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Implementation of computer-integrated manufacturing: a survey of integration and adaptability issues

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Abstract. Computer-integrated manufacturing (CIM) as a strategy helps to improve the performance of a manufacturing firm by integrating various financial areas of manufacturing, both in terms of material and information flow. There are many reports that deal with the technological and operational aspects of CIM, but the issues of integration and adaptability as key objectives in the design and implementation of CIM are not paid due attention. Realizing the importance of CIM, an attempt has been made in this paper to review the literature available on the implementation of CIM with an objective to gain more insights into the integration and adaptability issues. This paper focuses on improving integration and adaptability as design and implementation objectives of computer-integrated manufacturing systems. A conceptual model has been developed to illustrate the key issues of integration and adaptability of CIM. The model has been explained by surveyed observations. In addition, a new framework has been proposed in this paper for the design and implementation of CIM and some future research directions are suggested.

1. Introduction

CIM is the architecture for integrating the engineering, marketing, and manufacturing functions through information technologies. In the broad sense, CIM involves the integration of all the business processes from supplier to end consumer. CIM can be used as a strategy for enterprise resource planning for business-wide level of integration. This indicates the relationship between business process reengineering and computer-integrated manufacturing with an objective to achieve the enterprise integration and management for improving productivity and quality. The motivation for CIM has been based on the perceived need for the manufacturing industry to respond to changes more rapidly than in the past. CIM promises many benefits including increased machine utilization, reduced work-in-process inventory, increased productivity of working capital, reduced number of machine tools, reduced labour costs, reduced lead times, more consistent product quality, less floor space, and reduced set-up costs.

The integration and adaptability issues are generally affected by factors such as business strategy, manufacturing strategy, availability of knowledge workers, software professionals, complexity of material flow, information flow pattern and decision making processes, product and process complexities, supplier/purchasing activities, behavioural issues, etc. The major components of CIM and CAD and CAM technologies, computer numerically control (CNC) equipment, robots, and FMS technology (Groover 1987). The computer system is used to integrate design and then manufacturing process and other production planning and control systems (such as inventories, materials, schedules, etc.) and the integration of manufacturing activities with both vendors and suppliers (Levary 1992).

Most of the published reports concentrate on the technological and operational issues at too early a stage of the development of CIM. However, the role of strategic, organizational and behaviour issues needs to be given due consideration for improving integration and adaptability of CIM. Therefore, realizing the role of such managerial issues in improving integration and adaptation, the implementation of CIM has been discussed in this paper with reference to strategic, organizational, technological, behavioural

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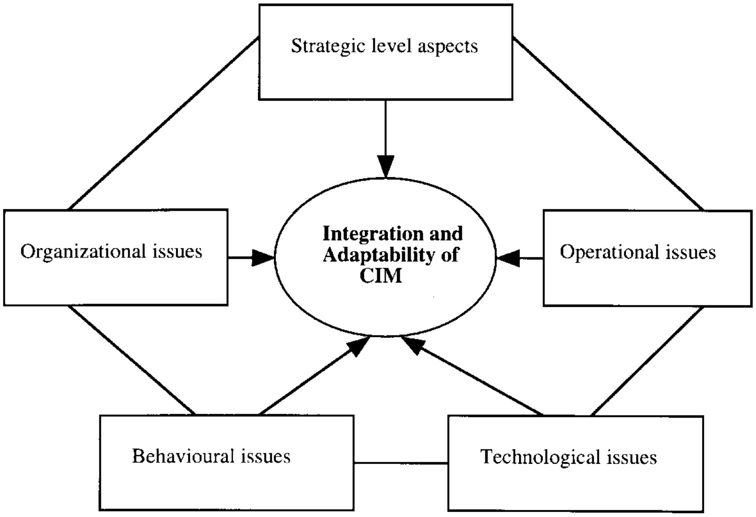

Figure 1. Integration and adaptability issues in the implementation of CIM.

and operational issues. Furthermore, there is no systematic framework available for improving the integration and adaptability of CIM taking into account different managerial, technological and operational issues. Hence, there is the need for a framework to identify major critical success factors for integration and adaptability of CIM. An attempt has been made in this paper to develop such a framework after surveying the issues of the implementation of CIM.

The organization of the paper follows as: Section 2 presents the integration and adaptability issues of CIM. A review of the previous literature on the implementation of CIM is presented in Section 3. Section 4 deals with insights obtained from the survey of integration and adaptability issues in the implementation of CIM. A new framework to improve the integration and adaptability of CIM is presented in Section 5. Summary and conclusions are presented in Section 6.

2. The integration and adaptability issues in the implementation of CIM

Integration and adaptability are the key issues of the implementation process of CIM. Therefore, it is appropriate to discuss the main elements of integration and adaptability of CIM and how these issues should be taken into account during the implementation of CIM. The integration of systems is frequently hindered by the resistance to converge the activities of different functions within the business. Organizational integration and the elimination of departmental barriers are proving to be more difficult to achieve in practice and will in turn hinder the technical development of the 'seamless' integration required. The integration of computer-aided design (CAD) and CNC machines made a huge impact on the development of CIM. In support of the critical roles that humans play in the success of CIM, the most common recommendation found in almost all recent literature is the dire need for education and training in relation to the adoption of CIM. It could even mean a redefinition of responsibilities from the top to the bottom of the organization. Research in CIM design and implementation has mainly been in the area of production. However, the major issues in CIM are directly related to information systems (Gowan and Mathieu 1994).

