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Strategic and Organizational Implications of Computerized Manufacturing Technology

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STRATEGIC AND ORGANIZATIONAL IMPLICATIONS OF COMPUTERIZED MANUFACTURING TECHNOLOGY

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FOREWORD

In the area of science and technology our Institute is trying to identify a focus where we can build some comparative advantage and where knowledge, useful for our constituency, can be derived.

For a few years a strong candidate has been the problems of flexible manufacturing systems, diffusion, and related policy issues on different levels of the national economy. Even the much less than exhaustive bibliographical search reveals that in the recent past several governments and institutions are exploring this problem, and searching for proper policy instruments to enhance their introduction.

This paper by Dr. Gerwin gives a substantial overview of the most recent problems (and their potential solutions) that a corporation encounters when introducing computerized manufacturing technology. There are several important messages in the paper but their common denominator is perhaps that the introduction of this technology needs qualitative changes not only in the necessary skills of the factory personnel working on the shop floor but also in the procedures and value judgement at every level of the company hierarchy.

The introduction of flexible automation is connected with many technical, economic and even social traps that the management of a successful company must avoid. It is research that has to deliver the necessary knowledge. This paper is a step in this direction.

Boris Segerstahl
Deputy Director

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ABSTRACT

The new competitive conditions of the 1980's have thrown American and European maunfacturing into a turmoil. Computerized process technology can help ease the problems through increasing productivity, quality, and flexibility. However, its benefits will not be realized unless manufacturing managers attend to the technology's strategic and organizational implications. Issues in specifying the connections between computerized processes and strategic objectives are discussed. A conceptual framework is proposed which identifies some of these connections. Determining the appropriate work organization and compatible systems and procedures are also discussed. Recommendations are made for dealing with these issues.

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STRATEGIC AND ORGANIZATIONAL IMPLICATIONS OF COMPUTERIZED MANUFACTURING TECHNOLOGY

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INTRODUCTION

Just fifteen years ago the major problems of American and European manufacturing appeared to be solved and interest was turning to our rapidly developing service sectors. Since then the pendulum has swung back with an impact that has left us in turmoil. Clearly, fundamental changes are needed in the management of manufacturing and in manufacturing's relationships with the rest of the firm.

Considerable attention is being paid to solving our manufacturing problems through the introduction of computerized production technology. Productivity, quality and flexibility should all be improved as programmable automation works its way into design, fabrication, material handling, assembly, storage, inspection and production control. Computer aided design (CAD), computer aided manufacturing (CAM), robotics, automated guided vehicle systems (AGVS), and computerized material requirements planning are becoming essential ingredients of the modern factory.

However, we have been slow to learn that increases in manufacturing effectiveness cannot result automatically from the introduction of new technology. Computerized automation must be integrated with human activity in virtually every corner of the factory if it is to realize its potential. Changes will be required in skills, attitudes, systems, procedures, structures and even business policies. They will affect managers, workers and technical specialists; that is just about everyone in the factory no matter the function or hierarchical level.

In this paper I discuss some of these strategic and organizational implications of computerized manufacturing technology and recommend some ways of dealing with them.

APPLICATIONS OF THE TECHNOLOGY

Figure 1 provides a compact way to understand important aspects of the new technology and where they are having their impacts. The manufacturing world is divided into four compartments which specify the nature of the task to be performed (fabrication and assembly) and the type of manufacturing process (batch and mass production). The areas of batch assembly and mass fabrication have been less affected than the other two. Yet they are likely to witness significant future developments if current research is a reliable guide. In the United

	BATCH PRODUCTION	MASS PRODUCTION	
FABRICATION			
ASSEMBLY			

Figure 1 A schema for computerized manufacturing applications.

States, research is already being conducted into automated assembly for small motors, and machine tool builders are developing computer numerically controlled (CNC) transfer lines for the auto industry.

Perhaps the most sophisticated example of the considerable impact on batch manufacturing is the flexible manufacturing system (FMS). With an FMS it is possible to automatically produce a mix of related parts, change the composition of the mix over time, reroute production if a machine breaks down, handle engineering design changes for a certain part and machine different parts in random order.

An FMS is a highly customized manufacturing system which typically has several general-purpose and specialized CNC machine tools, an automated material handling system and a central computer. The parts to be machined are fixtured and loaded onto vehicles which are individually routed through the system by the computer. When a machining destination is reached the part is transferred and the designated operations are performed under computer control. For further details see Cook (1975).

