Total manufacturing information system: a conceptual model of a strategic tool for competitive advantage

Choong Y. Lee
Gladys A. Kelce College of Business, Pittsburg State University, Pittsburg, Kansas, USA

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Abstract
Recent advances in manufacturing and information technologies present promising strategic alternatives for designing a new manufacturing information system. Total manufacturing information system is an integrated system of manufacturing technologies and business strategy into an information system. It is a strategic tool for achieving competitive advantage, which enables firms to respond quickly to market changes, achieve flexibility of products and processes, and manage the complexity of today's manufacturing environment.

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Introduction

Recent advances in manufacturing and information technologies present promising new strategic alternatives for designing a new manufacturing information system (Tan and Uijttenbrock, 1997; Coates, 2000). More firms have begun using information systems strategically to reap significant competitive advantage in their operations. They are increasingly interested in managing the strategy-technology connection to develop new systems of achieving competitive advantage (Das *et al.*, 1991). Firms integrate manufacturing functions and business strategy all together into an information system. By successfully extending the integrated system concepts beyond the ordinary manufacturing functions, manufacturing firms are able to achieve an optimal balance of product standardization and manufacturing flexibility. Information technology is a key ingredient in this emerging recipe for competitive advantage through manufacturing (Coates, 2000; King and Teo, 1997; Lederer and Sethi, 1996; Sambamurthy *et al.*, 1993).

The total manufacturing information system (TMIS) is such a powerful alternative which blends recent developments in manufacturing and information technology to achieve competitive advantage. TMIS implies movement toward total integration of manufacturing technologies and business strategies into an information system. It includes all the business functions today's manufacturers should have, from market analysis to quality control and management with business decision support capabilities. TMIS enables manufacturing firms to respond quickly to market changes, achieve flexibility of products and process, and manage the complexity of today's manufacturing environment. It supports and shapes an organization's competitive strategies, and provides competitive advantages to a firm. TMIS becomes more powerful as they cope with changes in technology, resources, demands and responsibilities.

This article provides a framework for defining TMIS and its component technologies in a business rather than a technical context. The framework identifies environmental threats and opportunities, TMIS capabilities, and related marketing, manufacturing, organizational design and information systems development strategies. Broad strategic directions are also identified to formulate a vision of how TMIS can be used as a competitive weapon.

Development of TMIS

Integrated systems concept

Virtually all manufacturing systems today can trace their concepts and structures back to Adam Smith's idea of specialization of labor and the consequent fragmentation of work. The specialization makes sense of mass production of highly standardized products. Furthermore, Henry Ford's idea still convinces many manufacturers today that they can have either standardization at low cost or flexibility at high cost, but not both. This idea has been challenged by the success of Japanese automobile and electronics industries that are based on an integrated systems concept.

An integrated systems concept is not a conglomerate built with vertical integration. Instead, the integrated manufacturing system consists of several independent components, with suppliers at one end and customers at the other end (Coates, 2000; Santacecilia, 1992; Tirpak, 2000). To make the system operate efficiently, the manufacturing system should be designed with a greater functional integration, fewer

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layers of hierarchy, and more external partnerships.

Slow or inadequate flow of information between production and other vital functions, such as marketing or R&D, is a common problem in many manufacturers (Brancheau *et al.*, 1996). Coordination efforts are ineffective due to deep organizational hierarchy and excessive specialization. Decisions are most often made sequentially when they should be integrated. While each function seems to perform its tasks competently, the overall result may still be far from optimal. To maximize organizational performance, all functions should work together as a system instead of seeking sub-optimization at individual functions (Byrd *et al.*, 1995; Earl, 1993; Sambamurthy *et al.*, 1993).

Total integration of manufacturing and business information

Most of the current manufacturing information systems are just individual applications of computer and/or information systems, and their efforts have focused on how to computerize advanced manufacturing technologies (Chan and Huff, 1992; Reich and Benbasat, 1996). However, TMIS seeks to incorporate these individual engineering, manufacturing and business applications into a totally integrated information system. Figure 1 illustrates how an information system integrates advanced manufacturing technologies and other supporting functions, making possible a new approach to designing an ultimate manufacturing information system. It provides a shared database, a database management capability, and a communications network to link marketing, product development, design and engineering, procurement, manufacturing, and quality control functions, etc. This integration provides enhanced business capabilities which cannot be fully attained by the individual system's objectives (King and Teo, 1997; Tirpak, 2000).

