Computer Integrated Manufacturing: Empirical Implications for Industrial Information Systems

JOHN JOHANSEN, UDAY S. KARMARKAR, DHANANJAY NANDA,
AND ABRAHAM SEIDMANN

JOHN JOHANSEN is Professor of Manufacturing Management at the Southern Denmark Business School. His current research interests include production planning and control, management strategy and design of production management systems, logistics, and supply chain management. Professor Johansen holds a master of science degree in production management from the University of Aalborg. He has participated in several national and international research programs.

UDAY S. KARMARKAR is Times Mirror Professor of Strategy and Director of the Center for Technology Management (CTM) at the Anderson Graduate School of Management at UCLA. His research interests include manufacturing management, technology management, and operations strategy for manufacturing and service firms. Professor Karmarkar holds a B.Tech. degree in chemical engineering from I.I.T., Bombay, and a Ph.D. in management science from M.I.T. He previously taught at the GSB, University of Chicago, and at the Simon School, University of Rochester. Professor Karmarkar is a founding editor of the *Technology and Operations Review*, and coeditor of the series *Perspectives in Manufacturing and Technology* (Harvard Business Press). His research has appeared in *Management Science, Operations Research, Econometrica, Harvard Business Review, IIE Transactions, European Jounal of O.R., Naval Research Logistics Quarterly*, and *Organizational Behavior and Human Performance.*

DHANANJAY NANDA is a doctoral student at the William E. Simon Graduate School of Business Administration, University of Rochester, Rochester, New York. He received his bachelor of science in mathematics from St. Xaviers College, University of Bombay, his masters in management studies from the University of Bombay, and a master of science in management science from the University of Rochester. His main interest is in the field of production economics as it relates to modern manufacturing and service systems, the study of incentives and contracting in supply chains, and modern planning and control systems.

ABRAHAM SEIDMANN is the Xerox Professor and Areas Coordinator of Computers and Information Systems, Management Science and Operations Management at the William E. Simon Graduate School of Business Administration at the University of Rochester, Rochester, New York. Professor Seidmann is the author of numerous research articles and is a Department Editor on Interdisciplinary Management Research and Applications in *Management Science*. He is also an Associate or Area Editor for *IIE Transactions, Production Planning and Controls, Journal of Intelligent*

Journal of Management Information Systems / Fall 1995, Vol. 12, No. 2, pp. 59–82

Manufacturing, Production and Operations Management, and *International Journal of Flexible Manufacturing Systems*. His current research and consulting activities include strategic business information systems, business process reengineering, information economics, management and analysis of financial information systems, risk management and internal controls. He has several years of experience as a senior banking officer. Professor Seidmann has consulted with many leading corporations and presented research or executive seminars in four continents.

ABSTRACT: This paper describes the results of a recent field study of computer integrated manufacturing (CIM) adoption strategies in U.S. manufacturing firms. The purpose of the study was to identify the extent to which CIM technologies are in use in U.S. firms, the impact of a facility's process characteristics on the CIM development process, and the adoption policy being followed implicitly or explicitly. The survey focused on manufacturing process characteristics, the CIM development process, the CIM architecture, and perceived value and benefits. Our results indicate that CIM implementations follow a definite temporal pattern with respect to the adoption of certain information technologies. We also find evidence of labor substitution through CIM, although the direct labor jobs that are lost are partially replaced by engineering and design tasks. While most CIM users find that their CIM projects successfully meet their initial operational goals, the technology seems to be poorly integrated in most sites. More crucially, it appears that CIM does not live up to its promise: it is not being adopted as a strategic information system for competitive missions. The initiative for CIM programs is usually generated from the bottom–up by small groups of technical experts who tend to focus on localized data-processing concerns. This gradual bottom–up approach appears to severely restrain, rather than enable, plant-wide integration for critical crossfunctional business processes such as order fulfillment or the introduction of new products. The decentralized, bottom–up, development pattern of these information systems reinforces the existence of many incompatible divisional islands of automation, thereby negatively affecting the competitive capability of the firm.

KEY WORDS AND PHRASES: adoption of information systems, computer integrated manufacturing.

COMPUTER INTEGRATED MANUFACTURING (CIM) IS A TERM THAT IS BROADLY applied to the set of computer and communication technologies employed in manufacturing management. While CIM has different interpretations, we take the term to encompass three major subareas:

1. Factory communication hardware and software;
2. Data management, including collection, storage, and retrieval;
3. Applications software and hardware, including material planning and control, quality systems, inspection and vision, computer-aided design/computer-aided manufacturing (CAD/CAM), and computer-aided process planning/computer-aided engineering (CAPP/CAE).

The unified flow of information across various business functions places particularly high demands on the integration requirements at the organizational level. The exchange of data between departments also gives rise to complicated data-transfer procedures. For instance, sharing geometric CAD files with production requires that the information implicit in the CAD system be automatically assimilated into the primary data for the bill of materials. In addition, the data required for process planning and design-stage cost estimation must also be available. The interdependence of order management, product design, production planning, material management, quality assurance, and process control presents a clear challenge to hardware and software vendors who must coordinate their independently developed systems for technical and business use.