The application of programmable automation in mass assembly is illustrated by the mechanizing of body framing in auto plants. Body framing is the most critical assembly operation because none of the subsequently attached components will fit properly unless the body is dimensionally correct. An automated system, when compared to manual framing, offers increased productivity and quality while preserving some of the flexibility.

In one of the U.S.'s most advanced assembly plants body framing is under hierarchical control by programmable controllers. First, the underbody and sides are loosely fit together mechanically using a transportation system whose carts have individual drive mechanisms. Depending upon the body style the subassembly is then conveyed to either of two special framing units. It is automatically fixtured and critical welds are placed by robots. The next operation is roof welding. Then the entire body is re-spotted using robots.

STRATEGIC IMPLICATIONS

It is now well accepted that advanced manufacturing technology has significant implications for company strategy. However, there has been virtually no research which indicates the nature of these connections. What characteristics of the technology impact on which aspects of strategy and in what way? Until some answers are provided managers will have difficulty understanding how to utilize programmable automation effectively.

In order to provide some intitial answers it is useful to consider the changing nature of the manufacturing sector's environment. Changes in tastes, in foreign competition, in governmental regulations, in technology, and in fuel prices are creating highly uncertain competitive conditions. Now there is a premium on the ability to adjust to uncertainty through shorter production runs, customer specials and wider product lines. New production equipment must offer flexibility as well as low cost and high quality. It is flexibility which has the greatest potential for influencing strategic objectives.

For small firms engaged in one of a kind or small batch production this is merely an intensification of a situation they are already used to living with. However, many large concerns engaged in large batch and mass production face novel problems in learning how to adapt. As Skinner (1984) observed, the American auto industry needs to learn how to bring out a new model every two or three years rather than every six or seven, and to do so it must replace its rigid capital equipment, which has kept its product strategy captive to its operations technology.

Connections Between Strategy and Technology

The link between strategy and process technology arises from flexibility. What is flexibility and how does it function to connect the two? Table 1

recognizes six different kinds and relates each to a primary strategic

Table 1 Relationships between flexibility and strategy.

Flexibility Dimensions	Primary Strategic Objectives
Mix	Diverse Product Line
Component	Product Innovation
Modification	Customer Responsiveness
Rerouting	Customer Due Dates
Volume	Meet the Production Schedule
Material	Product Quality

objective. Given a priority ordering of strategic objectives, there is an associated order of flexibility dimensions. Knowledge of these constraints can help specify the design of a manufacturig technology. This design would include technical components such as hardware, software and layout, and social aspects such as people, tasks and work organization.

In Table 1:

Mix flexibility is the ability of a manufacturing process to produce a number of different components at the same point in time. It is associated with the strategic objective of a *diverse product line*.

Component flexibility is the ability of a process to substitute new components for those currently being manufactured. It facilitates the strategic objective of *product innovation*.

Modification flexibility is the ability of a process to implement design changes in a given component. The associated objective is *responsiveness to customer needs*.

Rerouting flexibility facilitates the strategic objective of *meeting customer due dates*. It is the degree to which the sequence of machines through which a given component passes can be changed.

Volume flexibility is the ability to make changes in the aggregate amount of production of a manufacturing process. It is associated with the objective of *meeting the production schedule*.

Material flexibility is the ability to handle unexpected variations in a process' raw material inputs. It facilitates a *product quality* objective.

Examination of the table indicates that each type of flexibility represents the creation of variety whether in terms of components, routings, volume or raw materials. One manufacturing process is more flexible than another on a particular dimension if it handles a wider range of possibilities. However, as Slack (1983) has indicated, the cost and time of moving from one possibility to another must also be considered. Two technologies may be able to adjust production volume throughout the same range but the more flexible one will accomplish the changes with lower time and cost.

The strategic objectives are oriented toward customer service. Goals such as product variability, on-time delivery, volume and quality reflect meeting the market's needs. They are obtained at the expense of short run efficiency as is evidenced by the absence of cost reduction from the list. Research by Abernathy (1978) in the American auto industry supports this view. He found that the connection between products and production processes evolved from one emphasizing product variability to one stressing cost efficiency.

