Survey of the Computer-integrated Manufacturing Literature: A Framework of Strategy, Implementation and Innovation

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ABSTRACT *A model of computer-integrated manufacturing as the integration of strategy, implementation and innovation is presented. Strategy emphasizes a clear understanding of the objectives and goals of the organization. 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.*[1]

Introduction: The Evolving Concept of CIM

Computer-integrated manufacturing (CIM) is an evolving set of concepts of computers, advanced manufacturing systems and management practices. An early description of CIM emphasized a completely automated manufacturing facility.[2] Traditional manufacturing decisions have been based on performance standards such as machine downtime, work-in-process inventories, etc.[3] The objective was to increase the operational efficiencies by eliminating labor costs, so providing greater quality at a lower cost. Maintaining or gaining competitive position was a consequence of increased levels of operational efficiency.

Under this early strategic context, CIM was concerned with providing computer assistance, control and high-level, integrated automation at all levels of manufacturing.[4] The growing emphasis was on linking islands of automation into a distributed processing system.[5] The scope of CIM in those early days included the following:

- evaluating and developing different product strategies;
- analyzing markets and generating forecasts;
- analyzing product market characteristics and generating concepts of possible manufacturing systems;
- making total processes more productive and efficient;
- increasing product reliability;
- decreasing production costs;
- reducing the number of hazardous jobs;
- integrated computer-aided design (CAD)/computer-aided manufacturing (CAM) systems.

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Figure 1
The CIM Model

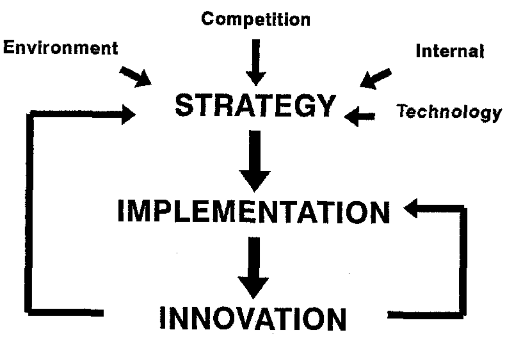

Figure 1. The CIM model.

From this beginning, CIM has now evolved to be broadly defined as a strategy for improving the competitive effectiveness of a manufacturing enterprise. Such a strategy integrates information processing technologies, communication protocols and manufacturing systems with business planning.

Recent approaches consider CIM to be a philosophy rather than just a technology;[6] CIM is generally accepted as the highest level of integrated automation in a manufacturing plant. Appleton[7] added the enterprise management aspect to CIM. In this respect, CIM evolved from a technological framework into one that considered the broader view of a manufacturing enterprise.[8]

The newer concept of CIM involves a major change, viewing manufacturing as 'knowledge work' utilizing a variety of computer and communication technologies rather than a set of physical and mechanical operations on material.[9] The manufacturing technology will have an impact on strategic issues, such as the introduction of new product lines. It will also affect detailed operational issues, such as whether or not to accept a short lead time customer order, agree to an engineering change or alter a stock reorder point. Tactical issues of control and feedback are also to be considered.[10]

The main challenge of CIM is to implement the correct level of technological sophistication to achieve competitive advantage without over-investment of capital and time. The most important opportunities offered by CIM technology can be realized by integrating business strategy with technology. Innovative use of CIM can be an instrument of strategic change.[11] It can help to incorporate a new social process into the manufacturing culture for delivering increased value to the customers.[12]

The CIM model is an integration of strategy, implementation and innovation (Figure 1). Strategy development is a complex process for the determination of the basic long-term goals and objectives of an enterprise.[13] It involves the integration of environmental, competitive, internal (both economic and political) and technological forces,[14–16] However, a successful strategy is contingent upon a successful implementation. Innovation is then the desired outcome of an implemented strategy. It is the continual iterative and incremental process of organizational learning and adjustment.[17–19]

Objectives of the Manufacturing Enterprise

Integration of the following divergent technological objectives is vital in the formation of an effective corporative strategy of a manufacturing enterprise:

- outward-looking marketing concerned with customers;
- inward-looking innovation concerned with producing products to satisfy customers.

The marketing arm of a manufacturing enterprise must identify the customers and their needs, and understand their competitors. Innovation strategies are concerned with both the product and process technologies necessary to bring the products to market.