Much of the rapidly proliferating literature on CIM has dwelt on its technological aspects and its potential. There is perhaps a natural tendency to present the technology as a panacea and to emphasize the outstanding "high water marks" of its implementation, such as the well-known Fujisawa plant of IBM Japan [29] or the Pratt & Whitney and General Electric factory showcases [26]. Rosenthal's [30] extensive 1982–83 factory automation survey dealt with some of the early technologies preceding the personal computer revolution. It focused on future adoption plans by various companies but had limited data on the actual ex-post business benefits of CIM. The survey showed that most users proceeded in an incremental fashion. Our current results corroborate these early findings. Moreover, we explain and evaluate them in a different manner based on the relative characteristics of the users.

De Meyer [9] studies the computerized integration of several business functions, such as inventory planning, accounting, and product design, in European firms. In a series of cross-sectional studies, he shows that the most often integrated functions include sales planning with master production scheduling and process control with quality reporting. His study does not address the technological impediments to integration or the relative contributions of the various enabling technologies. Over time the decline in the cost of automation technologies has enabled manufacturers to adopt sophisticated production systems. Initial adoption of these systems has forced competitors to follow the leaders in the implementation effort or exit their industries. Although factory automation seems to be critical to the survival of many firms, it is still not clear from current MIS or operations management research literature whether CIM has been used mainly as a ubiquitous support function or as an important element in achieving a sustainable competitive advantage in products or markets [5, 6, 27].

Our survey of randomly selected plants had two main objectives. First, we sought to analyze approaches to adopting CIM across a wide spectrum of U.S. firms. We expect that the example of CIM will provide tentative insights that can transfer to other plant-wide information technologies; for example, we expect that there are natural parallels with the adoption of electronic data interchange (EDI) in supply chains or the use of information and automation technologies in service industries with respect to the integration of functions. Second, the survey investigated the temporal deployment patterns of CIM in an attempt to identify the interaction between the adoption of the technology and product or process characteristics. Identifying the interaction may help identify the characteristics of plants with greater technological integration. Understanding their product, process, and plant characteristics will assist in evaluating and formulating more effective integration and standardization policies in the future.

processes, system performance, and functionality. In this context, integration suggests that no part or function of the company should be considered in isolation; each should be viewed as part of a coherent whole, including marketing, sales, design, engineering, production, accounting, and finance. It is apparent that there are many ways of achieving integration without computer technology, ranging from JIT and TQM to changes in organizational structure and incentives. Business process reengineering is perhaps the latest attempt to address some of these issues.

CIM implementation necessarily goes far beyond the technology; the human and organizational aspects of CIM also play an important role [20]. Research on CIM has broadened in recent years to include more emphasis on understanding these other aspects of CIM in all phases of a system's life-cycle. Examples of practical approaches to implementation include Mortimer [25], Gunn [14], Feeney [12], and Benhabib et al. [2]. These approaches have many similarities, such as a call for top–down implementation. A common issue is the question of whether a top–down or bottom–up approach is appropriate. Tracy et al. [34] conclude that there is no unequivocal answer to this question; each of the approaches is valid for some, but not all, situations. Another important organizational aspect is the rapidly declining price to performance ratio of hardware, which is facilitating the incorporation of more decentralized control architectures on the shop floor [4].

A Framework for Adoption of CIM Technology

IN THE INTRODUCTION WE MENTIONED TWO ALTERNATIVE PARADIGMS for technology adoption: bottom–up and top–down. Here we outline a more extensive framework for analyzing the extent and nature of adoption.

Technology adoption is a process that evolves over time. When an entire family of related technologies (e.g., CIM) is considered, the process includes many steps in the acquisition, interfacing, and integration of the technologies. To ensure a homogeneous and continuous migration path, one must consider all areas of the company. Most design methodologies addressing this issue include the following steps [7]:

- Initiation and motivation;
- Justification;
- Design (general architecture, detailed design);
- Integration;
- Implementation;
- Operation.

These steps are not necessarily sequential; for example, design may or may not precede justification, depending upon the complexity of a specific technology or case. Similarly, steps such as integration may occur repeatedly as new technologies are acquired. Some steps in the adoption process must necessarily occur at the detailed functional level (e.g., detailed design and operation). However, other steps can occur in a top–down or a bottom–up manner; thus, initiation of the adoption process, or justification of a system, could be through either strategic initiatives or local initiatives.

From the organizational viewpoint, we can categorize steps in the process as business or technical decisions. In general, technical decisions will tend to be made at local levels. However, the central issue in CIM—integration—can be pursued from above or below.

In order to reflect these process and organizational issues, we collect the observations and conclusions from our study into three hierarchically organized levels:

Business strategy: initiation and justification;
Technology management: design and integration;
System status and success factors: implementation and operation.

Each of these levels rests to some extent on the observations made at lower levels. As might be expected, the conclusions at the "higher" levels are more qualitative. In the next sections we develop our hypotheses, present the results of our statistical tests, and discuss the conclusions.