The relationships between the two columns of Table 1 are undoubtedly much more complex than depicted there. While each flexibility dimension is associated with a main objective in the table, it may also have secondary impacts on other ones. Material flexibility has the main impact on quality. However, rerouting flexibility can adversely affect quality if emergency sequences do not insure precise machining. Modification flexibility permits minor design changes which can improve quality. Determination of the complete web of interrelationships requires a good deal of further research.

The dynamic aspect of the technology-strategy connection also needs to be considered. Over time the market conditions faced by a firm may change. A company with *strategic adaptability* will be able to change the priority ordering of its objectives to take advantage of the new situation. It will also need to possess *flexibility responsiveness*, the ability to adjust the ordering of its flexibility dimensions. This in turn requires that the manufacturing technology be designed so that alterations can be made.

Gerwin (1983) utilized aspects of the above framework to investigate the impact on manufacturing flexibility of the latest computerized processes for body framing in two U.S. auto assembly factories. Respondents were asked to indicate, using a scale, how much of each of the six flexibility dimensions had changed. Comparisons were made with conventional body framing processes that either had existed or were existing in the same plant.

The changing nature of flexibility in auto assembly was uncovered. Modification flexibility has increased due mainly to the ability to reprogram the robots. Volume flexibility has increased because of very high capacity limits. Mix flexibility in terms of the potential for handling a number of different kinds of car bodies has also increased, but the bodies are more similar to each other than before. Rerouting and material flexibility have decreased, the latter due to the reduction in human inputs. The change in component flexibility varied depending upon the rigidity of the conventional process to which comparisons were made. In one plant there was an increase and in the other a decrease.

The findings demonstrate that it is unwise to talk about changes in manufacturing processes leading to either increases or decreases in flexibility *per se.* The introduction of computerized automation can have conflicting impacts on the various aspects of flexibility. Consequently, manufacturing managers must have a clear idea of which flexibility dimensions they need and which can be sacrificed. Then they must actively enter into the process of design and selection of manufacturing systems to see that the company's flexibility needs are met. The traditional approach of analyzing capital proposals solely in financial terms is no longer appropriate.

Capital Appropriation Decisions

Why, as Skinner (1984) put it, does the introduction of advanced manufacturing technology with all of its strategic advantages often take a back seat to new product development and marketing management? For one reason, not enough attention is paid to the interface between strategic planning and capital budgeting. A need exists to identify capital projects in relation to strategic objectives. This can not be done where managers have trouble with the equipment's technical complexity, and where they rely on a narrow, quantitative approach to selecting projects.

Computerized manufacturing systems exhibit a great deal of technical complexity. An FMS, for example, produces interactions between machines, computers, material handling equipment, software, humans and the components being manufactured. It is little wonder that managers are often unwilling, due to lack of time and training, to inquire into the technical aspects of equipment proposals (Skinner, 1978). Often there is not a complete understanding of what the equipment can do, how it functions, and what it requires. Consequently, they cannot judge whether proposed machinery is compatible with strategic objectives.

As an illustration, consider the large U.S. firm discussed by Gerwin (1982). It adopted CAM technology with the single-minded intention of manufacturing a specific part. When demand slackened it was not prepared to add new ones. It rushed to come up with new tooling, fixtures, and parts programs while idle time mounted.

In order to avoid coping with technical complexity, strategic managers may rely too heavily on their main area of expertise, financial analysis. Proposals become analogous to investment opportunities in a financial portfolio rather than alternative means of satisfying strategic goals. However, managers may soon discover that traditional financial tools, such as discounted cash flow, can not provide a comprehensive understanding of whether or not to invest (Hayes and Abernathy, 1980; Kaplan, 1983). The main strategic benefits of computerized technology tend to be intangible. The advantages of flexibility are difficult to quantify because it is not known what parts will be machined in the future or when. Inevitably, a too narrow application of financial analysis tends to favor conventional equipment over the new technology.

For evidence, consider the recent study by Rosenthal and Vossoughi (1983) of American vendors and users of CAM technology. Eighty-one percent of the vendor respondents reported that incomplete understanding of the technology was (very) significant in the decisions of potential users not to buy their equipment. Seventy-six percent said inability to quantify the benefits was a (very) significant factor.