A conceptual model illustrating the integration and adaptability issues of implementing CIM is presented in Figure 1. The organization has to develop a strategy which best fits the environment in which it operates. The model explains the importance of the alignment between various implementation strategies for improving integration and adaptability of CIM. For instance, strategic-level issues such as the alignment between business and manufacturing strategies require suitable organizational structure, technology, employee involvement and the nature of production planning and control system. Therefore, this relationship is represented by the closed loop as shown in Figure 1, to explain the interaction and dependency between managerial, technological and operational level issues. The details of each of these issues are presented in Table 1. There is a number of organizational issues which companies meet when analysing, designing and managing the implementation of CIM systems. Organizations appear to have paid only limited attention to finding ways of managing design projects that are conducive to the multidisciplinary

Table 1. Integration and adaptability issues in the implementation of CIM.

Areas	*Issues*
Strategic	Alignment between business and manufacturing strategies
Organizational	Structure, Communication
Behavioural	Leadership, Teamwork, Incentives, Motivation, Empowerment, Concurrency, Collaboration, Agility
Technological	Networking, Communication Systems, Databases, Knowledgebases, Groupware
Operational	Design, Engineering, Production planning and control system, Accounting

and innovative team work. The organizational structure should support the kind of communication and decision making together with the responsibilities to facilitate the implementation of CIM and vice versa. The behavioural aspects should be given due attention as they are related to human relations and human–machine interface that play a significant role in obtaining the co-operative supported work not only just for the implementation of CIM, but also for the operations of CIM.

In the following section, the literature available on CIM implementation is classified and reviewed with an objective to gain further insights into the integration and adaptability issues.

3. Previous research on implementation issues of CIM

A more systematic approach for the classification and review of previous research may provide a clear insight into the implementation issues of CIM, considering the integration and adaptability as key issues. Therefore, previous research on the integration and adaptability issues of CIM has been reviewed in this section, based on the nature of the major issues such as strategic perspectives, and technological, operational, behavioural and organizational issues. The objective of this review is to identify the most critical and pressing issues in the implementation of CIM in practice. The details of the classification scheme proposed are presented in Tables 2(a) to 2(e).

The available literature on the implementation of CIM has been reviewed based on the classification as shown in Table 2 and the details follow hereunder.

3.1. *Strategies for the implementation of CIM*

The manufacturing strategy should fully support the objective of the business strategy. Moreover, there is a need for the alignment between manufacturing strategy such as CIM implementation and business strategy to achieve full potential and benefits of implementing CIM. The characteristics of a company in terms of capital, knowledge workers, complexity of the material flow, layout types, etc should be considered while designing and implementing CIM.

Babbar and Rai (1990) propose that while CIM integrates the system components, it does not necessarily introduce flexibility into the system. The focus should not be on integration alone, but on the simultaneous introduction of flexibility as part and parcel of the integration process. Computer-integrated flexible manufacturing (CIFM) is a long-term proposition and entails significant capital investment. Such a top-down strategy should receive strong support from upper management, and team effort should be emphasized. However, they seem not to have offered a strategic framework to improve flexibility in the implementation of CIM, in particular where automation warrants a kind of standardization of products and processes.

Bolland and Goodwin (1988) argue that the traditional cost accounting systems generally fail to detect the many benefits of automation. The inability to financially justify an investment in CIM often has been cited as the reason for not proceeding with an automation project. However, automation's benefits can be more favourably highlighted by use of a discounted cash flow method such as net present value. Discounted cash flow produces a single figure so the total of cash inflows and outflows over the equipment's lifetime can be determined. Jain (1989) writes that an effective CIM requires that every employee understand, accept, and endorse the need for attaining a competitive advantage. The importance of quality, customer service, product innovation, quick response to market needs, and competitive prices must be part of the organization's collective objectives.

The justification of a CIM system is one of the foremost important steps in implementing CIM. Factors such as reduced costs of material, direct and indirect labour, and reduced scrap, rework and inventory would justify the scope of CIM implementation together with organizational and strategic issues. Nevertheless, issues such as reduced cycle time, increased capacity, improved quality of products and customer services are less obvious items but are very important (Kaltwasser 1990). The CIM as a strategy for integration must physically link parts of the facility, and handle the flow of information, especially in the context of improving the speed of the material flow. According to O'Hara (1990), many firms begin a computer-integrated manufacturing (CIM) project without proper information about the firm's

Table 2. Previous CIM research.

(a) Strategic issues

Manufacturing Industry (characteristics)	*Integration* *Problems*	*Strategies/Policies/ Technologies*	*Adaptability* *Problems*	*Strategies/Methods*	*Sample references*
General	Absence of total management system	Top management support	Lack of knowledge about CIM	Highly skilled workforce	Allen (1988), Horn (1988)
General	Barrier to automation, Lack of investment justification methods	New cost accounting systems (ABC)	Lack of co-operative supported work and justification methods	Activity-based costing, Training in sophisticated and proven financial analysis	Bolland and Goodwin (1988)
General	Management of information, Mechanical integration	Compatibility of MIS, CAD/CAM, ISO 9001, Logistics planning	Information	Building CIM teams, Common database, A time-based implementation, Computer-supported collaboration	O'Hara (1990), Blass (1992), Arcelus and Wright (1994), Nof (1994)
Flexible Manufacturing Systems	Alignment between business and manufacturing strategies, Flexibility	Capital investments, CAD/CAM, FMS, Top management support	Top-down business oriented strategy	Team efforts, Human competence re-engineering	Babbar and Rai (1990) Clemons (1991), Levary (1992)
Manufacturing	Lack of information technologies	Organizational system design	Handling variability	Investment in flexible technologies	Duimering *et al.* (1993)
Manufacturing	Lack of user involvement and tolerance	Innovation, Gradual implementation process	Organizational learning and change	Implement enough of the technology, Users involvement and tolerance	Fjermestad and Chakrabarti (1993), Forrester *et al.* (1995)