Product and Process Strategies

Product strategies deal with the differentiation of products, market definition, market size and growth rate, and the enterprise's size. A successful product strategy would include appropriate product positioning in different market segments or niches. The organizations must decide what to develop, what to maintain and what to phase out in the life-cycle of a product, based upon a clear definition of the market and business objectives.

Product strategies can assume one of three different types: cost leadership, differentiation or focus.[20] Cost leadership strategies require that the organization achieves the lowest costs of production and distribution, so that it can position its products based on a lower price. Differentiation stresses uniqueness and product attributes relative to price, while focus emphasizes market segmentation (niche markets).

Process strategies deal with the span of operations along the commercial chain that links raw materials to customers; the scope of the business; and the relationship between the enterprise, the customers, the suppliers and the competition. The process strategies are closely related to the product range and volume of the products. Products that are designed to compete based on price alone would require technologies that emphasize efficiency and volume production over quality and product differentiation.

CIM Technologies

CIM is the information technology that links information control with people, technology, products and processes. It looks simultaneously at the information requirements from the top down and at the individual users. CIM is expected to improve the productivity of indirect and direct labor by reducing the amount of redundant and incorrect information, the need to reconcile data from different sources, and the time currently lost waiting for parts and information to arrive. Common data are shared between functions and maintained at discrete points in the organization. In this way, the strategy (product, process or both) is constantly being monitored (feedback). CIM must be able to support the current needs and be adaptable to change.

CIM is a label for a set of techniques that are making fundamental changes in manufacturing. The techniques incorporate the product and the manufacturing process. CIM has also been portrayed as multiplying the benefits of separate computer systems, compared with the benefits in a non-integrated environment.[21] Four categories of these CIM techniques have been identified:[22] CAD/CAM; process planning; flexible manufacturing systems; materials requirements planning (Table 1).

CAD/CAM. CAD/CAM has been considered to be one of the first CIM tools.[23] CAM/CAM technology can be integrated into product and process strategies. Primarily,

Table 1. CIM components and techniques utilized to improve product and process strategies

CIM techniques and components	Product strategy	Process strategy
CAD/CAM	(1) Faster response (2) Design flexibility (3) Lower product development cost (4) Reduce the need for physical prototypes (5) Increase innovation capabilities (6) Improve quality (7) Improve reliability (8) Improve data consistency	(1) Manufacturing flexibility (2) Improve manufacturing performance (3) More efficient use of experts (4) Improve standards of desirabilities (5) Reduce repetitive input
Process planning computer-aided process planning (CAPP), group technology (GT)	(1) Design and part classification schemes (2) Reduce design time (3) Improve quality (4) Reduce cost and the design to manufacturing time	(1) Improve process synergy (2) Improve shop-floor productivity (3) Reduce tooling requirements (4) Reduce set-up time (5) Improve quality (6) Simplify numerical control
Flexible manufacturing systems (FMS) Flexible manufacturing cells Numerical control systems Robotics Material handling	(1) Improve product quality (2) Increase design freedom (3) Increase part flexibility (4) Improve response time	(1) Improve flexibility (2) Improve reliability (3) Improve quality (4) Reduce operation costs (5) Reduce storage costs (6) Reduce operating costs (7) Reduce set-up time and costs
Material requirements planning (MRP) MRP, MRP II JIT[a] EDI[b]	(1) Reduce product obsolescence (2) Reduce product development cycle time (3) Reduce product rework (4) Improve product quality (5) Improve delivery time	(1) Reduce inventory costs raw material and work in progress (2) Improve production capacity control (3) Reduce order cycle time (4) Improve quality control (5) Reduce factory overheads

[a]Just-in-time. [b]Electronic data interchange.

CAD/CAM is used in product design. In this respect, it can affect decisions about the products an organization chooses to make, how these products will respond to between cost and performance trade-offs, materials and quality, product differentiation and process technology, and customers and suppliers.[24] The use of CAD/CAM can result in a reduced development cycle, through the aid of its database and rapid prototyping capabilities, improved product cost or performance via the graphic display technologies, and more efficient use of expert knowledge. Additional benefits can be derived from its ability to transfer design data directly to production control systems.[25] Operational efficiencies and effectiveness would then be augmented by reducing administrative support, reducing repetitive data input and improving the data consistency through standardization.