An alternative to the single-minded pursuit of maximizing efficiency is to minimize disaster. Adherence to this criteria leads to consideration of flexibility as a means of coping with unwelcome surprises. The company studied by Gerwin (1981) explicitly adopted minimizing disaster in selecting an FMS over a modified transfer line for a new product line. When it became clear that reliable sales forecasts could not be made, concern centered on reducing the impact of any sales disaster. If the new product line turned out to be a commercial failure, an FMS would be able to machine a redesigned one without a great deal of difficulty.

ORGANIZATIONAL IMPLICATIONS

Little is currently known about the implications of computerized technology for the social structure of the factory. However, bits and pieces of research are beginning to emerge which eventually can form a coherent picture. This section concentrates on two aspects of structure, work organization and systems and procedures.

Work Organization

The appropriate work organization for computerized manufacturing depends in part on the nature of the technology but also on the individual and social needs of those people assigned to the equipment. While there has been a great deal of speculation on needs in this context, little empirical work has appeared. Blumberg and Gerwin (1984) however studied supervisors and workers on an American FMS in order to learn about perceived job characteristics, satisfaction, and stress.

The work organization was in the traditional manner with man-to-man supervision and specialized tasks. Each of the two shifts had a supervisor, a mechanical maintenance man, a tool setter, four loaders, and three operators to monitor the machines. Eighteen of the twenty men responded to a structured questionnaire. Results were compared to those for existing normative samples.

The findings for workers on perceived job characteristics indicated that most of them viewed their tasks negatively. On autonomy, the degree to which the job provides freedom in determining procedures, all four job classifications had scores below that of the normative sample. Three groups were below the norm for experienced responsibility, the degree to which the employer feels personally responsible for results, and on task identity, the degree to which the job requires completion of an identifiable piece of work. Two groups were below on each of the remaining characteristics. Mechanics were above the norms on seven out of the eight factors and tool setters were above on four. However, operators were below on all of the dimensions and loaders were below on all but one.

The job satisfaction findings demonstrate that most workers were dissatisfied with important aspects of their jobs. At least three of the four job groups had scores below that of the normative sample for every satisfaction factor except one. This applied to satisfaction with comfort (all four), resource adequacy (all four), challenge (3), promotions (3) and relations with co-workers (3). Mechanics scored higher than the norms on a majority of dimensions but the other three groups were dissatisfied with practically every factor.

In general, the workers found their jobs stressful. At least three of the four job groups scored below the norms on a majority of the characteristics. This applied to stress resulting from inability to use valued skills (all four), resource inadequacy (3), and likelihood of job loss (3). Mechanics suffered the least, being above the norms on four of the five factors. The other three groups were each below on four out of the five.

The two FMS foremen had to cope with high performance pressures and loss of control. The large initial investment in the system prompted demands for high machine utilization. The equipment's technical complexity reduced machine reliability, a problem which could only be handled by technical specialists. Although performance pressures were not measured directly, it was found that supervisors were the only occupational group to score below the normative sample on all five stress factors. Lack of control is suggested by their having the second lowest score on autonomy. Thus, at the same time that more is expected from them they have lost some of their freedom to maneuver.

The automated nature of production requires that foremen have solid technical skills. They must have a good working knowledge of the equipment so that they can decide on when it is necessary to call a maintenance person and what kind of expertise is needed. The need for motivational skills however has not diminished. They must be able to solicit the cooperation of technical people responsible for maintaining and controlling the equipment. It is also necessary to motivate workers since their activities still influence the cost and quality of production. The relatively high perceived skill variety score of the foremen reflects their dual role.

It appears that where the work organization for an integrated manufacturing system is based on traditional approaches problems in motivation and satisfaction will occur. Moreover, those people who do the most routine tasks will have the most problems. In the survey, operators and loaders, the only groups which worked according to written instructions, consistently scored the lowest.

The relatively self-contained nature of tasks in an integrated system suggests that a work organization based on group concepts (Trist, 1981) may be more appropriate. The group might consist of operators and loaders with each participant having an opportunity to share in all or most tasks. There would also be collective responsibility for job-related decisions such as member selection and the assignment of tasks. Foremen would concentrate less on supervising the workers and spend more time insuring that the necessary resources are available. Technical people would act as consultants to the group and be responsible for solving complex problems. The result should be higher scores on such factors as autonomy, task identity, responsibility, challenge, co-worker relations, utilization of valued skills and resource adequacy.