(b) Organizational issues

Manufacturing Industry (characteristics)	*Integration* *Problems*	*Strategies/Policies/ Technologies*	*Adaptability* *Problems*	*Strategies/Methods*	*Sample references*
General	Absence of total management system	Top management involvement, Reorganization	Lack of knowledge of CIM, Discouraging measurement system	Highly skilled workforce Training and education, ABC	Warendorf and Merchant (1986) Allen (1988), Horn (1988), Hazeltine (1990), Levetto (1992)
Manufacturing	Lack of human–machine interaction	Infrastructure, flexibility, Compatibility, Organizational change, Communication	Lack of business process characteristics and quality of work life	Self-autonomous teamwork, Joint optimization of technology and organization	Zhao and Steier (1993)
Manufacturing	Lack of information technologies	Organizational system design	Handling variability and conflicts	Investment in flexible technologies	Duimering *et al.* (1993), Gasser (1994)
Manufacturing	Lack of user involvement and tolerance	Innovation	Organizational learning and change	Implement enough of the technology	Fjermestad and Chakrabarti (1993), Forrester *et al.* (1995)

Continued

Table 2. Continued.

(c) Behavioural issues

Manufacturing Industry (characteristics)	*Integration*		*Adaptability*		
	Problems	*Strategies/Policies/ Technologies*	*Problems*	*Strategies/Methods*	*Sample references*
General	Lack of flexibility and reduced workforce	Manned control room, Employee participation	Lack of motivation	Computer training and training in self-management and conflict management	Yoshikawa (1987)
Manufacturing	Safety requirements	User participitation, Use of sensors on the shop floor, Top management support, Organizational change	Difficulty in operating and maintaining the CIM system	Account for human factors in the early stage of planning CIM, Proper training, Human/ machine interaction, Safety enablers	Rummel and Holland (1988)
Manufacturing	Lack of human involvement in the implementation of CIM	Organizational change, teamwork	Resistance to change efforts	Training with the help of suppliers, Job enrichment	Ebel (1989)
Manufacturing	Lack of co-operation	Collective incentive scheme, Logistics re-engineering	Lack of action-oriented strategies	Workers' pride and positive attitude, Evaluation and training	Sage and Fox (1989) Arcelus and Wright (1994), Eberts and Nof (1993)
General	Lack of top management support	Executive training on CIM	Risk of production loss	Gradual implementation	Warendorf and Merchant (1986)
Manufacturing	Installing an integrated business system	Management involvement, Personality and strength of the project manager	MRP II systems installation	Education and training	Howery *et al.* (1991)

Continued

management of information. To ensure that goals are attained and that the new system is compatible with a firm's strategic direction, an information flow profile needs to be created. However, these authors have not discussed the availability of computers and their integration taking into account various cost trade-offs.

A CIM project succeeds only if it allows a business to achieve specific business and manufacturing goals and strategies (Clemons 1991). The business strategies that detail the specific goals and objectives of the business should be developed first; then, manufacturing strategies can be developed from the business strategies. Once the business and manufacturing strategies are completed, the CIM strategies should be developed. The CIM integrates business systems with factory floor systems. Blass (1992) presented the gradual implementation procedure of a CIM in Allen-Bradly, a world-wide manufacturer of industrial automation controls and systems. A three-phase plan, one for each year of the process, was begun. Phase 1 (1989–1990) planned for meeting the existing demands for capacity, integrating new production processing capability using CAD data. Phase 2 (1990–1991) dealt with mechanical integration issues, such as increasing throughput and quality while reducing the level of inventory. This also included increasing quality through immediate total process control. The third phase, which was started in 1992, deals primarily with the computer integration of facility and continuous improvements. However, CIM has not been considered as a strategy on most occasions that requires a change in the organizational structure.

CIM can be seen as business and organizational concept, not simply as a technology. Forrester *et al.* (1995) have presented a brief review Computer-Integrated Manufacturing Programmed Learning (CIMple) composite model of CIM and methodology

Table 2. Continued

(d) Technological issues

Manufacturing Industry (characteristics)	Integration: Problems	Integration: Strategies/Policies/ Technologies	Adaptability: Problems	Adaptability: Strategies/Methods	Sample references
Manufacturing	Incompatible computer systems	Computers, Standards in data communication, Robots, CAD/ CAM, AGVs	Insufficient internal skills	Education and training in new technologies	Kaltwasser (1990), Horn (1988), Boubekri *et al.* (1995)
General	Lack of co-operation between and management information systems and manufacturing	Bottom-up approach to production operations by integrating systems and devices on the shop floor	Lack of management information system	Top management involvement in the process of selecting software and hardware	Groover (1987), O'Hara (1990) Groves (1990) Gowan and Mathieu (1994)
General	Lack of integration enterprise engineering	Information engineering approach, FMS, Robots, AGVs, EDI, CE	Inability to migrate to future technology	Top management commitment and worker involvement	Grant *et al.* (1992) Ngwenyama and Grant (1994) Sarkis *et al.* (1995)
Manufacturing	Lack of infrastructure	Build interfaced systems	Lack of understanding and co-operation	Global sharing of data, Training and education	Hayes and Jaikumar (1988), Kellso (1989)
General	Communication systems	Radio Frequency Data Communication systems	IT strategy must offer a consistent approach	Reliable vendors, Material handling systems	Hiscox (1994)
Lumber Industry	Short tool life, Frequent job changes and long set-up times	Computerization and communication, Quality improvements	Lack of co-operation from employees	Empowerment, Job enrichment, Incentives, Training and education	Parkin and Cutri (1993), Arcelus and Wright (1994)