Capabilities of TMIS

TMIS helps firms to build a strategic tool which functions at every stage of manufacturing operations, from gathering and analyzing information for new products to developing business strategies through a totally integrated information system. It enables firms to produce efficiently multiple products, respond quickly enough to rapid market changes, reduce time-to-market, adapt to shorter product life cycles and develop high quality custom designs. Therefore, it provides competitive advantages through time-based competition across products or markets. Furthermore, with decision support capabilities, TMIS also enables firms to manage an increasingly complex manufacturing environment. As firms develop TMIS capabilities, changes in strategic thinking occur.

Structure of TMIS: an integrated system of information

TMIS is an integrated system of all functional activities and processes required for manufacturing products. It is a set of computer-based integrated applications which provide manufacturers with a common framework and a single access and control mechanism for all items of information, both hardware and software. It consists of seven subsystems:

1 business and market analysis;
2 product research and development;
3 computer integrated manufacturing;
4 production planning and control;
5 quality control;
6 business decision support;
7 feedback.

Each subsystem needs improvement not only by itself, but also as an integrated system to reduce product development times and enhance the overall efficiency.

Multi-discipline teamwork is the key to success in a TMIS. Suppliers, design engineers, production managers, marketing managers and even customers all have something important to add to the system. The concept is that if all these contributions are included or considered at the beginning of the project, then the process should be right first time and different stages of production activities can begin simultaneously, hence the quality product can be introduced in the markets just on time (Coates, 2000; Sofranec, 2001).

Pre-product development phase (business and market analysis)

Gathering and analyzing business information is the starting point of TMIS. A business intelligence system (BIS) can be used to collect, organize, and analyze business information. The use of information through BIS will enhance firms' knowledge in key areas, thus enabling them to manufacture exactly what markets demand.

Quick response to the changes and new developments in markets is critical to take competitive advantages, such as introducing new products to the market as quickly as

possible. Lee *et al.* (1999) have developed a time-based strategy – total quick response (TQR) system. The concept of TQR system requires that a manufacturing firm should have the capacity of quickly anticipating and comprehending competitive conditions and environmental changes in the markets. It helps firms develop a proactive attitude on strategic directions and to deploy the available resources quickly toward the existing or potential problems (Lee *et al.*, 1999).

Recently, a similar system referred to as competitive intelligence (CI), has been introduced for the same objectives. It is a formal mechanism to collect, process, analyze, and disseminate CI in order to formulate winning competitive strategies and implement them effectively. This CI can provide better understanding of competitors and insights into future competitive strategies. It enables managers to understand what the competition can do, and when and where it plans to do it.