Process planning. Process planning technologies include group technology and computer-aided process planning (CAPP). Process planning bridges the gap between parts, machine tools, equipment and the processes required to produce the products. The technology has an impact on product strategies by improving the control over design and part classifications,[26] promoting reductions in design time and costs, improved product quality and reduced design-to-manufacturing time. The impact on process strategies is through improved synergy and shop-floor productivity. The shop-floor productivity is a result of reduced tooling requirements and set-up time. The product quality is then further improved via more reliable and controlled processes.

Flexible manufacturing systems. Included among flexible manufacturing systems (FMS) are computer numerical control (CNC) systems or numerically controlled machine tools (NCMT), robotics, flexible manufacturing cells and material handling systems.[27] Numerical control systems are those involving relays, switching and programming that control the actual production machinery.[28, 29] Robotics are more advanced CNC machines with greater flexibility, capable of emulating some aspects of human action.[30] In general, material handling systems will include anything that moves material to or from an area, such as warehousing systems, pallet movers, automated guided vehicle systems and conveyor systems. FMS can incorporate all the above, while also being flexible enough to be used for many different products of varying batch size.[31]

The strategic product benefits resulting from FMS are improved product quality, increased design freedom and parts flexibility, and improved response time. The strategic process benefits are reduced scrap, waste and set-up time, resulting from improved process flexibility and reliability. Other benefits include reduced storage costs and space, and an overall reduction in operation costs through cycle time reductions.

Material requirements planning. Materials requirements planning (MRP), and its related technologies of manufacturing resource planning (MRP II), just-in-time (JIT) and electronic data interchange (EDI), are used extensively for planning and scheduling material deliveries with manufacturing capacity.[32,33] The strategic product benefits derived from these technologies have been improved product quality, reduced product obsolescence and reduced development and rework times. The strategic process benefits are the result of reduced inventory costs, manufacturing cycle time, delivery time and factory overheads. Furthermore, these benefits then have multiplier effects which result in increased production capacity and improved quality control.

Strategy Development

A strategy is a way of developing and putting into action organizational resources and policies that govern management behavior.[34] Other aspects of strategy include the determination of the basic long-term goals and objectives of an enterprise,[35,36] competitive advantage[37–39] and patterns of decision making under a structural adaptation process.[40] Hahm[41] suggests that strategy consists of the management processes of formulation, implementation and supervision of innovation.

Historical Perspective of Manufacturing Strategy

Skinner identified the following characteristics as important dimensions of mass production systems:

- long runs;
- stabilized engineering designs;
- concise product lines;
- repetitive operations;
- a higher percentage of cost on direct labor;
- intensive use of labor standards and incentives;
- the use of many identical machines in the facility;
- batch processing and job–shop layouts;
- job units base on industrial engineering time-and-motion studies.

Before the 1960s, demand generally outstripped supply. The main product strategy was to be a low-cost leader, while the process strategy emphasized efficiency of production.[42,43] In the 1970s, the strategic focus shifted from price to quality. Then the increased level of competition during the 1980s required that manufacturing add product differentiation to its set of critical success factors. Manufacturing strategy in the 1990s emphasizes price, quality, product and uniqueness of market niches. This last factor requires a large amount of innovation, because the product is geared to an individual customer's needs.

Bolwijn and Kumpe[44] presented a phase model of product and process strategies, showing their evolution within the manufacturing industry. Product strategies shift from price to quality, to product line, and finally to uniqueness. The process strategies shifted from efficiency to quality, to flexibility, and will shift to innovativeness in the 1990s. The authors suggest that each is a different phase and that a phase cannot be skipped very easily.

Table 2 summarizes the observations of Bolwijn and Kumpe[45] and integrates Skinner's[46] manufacturing dimensions with the product and process strategies and CIM technology of Table 1.

Current Analysis

Increased competition, social change and new technology are transforming the manufacturing environment. These changes are increasing the demands, complexity and change rate of the factory. These factors are in turn changing at different rates, depending on the type of industry and organization. The new characteristics are being implemented as a result of pressures from outside the firm, new problems within the firm and the advent of new technology.[48–51]

The 1990s are going to be characterized by environmental uncertainty, turbulence, new competition, shorter product life-cycles, demand for higher quality, demand for