Research Methodology and Statistical Analysis

AS STATED EARLIER, THERE ARE ONLY A FEW FIELD STUDIES on the deployment process and the actual business impact of CIM in the United States [33]. We therefore started our research with hypothesis building as proposed by Eisenhardt [11]; the hypotheses were based on several in-depth field case studies conducted by us at several plants of Xerox, General Motors, IBM, and others. Analyzing this set of comparative case studies led to our key hypotheses and a detailed survey questionnaire.

1. We expected justification and initiation to be done at a higher level, or top–down, because integration projects supporting the strategic dimensions of CIM require major capital investments and plant-wide organizational changes.
2. Given the high cost of acquiring CIM technologies, the scale of manufacturing operations must be large enough to justify the implementation effort. Hence we expected to find a greater degree of CIM in large facilities, both in terms of production volume and in terms of the number of employees. In addition, one of the anticipated benefits of CIM is its ability to help in dealing with the multitude of coordination tasks in a manufacturing environment, so the scale of CIM should be positively related to the complexity of both product and production process.
3. CIM has been traditionally perceived to automate facilities, and in so doing is thought to substitute capital for labor. One should then find the degree of CIM related to a reduction in direct labor and an increase in the employment in support activities such as design and engineering.
4. Finally, the level of CIM should be directly related to a reduction in lead time, reject percentages, setup time, and downtime. In particular, we expected control-oriented technologies to be positively associated with a reduction in queuing, lead times, setup times, yield rates, and downtimes.

Having formed several key research hypotheses, we mailed an extensive questionnaire to 400 manufacturing facilities located throughout the United States. The plants belonged to SIC codes ranging from 33 through 39 and thus comprised a varied cross-section of manufacturing industries. The responses do not include more than one plant for any one company. This is desirable, since we avoid firm-specific effects that could confound the cross-sectional impact of CIM. We received thirty-three completed questionnaires. The sample is definitely not representative of U.S. industry because of a response bias arising from the fact that only plants with a certain level of CIM have responded. We thus make no conclusions about the aggregate use of CIM in the United States.

Our sample consists of plants that are fairly representative of their respective industries, in terms of size. Almost half the facilities that responded were similar in size to an average plant within their respective industries; about 25 percent were larger, and the remaining 25 percent were smaller. The mean number of employees per plant was 589, but only 13 percent of the sample had more than 1,000 employees, and only 12 percent had fewer than 100 employees (a detailed discussion can be found in [17]). Almost 90 percent of the plants that responded used multiple shifts (two or more). The sample also has a variety of process types and characteristics. Only 18 percent of the plants use a continuous flow process, and 79 percent work in a make-to-order mode. A number of the facilities use multiple process types. One-third of our sample uses synchronous processes, either continuous-flow or batch processes. One-third of the plants also face seasonal variation in production. The plants display a variety of process and product complexity; 72 percent have fewer than five stages in a typical bill of materials of their products, and 55 percent have fewer than ten operations in a typical route sheet.

The Measurement Indices

To study the adoption and impact of computer integrated manufacturing we constructed measures that allowed us to create a metric, through simple aggregation, and helped simplify the statistical analysis. These indices measure the degree of automation, the number of CIM technologies that have been adopted, and the number of areas affected by CIM or the number of production management functions that it serves within the facility. These indices are described below.

Automation Index (AUT)

Respondents were asked to indicate the degree of automation on a four point scale varying from no automation (0) to highly automated (3). The mean score was 1.27.

CIM Index (CIM)

This measured the number of distinct CIM technologies that the facility uses. We provided a list of thirty key manufacturing information technologies (see figure 1) that

Time Scale	CIM Technology	Production Function
Days	Computer Aided Design (CAD)	Design
↑	Computer Aided Engineering (CAE)	|
|	Relational Data-base for Product Design (RDB-Product)	|
|	Technical Office Protocol for Office Data Networks (TOP)	|
|	Automated Shop Scheduling System	|
|	Computer Aided Process Planning (CAPP)	|
|	Electronic Data Interchange (EDI)	Planning
|	Group Technology (GT)	|
|	Material Requirement Planning (MRP)	|
|	Relational Database for Manufacturing Resources (RDB-Mfg.)	|
|	Tool Requirements Planning Information System (TRPIS)	|
|	Local Area Network (LAN)	|
|	Manufacturing Resource Planning (MRP II)	|
Hour	Tool Management Systems	|
|	Automated Data Collection Equipment (ADCE)	|
|	Automated Statistical Process Control	Scheduling
|	Bar Coding and Scanning	|
|	Cell Controllers	|
|	Computer Aided Inspection (CAI)	|
Min	Computer Aided Manufacturing (CAM)	|
|	Just-In-Time Manufacturing (JIT)	|
|	Machine Vision	|
|	Manufacturing Automation Protocol for Data Networks (MAP)	Control
|	On-line Machine Diagnostics (OLM/C)	|
|	Pallet Management Systems	|
|	Process Controllers	|
↓	Real Time Shop Floor Control (RSFC)	|
Sec	Sensor Systems	|
N/A	AI/Expert Systems (AI/ES)	Other
N/A	Decision Support Systems (DSS)	Other

Figure 1. CIM Technologies Comprising the CIM Index

are associated with CIM, and respondents had to indicate the ones that were in use at their facility. On average, a plant had nine of these technologies, and the scores ranged from 0 to 22. Over 60 percent of the plants had implemented fewer than ten technologies. The CIM index was further disaggregated into four distinct subindices depending on the basic function that a particular technology served: planning (P), control (C), design (D), and other (O). This disaggregation allowed us to study a particular area of CIM and gauge its impact on the organization.