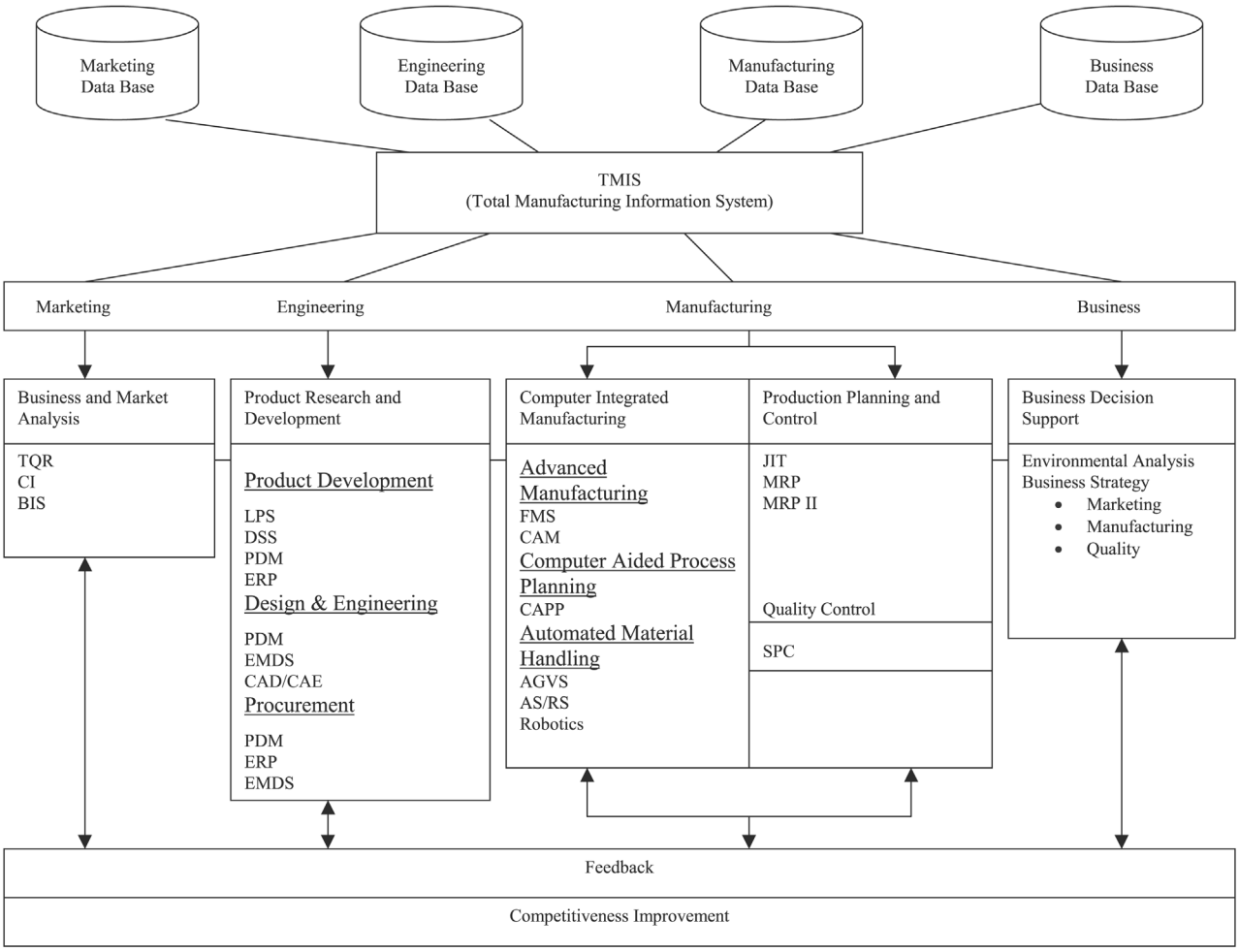
Product research and development phase

A manufacturer's ability to accelerate speed to market hinges on eliminating wasted time and effort in the product development process (Davenport, 2000; Fulcher, 1998; Kempfer, 1998). Most manufacturers can cut product development cycle times by addressing four areas in their manufacturing systems through TMIS. First, a comprehensive product line planning system should manage the overall content and quality of the product line. Second, a development calendar is needed to track timing and responsibility for completion of development tasks. Third, a single product specification and information system should capture all pertinent information about product construction. Finally, these individual system components should be integrated.

Product development

A line planninng system (LPS) establishes the overall guidelines by which the line will be developed. It identifies the target

Figure 1
Integration of manufacturing technologies and supporting functions



consumer, desired fit and materials, design specifications with high market potential, target figures for profitability and volume, timing and channels of distribution, high level sourcing plans and other related important information. Once the initial direction of the line has been set, the LPS should ensure the content and quality of the line are maintained throughout the development process (King and Teo, 1997).

After the initial ground rules and high level structure of a line are defined, a development calendar system (DCS) generates an initial schedule of tasks to be completed based on information in the LPS. It then determines the entire set of tasks, durations and deadline dates needed to develop, create and approve necessary samples of the skirt. It also ensures the product will be manufactured and in the warehouse on time for delivery.

A design specification system (DSS) provides a single source of current information to product developers, merchandisers, purchasing agents, sample makers, costing engineers and other individuals involved. A DSS is a single repository for disparate bits and pieces of design information trickling in from different sources, ultimately including the final product design. Most important, the DSS should serve as the primary communications tool for the design during the development process. It eliminates reworks due to inaccurate, out-of-date data, as well as the continual distribution of design changes and the mountains of paper that such distributions of design changes generate.

While implementing an LPS, DCS or DSS independently is beneficial, these systems are most effective when tightly integrated since integration of these systems eliminates duplicate keying of data into multiple systems, requiring less to keep the same information in multiple systems, and eliminating keying errors and inconsistent data.

