Journal of Operations Management 19 (2001) 307–333

JOURNAL OF OPERATIONS MANAGEMENT

www.elsevier.com/locate/dsw

An evaluation of the relationship between management practices and computer aided design technology

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Received 20 July 1999; accepted 23 August 2000

Abstract

Technology has been the engine of growth for the United States economy over the last decade, and it is reasonable to expect that appropriate selection and management of technology within the firm would continue to be highly critical to its success well into the future. Operations managers constantly struggle to seek answers to the right set of managerial actions that can be used to leverage technology for process effectiveness. This study takes a step in that direction by empirically examining the management of computer aided design (CAD) technology and outcomes of the product design process within manufacturing firms. In particular, the level of functionality and sophistication of the CAD system are examined with respect to the use of several structural and infrastructural management levers such as the degree of a firm's formalization and decentralization, the extent of the use of teams, the extent of training of CAD designers, and the equity of the incentives within the product design process. The influence of these management levers upon the CAD system performance is analyzed through the use of moderated regression analysis conducted on a cross-sectional data of 143 firms representing the vehicular industry in the USA. Our findings indicate that CAD functionality and sophistication are positively related to product design quality, flexibility, and overall performance. The impact of management levers on this relationship is a mixed one. Decentralization has no impact on the CAD technology–performance relationship, formalization has some positive effects, and the use of teams is helpful only in moderating the influence of sophistication on overall performance. Equity of incentives enhances design quality, while training is very important in improving performance across the board. In general, sophisticated "state of the art" CAD systems require much more proactive management than highly functional ones. Recommendations emerging from this study hopefully provide insights into a better management of not only CAD systems, but other process level technologies as well that are relevant to firms in the manufacturing sector. We also discuss implications of technology management provided by this research for creating leading edge enterprises.

Keywords: Computer Aided Design (CAD); Technology management; Management levers; Interdisciplinary

1. Introduction

In order to compete well in world markets, organizations have been forced to reengineer, empower employees, get lean, and become increasingly flexible while maintaining low prices. The paradigm for competing is no longer the simple dichotomy of low price-high volume or high price-customized products.

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0272-6963/01/$ – see front matter
PII: S0272-6963(00)00063-2

Customers demand high quality products that are delivered on time in small lots with the capability for frequent engineering changes on short notice. Yet, the intense competition in a worldwide marketplace simultaneously mandates low prices. One way to achieve so many different objectives, which at times conflict with one another, may be to effectively use technological advances. Thus learning to manage technology has become an extremely important issue for both practitioners and academics alike as we move into the next millenium. This study is focussed on examining these issues within the context of computer aided design (CAD) technology, and its effective deployment within manufacturing firms in the US.

In general, firms have been looking for ways to get the most out of their current technology and thereby sustain their competitive advantage. Many manufacturing related technologies such as CAD, computer aided manufacturing (CAM), flexible manufacturing systems (FMS), and computer integrated manufacturing (CIM) have been acquired and implemented. Unfortunately, with reports of insignificant flexibility or productivity gained through their adoption and implementation (O'Leary-Kelly and Vokurka, 1998; Grant et al., 1991; Meredith and Hill, 1987; Jaikumar, 1986), the benefits of these technologies have not been commensurable with their large investments. Since it has been discovered that installing new technologies in USA has not always insured improved performance, better management practices that can leverage investments in technology and provide a competitive advantage need to be examined.

It has been shown that in many cases the application of new technologies to replace existing manual or mechanical systems yield meager performance improvements (Benjamin and Levinson, 1993; Schnitt, 1993; Jaikumar, 1986). The design of jobs, social structure, and organizational infrastructure often need to be changed significantly to fully exploit the capabilities of the new technology (Shani et al., 1992; Grant et al., 1991; Hayes and Jaikumar, 1988). Yet, research shows that these infrastructural and social changes are often overlooked (MacDuffie and Fisher, 1996; Maffei and Meredith, 1995; Meredith, 1987).