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that offers a business-oriented approach for the design and implementation of CIM. CIMple is essentially a set of guiding principles highlighting alternative choices and approaches for management decision makers, project managers and systems designers through the various phases in the design of and implementation of CIM systems. It avoids the architectural 'building block' approach of other methodologies and takes into account the various, often conflicting, views of CIM from a number of perspectives. The CIMple design process is primarily a 'top-down' business-oriented approach. However, most of the reports do not clearly explain the various management issues in the implementation of CIM to achieve integration and adaptability.

Fjermestad and Chakrabarti (1993) presented a model of CIM as the integration of strategy, implementation, and innovation. Strategy can be understood in terms of the interaction between product and process strategies, critical success factors, and product-life cycle. Implementation stresses an iterative incremental process based on strategy, user involvement, and tolerance. Innovation is the result of a successfully implemented strategy. It is both organizational learning and change. While many large companies such as General Motors and IBM have implemented CIM, small firms have rarely achieved company-wide integration of all computer systems (CIM). This is because small firms often feel that they lack the in-house expertise to implement new computer technologies and the cost of hiring a consulting firm to assist will also be too expensive. A number of companies are slow in adopting CIM in their systems. This is especially problematic in today's consumer-oriented marketplace, where global competitive pressures are forcing firms to develop highly integrated information systems. The CIM system relates primarily to two areas of operation – logistics planning

Table 2. Continued

(e) Operational issues

Manufacturing Industry (characteristics)	*Integration*		*Adaptability*		
	Problems	*Strategies/Policies/ Technologies*	*Problems*	*Strategies/Methods*	*Sample references*
Manufacturing	Lack of communication systems and integration	Computers, Automation, Standardization, Protocols	Market needs, Quick response, Competitive price	Highest and fastest potential payoffs, Top management commitment, Integration of all components	Jain (1989), Sakakibara and Matsumoto (1991), Rajan and Nof (1992)
Service Industry	Integration of all functional areas, Total integration of all information technology	Computer integration	Lack of suitable information systems and technology	Global information technology, Single-source data entry, a similar 'look and feel' for all applications, 'User seductive' interfaces, Online education	Groves (1990), Waldoch (1990)
General	Integration of all functional areas	Functional integration by computers, Prototyping	Lack of infrastructure	Program integration, Concurrent engineering, Collaborative coordination	Sommerville (1987), Aletan (1991), Nof (1992)
Manufacturing	Integrated factory using various technologies	Networking, Automation	Multiple vendors, Software scarcity	Skilled workers in networking and software	Snyder (1991)
General	Environment problems	Organizational restructuring, computers	Continuous improvements	Systems development life cycle approach	Willis and Mitchell (1991)

and human competence engineering (Arcelus and Wright 1994).

CIM is a manufacturing strategy for improving productivity and quality. It is essential that the organizational characteristics in terms of infrastructure and nature of the products manufactured should be taken into account while we select the manufacturing strategy as CIM. The implementation of CIM requires a clear, precise, corporate strategy, the success of which will depend upon careful planning of several logical steps, namely: prime the corporate culture for change, clearly define expectations, appoint a champion for CIM design and implementation, establish a project team, perform a comprehensive environmental analysis, identify the technology the strategy requires, formalize operating policies, establish working partnerships with suppliers and vendor, and track and report progress. Summarizing the strategic aspects of implementing CIM, there is a need to develop a framework for the alignment between business and CIM as a strategy.

3.2. *Organizational issues*

Organizational structure can be seen as the assignment of people with different tasks and responsibilities. Interdepartmental integration can be achieved by authority, centralization, and regulation. An ideal organization should embrace cultural diversity in terms of education, skills, gender, race, ethnicity and nationality, and managers to oversee the change processes. The characteristics of an organization such as full structural integration, unimpeded interpersonal communication, absence of prejudice, low levels of conflict with users and vendors, and pluralism will resolve the conflict between Management Information System (MIS) and manufacturing. It is important that people should be trained in the organizational changes that CIM will introduce to the factory. Central to this discussion will be cross-functional training where MIS learns manufacturing concepts while manufacturing learns about methods for Information System (IS) analysis and design. In a CIM system, there is a need for correlation and integration of data across the planning, design, implementation and operation phases.

The implementation of computer-aided production management system (CAPM) depends upon the complexity of the overall manufacturing systems. The implementation of CAPM can be made easy if the overall manufacturing is first simplified. Second, any methodology must include a software specification as most companies will require a computerized solution. Third, the overall performance of the system may be enhanced by suitable changes in the infrastructure that supports the software and integration.