Design/engineering

Product simplification improves manufacturing efficiency, materials handling, and quality. By using a cross-functional team, manufacturers are able to simplify the design of the product, making it easier to assemble. A cross-functional design team can also facilitate a modular approach to product design. This approach provides a viable product design strategy to meet changing demand, with the advantage of standardization. With TMIS, manufacturers can invest heavily in designing parts that can be combined in a number of ways and used interchangeably among several different models of the products.

A product data management (PDM) system is an enterprise solution that enables employees across the firm to quickly access product information. Manufacturers are able to optimize design, procurement, and manufacturing simultaneously by tightly integrating a PDM system with a component and supplier management (CSM) system or enterprise resource planning (ERP) system. PDM systems provide a centralized data repository that enables authorised users throughout a firm to access and update current product information, while ensuring that they follow specific procedures. Sharing information between PDM and ERP is essential for optimizing design and manufacturing processes. PDM and ERP are the heart and soul of managing the overall product definition and production life cycles (Fulcher, 1998; Kempfer, 1998; Miller, 2000).

In today's competitive environment, where time to market, cost control, compressed cycle times, and innovation are the prime drivers, more organizations are furiously looking to optimize their business processes by linking a PDM system to their ERP systems. By tightly integrating a PDM system with an ERP system, manufacturers are able to optimize procurement, design, and manufacturing simultaneously. The ability of companies to link effectively those two technologies will dictate the success of manufacturing organizations (Coates, 2000; Davenport, 2000; Sofranec, 2001).

Procurement

Once the internal cooperation is strengthened and coordination is completed between individual functions, the integrated systems concept should be effectively extended beyond the plant into materials supply sources. In many cases, close relationships with either distribution chains or suppliers imply exercising control and are perceived to be possible only through vertical integration. However, the basis of the integrated systems concept is effective informational flows and cooperative relationship.

The vertical linkage with suppliers provides valuable information for technological innovations and other developments enhancing productivity (King and Teo, 1997). Traditionally, vertical linkages between manufacturing firms are weak, and the flow of information about markets and technology are often hindered by proprietary concerns and suspicion. TMIS helps manufacturers to be more willing to extend the partnership with their suppliers.

Manufacturing phase

The manufacturing subsystem in TMIS is not simply a computer-integrated manufacturing (CIM) system with advanced manufacturing technologies. Past factory automation efforts have focused on "stand-alone" applications of CIM component technologies, such as computer numerical control (CNC) machines, robots, and computer-aided manufacturing (CAM) (Miller, 2000). TMIS seeks to integrate these stand-alone engineering, manufacturing and business applications all together in a system.

An engineering manufacturing data system (EMDS) is a set of computer-based integrated applications which provide a firm with a common framework and a single access and control mechanism for all items of information, both hardware and software. It enables a firm to manage the costs incurred by the identified hidden factory. Changes to product design, inefficient purchasing and incident reports are now quantified and the implications effectively cross-referenced. This has provided invaluable information, which is being fed back into the process.

As firms move toward TMIS, manufacturing components will be linked by both information flows and physical flows. TMIS provides a shared database, a database management capability, and a communications network to link engineering, flexible manufacturing and business decision support systems (BDSS).

Production planning and control phase

In a typical TMIS, just-in-time (JIT) and manufacturing resource planning (MRP II) are two most popular tools for production planning and control that can be combined in a complementary manner. JIT can be used for short-term scheduling according to precisely timed customer delivery requirements. In contrast, MRP II is useful for longer term planning of labor availability, material procurement and capacity requirements. Although JIT is a scheduling technique, it might be more properly viewed as a business strategy for designing manufacturing systems that are responsive to customer requirements.

MRP II is basically a planning system, having little association with the actual manufacturing process. JIT, on the other hand, is almost exclusively an execution system that does not concern itself with planning. Although the two systems are concerned with different functional areas of production, the objectives are similar: to get the right part to the right place at the right time. An integrated system, resulting from a "marriage" between the two, can be a more effective manufacturing system which utilizes the best attributes of each. Future manufacturing systems need to accommodate the best planning features of MRP II and the best execution features of JIT to address the changing needs of industry (Lee *et al.*, 1999; Coates, 2000). This is the reason why TMIS uses a hybrid system of combination of JIT and MRP II for production planning and control.