Table 2. Environmental conditions and manufacturing strategy

Environment and decade	Market requirements	Product strategy	Process strategy	Manufacturing characteristic	CIM technology
Stable, 1960s	Price	Few varieties	Efficiency	Long runs	None
New competition, 1970s	Price, quality	Quality	Efficiency, quality	Quality	CAD/CAM, MRP II
Increased competition, 1980s	Price, quality, product	Quality, differentiation, wide assortment	Efficiency, quality, flexibility	Short manufacturing throughput	CAD/CAM, MRP II, CAPP, FMS
Dynamic, 1990s	Price, quality, product, uniqueness, niches	Quality, differentiation, constant stream of new products	Efficiency, quality, flexibility, innovation	Strategic: the ability to change and renew quickly	Fully integrated CIM

Adapted from Bolwijn & Kumpe.[47]

greater return on investment, new technologies, social changes, and more.[52–55] These changes are increasing the demands, complexity and rate of change of the manufacturing enterprise. For manufacturing to remain or gain competitive advantage, the manufacturing strategy must be integrated with the enterprise strategy.[56,57]

If a company's manufacturing strategy is consistent with the company's competitive corporate strategy, then manufacturing can become a competitive weapon. However, if this is not the case, it will become a negative effect and hinder any corporate strategy.[58] Skinner[59] reports that a top-down management approach that starts with the role of manufacturing in the corporate strategy leads to a strategy for making consistent and basic focused policy decisions in the design and management of manufacturing operations.

Skinner also states:[60]

> Technology, competition, and social change have brought serious problems for manufacturing. Further technology and social changes will take place and, in combination with the natural competitive processes, will continue to force an accelerating evolution in the factory.

Critical Success Factors

Gerelle and Stark[61] developed a measurement scheme based on critical success factors (CSFs) which integrates enterprise strategy with manufacturing. These CSFs of quality, productivity, adaptability and flexibility provide a strategic framework for integration and the cost justification for systems implementation. The major definitions and measurements[62–67] of the CSFs are provided in Table 3. Rockart[72] suggests that CSFs will be different for each industry and company. The ones present here are only a sample of the many possible CSFs that can be used.

The CFSs can be integrated with the product and process strategies and CIM technologies to build Table 4. This table also highlights the justification and ways of incorporating people into the strategy. Employee involvement is one of the most important strategic elements in CIM. See the work of Boddy & Buchanan,[73] Steudel & Desruelle[74] and Tidd[75] for a review of this important issue.

The Strategy for Today

The 1990s are characterized as being turbulent;[76,77] uncertain;[78,79] with new competition;[80,81] having a demand for higher quality products;[82,83] possessing shorter product life-cycles;[84,85] and undergoing many social changes.[86,87] Under these conditions, how does an organization develop a strategy and what is the strategy? Skinner[88] suggests that manufacturing industries require a long-term strategy, because long lead times are needed to make changes in the facilities, equipment and processes. Typically, there has been a short-term view (schedule and costs) from an operational perspective. Also, manufacturing has tended to focus on productivity and efficiency. These criteria need to be expanded to include the CSFs selectivity, quality, service, delivery, investment and flexibility for change.

Skinner[89] also suggests that management should focus on the structural issues of number, size and location of plants, choices of technology and equipment, and basic systems for controlling operations. This leads to the main point, namely that the manufacturing strategy must be linked to corporate strategy.[90] For manufacturing to be a competitive weapon, the corporate strategy must be the same as the manufacturing

Table 3. CSF definitions and measurements

CSF	Definition	Measurements
Quality	(1) Goodness (2) Excellence (3) Superiority (4) Exceptions to standards	(1) Cost of engineering (2) Cost of scrap and rework (3) Inventory costs (4) Field repair frequency and costs (5) Organizational overheads (6) Market share loss on defects (7) Lateness
Productivity	(1) How well the enterprise is operating	(1) Ratios of inputs to outputs (2) Resource utilizations
Adaptability	(1) Product and process technologies relative to investment (2) The ability to develop new products	(1) Number of new markets entered (2) Number of new products (3) Number of new product features (4) Development cycle time (5) Product life-cycle
Flexibility	(1) Versatility of the enterprise manufacturing process (2) Ability to respond to change by taking the appropriate action (3) The ability to function in more than one state	(1) Change-over cost (2) Change-over time (3) Number of different tasks it can perform

Adapted from Chambers,[68] Gerelle & Stark,[69] Macfarlane[70] and Tidd.[71]

strategy. This can be achieved by applying communication and computer technology to the three distinct levels of the organization:[91] the industry level, the firm level and the strategy level.