Allen (1988) explained that attempting to install CIM without a total management system driving the company leads to failure. The decision to install such an all-embracing system cannot be summarily turned over to the data processing staff. Therefore, Allen said that the chief executive officer must lead the charge. On the other hand, Horn (1988) and Alter (1989) both believe that CIM is not workable without highly skilled workers. They refer to production and plant managers, supervisors and operators, who all often know more about how things should and should not work than anyone else in the company. However, the most important cause for a company's failure at implementation is its lack of understanding of what is really needed for any of these techniques to be successful (Hazeltine 1990). Thus the main approach used in the CIM system for dealing with organizational variability is to increase the level of flexibility in order to handle variability at the point of impact (within manufacturing). However, both the integration and variability handling within the CIM system are purely technological issues rather than organizational issues (Duimering *et al.* 1993).

To be successful, an initiative must have the direct involvement of top management. Top management must not only commit itself, invest company resources and accept long-term results, but must eventually modify the company organization as required. Those employees whose normal work tasks are touched by the project must be trained, involved and motivated. Although performance measurement is necessary, it must be remembered that measurement is a tool, not an end in itself. If normal company operating procedures must be bypassed to obtain timely results, then the company bureaucracy is the real problem and a reorganization with trim procedures should be the real objective (Levetto 1992). However, there is no framework developed on how to motivate top management in the implementation of CIM. The implementation of advanced technology requires an interactive incremental process-based implementation, user involvement, and tolerance. The implementation of CIM needs both the *organizational learning and change* (Fjermestad and Chakrabarti 1993). The role of Business Process Re-engineering (BPR) can play a tremendous role in the implementation of CIM.

According to Zhao and Steier (1993), CIM technology implies the overall integration of managerial functions: marketing, design, engineering, accounting, personnel, and finance. The higher degree of cross-functional integration demands strong infrastructural support to the efficient operation of the manufacturing systems. When implementing the technology, management must be sure that the whole organization, including its structure, strategy, people, and power and authority distribution is compatible with the CIM. As many authors have pointed out, organizational issues play a predominant role in accepting new technologies. However, it is a kind of two-way process; one is from the technological perspectives such as the suitability of CIM, and the other from organizational perspectives such as infrastructure, business process characteristics and skills available.

Differences in functional goals produce a large number of incompatible activities, which are a major source of variability for the production system. Production and administrative throughput times can be reduced only if functional goals are aligned. The most effective means of aligning them is redesigning the organization structure such that members of different functional groups work together more closely. True organizational integration amounts to correcting the problems that have created poorly integrated, loosely coupled organizational systems in the first place. If these problems—which are essentially organizational rather than technological—are ignored, CIM implements run the risk of institutionalizing ineffective organizational procedures and communications linkages by automating them rather than correcting them.

3.3. *Behavioural aspects*

CIM requires a teamwork approach in which every member has a key role to play. CIM has been implemented successfully in companies such as Allen-Bradley, Continental Can Co. Inc., and Texas Instruments. One of the biggest obstacles to CIM implementation is that systems are conceived by corporate headquarters and then pushed down onto a plant manager. Training and involvement help to minimize worker resistance. However, it ultimately comes down to corporate culture. The effectiveness of the training should be evaluated and based on learning objectives. Some of the types of training that can be used for CIM are classroom instruction, computer-based training, workshops, and videotapes. Warendorf and Merchant (1986) emphasized the importance of the involvement of top management. They said that this is one ingredient that should not be overlooked. However, it is not enough to throw corporate resources at the task, which makes the challenge of CIM an executive one.

An unmanned or unattended factory with a manned control-room can be a solution to the ever-reducing number of workers in factories. The manned control-room should be made and kept clean and comfortable for supervisors. These workers would mostly be engaged in planning and programming the manufacturing process of the unmanned factory. The future plant requires computer training and training in self-management and conflict management. The Monsanto Chemical Company's experiences on this matter involved employees' participation in extracurricular activities, such as design committees, quality circles and improvement teams, which give the workers' ideas validation and routes to implementation. However, the major benefits that were envisioned by CIM will not happen if the importance of human resources is not taken into consideration, or strategic planning is ignored. Furthermore, the process of creating change and implementing new systems is to be understood in order to successfully achieve the benefits of CIM (Yoshikawa 1987).

Human factors should be considered at the earliest stages of the planning and implementation of CIM systems. If not, a CIM project may fail as workers struggle to operate and maintain a system superficially designed to prevent their efforts. Human factors are important in areas such as installation, operation and maintenance, and safety. Installation requires workers well trained in automation principles. Operation and maintenance requirements include workstations and computer interfaces, designed according to established human factor principles, and work environments that provide human interaction during the job performance and scheduled breaks in order to prevent feelings of isolation. In addition, safety enablers should include minimizing contact between humans and automated equipment, use as sensors and intruder alarms that stop equipment when a human enters the workcell or crosses the path of an automated vehicle, and installation of panic buttons accessible from anywhere in the workcell (Rummel and Holland 1988).

Sage and Fox (1989) suggested that firms should implement action-oriented operation strategies that stress integration of human values, taking into account the critical success factors such as workers' pride and positive attitudes which contribute to any successful operations strategy. CIM's initial implementation requires long-term strategies, a great amount of research and development, and possibly forgoing immediate financial benefits. The most essential element in such a strategy is the preparation of the workforce for the impending changes. This requires consultation at all levels and a systematic training effort. Moreover, such training needs to be carried out mainly by the companies themselves in co-operation with systems suppliers, since CIM systems are tailor-made to specific companies. Since the need for human work is reduced in the automated functions, training and job enrichments of the existing people are a necessity (Ebel 1989).