Management within manufacturing firms has begun to recognize this balance within the firm. The work force or human issues have been shown to be important, and have significant impact on strategic success (Boyer et al., 1997; Malhotra et al., 1996; Kelley, 1994; Hayes and Jaikumar, 1988; De Meyer and Ferdows, 1987; Fine and Hax, 1985). In two recent studies, the organization structure and use of human resources in manufacturing firms were found to be stronger contributors to flexibility than the technology itself (Upton, 1995; Zammuto and O'Connor, 1992). Firms are thus reorganizing to become decentralized, democratic organizations, where versatility and continuous change are the goals (Pasmore, 1995; Kelley, 1994; Ferdows and Skinner, 1986). If a firm can address all organizational elements and keep them in balance, it will potentially develop a distinctive competence that can set it apart from its competition.

This study has been motivated by two major limitations in prior work. First, although several models testing the impact of management levers on performance have been presented in the management literature, few of these technology models examine the impact of individual management levers upon the performance of the technology. Often, the researchers examine clusters of policies that commonly are found together, using constructs such as 'control' versus 'commitment' human resource systems (Arthur, 1994), 'progressive' human resource management (Delaney and Huselid, 1996), worker empowerment (Boyer et al., 1997), 'human capital enhancing systems' (Youndt et al., 1996), 'lean production policies' (MacDuffie and Fisher, 1996), and 'management committees' (Kelley, 1994) on technology performance. These levers are unique combinations of variables that fit the specific situation addressed by the researcher. This combination of variables, while providing a concept that is understandable and aesthetically appealing, does not provide an understanding of the individual impact of each variable. This limits the generalizability of the findings.

The second motivating factor for this study is that in general there has been a lack of research in manufacturing at the process level. Technology research has generally focused at the individual operator level (Swamidass and Kotha, 1998; Robertson and Allen, 1993; Collins and King, 1988), or at the organizational level with plant-based or strategic business unit (SBU) level-based performance measures (Boyer et al., 1997; Miller and Roth, 1994). The technology–process level is positioned in between the individual and organizational level. Technological systems often overlap several business processes, but in many cases, their major impact is on one specific business process. By making observations at this level, the results are not as diluted as they would be at the organizational level, where many other factors can impact performance. Yet they are much more global and generalizable than observations at the individual levels. It is thus the intention of this research to use a technology–process experimental unit. Since technologies are implemented and evaluated at the process level, empirical work needs to be focused there.

This research will build upon the preliminary work by Collins and King (1988), whereby the influence of individual management levers will be examined. Both the task and social aspects will be explored here as distinctly different from technology, but equably important and collectively necessary to achieve performance. We will also examine a specific manufacturing related technology in detail. Thus by controlling for the variations in the process and examining five individual management practices, we hope that this research will contribute to our understanding of the role of technology in the workplace.

We first motivate the selection of the CAD technology for this study before presenting the research framework and model. Subsequently, we present theoretical foundations that form the basis of hypotheses represented in the research model. This is followed by the description of the survey-based methodology used for large-scale data collection. The next section thereafter provides a discussion of results and major findings. We finally conclude with a set of managerial recommendations and directions for future work in this area.

2. Selection of CAD technology

In order to examine the influence of management levers on the technological process, a technology needed to be selected for this study. The following four criteria were used to select a technology for this research.

- Its use should be *prevalent* in manufacturing firms. This is obviously so that an adequate response rate can be achieved, and the importance of the findings will be meaningful across a broad spectrum of firms.
- It should be an *evolving technology* that has experienced significant upgrading in recent years. Under such conditions, firms would have experienced a change in technology and potentially also its management.
- The technology should be specifically *related to an important process*. This makes study of the technology–process relationship clear, and simplifies the identification of the process for the respondent.
- There should be *variations in effectiveness* of the technology due to the context within which it is used and managed.

CAD technology adequately met these criteria. It is highly prevalent in the manufacturing industry. The research by Swamidass (1994) showed it to be present in 84% of the firms. It is also evolving, as evidenced by the 1993 Department of Commerce statistics that show that over 60% of the firms had new CAD adoptions over the previous 5 years (Unites States Department of Commerce, 1993). Although it may not be considered as a 'new' technology, recent software improvements have significantly changed CAD capabilities. It is used specifically in the product development process, and is as such a process-specific technology. Finally, empirical work on CAD has shown that its benefits are dependent on how it is used, and that mismanagement can yield poor performance results (Collins and King, 1988; Robertson and Allen, 1993).