Impact Index (IMP)

This index measured the number of production management functions that are supported by the CIM system (see figure 2). The respondents were provided with a list of eighteen functions and the sample scores ranged from 0 to 15. The mean impact index was 7.4, and 70 percent of the sample scored less than 10. A high impact index coupled with a medium or low CIM index shows the presence of more general-purpose technologies. A high impact index also indicates a need for integration of heterogeneous technologies. In the absence of an integrated effort, adoption leads to islands of automation that work at cross-purposes. Thus, the number of production management functions serves as an index of the need for integration.

The statistical analysis was intended to test the hypothesized relationship between adoption of CIM technology and the various characteristics of the surveyed plants. We divide this section into subareas that explain the interaction of the goals of CIM deployment with the process used in implementation, the interaction of the level of CIM with plant and process characteristics, and the impact of CIM on plant-wide performance measures and the level of employment in key areas. Many of the relationships are too complex or fuzzy to be clearly stated as statistically testable hypotheses. Furthermore, this complexity, when combined with the size of the data set, makes it difficult to achieve high significance levels with statistical tests. As a result, we have taken a mixed approach to the analysis of the responses. In some cases, statistical methods can indeed be applied. In other cases, where the nature of the issue or the scarcity of the data precludes a clear technical analysis, we have presented the data directly and commented on the observed patterns. Some of the observations are based on the case studies and the extended comments made to us by survey respondents.

The Strategic Role of CIM

The vast majority of our firms used a bottom–up approach to adoption, which restricted our ability to test for correlation of implementation strategy with the size variables. Tables 1 and 2 provide summary statistics of the goals of CIM deployment and its implementation process. The overwhelming majority (76 percent) of the CIM implementations were motivated by a need for *operational improvement*, and respondents did not perceive CIM as a strategic weapon. The operational improvements cited were *direct cost savings*, *quality enhancement*, and *enhanced manufacturing performance*.

	Function
1.	Backward/Forward Scheduling
2	Bottleneck Planning
3.	Capacity Requirements Planning
4.	Cyclic Planning
5.	Gantt Chart-based Planning and Machine Load Techniques
6	Group Technology (GT)
7.	Hybrid Planning Methods
8	Input/Output Control
9.	Just-In-Time (JIT)
10.	Kanban
11.	Lot Sizing
12.	Master Production Scheduling
13.	Material Requirements Planning
14.	Net Change MRP
15.	Production Activity Control
16.	Rough-cut Capacity Planning
17.	Shop Floor Control
18.	Total Quality Assurance (TQA)

Figure 2. Production Management Functions Comprising the Impact Index

Only one firm deployed CIM to *integrate* its processes. The use of internal departmental or interdisciplinary teams to conduct the implementation seemed to dominate the responses (92 percent); only two firms used external vendors or consultants. With the proliferation of consultants and vendors, one would have expected to find widespread use of external teams, yet our results indicate otherwise.

We classified the implementation process into three categories. The *big leap* is a concerted effort to deploy CIM over a wide range of production management functions. If the implementation is conducted piecemeal or as a coordinated set of projects, it is referred to as a *phased change*. Finally, a fragmented type of deployment is referred to as *uncoordinated projects*. The evidence reflects the popularity of the phased-change process, with 48 percent of the respondents admitting to using it. Surprisingly, 32 percent of the respondents implemented CIM in a series of uncoordinated projects. The choice of the process does not seem to be influenced by the goals of the firm regarding CIM.

Table 1 Analysis of CIM Goals and Development/Deployment Strategies

CIM goals	System integrator		Total
	External vendor	Internal team	
Strategic	4.0%	20.0%	24.0%
Operational	4.0%	72.0%	76.0%
Total	8.0%	92.0%	100.0%

Table 2 Analysis of CIM Goals and the Implementation Process

CIM goals	Implementation process			Total
	Big leap	Phased change	Uncoordinated projects	
Strategic	4.0%	8.0%	12.0%	24.0%
Operational	16.0%	40.0%	20.0%	76.0%
Total	20.0%	48.0%	32.0%	100.0%

CIM and Plant/Process Characteristics

Table 3 displays the correlation between the extent of automation, our indices, and the process characteristics of the plants. Despite the small sample size a number of correlations show predictable significance.