Quality control and management phase

A well-implemented TMIS minimizes the time required for engineering changes, contains costs, reduces scrap and rework, and speeds products to market. In doing so, TMIS supports the quality effort in the broadest sense – meeting customers' needs and expectations for a "good" product at a competitive price in a short time frame. In fact, TMIS aids quality in three basic ways by:

1 enforcing procedures for document and design control;
2 ensuring that engineers, managers, and other users can access the product information they need when they need it; and
3 providing tools for evaluating business processes and measuring the quality effort.

All manufacturers must ensure that manufacturing uses only approved parts. Without PDM, workers could violate product configurations by calling out obsolete or unapproved parts for use in manufacturing. Manufacturers need a way to update automatically an MRP system's product configurations in near real time. PDM systems serve this purpose by transferring approved configuration data to the MRP system. Manufacturers are certain with PDM that they are using the right parts (Fulcher, 1998). Now quality workers focus on other quality issues rather than on parts usage.

Business decision support phase

TMIS is an integrated decision support system, an expert system, and an executive information system. It supports the operational, tactical, and strategic decision making process of global firms in an attempt to integrate organizational decision making across functional fields, planning horizons and national boundaries.

BDSS are interactive computer-based systems directed toward the ill-structured decision problems of upper management (King and Teo, 1997). It is a system that is designed to help the firms to formulate their generic competitiveness strategies, to test

them, and to establish when and how to make a specific plan or a combination of actions. This formulation supports the achievement of basic long-term directions and mission, key strategic and financial objectives, overall business strategies, specific functional strategies, and recommended actions.

BDSS help firms to:

- define their strategic business units (SBU);
- diagnose the current competitive status of the relevant SBUs;
- define the key competitive capacities on which success is based;
- identify the core competencies;
- design and formulate competitive strategies; and
- implement their core competitiveness strategies.

In other words, BDSS help firms to convert the mission and directional course into designated performance outcomes in order to leverage the firms, to achieve an adequate CI and to craft a competitive strategy plan.

Feedback phase

TMIS, like other management systems, needs feedback from its components for improvement. Feedback makes TMIS generate enhanced output and enables users to get updated information and make better decisions based on it. For the successful implementation of TMIS, the extensive feedback mechanisms are required among its components.

In general, TMIS requires top management's commitment, empowerment and employee participation. They are inherent in the concept of an adaptive organization. Without top management's commitment, nothing could be done in a TMIS. With strong participation and adequate authority, employees could feel more comfortable not only in collecting information from every source they can access, but also in analyzing the problem on a first hand basis. The firm should establish a mechanism to allow feedback between top management and employees. The aim of feedback mechanisms is to allow everybody in the firm to participate spontaneously in every phase of the system.

Integrating business strategy into TMIS

Implementing TMIS components can often be justified by their individual system's objectives. However, as many components of manufacturing and information technologies are implemented, the focus of TMIS planning efforts shifts away from individual system's objectives toward the enhanced business capabilities provided by integrated manufacturing systems. It is the capability to integrate marketing, engineering, manufacturing and business databases into a decision support system which distinguishes TMIS from other conventional computerized manufacturing systems, such as CIM and FMS, etc.

The challenge of TMIS is taking advantage of rapid changes in information and manufacturing technology to design new business strategies. Business strategy focuses on competitive advantage and emphasizes creating synergies among major functional policy decisions such as manufacturing system design and product line policies. Figure 2 illustrates a conceptual framework for integrating business strategy into TMIS. In this framework, business strategy is viewed as the way in which a firm attempts to accomplish its organizational and manufacturing performance objectives by applying its resources to cope with the environment (King and Teo, 1997). Although many resources must be considered in formulating business strategy, Figure 2 focuses on the technological resources necessary to achieve TMIS development success.

TMIS development success

TMIS development success is the extent to which business-level rather than project-level objectives for TMIS planning have been achieved. These TMIS planning objectives describe the enhanced business capabilities provided by integrated manufacturing systems. They include:

- quick response (or reduced time-to-market);
- increased flexibility;
- the ability to manage complexity;
- improved control; and
- enhanced integration.