Lockheed Missile & Space Company Inc., Austin (Texas) Division, is one of the companies that has implemented an MRP II system as the key component of CIM. The implementation took more than 4 years and required a $5-million investment in software and hardware. Lockheed's approach to assembling a project team is a good model for this first step in implementation. The major responsibility for defining detailed system specifications, developing user manuals, and the like fell upon representatives from manufacturing, material, and product assurance. The company's experience shows that a successful implementation requires a well-informed and actively involved management group, education and training, a strong project manager with the skills and authority to make things happen, psychometric profile to master project team members and adequate staffing of the project team with committed and capable personnel (Howery *et al.* 1991).

3.4. *CIM technologies*

The key elements in any CIM application are: information management and communication systems, material management and control systems, process management and control, and integration. The information management and communication systems are the computers that link the various developments and decision making activities to each other. The second area of control involves material flow control. The third area of control is process control and this includes downloading of the appropriate inputs or process instructions and monitoring the process itself. Finally, the systems are integrated using computers (Kellso 1989). If a CIM solution is practical, there must be common operating plans for all affected departments, with an integrated system using a common database. However, the aspects of human–machine interfaces are to be considered in designing key elements of the CIM system.

The programmable automation, including Internet, Multimedia, flexible manufacturing systems (FMS), robots, AGVs, and EDI in business transactions, can make possible tremendous improvements in manufacturing. The reluctance of many US companies to adopt these new technologies may reflect gaps in their capital budgeting processes because of the lack of understanding. The companies that are able to exploit the hidden capabilities of a new technology most effectively are generally those that adopt it early, continually experiment with it, and keep upgrading their skills and equipment as the technology evolves (Hayes and Jaikumar 1991). According to Grant *et al.* (1992), the fundamental problems in the development and implementation of computer-integrated manufacturing information systems (CIMIS) include lack of integration, islands of automation, sub-optimization of resources, and inability to migrate to future technology.

The organization with CIM technology gains the capability of concurrent engineering, that is, design and manufacturing of desired products can take place simultaneously. However, the connecting mechanisms with customers such as understanding of customer demands, forecasting of market segment change and quality improvement of products have to be built in the production process by management. In order to regain the competitive advantage through implementing the CIM technology, concurrent engineering technique and philosophy must also be used simultaneously.

According to Hiscox (1994), although the elimination of manually produced paper systems and keying-in-data, Radio Frequency Data Communications (RFDC) system has brought the benefits of improved efficiency to the everyday working environment. RFDC has become an operational tool for providing timely, accurate data necessary for the implementation of CIM. For example, RFDC-based warehousing and manufacturing operations are required to conform to the longer term business IT strategy. In addition, open system helps to maximize existing investment in system development and improve the performance of material handling systems. The application of MIS-oriented software design tools and methodologies to manufacturing applications have generally resulted in poor performance in manufacturing systems. However, the problems with software not only arise because of the complexities associated with driving and controlling various elements of the factory, but also in interfacing manufacturing software with both engineering and business software (Gowan and Matheiu 1994). The integration and adaptability problems arise in manufacturing due to lack of integration, islands of automation, sub-optimization of resources, and the inability to accept new technologies. There are few methodologies available to address these problems and one of them is the object-oriented approach to modelling of manufacturing enterprises (Ngwenyama and Grant 1994).

Many companies have implemented CIM and are successful in achieving integration of various operations. Sarkis *et al.* (1995) presented an 'enterprise engineering methodology' for the strategic management of technologies in CIM. This methodology is based on preparing the manufacturing system that will accept the CIM effectively. Boubekri *et al.* (1995) argue that the design of automated equipment such as robots, computers and CNC machines conform to high-level standards of communication protocols to develop an intelligent manufacturing cell. The following are the reasons why companies select not to go for a CIM environment: the amount of investment required, insufficient skills, difficulty of implementing computerized systems, limiting or multiplying synergy, different support infrastructure, and lack of a unique set of standards that fulfils all the requirements of a system (Boubekri *et al.* 1995).

The integration of various activities at strategic, tactical and operational levels primarily involves design of hardware such as CNC machines, AGVs and software such as MRP II and Kanban. There is a need for integrating them with business processes for improving quality and productivity and hence its competitiveness. However, there is a need to examine manufacturing organizations to recognize the wide range of technological options for transmitting information, including fax machines, electronic mail systems, even telephones. Lack of integration is not, therefore, the result of a lack of information transmission technology or even a lack of available information. However, it is rather a lack of motivation on the part of individuals to use the available options.

3.5. *Operational issues*

To reduce administrative throughput times, the focus of improvement must be placed on the information processing portion of the equation. To reduce processing times, the actual activities performed by various functions must be co-ordinated. The use of software packages such as SIMAN and CINEMA is very important to model the behaviour of the CIM system and to build a simulation-driven animation of the manual manufacturing system and the proposed CIM system. Using this methodology, Sommerville (1987) developed a model for CIM design and the model views the development process as a sequence of activities that follow the traditional sequential waterfall model of software engineering. Because of the price and performance of today's computer technology and its highly interactive interface, their development process is based on successfully developing more sophisticated prototypes at all stages of the life cycle. This is an interactive approach to system design which identifies the problems at early stages of the life cycle and minimizes the risk of major system design flaws. For example, to achieve competitive advantage through implementing CIM technology, concurrent engineering techniques and philosophy can also be used simultaneously. Moreover, the success of CIM system depends upon effective scheduling and control.