CIM and Plant Size

There were three measures related to the scale of manufacturing operations: the number of employees, the number of shifts, and the size of the plant relative to others in the industry. The CIM index and the degree of automation are both positively and significantly correlated with the number of shifts in the plant (0.357 and 0.377, respectively). Only the CIM index is related to the number of employees in the facility (0.486); this provides evidence that larger plants are more likely to have greater automation, a finding that is corroborated by Swamidass [33]. All the subcategories of the CIM index were related positively to the number of employees. On the other hand, the relative size of the plant had no significant association with any of the indices, which implies that CIM and other automation technologies are likely to be concentrated within industries characterized by large-scale plants. Swamidass also finds that automation technologies, both "hard" and "soft," are found clustered among certain industries. Among the four subcategories of the CIM index, only the control index (C) is related positively and significantly to the number of shifts. Plants with more shifts are generally characterized by high production volumes with standard and repetitive

Table 3 Correlations between Performance Indices and Sample Process Characteristics

Index	Process characteristics								
	Number of employees	Number of shifts	Relative size	Make-to-order production	Batch production	Continuous flow production	Number of stages in BOM	Number of stages in route sheet	Production seasonality
Automation	0.138 (0.44)	**0.357** **(0.04)**	0.156 (0.38)	**–0.384** **(0.02)**	0.182 (0.31)	–0.263 (0.14)	0.186 (0.30)	0.269 (0.14)	0.081 (0.65)
CIM	**0.387** **(0.02)**	**0.288** **(0.10)**	0.119 (0.50)	**–0.423** **(0.01)**	**0.396** **(0.02)**	0.272 (0.12)	0.132 (0.46)	**0.334** **(0.06)**	0.042 (0.82)
Impact	0.146 (0.41)	0.106 (0.55)	0.231 (0.19)	0.041 (0.82)	**0.299** **(0.09)**	**0.507** **(0.00)**	0.006 (0.97)	–0.115 (0.53)	–0.208 (0.24)
Planning	**0.434** **(0.01)**	0.184 (0.30)	0.044 (0.80)	–0.213 (0.23)	**0.301** **(0.09)**	**0.362** **(0.04)**	–0.125 (0.95)	0.198 (0.28)	–0.046 (0.79)
Control	**0.460** **(0.00)**	**0.329** **(0.06)**	0.160 (0.37)	**–0.431** **(0.01)**	**0.354** **(0.04)**	0.206 (0.24)	0.101 (0.57)	0.275 (0.13)	0.074 (0.68)
Design	**0.327** **(0.06)**	0.174 (0.33)	0.112 (0.53)	–0.272 (0.12)	**0.350** **(0.04)**	0.239 (0.18)	**0.400** **(0.02)**	**0.309** **(0.09)**	0.175 (0.32)
Other	**0.507** **(0.00)**	0.203 (0.25)	–0.283 (0.11)	–0.160 (0.37)	0.198 (0.26)	0.197 (0.27)	0.025 (0.88)	0.166 (0.37)	**0.345** **(0.04)**

Significance levels indicated in parentheses.
Correlations significant at 10% or less indicated by boldface.

manufacturing tasks, since they require greater operational coordination and demand better process and product controls to assure consistent outgoing quality.

CIM and Process Type

There is some interaction between the process type and the nature of the CIM implementation. Nonrepetitive and specialized facilities are not as likely to automate. Both the degree of automation and the CIM index are negatively correlated with make-to-order production (–0.384 and –0.423, respectively). The control function is the least prone to automation (–0.431) in these plants. The specialized, nonrepetitive nature of production in these plants is not conducive to existing automation technologies. Batch production tends to be more repetitive and requires greater flexibility in setups and changeovers. The CIM technologies that are likely to be used in this environment are general-purpose systems that improve overall throughput and efficiency. The presence of batch production is positively correlated with the CIM and impact indices (0.396 and 0.299, respectively). Plants operating continuous-flow processes, such as chemical facilities and high-volume assembly systems, are capital-intensive and designed from the outset as integrated units, so CIM would contribute to integration mainly in the production planning stage. Planning-oriented CIM technologies are associated with flow processes (0.362), and the impact index (0.507) is indeed the only one significantly correlated with these plants.

CIM and Operational Complexity

We studied the relationship between CIM and the complexity of operations with respect to product process and environment. The measures for complexity are the number of stages in a typical bill of materials, the average number of operations in the route sheet, and seasonal production. As expected, we find that the number of stages in the bill of materials is positively correlated with the deployment of design-oriented CIM (0.400) because firms find these technologies beneficial when product complexity is higher. Similarly, the number of stages in the route sheet is positively related to the level of CIM (0.334), and more specifically to design-oriented CIM (0.309). Moreover, greater process complexity (as measured by the number of stages in the route sheet) is positively associated with the impact index (0.499), since a larger number of production functions must participate in the CIM effort.

CIM and Human Resources

We measure the impact of CIM and automation on the change in employment in various categories of jobs within the facility. Automation and technology are often thought to substitute for labor resources in manufacturing. We find some support for this observation. Table 4 shows that the technology index is negatively correlated with the change in the number of employees (–0.449) and with the change in the amount of direct labor (–0.369). The degree of automation is associated with the reduction in direct labor (–0.368) and the change in the number of administrative employees (–0.535) but does not significantly affect the number of engineering employees. This is likely since adoption of new technology expands the relative size of the engineering function within the organization. Surprisingly, the reduction in the number of employees is related to the use of decision support systems and AI/expert systems (–0.616), as is the change in direct labor. Advanced information technologies thus tend to be associated with a reduction in total employment for a facility.

CIM and Impact on Manufacturing Performance

We classify the gains associated with CIM adoption into two categories, strategic and operational. The following describes the measured association between the level of CIM and improvements in performance.