In developing TMIS planning objectives, the need for integration should be clearly justified. It has been found that both flexibility and the ability to manage the complexity of a multi-product facility are essential to achieving economies of scope. It is also contended that improved control and integration will enhance product quality and customer service.

The TMIS planning objectives can also be used to evaluate how well the TMIS is implemented in a firm and assess the success of a firm's overall TMIS implementation efforts by comparing with other firms. Success in achieving these objectives provides a firm with new capabilities for coping with its

environment. These new capabilities can be used by top management to devise and implement new competitive strategies which turn environmental threats into opportunities.

Environment

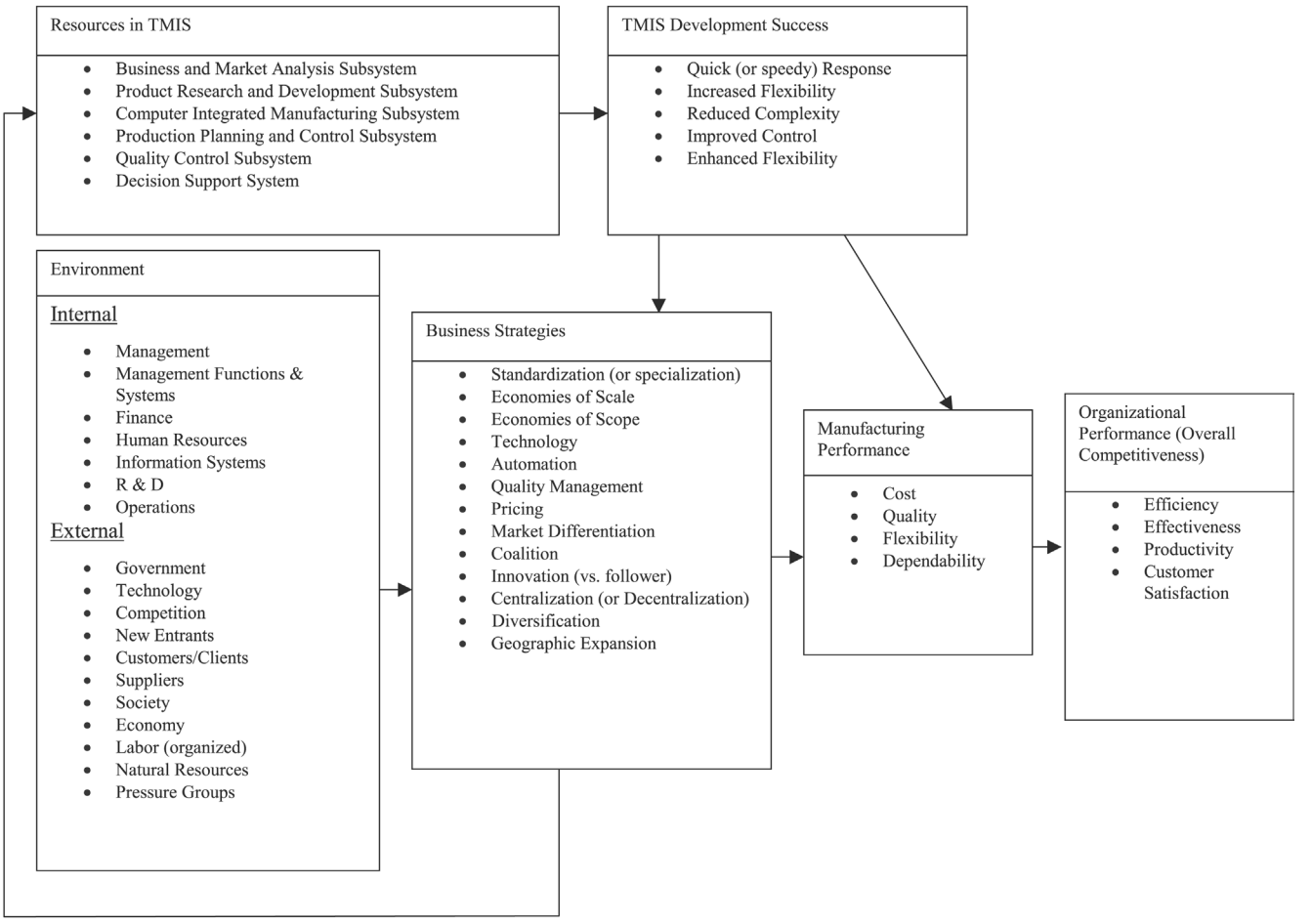
Changes in the business environment usually increase cost and complexity as firms try to adjust themselves to a new environment. However, TMIS capabilities enable firms to turn environmental threats such as rapid market changes, increasing complexity, and declining possibilities to achieve economies of scale into opportunities to achieve competitive advantage. Also, TMIS improvements in cost and quality should enable firms to mitigate the threats posed by low cost international competition and increasing consumer demand for high quality products.