A work organization utilizing some of these principles has been designed for West Germany's first rotary FMS (Asendorf and Schultz-Wild, 1983). There is one team leader and five workers per shift. The workers will be responsible for loading and machine monitoring, and some quality control, computer programming and maintenance. Each is being trained to perform these functions on the different types of hardware in the system. The team leader will coordinate the overall system, do production scheduling and supply tools and materials.

Systems and Procedures

Technical specialists in accounting, quality control, maintenance, production control, process planning and other functions must design systems and procedures which control and maintain computerized technology. In doing so, they are forced to cope with the conflicting forces illustrated in Figure 2.

The technical complexity of the equipment pushes for attaining some desirable level of novelty in procedures. Technical constraints such as the state of the art and the availability of data, lack of experience with computerized equipment, and time pressures are forces for relying on existing routines. All too often the result is a compromise which does not completely satisfy either set of demands. As a result, the very basis for judging and improving operating efficiency can be endangered (Gerwin, 1981; Blumberg and Gerwin, 1984).

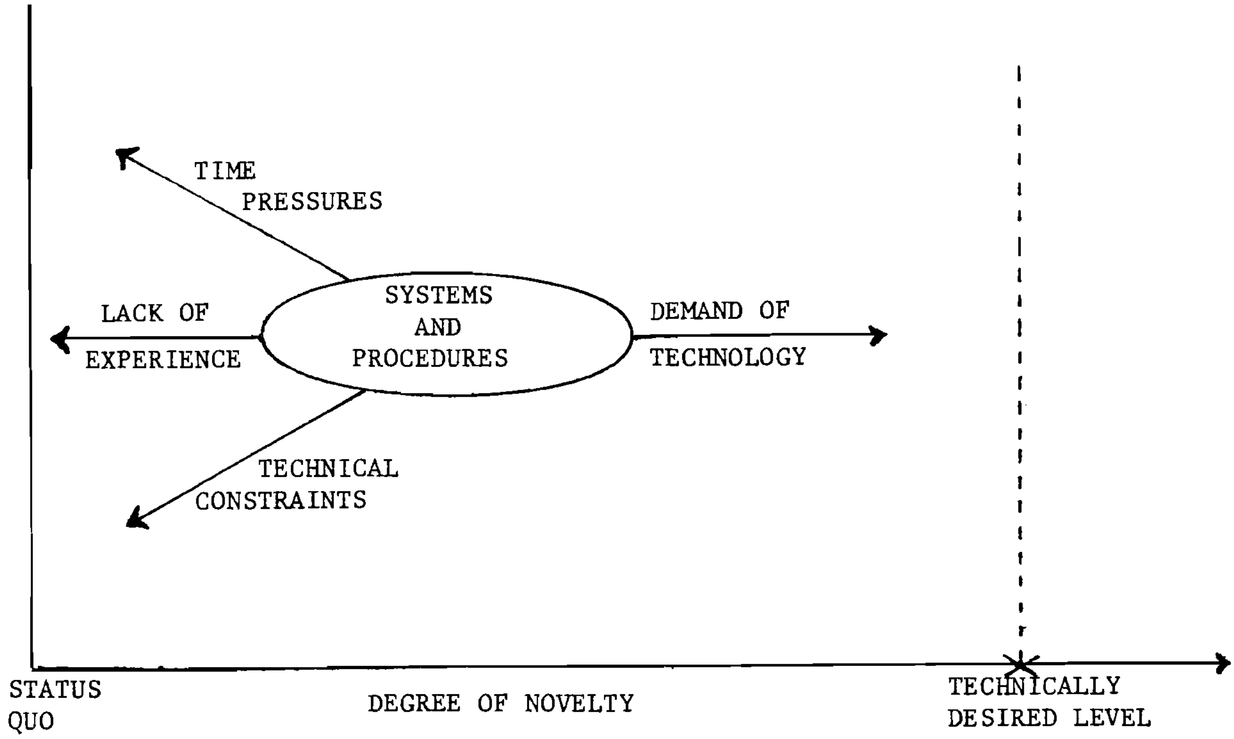

Figure 2 Factors influencing the novelty of systems and procedures.