Table 4 Correlations between CIM Indices and Employment

Index	Employment category			
	Employees	Direct labor	Engineering employees	Administrative employees
Automation	–0.337 (0.15)	**–0.368** **(0.10)**	–0.272 (0.25)	**–0.535** **(0.01)**
Technology	**0.449** **(0.04)**	**–0.369** **(0.09)**	–0.056 (0.82)	–0.057 (0.80)
Function	–0.038 (0.88)	–0.301 (0.22)	0.226 (0.38)	0.248 (0.32)
CIM	–0.182 (0.44)	–0.204 (0.38)	0.049 (0.84)	0.169 (0.46)
Impact	**0.448** **(0.05)**	**0.389** **(0.08)**	0.257 (0.27)	0.262 (0.25)
Planning	–0.112 (0.64)	–0.152 (0.51)	0.093 (0.69)	0.276 (0.23)
Control	–0.051 (0.82)	–0.051 (0.82)	0.182 (0.44)	0.210 (0.36)
Design	–0.294 (0.20)	–0.283 (0.21)	–0.278 (0.23)	0.044 (0.85)
Other	**–0.616** **(0.00)**	**–0.489** **(0.02)**	–0.002 (0.99)	0.070 (0.76)

Significance levels indicated in parentheses.
Correlations significant at 10% or less indicated by boldface.

CIM and Strategic Performance

There is a strong positive relationship between the impact index and gains in market share (0.417) (Table 5); general-purpose technologies are thus associated with better market performance. This is not surprising, since the most commonly used general-purpose technologies, such as JIT, TQM, and SQC, are implemented from the top–down and naturally integrate a number of organizational functions. Top management commitment is gained through the realization that these technologies and methods have significant product-market implications. Technologies with narrow domains of applicability tend to be functionalized, and their adoption is driven by the tactical needs of departments within the firm. Thus, the benefits of technologies aimed at narrow domains are not strategic to the company. The CIM index itself had no significant impact on competitiveness, delivery performance, or market share. Thus, the scale of CIM has no appreciable impact on gains in strategic performance: what matters is not the addition of technologies, but the functional integration across areas.

CIM and Operational Performance

Table 5 shows that design improvements were positively associated with the adoption of other (O) CIM technologies (0.495), such as AI/expert systems and decision support systems. However, we also found an increase in material-handling lead times associated with the use of such technologies (0.416). These technologies also improved quality detection (0.458) and reduced reject percentages (–0.488), but we observed no significant effect on the other variables that describe manufacturing performance.

Analysis and Discussion

THE FUNDAMENTAL PURPOSE OF CIM IS TO INTEGRATE FUNCTIONS that affect manufacturing. Our discussion is divided into three sections that explain the integrative effects of CIM. The first section considers whether CIM is integrated with the business objectives of an organization. In the second, we describe the informational role it plays for technology management, and we also discuss the temporal patterns observed. Finally, the issue of successful deployment is discussed in conjunction with our empirically observed patterns of implementation; the relationship between successful CIM and manufacturing characteristics is also highlighted.

Strategic Implications: "Top–Down" or "Bottom–Up"

The most important general conclusion is that CIM is not being used as a competitive weapon or as part of a strategic program, despite claims about its value. This is in pronounced contrast to the proliferation of TQM and JIT as strategic programs embraced by top management. We suspect that TQM is much simpler for nontechnical managers to grasp, and that the business benefits of TQM are more obvious and easier to measure. The same could also be said of JIT. Furthermore, TQM and JIT can be initiated and implemented more easily. CIM, on the other hand, is more difficult to evaluate or justify economically [19], technically harder to understand, and often very dependent on the specific characteristics of particular plants and firms.

A corollary to this observation is that CIM is predominantly implemented "bottom–up." Individual areas and line managers have undertaken CIM projects based on their own local needs. The frequency of "bottom–up" implementations suggests that CIM systems grow through local adoption. Hence, crossfunctional integration among various business functions will not be a major issue, at least initially. Subsequently, machine and equipment developers will supply capabilities that make integration straightforward, just as plumbing or personal computer systems can be easily assembled. The key issue for a vendor will be the development and deployment of standards that allow decentralized development of specific CIM components. However, this approach results in islands of automation with localized benefits, systems that tend to become more and more specialized over time, and the integration of these systems often remains neglected. They employ dedicated hardware, LAN protocols, operating

Table 5 Correlations between CIM Indices and Facility Performance (percent changes)