At the industry level, the CIM technologies can be applied to the product and process technologies. CAM/CAD technologies can be used to decrease the new product or differentiated product development times. Automated material handling systems will reduce shipping costs and time, as well as lowering inventory space requirements. Customer order entry systems can provide easy access to products and shipping schedules.

The CIM technologies can have an impact at the firm level by integrating the buyers and suppliers directly with manufacturing. The installation of a quality control system by an automobile firm forced the supplying steel firms to be more quality conscious.[92] FMS can be used to manufacture products of high complexity, which then can create new entry barriers.

At the strategic level, the choices of technology, how they are implemented and the resulting policies and procedures can produce competitive advantage.[93] For example, a strategy to achieve a differentiated position requires a perceived uniqueness in design or in product feature. The required technology that will enable this strategy is linked by

Table 4. Strategy based on CSFs

CSF	Product strategy	Process strategy	Technology	People	Justification
Quality	Improve product quality	Reduce rework and scrap levels	CAD/CAM	Quality circles	Increase unit price
Productivity	Reduce work-in-process inventory	Reduce time spent in queue	JIT, MRP, FMS	Job enrichment, reduced job classification	Decrease unit cost
Adaptability	Increase number of product features	Reduce set-up time	CAD/CAM, FMS, GT, CAPP	Product teams	Increase product investment
Flexibility	Improve response to Market demands	Produce units of one	CAD/CAM, FMS, GT, CAPP	Retrain and educate	Decrease product cost

CAD/CAM to a FMS. In this capacity, both the product and process technologies are affected.

Strategy development is not just a one-time undertaking; it must be monitored, adjusted and rethought. Skinner[94] states that a successful manufacturing plant does not stay successful for long; somehow, the competitive, efficient operations deteriorate to become a corporate liability. Several guidelines are proposed:

- manufacturing to understand the corporate and market strategy, and vice versa;
- if they do not fit, then adjust to fit;
- monitor the strategy—if a new product is needed, see if it fits the current manufacturing strategy; if not, then adjust strategy accordingly; use the audit of manufacturing policies, tasks and structure;
- recognize the trade-off in design;
- learn to focus on a limited, concise manageable set of products, technology, volumes and markets (create a niche).

The corporate strategy that focuses on a narrow product mix for a particular market niche will outperform the conventional plant which attempts a broader mission. According to Skinner,[95] the equipment, supporting system and procedures for niche marketing can concentrate on a limited task for one set of customers, and its costs and overheads are likely to be lower than those of the conventional plant. This is an economy of scope.

Conventional factories produce many products, for numerous customers, in a variety of markets. This requires a multiplicity of manufacturing tasks, all at once, from one set of assets and people. This is an economy of scale. The strategy then is as follows:

- develop a long-term strategy;
- focus on the CSFs (i.e. quality, adaptability, flexibility and productivity);
- link manufacturing strategy to corporate strategy;
- learn to specialize;
- create uniqueness;
- create complexity;
- create diversity;
- create teams;
- incremental approach;
- innovate.

Implementation

A successful strategy is contingent upon a successful implementation.[96–98] The secret of success is to create success. One of the early theories of implementation[99] suggested start small and develop a series of successful implementations. Success then generates more success. Keen[100] and Ferravanti[101] suggest that a small amount of success alters social inertia, which hinders implementation, by creating a 'band wagon' effect. Successes also deflate the political pressures to resist change, simply by showing success.

Leonard-Barton and Kraus[102] observed that successful implementations were contingent upon successful project managers. The successful project managers had developed the necessary skills to accomplish the following:

- observe current job routines;
- listen and discuss procedures with users;

- collect information for decision-making;
- discuss the frustrating and rewarding parts of the job with the workers;
- examine how the procedures integrate with other groups.

Leonard-Barton and Kraus[103] also suggest that implementation success is closely associated with the level of management involved with the project and the project functionality. Thus, the higher the management level involved, the greater is the success, and the closer the solution fits the needs of end users, the greater is the success.

Gould and co-workers[104] have developed a set of usability design principles which emphasize the following:

- an early focus on the user;
- integrated design;
- early and continued user testing;
- an iterative design.

These usability principles agree with the observations reported by Leonard-Barton and Kraus[105] in that implementation success is contingent upon user involvement and application fit.