Business strategy

Today's global manufacturers cannot rely on only a single competitive advantage. They should be multi-dimensionally competitive organizations, which should rely on many key competitive factors for success, including quality, cost, flexibility, innovation, service, responding to and influencing the environment, time-based competition, and closeness to the collaborative alliances, etc. (Coates, 2000). Business strategies need to include all the competitive factors. Despite its importance, marketing has had a limited role in planning TMIS installations. As advances in computerized manufacturing technology widen the technological window (i.e. the range of products a TMIS installation can produce), marketing executives must play an increasingly important role in TMIS planning.

Marketing must be included in a partnership of engineering, information system and manufacturing (Coates, 2000). This partnership should rethink how TMIS capabilities can change the way in which their firm coordinates marketing and manufacturing strategies. For example, firms may use TMIS capabilities to design custom products for finely tuned market segments,

Figure 2
Conceptual framework for integrating business strategy into TMIS



quicken the pace of market changes and further shorten the product life cycle.

TMIS development success changes the nature of manufacturing economies in multi-product facilities by increasing the importance of economies of scope and reducing or eliminating the traditional tradeoff between efficiency and flexibility.

The traditional tradeoff between flexibility and efficiency had encouraged management to seek ways of buffering their technological core (i.e. production) from market uncertainty and changes. Buffers absorb uncertainty from the environment in order to make the technical core as efficient as possible.

Manufacturing performance

Manufacturing performance is often measured by cost, quality, dependability, and flexibility. Improved competitiveness means that the firm has improved on one or more of these dimensions relative to its competitors. This research has linked all the functional processes to organizational performance. This model predicts that increased organizational performance will result in a more innovative firm, with shorter lead times, improved quality, and higher customer dependability.

Organizational performance

Organizational performance is defined as the long-term competitive advantage the firm has gained over its competitors. Therefore, the business firm's organizational performance is judged relative to competitors by combining measures of manufacturing, marketing, and financial performance. In other words, the business firm's organizational performance is more than a function of the profit and loss statement. Rather, it should be represented in terms of a broader measure of goals or objectives pursued by the firm (Reich and Benbasat, 1996; Santacecilia, 1992).

Summary and conclusions

TMIS, a new strategic tool of competitiveness, presents a unique challenge to firms due particularly to the complexity and magnitude of requirements. It basically serves three primary purposes. First, it serves as organization-wide information flows and provides vital assistance in information management. Second, it helps managers in every level to understand operations as a set of processes and activities. Managers must be familiar with the available process measurements as well as ways of presenting the information gathered in a systematic way that will be understandable to the workers involved in the process. Manufacturers need to be sure it is receiving the necessary "on-line" information for making the right decisions and developing competitive strategies effectively. Third, TMIS is a natural extension of competitive strategy activities. It requires a thorough understanding of the planning process, the particular requirements and capabilities of the process, and business strategies. Successful TMIS requires leadership of a higher order than has ever been required. A key aspect of this leadership is the development of a vision that links business processes to customer needs and competitive realities. Teamwork has always been required in business, but successful TMIS requires cross-functional and cross-unit teamwork of a new kind.

In a TMIS, there are several issues for the successful implementation. The single most critical issue is to develop the necessary leadership for changes in a strategic competitiveness improvement program. The leaders of an organization undergoing TMIS must be capable of managing radical change and at the same time maintaining the ongoing business. The second most critical issue is to discover how to get people to think and act in terms of business processes rather than functional processes. Process thinking is new compared with the functional thinking that has guided organizations for so many years. However, the third issue, developing new matrices and reward systems that reinforce business process thinking, is judged to be most important in changing behavior. The fourth issue is to figure out how to develop the ability to manage organizational perceptions, fears and resistance as major change occurs.

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