Our definition of the CAD system is consistent with the interpretation used in prior studies. It is a well-known technological system which combines hardware and software, and uses computerized graphics to provide computer generated part or product drawings (Majchrzak and Salzman, 1989). CAD systems can vary significantly in scale and capability. In general, CAD has three applications — generation of mechanical or electrical engineering drawings, conceptual design analysis, and communication with relevant departments, customers and suppliers (Robertson and Allen, 1993; Forslin et al., 1989; Voss, 1988). CAD systems are targeted to meet goals such as reducing design to production lead times, creating higher quality drawings for better communication with relevant parties, providing better a priori engineering analysis, allowing additional flexibility and faster response with regard to design modifications, and providing input to computerized manufacturing.

What makes our study particularly interesting is that CAD system benefits have often not been fully realized due to a variety of reasons (Robertson and Allen, 1993; Badham, 1989; Collins and King, 1988). Firm performance has not been enhanced in cases where the product development process was not changed along with the implementation of the system. Therefore, the process level examination of CAD use and management should help in explaining and clarifying some of the prior research findings. At the same time, it can provide insights into how this technology can be better managed to improve the product design process.

3. The research framework and model

It is the intention of this research to empirically examine the effectiveness of CAD within the context of the management levers employed in the firm. The unit of analysis will be the technology–process level within the firm. This is to be interpreted as the technology itself, independent of its context and the major process (product design) within the firm that it impacts. The general model to be tested here is referred to as the technology effectiveness model, and is schematically represented in Fig. 1. This model shows that the attributes of the technology influence its effectiveness in the firm, while the management levers moderate these effects. By examining the organizational structure's influence on the product design task, and the use of teams, training, and incentives to enhance workforce capability in conjunction with the CAD technology, a better understanding of technology management should be attained.

This model proposes that there is a base relationship between the technology attributes and its effectiveness. Technology enhancement is expected to improve process performance, otherwise there would be no justification for its adoption. Several management levers moderate this relationship by changing the strength of the relationship between technology and performance. The implication of management levers is that they can help or hinder the effectiveness of the technology. The premise that the management levers moderate performance can be justified by logic and by previous research.

There is some evidence indicating that a moderating model such as this one will properly represent the effect of the management levers (Gupta et al., 1997; Boyer et al., 1997; Maffei and Meredith, 1995; Arthur, 1994; Kelley, 1994). These authors have empirically tested models of certain technologies and their impact on performance, and found factors that would be categorized in this research as 'management levers' to moderate this relationship. While the importance of management levers has been well established, the effectiveness of technology has often interpreted by business performance only, without reference to its flexibility, quality, or overall process level outcomes. This research will consequently test the use of certain management levers for their impact on technology performance at the process level. The general

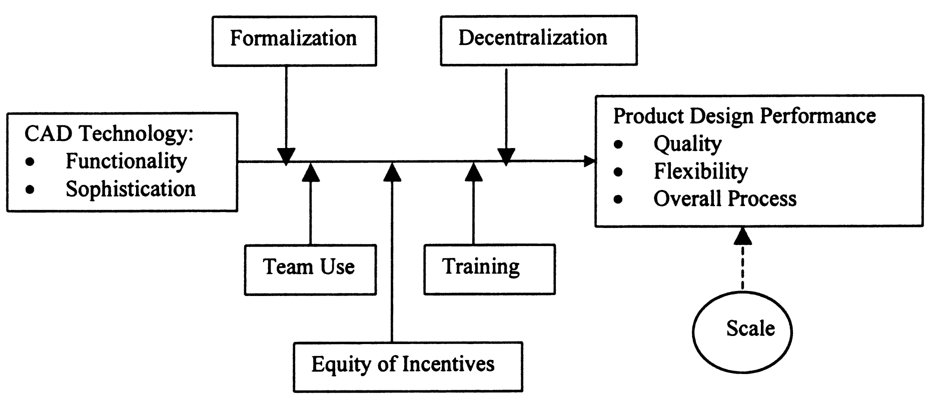

Fig. 1. The technology effectiveness model (TEM).