The implementation team must also have a high level sponsor, a champion (a sales person, diplomat or problem-solver), and a project manager who is an integrator and a communicator, and who can manage conflicts.[106,107] Other key attributes are as follows:

- being able to monitor resistance;
- plan for fear of loss of power, and control among the users;
- ensure that there are benefits for the user;
- be aware that new technology requires new performance measures.

Gupta and Wilemon[108] report that CIM failures result from lack of management support, lack of resources and poor project management. These characteristics suggest that it is not the implementation that is at fault but the initial strategy. The lack of management support is a political anomaly[109] associated with resistance and counter-implementation. The lack of resources and poor project management suggests that the strategy did not define the projects.

Adler[110] states that the new CIM technology creates unique problems. Solutions to these problems require an organizational culture of cooperation, a commitment to learning, and the establishment of a culture with supporting strategies, structures and procedures. Other requirements include the following:

- a long-term relationship with suppliers;
- a good fit of technology, process and product;
- a clear strategic vision on the part of the user;
- both hands-on and theoretical training;
- plan for effective implementation.

As the learning process can be very lengthy, this tends to compete with other needs, namely production. Training also becomes an issue in that it requires continual investment; it requires the responsibility to shape a new attitude. Expertise becomes problem-solving as opposed to task oriented, and the interaction becomes teamwork.

Dean *et al.*[111] integrate the ideas of Keen[112] and Leonard-Barton and Kraus[113] by concluding that implementation consists of making and implementing a series of decisions. The decisions are a set of system functions, resource commitments, location of

Table 5. Requirements for implementation success

Factor	Economic objectives	Political objectives	Technical objectives
Tolerance: expectations of success	(1) CSFs (2) Clear strategy	(1) Create success: iterative and incremental (2) Develop a consensus (3) A champion (4) User involvement in design (5) Continued communication	(1) Functionality of technology (2) Usability of technology
Level of resources available for the project	(1) Long-term strategic goals (2) Financial position	(1) User and sponsor optimism	(1) Design for ease of manufacturing (2) Reduce complexity
Trade-offs and Interactions between objectives	(1) Cost *vs* performance (2) Level of commitment from vendors, users and managers	(1) Cost *vs* training (2) Visibility of inter-functional management	(1) Pilot *vs* full implementation (2) Creation of a culture for change

Adapted from Dean *et al.*[115]

pilots, and schedules. The decisions have technical, economic and political objectives. The economic objectives are expressed in terms of payback period, return on investment (*ROI*) and net present value (*NPV*) (see Kapland[114] on cost of CIM). The technology objectives can be expressed in terms of CSFs and the proper fit and placement developed from the strategy. The political objectives in turn ensure that the systems satisfy sponsors, users and strategy goals. These objectives include the following factors:

- *tolerance*—fit of technology; length of time to reach or get close to goals; functionality/usability approximation;
- *resources*—the amount and skill of technical, economic and political resources available;
- *trade-offs/interaction*—direction of relationships (the interaction and strengths of the resources); the more positive the relationship is between any pair, the greater is the probability of success; the greater the balance is between any of the factors, the greater is the success.

The strategic potential of the CIM technologies can only be achieved if the technologies have been implemented. This in turn depends on the quality of the decisions that constitute the implementation process.

The three-dimensional model (Table 5) developed by Dean *et al.*[116] defines implementation as a decision process in which the set of decisions, objectives and factors are interrelated with each other. Dean *et al.*[117] suggest that there are several ways that can improve the success of the implementation: increasing the technical resources, and increasing the economic and political tolerances.

Simplifying the system is equivalent to increasing the technical resources. One way of rationing technical resources is to select carefully areas for piloting—this is an example of an incremental implementation. It is better to pilot a new system in a simple area and then move to a more complex area as the problems with the technology are resolved. The entire area should be simplified before automating.[118] (See also Cranfill[119] and Kramer[120] on a seven-step manufacturing improvement and simplification plan.)

Economic tolerance can be increased by following the strategic goals and objectives, i.e. the CSFs. According to Huber,[121] implementation success has been measured by meeting cost-reduction goals. However, the greatest benefits have occurred in terms of quality, productivity, flexibility and adaptability. Therefore, if there is greater tolerance in terms of cost reduction, a more successful implementation can be realized.

Political tolerance can be increased by small successes. Projects which have a high probability of success rather than a high return should be chosen. Being successful brings credibility with users, and can lead to a greater tolerance when problems are encountered with more challenging projects. Big projects take many years with only one success, during which time the technology and the environment change.