Technical complexity creates a need for novel systems and procedures, as is illustrated by problems in quality control and accounting. With an FMS there are no natural pauses during the machining sequence for manual quality control to be exercized. Automated continuous monitoring is still too limited in scope to perform most sophisticated tests (Senker, et al., 1981). If quality checks are made at the end of the machining sequence there can be too long a delay from the occurrence to the detection of the defect. Difficulty in finding the source of a defect due to the many interacting subsystems is a complicating factor.

Consequently, the usual methods of exercising quality control may not turn out to be appropriate.

Machine utilization is one of the basic parameters used to control shop operations. Accountants calculate it by comparing the actual value during some time period to a standard value. The latter usually contains a correction for time lost due to normal machine breakdowns. If a machine belonging to an FMS stops running, the parts to be produced can be automatically rerouted through another machine in the system but often at a higher cost. In other words, there is no breakdown in parts production but it is accomplished less efficiently. Under these conditions a new way of calculating the correction is needed (Gerwin, 1981).

Technical specialists' lack of experience with computerized manufacturing hinders the development of routines to solve these and similar problems. Gerwin (1984) reported on a British motor producer with virtually no exposure which had to schedule installation of a planned DNC system over several years. Meanwhile, a German aircraft manufacturer with considerable NC experience was able to implement its new FMS much more quickly. Although the company was doubling its capacity, it chose not to build a new factory. It wanted to take advantage of the experience of its staff personnel in the existing plant.

The lack of experience of operating people also retards the development of new methods. A company studied by Gerwin (1981) purchased an FMS. The cost of machining a part could no longer be expressed in terms of direct labor hours because labor had become a part of the burden. A machining hours basis was selected but manufacturing managers found it difficult to understand the new concepts. Their ability to control shop operations was rooted in informal procedures based on direct labor hours that they had developed over many years. These were of little use in controlling the FMS.

When the size of the initial investment in a computerized system is large, management may pressure for immediate returns. If the investment decision has been made on a narrow, quantitative basis the pressures will be greater. Once the equipment is installed, management will want it to operate at full scale as quickly as possible. Technical specialists will not have a good chance to learn about the system's capabilities and limitations. Foremen and workers may not be adequately trained in how to operate it. Two of the firms studied by Gerwin (1984) noted these problems.

Finally, various technical constraints impede the development of new systems and procedures. The state of the art in a certain area may not be advanced enough to meet the equipment's needs. Kaplan (1983) has noted that new managerial accounting techniques may be needed to replace the standard cost model.

Once more, data availability becomes a problem in such a novel situation. In Gerwin's (1981) study a company which had purchased an FMS to build a new product line discovered that there was little information available from other firms or from its own shop for calculating standard cost parameters. Even after several years a completely reliable data set had not been compiled for some major cost components such as maintenance and rework.

CONCLUSIONS

The adoption and implementation of computerized manufacturing technology is not just a technical problem of calculating rates of return and installing new equipment. Strategic and organizational issues must be considered if the equipment is to function effectively. It is little wonder that Rosenthal and Vossoughi (1983) discovered that over nine out of ten of the CAM experts they interviewed agreed that while technical issues existed, the toughest problems are managerial.

Some of the more critical problems have been discussed in this paper. Strategic managers must be able to identify features of new manufacturing systems which are compatible with company objectives. They must also insure that the design and selection of a system reflects their priorities rather than those of engineers. First line supervisors and workers need to be motivated through the choice of a suitable work organization in order to avoid problems with job perceptions, satisfaction and stress. Technical specialists must develop adequate systems and procedures in the face of technical constraints, time pressures, and lack of experience.

What can be done to facilitate the integration of computerized technology into the factory? Vendors need to realize that the design of a manufacturing system is not simply an engineering problem. It should also be designed to fit the degree of sophistication of a company's infrastructure. Potential users should not always assume that the most sophisticated equipment will provide the best answer to their manufacturing problems. Less complex alternatives which are compatible with strategic needs and organizational capabilities may be more effective.

Special attention should be given to having a comprehensive strategic and organizational development plan ready before the equipment arrives.

Some specific suggestions from this paper could be incorporated into the plan. The strategic framework discussed here is an initial step towards revealing the nature of the connections between manufacturing technology and a company's objectives. A work organization based on group concepts instead of the traditional approach should be considered. Little can be done about the technical constraints faced by the designers of systems and procedures, but lack of experience and time pressures can be mitigated by a gradual buildup of equipment. This mixture of new ideas and common sense is essential if the potential of computerized manufacturing is to be realized.

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