Experience with the design and implementation of CIM in Novatel Company has been presented by Groves (1990). The management of Novatel has approached the problem first by identifying the limits of CIM with an objective to achieve a fully computerized and networked organization. The strategy, starting with identifying the limits, is called the computer-integrated enterprise (CIE). Novatel started with implementing a computer network based on workstations from Hewlett-Packard's Apollo division for an organization-wide system. The network has no central workstation, allows anyone at any workstation to communicate with an other workstation. This idea of CIE reaches well beyond manufacturing into every aspect of the company's operation from business system to product development and prototyping. For example, in the design area, Novatel identified the limitations of conventional sequential approaches to engineering and therefore, adopted the alternative of concurrent engineering. This particular approach permits the company to carry out the development activities in parallel to get to market sooner with a better product.

The basis of the CIM concept is the integration of various technologies and functional areas of the organization to produce an entirely integrated manufacturing organization (Snyder 1991). However, the networking that is essential to CIM implementation is difficult to achieve. The CIM literature cites several problems related to CIM networking, including multiple vendor installations, scarcity of software applications, immaturity of connectivity products, and network management. CIM should not be looked upon as a panacea, but as one viable tool for companies to use to stay competitive in the international market (Aletan 1991). Therefore, operational refinements should be carefully reviewed with the intention of providing for what the Japanese call kaizen, or continuous improvement. A study examines continuous improvement in processes (CIP) as a pre-implementation strategy (Willis and Mitchell 1991) for CIM. Furthermore, a systems development life cycle approach can be used to identify the activities that should be initiated before a CIM strategy.

4. Insights from the survey of the integration and adaptability issues in the implementation of CIM

The following discussion offers several insights gained by reviewing the literature on integration and adaptability issues of CIM implementation of in practice:

(i) CIM should be implemented only after the basic foundations are put in place in the company. It may be more productive to redesign the organizational structure before implementing available technology than to hope the technology will, bring about manufacturing effectiveness. Simplification of information flow and material flow establish a solid foundation for adopting CIM technology.

(ii) Integration and adaptability issues of CIM should be evaluated considering the lack of knowledge about CIM and its potential, strategic implications of longer term planning, effect of delaying CIM implementation on company competitiveness and the effect of operations integration.

(iii) The integration and adaptability issues of CIM are influenced by factors such as the required hardware platform, integration requirements, and data processing skills. Therefore, there is a need to consider these factors while implementing CIM. Knowledge workers such as computer operators and software engineers, and a multi-functional workforce are essential to improve integration and adaptation in the implementation of CIM.

(iv) Human workers play a significant role in influencing the integration and adaptability issues of CIM especially by co-operative supported work. This reveals the importance of providing a comprehensive training to equip workers with the knowledge of automation, computer technologies, and manufacturing process.

(v) Despite the arguments regarding flexibility of CIM, the experience from practice is that automation is frequently too rigid to adapt to changing market needs and the production of new products. This indicates the importance of flexibility of CIM while designing the system and reorganisation of the production planning and control system.

(vii) There is a need for a unique set of standards that satisfies all the requirements of a CIM system.

5. A suggested framework for the implementation of CIM

The strategy for the successful implementation of CIM should include the use of computers for integrating information and material flows, small batch production with on-line production control system (e.g. FMS), and a local area network (LAN) for integrating the information flow within the organization. A conceptual framework is presented in Figure 2 to explain the main issues involved in improving the integration and adaptability aspects of CIM. The model presents a set of major elements of CIM implementation that includes strategic, organizational, behavioural, technological and operational issues. Each of these elements is discussed from the view of improving integration and adaptation in the implementation of CIM. The details follow hereunder.

Strategic aspects

Top management selects CIM as a manufacturing strategy based on the business strategy considering the internal and external factors as discussed earlier. Middle management should work out the CIM development programme. The workers along with middle management staff are responsible for the implementation of CIM. The company's limitations in terms of capital, knowledge workers, complexity of the material flow, layout types, etc. should be considered while designing and implementing CIM. In addition, the achievement of objectives should be used to justify the adoption of CIM technology.

Organizational issues

CIM requires cross-functional co-operation, and high involvement of employees in product development process. To be successful in the implementation of CIM, an initiative must have the direct involvement and commitment of top management. Top management also invests company resources and accepts long-term results, by eventually modifying the company organization as required for a successful CIM. Effective implementation of CIM requires a strong degree of communication and co-ordination among interdependent units in companies. The internal factors such as product and process characteristics, infrastructure and skills available, and external factors such as market characteristics, and government support and regulations tremendously influence the implementation process of CIM. The process of integration using CIM concepts becomes somewhat easier