In conclusion, a successful implementation is a stream of interrelated decisions which are iterative in nature. These decisions take the political, economic, technical and interaction of these dimensions into consideration. The organizational context (strategy) is affected by the implementation process, creating new contexts which can be defined as innovation.

Ferravanti[122] suggest a simplified approach to either product or process implementation with a MRP system. A product implementation would consist of implementing one product or class of products at a time. A process implementation would consist of implementing one functional area at a time (i.e. manufacturing, then warehousing, then quality control, etc.). The implementation team achieves quick success and can work out technical problems more smoothly.

Peters[123] also suggests a flexible implementation plan consisting of the following factors:

- get everyone involved and the corporate mission becomes the enacted or implemented strategy;
- use self-managing teams which are multi-disciplined;
- collect data (listen, share) and integrate information;
- provide training retraining, incentive pay and employment guarantees;
- simplify/reduce structure;
- reduce layers of management;
- assign support staff to the field reporting to line management;
- provide for wide spans of control;
- de-bureaucratize, i.e. reduce paperwork and unnecessary procedures.

Innovation

Innovation within a CIM environment is the outcome of the interaction between ideas and processes.[124] CIM is the tool which will amplify the ability to produce. Engineers using tools such as CAD/CAM will be able to design greater flexibility and adaptability into the product, while simultaneously matching exact customer requirements. Managers will be able to concentrate on cultural change for greater internal and external collaboration. The workforce will be able to focus on teamwork, inter-functional cooperation and problem-solving.

Innovation is a continual process of organizational learning. If the objective of a firm is to become flexible as part of its competitive advantage, it must first learn to become quality conscious. If the quality is not part of the enterprise's strategy, processes will be delayed, costs will escalate and flexibility will not be realized.[125]

Innovation is the creation of a product or process which is new to the enterprise business unit.[126] Many innovations are revolutionary in nature, e.g. the results of major breakthroughs.[127] However, the majority of innovations are the cumulative effects of incremental changes in the product or process, or the creative combination of existing techniques, ideas or methods.[128,129] Innovation, then, can be defined as the continual incremental integration of market needs with technology and manufacturing processes.

In a recent paper, Steingraber[130] suggests that the business strategy for the 1990s must include the following:

- a global presence;
- the concept of continuous improvement;
- a teamwork and collaboration philosophy;
- quality conscious in every aspect of business;
- perceived customer value.

The measurement scheme for monitoring these strategies must include the following:

- developing new products faster;
- faster cycle times from order processing through manufacturing;
- flexible response to customers.

Shorter cycle times mean cutting the intra-organizational boundaries. To do this, a cultural change is required. This will consist of the following:

- a communication system that permits non-routine events to surface quickly at the highest levels;
- individual must be empowered to create change;
- implementation must be iterative and cyclic, so the organizations can respond to problems and business opportunities;
- more or less product line breadth or depth;
- more or less vertical integration;
- a global presence;
- a synergy across business units and functions;
- low cost *versus* customer value;
- responsiveness to competition, the environment and customers.

Goldhar and Jelinek[131] stated that CIM changes the manufacturing from a physical and mechanical system into one of information and knowledge worker activity. The facility is then under the economies of scope (the factory will no longer be an economic barrier to rapid rates of innovation, sophistication and intimate vendor–customer relations). In addition to the technology, the enterprise will need to make and develop new strategies based on timeliness, innovation, variety, product niches, sophisticated policies, organizational structure, human resource management and accounting systems.

The new business strategy will be based on complexity rather than on the mass market simplification, in terms of shorter product life-cycles, customization, rapid design and production cycles, and close coupling (linking) with the customers and suppliers over a long period of time.

Information has become more than just the fifth resource (money, materials, manpower, machines and information); it has become the main resource. CIM permits and requires close integration across business functions, so that engineering designs what manufacturing can make, with both carefully matched to what marketing has determined the customer wants. The integration must be matched by increased flexibility and rapid change-over, or else the competitors will seize the short-lived window of market opportunity. These changes in resources, technology and strategy create high levels of certainty, predictability and controllability in the manufacturing activity. This also permits an increase in variability in strategy, which is necessary to be responsive to