Index	Facility performance characteristics							
	Degree of competitiveness	Delivery performance	Market share	Production lead time	Material handling lead time	Design gain	Quality detection	Reject rates
Automation	0.004 (0.98)	0.153 (0.52)	–0.073 (0.73)	0.085 (0.68)	–0.196 (0.43)	–0.062 (0.78)	–0.039 (0.86)	0.023 (0.92)
CIM	0.097 (0.65)	0.027 (0.93)	0.076 (0.73)	–0.287 (0.17)	0.025 (0.92)	0.048 (0.82)	0.023 (0.91)	–0.139 (0.55)
Impact	0.011 (0.995)	–0.141 (0.55)	**0.418** **(0.04)**	–0.004 (0.98)	–0.212 (0.39)	0.133 (0.54)	0.173 (0.44)	0.237 (0.31)
Planning	0.204 (0.33)	–0.007 (0.97)	0.314 (0.14)	–0.121 (0.57)	–0.031 (0.90)	0.267 (0.22)	0.269 (0.22)	–0.252 (0.28)
Control	0.025 (0.90)	0.134 (0.57)	0.149 (0.49)	–0.073 (0.73)	0.101 (0.69)	0.113 (0.60)	0.076 (0.73)	0.031 (0.89)
Design	–0.208 (0.32)	0.097 (0.68)	–0.118 (0.59)	**–0.348** **(0.09)**	0.126 (0.62)	–0.267 (0.22)	–0.197 (0.37)	0.137 (0.56)
Other	–0.019 (0.93)	0.036 (0.88)	**0.387** **(0.06)**	–0.208 (0.33)	**0.416** **(0.08)**	**0.495** **(0.01)**	**0.459** **(0.03)**	**–0.488** **(0.02)**

Significance levels indicated in parentheses.
Correlations significant at 10% or less indicated by boldface.

systems, data dictionaries, and particular data structures in ways that make later plant-wide integration even more costly.

Our observations support the conclusions of an earlier study by McKenney and McFarlan [24], who identified a lack of integration as a major impediment to achieving desired coordination and performance objectives. Some respondents' comments supported a further conjecture that there is relatively little understanding of technology management at corporate levels in many firms. Supporting the previous observations, it is apparent that CIM is being motivated and justified on traditional grounds, such as reducing cost and improving productivity. Motivations such as increasing coordination, a need to learn about CIM, or increasing process automation are mentioned but are not major factors. With respect to the criteria for selecting technologies, respondents cite economic benefits (direct cost savings), organizational fit, and operational improvements as major reasons; quality enhancement and technological feasibility are not viewed as leading issues.

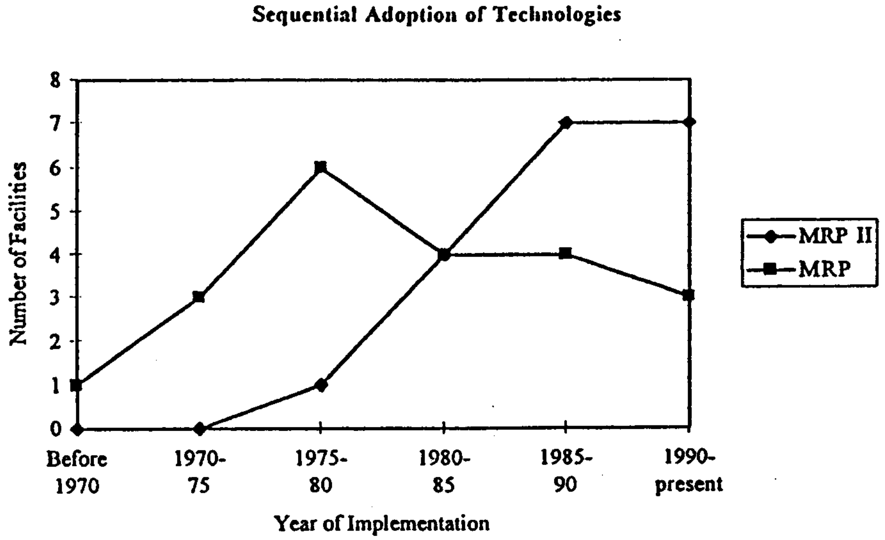

Figure 4. Sequential Adoption of Technologies
(This figure describes the adoption of two related technologies, MRP and MRP II. The adoption of MRP peaked in the late 1970s and early 1980s, and declined following the emergence of MRP II.)

manufacturing data seamlessly. Interestingly, automated statistical process control is the most popular technology being considered. This is an example of an important secondary technology that uses an existing CIM infrastructure, such as digital process sensors and CAD, to improve the consistency of production processes.

There are some patterns that can be discerned in the relationship between CIM implementation and firms' characteristics. Bigger plants tend to have a higher level of CIM technology, which may be the result of a greater need for coordination and of operating with standardized production processes. This refutes our hypothesis that smaller plants will have a higher level of CIM due to the relative simplicity of the data structures and the limited effort required to automate small-scale operations. It must also be stressed that these technologies are a substantial investment, and large companies and plants have the necessary economies of scale that can be exploited by CIM. Investment in CIM must also be of a critical size, below which the gains are not apparent. Smaller plants may not have the scale or the resources to achieve these dimensions in technology.

Furthermore, plants using batch processes have a higher average level of CIM implementation than make-to-order plants; most of the latter have a medium CIM level, while the majority of the batch plants with CIM are clustered around the higher values of the CIM index. This observation suggests that there is an efficient level of

CIM depending on the type of production strategy used. The interaction effect of both size and process type is especially significant; the larger batch plants have the highest levels of CIM. Moreover, there is some evidence that CIM substitutes for direct labor by automating existing operations (see the negative correlation in Table 4). On the other hand, the size of the engineering labor force shows no significant change.