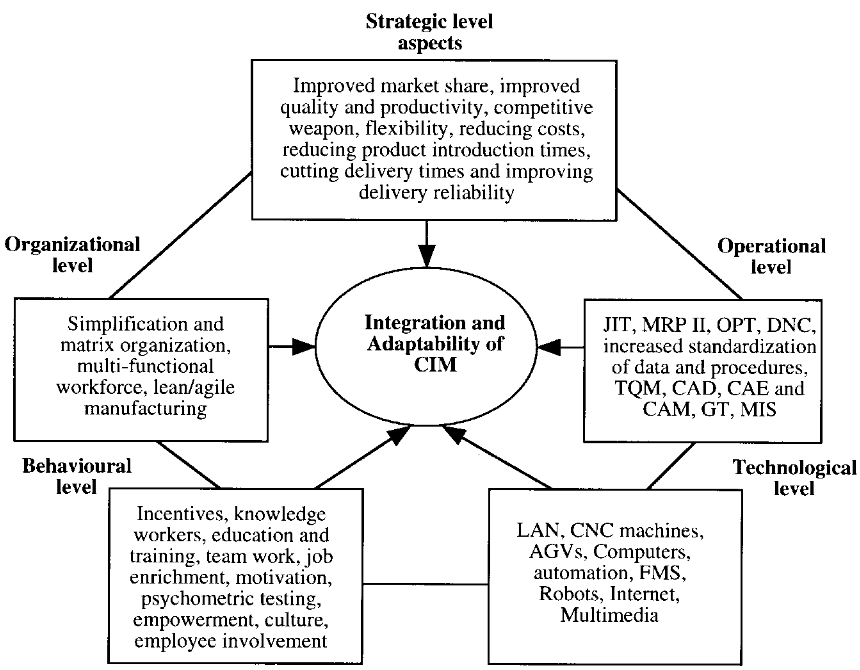

Figure 2. Integration and adaptability of CIM: a framework.

if the system has already a JIT production control system or manufacturing cell. Government support either in the form of financial or technical will help to minimize the risk of loss in production and business as a whole while implementing CIM. The level of integration should focus on the critical areas that influence the performance of manufacturing to overcome the financial constraints.

The major issue in the implementation of CIM is to reduce the overall complexity of the manufacturing system. This may call for process simplification, e.g. through the use of flow lines or cells using group technology. One should recognize that because of data volumes, most companies will still need a computer-based production management system, so that the approach must lead to a software specification. The overall performance of the system can be enhanced considerably through the infrastructure policies, procedures and practices that control business processes, so any solution must be a balance between software and the infrastructure.

Continuous organizational change driven by a need to be more competitive appears to be a major driving force for changing information systems. One should first study why flexibility is needed in CIM systems and level of flexibility required in software. Usually, two types of flexibility requirements are identified, namely changes in operational procedures and changes in decision making. A matrix organization will help to improve the cross-functional co-ordination in the implementation of CIM. CIM technology may enhance competitive advantage but, it must be recognized that the integration of various computerized systems produced by different vendors often leads to technological difficulties. In addition, the capital investments needed for the development and implementation of CIM are substantial. Hence, it is very important to provide a system after the necessary changes in the organization to facilitate the system for computer integration. CIM includes all the engineering and design functions of CAD/CAM, together with all the business functions such as sales, order entry, accounting, distribution, etc. (Groover 1987, Gunasekaran *et al.* 1994).

Behavioural aspects

Co-operation among different levels of employees can be achieved by smoother communication systems. The type of workforce involved in the implementation and operation of CIM is knowledge workers such as computer operators, software engineers, network managers and so on. Therefore, the type and level of training and education required should be determined taking into account the infrastructure, integration and adaptability issues. Effective teamwork (with empowerment and responsibility) has to be achieved to successfully implement CIM. This could be achieved by a collective incentive scheme, team work, training and job enrichment.

Technological aspects

A suitable CIM configuration should be decided before the implementation process that generally centres around the identification of tasks to computerize, the selection of feasible software packages, and improving software compatibility. In order to include flexibility in CIM, manual policies, procedures, and practices should be established. The integration and adaptability of CIM can be made considerably easier with FMS, cellular manufacturing systems and JIT production systems. Technologies such as Internet, multimedia and LAN can be used to improve the integration of various business areas of manufacturing organizations. Automated guided vehicle systems (AGVs) using computers can play an important role in improving the integration of material flow within the production system. Integration of operational activities with suppliers can be improved by on-line computer information systems such as an electronic data interchange (EDI). These also can play a vital role in an unmanned factory.

The integration of various functional areas (in terms of information and material flow) can be achieved using existing equipment and low-cost components such as contact sensors and relay systems. Hence, the old equipment can be partially replaced without affecting the remaining components of the cell. The system's design is modular and the component programmes are independent. The integration capability of the equipment is of the utmost importance. The application of standard communication protocols such as the open system interconnection reference model proposed by ISO, MAP, TOP or IEEE 802 standards may not be feasible for this application (Boubekri *et al.* 1995).

Operational aspects

CIM requires the reorganization of the production planning and control system with an objective to simplify the material and information flows. The manufacturing concepts such as JIT and MRP II and technologies such as CE and AGVs provide the base for easy implementation of CIM to improve integration and adaptability. The essence of CE is the integration of product design and process planning into one common activity, that is CAD/CAE. Concurrent design helps to improve the quality of early design decisions and has a tremendous impact on the life cycle cost of the product. The implementation of CE will facilitate integration and adaption in CIM.

6. Summary and conclusions

In this paper, the literature available on the implementation of CIM has been reviewed with an objective to improve integration and adaptability of CIM in practice. A conceptual model has been presented to illustrate the role of strategic, organizational, behavioural, technology and operational issues in the implementation of CIM. Based on the literature review, a framework has been provided to improve the integration and adaptability of CIM. The implementation process of CIM should not underestimate the magnitude of moving towards full integration as a major emphasis in undertaking the project. Emphasis should be placed on information automation to improve integration and adaptability in CIM. Future research areas of CIM are to develop suitable models for investment decision making in CIM projects and to determine the levels of skills and training required to develop and maintain a CIM system. In addition, a system such as computer-aided tools (e.g. artificial intelligence, expert systems) should be developed for evaluating different alternative processes of CIM development from the viewpoint of integration and adaptation. Moreover, a functional approach should be developed for integrating the concept of operational safety during the specification phase of CIM systems. A framework should be developed for designing CIM and building CIM systems by manufacturing personnel with little or no prior computer experience.

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