Table 6. Measures of innovation

Innovation	**CSF**	**Direction of change**
Product		
Number of product enhancements	Adaptability	Increased
Number of new products	Adaptability	Increased
Design cycle time	Productivity, adaptability	Decreased
Customer participation in design	Adaptability, quality	Increased
Product quality	Quality	Increased
Number of new markets	Flexibility	Increased
Customer satisfaction	Quality	Increased
Process		
Manufacturing cycle time	Productivity, flexibility	Decreased
Inventory levels	Productivity, flexibility	Decreased
Number of new pilots	Flexibility	Increased
Batch or order quantity size	Productivity, quality	Decreased
Number of products on same machine	Flexibility	Increased
Educational and training costs	Productivity, quality	Increased
Communication between departments	Productivity, flexibility	Increased
Number of new contracts with suppliers	Productivity, flexibility	Increased

rapidly changing demands. Thus, CIM emphasizes economies of scope via its flexibility and accuracy. CIM substitutes information for tooling, inventory, space, labor, time and supervision. The coordination role has changed from management of people, materials and cost to one of information, change and speed.

Table 6 relates innovations to CSFs and shows the directions of change.

Conclusions

Under the conditions of a turbulent environment, strategic planning becomes a process consisting of environmental scanning, interpretation and action.[132,133] Camillus and Datta[134] proposed a strategic planning system which consists of strategy development (monitoring the environment, analyzing and interpreting the issues), implementation of tactics and activities to support competitive advantage, and feedback (innovation) to ensure that the strategy is effective. The salient features are information and responsiveness, in that the strategy itself becomes iterative, incremental and cyclic. In other words, the strategy becomes innovation. Innovation in turn is responsiveness to competition. Therefore, CIM becomes the integrated tool set for quality, adaptability, flexibility, productivity and innovation by providing the information necessary.

Table 7 integrates the environmental conditions with the CIM framework. The scenarios derived represent the challenges facing the manufacturing enterprises. A strategy requirement required to solve these scenarios is suggested along with the implementation requirements, required innovation and a CIM technology. For example,

Table 7. Environmental conditions and CIM framework

Environmental scenarios	Strategy requirements	Implementation requirements	Required innovation	Technology
Increased domestic and global competition	Continuous learning; continuous environmental scanning	Integrated with strategy	Continuous and intensive collaboration and interaction within organization	Information-based integration; CAD/CAM
Continuous development of new technology	Issue identification interpretation and analysis; continuous improvement	Incremental	Continued experimentation	Logistics integration; MRP, EDI
Changing customer needs and requirements	Assessment and categorization; market specialization and and segmentation 'the niche'; provide customer value	Iterative	Cumulative changes; faster responsiveness	Flexible, accurate and adaptive—economies of scope; FMS
Truncated product life-cycle	Improve organizational effectiveness; product differentiation	Continuous, cyclic	Differentiation; faster responsiveness	Information-based integration; CAD/CAM, FMS, MRP
Higher new product development costs	Provide philosophy and culture	Continuous emphasis on training and education	Greater cognitive skills—communication, idea generation and problem-solving	Adaptability; CAD/CAM, FMS, MRP
Multi-organization product development effort	Monitor and measure performance	Multi-disciplinary *ad hoc* teams	Productivity	Logistics integration; MRP, EDI
Higher prices of raw materials	Cost effectiveness	Small–fast starts	Productivity	Materials requirement planning; MRP, EDI

Adapted from Halm,[135] Camillus & Datta,[136] Gupta & Wilemon,[137] Tushman & Nadler,[138] Peters[139] and Steingraber.[140]

under an environment scenario of changing customer needs and requirements, a potential strategy would be an assessment and categorization of those customer needs. Furthermore, the strategy would then be to segment the market and provide customer value. The implementation requirements would then be iterative, small changes in the product and process technologies as the market segmentation continues. The required innovation would be cumulative change in the organization, in terms of improved market assessment, reduced cycle times and faster responsiveness to these changes. The CIM technology to invest in would be flexible, accurate and adaptable, in order to fit the strategy and implementation; such technologies would be the FMS.

The strength of the proposed model lies in the integration of strategy, implementation and innovation. The challenge of CIM has been to implement enough of the technology, in order to achieve the best competitive advantage, without investing unnecessary time or capital. The organization has to develop a strategy which best fits the environmental conditions in which it is operating. The next step is to implement the necessary technology to satisfy the business strategy. The implementation strategy is iterative and incremental, with constant feedback to the business strategy and environmental conditions. The innovation is then the resulting change, i.e. the organization's adaptation to and control of the environmental conditions.

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