Managing the CIM Challenge

SUCCESSFUL CIM DOES TO A GREAT EXTENT DEPEND NOT ONLY UPON EXPERTISE in technology assessment and deployment, but also on the business objectives of the firm, its process characteristics, the presence of enabling technologies, and the entire environment in which it operates. Managers evaluating the potential value of new manufacturing technology in general, and CIM in particular, must understand the underlying business processes. The need for top management commitment cannot be stressed enough; it was the single most cited reason for the failure of CIM. Our conclusions, based on current practice in a small sample of U.S. manufacturing facilities, suggest that the success of computer integration will depend on the expertise of managers in implementing existing methods to take advantage of the potentials offered by new technologies.

Traditionally, research on strategic information systems has focused on transaction-based corporate data networks. In general, service systems, such as airline reservations, distribution support, and the like, have been popular areas for studying the implementation of information systems. Our research has focused on the manufacturing applications of information systems, and the particular characteristics of plants and processes that create specific needs. Generic solutions to technology requirements are not likely to work particularly well.

Another salient finding of our study has been the need for integration of complex technologies. Systems typically emerge over time and are based on an infrastructure developed for administering transaction processing. In contrast, the challenge that manufacturers face is to develop successful CIM solutions that require integration of transaction data (orders) with graphic information (solid models for design) and real-time monitoring of various machine types on the shop floor (an APT program for numerically controlled machine tools). Figure 5 illustrates the state of CIM as perceived by one of our respondents; technological islands with an elaborate system of "bridges" and "ferries" to transfer data among the various applications, while certain functions (such as testing and robotics) remain in isolation. Figure 5 also portrays the tendency of each function to purchase a "best of breed" technological solution without regard to crossfunctional compatibility. Lack of standards for data exchange among these technologies leads to an environment in which every firm must integrate on its own.

This process has proved to be time-consuming and requires a great deal of specific knowledge of the manufacturing process and the technology that is addressed. Furthermore, the drive toward adoption of these technologies presents a moving target. Once firms are comfortable with their choice, and are exploiting the economies it

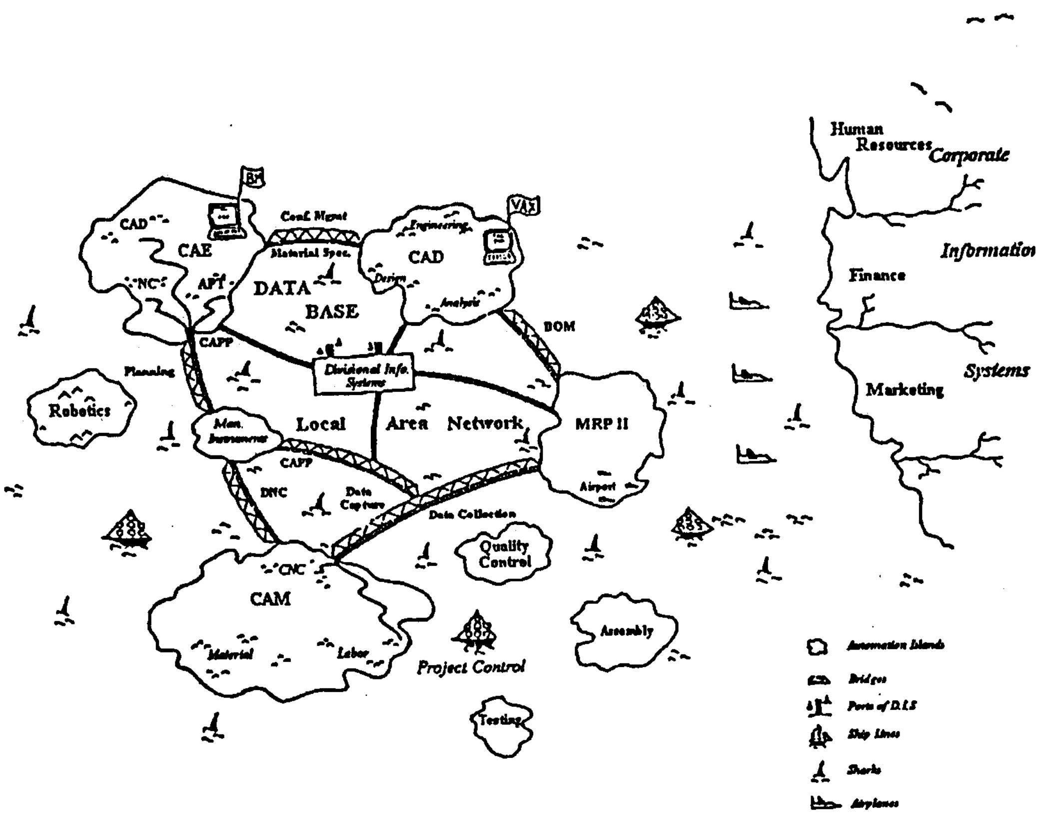

Figure 5. An Illustration of the Current State of CIM

provides, new technologies emerge that provide better solutions. Over time customer requirements evolve too. For instance, customers demand greater variety in products without the penalty of higher prices. Competitors will develop new solutions that provide better product-market results. The challenge to today's information managers is precisely the management of the decision process required by the adoption of these rapidly evolving industrial information technologies.

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