virginia. He has been a faculty member of the electrical engineering departments of Washington State and Clemson Universities, a faculty member of the University of Rochester, and held engineering positions at Bell Laboratories and the NCR Corporation. He has analyzed numerous problems related to the performance of computer communication systems. Prof. Daigle is an active Senior Member of IEEE, having served as chairman of the IEEE Communication Society's Technical Committee on Computer Communications and on the technical program committees of numerous IEEE conferences and workshops. He is currently publications editor for IEEE Network. Mr. Daigle holds the B.S.E.E. and M.S.E.E. and the Eng.Sc.D. in operations research, the latter from Columbia University.

Robert E. Johnson is Assistant Professor of Management Science in the College of Business Administration at the Pennsylvania State University, University Park, Pennsylvania. He has previously taught at the University of Rochester and the Ohio State University and has held engineering positions at Bell of Pennsylvania. Professor Johnson served as assistant director of the Center for Manufacturing and Operations Management at the University of Rochester, and has done research and consulting in problems related to the management of automated manufacturing systems. He is a member of ORSA, TIMS, and IEEE. He holds the B.S.E.E., M.B.A., and the Ph.D. in Operations Management, the latter from the University of Rochester, Rochester, NY.

Theodore S. Rappaport is Assistant Professor of Electrical Engineering at Virginia Polytechnic Institute and State University. He is a member of IEEE and the Radio Communications Technical Committee of the Communications Society. He holds a patent for an indoor antenna and is presently conducting research in indoor radio propagation, indoor communication systems design, and digital signal processing for cellular communications. He consults often for radio communication companies. He received the B.S.E.E., M.S.E.E. and Ph.D. degrees from Purdue University. He is a member of TBII, IIKN, NSPE, and is a life member of the ARRL.