Table 1
Construct definitions

Construct name	Definition
Technology attributes	
Scale	Scale captures the size of the technology
Relative scale	Size of the technology investment relative to similar systems used by competitors
Absolute scale	Number of workstations, pieces of equipment or employees, and replacement dollar value for the system
Functionality	Number of features the technology possesses, plus its ability to handle different products, parts, materials, dimensions, and functions
Sophistication	Extent to which the technology is 'state of the art'
Management levers	
Structural	
Formalization	Formal reporting relationships and procedures within the firm/process
Decentralization	Levels where decisions are to be made including how much the occupants of positions participate in decisions about the allocation of resources and determination of organizational policies
Infrastructural	
Extent of team use	Extent of use of formally organized groups of employees to handle specific job-related issues, share things they have learned about their technology, make improvements in the process and technology use, or form for a limited time to handle specific problem or accomplish specific goals (often cross-functional)
Extent of training	Formally organized, paid for by the employer, related to their work in the company
Equity of incentives	Fairness of the means by which employees are enticed to perform their work
Effectiveness (three constructs)	
Quality	High product quality and higher conformance to specifications
Flexibility	Customization, design variety, ease of changes to designs, design change speed
Process performance	Overall performance compared to corporate performance criteria or use of similar technology by your competitors

proposition that will be tested in this study is then stated.

Proposition 1. *The functionality and sophistication of technology will have an impact on that technology's effectiveness at the process level, and this relationship will be moderated by the use of management levers.*

Underlying this proposition is the contention that salient attributes of the technology should be considered in selecting the type of management levers to be utilized. An appropriate balance of structural and infrastructural management processes should provide an environment that maximizes the use of the technology and human resources of the firm. In order to explore and further develop this conceptual model, we need to operationalize and define the technology attributes, management levers, and process level performance measures. Each of these constructs is defined in Table 1, and discussed next in detail.

3.1. Defining technology

For purposes of this research, technology will be defined by the three constructs of scale, functionality, and sophistication. These variables are definable concrete measures, attributes that can be seen and recognized, removing the subjective nature of other traditional technology measures.

3.1.1. Scale

Scale captures the size of the technology, and has been shown to be a significant variable for technology's impact on performance (White, 1996; Swamidass and Kotha, 1998; Kelley, 1994; Tyre and Hauptman, 1992). A technology could be very simple (not complex) and unsophisticated, and yet could have significant implications for the firm because of its size. Scale for the CAD product design process is consequently used as a control variable in our research model of Fig. 1. It was measured in three distinct ways — as the logarithm of number of workstations in the system, as the logarithm of current replacement dollar value of the system, and as a perceptual measure of the relative size of the system compared to other firms. This construct consequently allows the impact of CAD technology to be compared across small, medium, and large firms.

3.1.2. Functionality

Functionality of the technology represents the number of features and its ability to handle different products, parts, materials, tools, dimensions, etc. A technology is more functional if it has more features or is able to perform more tasks over a wider range of dimensions. CAD systems can be very basic, without the ability to rotate parts, re-dimension changes, or animate designs. They can also be very extensive in the features offered. Operating variability has also been previously used to capture functionality, and represents the extent to which the technology allows work to be accomplished in a number of non-standardized ways (Thompson, 1967). Complexity has also been used to represent functionality, but there have been varying definitions of complexity by researchers, so that term is avoided here (Sarkis, 1997; Tyre and Hauptman, 1992; Weick, 1990; Thompson, 1967; Woodward, 1965). The number of functions and features of the CAD technology as measured by De Sanctis and Poole (1994) were modified to incorporate CAD specifics. In order to validate the perceptual measure, functionality was also measured using a more objective list of technology specific features.

3.1.3. Sophistication

Sophistication is represented by the capabilities of the system in comparison to the state of the current technology in the industry. It has also been defined as technology's novelty and the richness or innovativeness of features (De Sanctis and Poole, 1994; Tyre and Hauptman, 1992). Thus it is a distinctly different attribute of technology than functionality. Technology may be state of the art, but have low functionality. For example, rapid product prototyping in CAD systems is a state of the art method for developing a dimensionally accurate prototype of a newly designed part that can be used for tool and die-making. Conceptually it is very simple, using a laser to cut patterns that are formed into a model. The functionality is low, while its sophistication is high. Because it is state of the art, little is known about it and special innovative skills may be needed. Yet its impact on the firm could be significant.

The 'positioning on a state of the art timeline' definition by Souder and Shrivastava (1985) has been selected due to its inherent simplicity and ease in understanding and measurement. Others have studied sophistication, with similar definitions relating to the novelty of the technology (De Sanctis and Poole, 1994; Tyre and Hauptman, 1992; Shani et al., 1992). The definition by Souder and Shrivastava, while allowing for correlation with enhanced functions, will not require functions to be necessarily present. It allows us to position the technology along an evolutionary timeline based on the newness and uniqueness of its features.

3.2. The management levers

The management levers are the means by which the technology and human resources are managed by the firm. Five management levers are studied, based on their prevalence and contraindications in the literature. Two are structural measures while three are infrastructural measures. The organization structure is an indication of the formal reporting relationships and procedures within the process, and has two commonly used attributes of formalization and centralization as defined by Burns and Stalker (1961). The infrastructural measures address the softer social issues within the firm that are often manipulated through the use of teams, training and incentives.

3.2.1. Formalization

Formalization is defined as the level of detail in the specification of jobs and the explicitness of the rules for conformance (Fry and Slocum, 1984). It has two components, the rules and procedures, and the control that is used to enforce them. More formalized organizations are reported in the management literature to perform better in more stable environments, while less formal, organic organizations perform better in less stable situations (Gupta et al., 1997; Bartlett and Ghoshal, 1995; Goodhue and Thompson, 1995; Collins and King, 1988; Fry and Slocum, 1984). But, some operations management research literature has shown more formalized organizations to be more efficient (Ichniowski and Shaw, 1999; Kelley, 1994; Collins and King, 1988; Krafcik, 1988).

3.2.2. *Decentralization*

Decentralization reflects the decision-making progression up the organizational ranks, from low level (operators) to high level (upper management). It was originally referred to as the "centralization of power" (Hage and Aiken, 1967, p. 73). In general, a more decentralized organization gives operators more authority to make decisions, whereas centralized ones assign decision-making power to higher levels in the firm (Maffei and Meredith, 1995; Spreitzer, 1995; Georgantzas and Shapiro, 1993; Collins and King, 1988). It is also often referred to as 'autonomy' in the literature, since decentralization determines the amount of discretion workers have in dealing with their job, authority to make decisions regarding repairs, programming, maintenance and interacting with people in other functional areas (MacDuffie and Fisher, 1996; Lawrence and Hottenstein, 1995; Porras and Hoffer, 1986). The impact of decentralization on technology performance has shown mixed results in the literature, justifying the need for further examination (Adler et al., 1999; Gupta et al., 1997; Liden et al., 1997).

3.2.3. *Extent of team use*

Extent of team use implies voluntary or mandatory teams that can be formed to perform tasks on an ongoing basis. General problem-solving teams are sometimes used in firms for employees to handle labor disputes, benefits allocation, discipline procedures, and other company-wide issues. Project teams on the other hand are formed to handle specific job-related issues, share things they have learned about their technology, and to make improvements in the process and technology use for greater effectiveness. It is part of an attempt to have employees take responsibility for the firm's overall success, and encourage cooperation amongst employees and management (Arthur, 1994; Huselid, 1995; Kelley, 1994).

The use of teams is important to the use of technology since they lead to problem solving and enhancing cross-functional communication. Yet there has been mixed success with teams, since collaboration takes time and sometimes conflict prevents reasonable solutions to problems. But in dynamic work environments, they are found to be most effective (Dow et al., 1999; Liden et al., 1997; Ichniowski and Shaw, 1999; MacDuffie and Fisher, 1996; Georgantzas and Shapiro, 1992; Kelley, 1994). The use of teams and their ultimate effectiveness may be contingent upon the type of technology being used. This research will measure the extensiveness of team use in the workplace through two categories — project teams and employee involvement groups.

3.2.4. *Training*

Training is used to enhance skills. It is often done with new employees, but in many firms it is now required on an ongoing basis. It enables them to keep up on the latest developments with regard to their technology (Goodhue and Thompson, 1995; Robertson and Allen, 1993; Suarez et al., 1995). Training, in general, seems to be always desired, and always deemed to be a good thing to do (Campbell, 1988; Suarez et al., 1995; Kelley, 1994; Goodhue and Thompson, 1995; Robertson and Allen, 1993). The question then becomes, how much does it hurt process effectiveness to perform lesser amounts of training?

The training to be considered here is formally organized, paid for by the employer, and related to the work in the company. This would exclude work that is toward a college degree or paid for by the employee. The extensiveness of training is captured through hours and dollars invested, percentage of people trained, and its perceived importance (Snell and Dean, 1992).

3.2.5. *Equity of incentives*

The equity of incentives is an assessment of the perceived fairness and competitiveness of the compensation method. It is often an easy way to influence motivations for doing work in a certain way. But it is also difficult to change since employees are very sensitive about their wages. Common wage methods include straight wages (salary) not dependent on time or quantity of output, output-based pay, and performance-based pay that is linked to some specific goals (Snell and Dean, 1994). Bonus, incentives and recognition programs are also effective motivational tools (Karuppan, 1997; Arthur, 1994; Snell and Dean, 1994; Spreitzer, 1995). The equity of incentives construct used here was developed by Snell and Dean (1994), and is adapted here to fit the product design process. It measures the perceived fairness and competitiveness of the compensation program, and how adequately differences in contributions are recognized by wage structures.

3.3. CAD technology performance

The effectiveness of CAD in enhancing *performance* of the product design process is not a unidimensional construct. Establishing literature-based process level performance measures was somewhat difficult, since prior research is quite different from the work reported. First, most prior work has been conducted at the organizational or plant level (Swamidass and Kotha, 1998; Miller and Roth, 1994; Safizadeh et al., 1996; Vickery et al., 1993). Secondly, a composite measure for many types of technologies rather than CAD alone has been used (Swamidass and Kotha, 1998; Boyer et al., 1997). Finally, many researchers that did use multiple performance measures at the process level examined only productivity, or quality through scrap and rework levels (Arthur, 1994; Boyer et al., 1997; Chen and Adam, 1991; Collins and King, 1988; MacDuffie, 1995). Each researcher thus used different constructs for measurement, depending on what is readily available.

Two commonly measured dimensions at the process level are quality and flexibility, as well as overall performance compared to anticipated goals (Safizadeh et al., 1996; Maffei and Meredith, 1995; Kelley, 1994; Flynn et al., 1994; Gerwin, 1993). Measures such as cost and productivity have had problems with validity at the process level (Goodhue, 1998; Sarkis, 1997). For the perceptual measures, the changes in performance due to technology were compared with the anticipated performance goals of the CAD technology (Georgantzas and Shapiro, 1993; Sethi and King, 1994; Sun, 1994; Tyre and Hauptman, 1992).

3.3.1. Quality

The quality of output from a new technology is often significantly better than it was due to older technologies, and may be the impetus for purchasing a new technology. Quality has several sub-dimensions that may or may not move together. These include high level quality, consistency, conformance to specifications, and reliability (Vickery et al., 1997). This research will measure quality for the product design process by higher perceived product quality levels (better CAD drawings) and higher conformance to product specifications. These sub-dimensions have been shown to be important determinant of quality in prior CAD research (Robertson and Allen, 1993; Forslin et al., 1989; Voss, 1988).

3.3.2. Flexibility

Flexibility refers to the innovativeness of the CAD product design area in responding to changes, customizing designs, improving the speed of response, and in introducing designs into production. The need to respond quickly to changes is an increasingly important process goal. The throughput time to design a new product may be the key to obtaining a lucrative manufacturing contract. The standard dimensions of flexibility that are defined in the manufacturing literature, such as mix, volume, changeover, and other types of flexibility (Koste and Malhotra, 1999) are not directly applicable to the product design process. So the dimensions of CAD flexibility used in this study are taken from the research by Collins and King (1988).

3.3.3. Overall design process performance

An assessment of overall performance by the respondent provides an indication of the general overall performance of the technology that is commonly used in technology research (Swamidass and Kotha, 1998; Boyer et al., 1997). As well, there may be evidence that the management levers will influence overall perceived performance and not specifically the quality or flexibility of the product design process. The measures used for this research provide an assessment of the overall performance of CAD compared to corporate criteria and compared to CAD use by competitors (Boyer et al., 1997). Table 1 provides a summary of the definitions of all of the constructs to be used in this research.

4. Theoretical foundation and model hypotheses

The philosophy that underlies the proposed base relationship in the TEM model (see Fig. 1) centers around the general belief that highly functional and sophisticated technology offers the potential for enhanced flexibility and gains in higher levels of quality. The theoretical foundation of our model in

Table 2
Literature summary of impact of management levers on technology performance

Cite	Technology	Description	C[a]	F[b]	TE[c]	TR[d]	IN[e]	P[f]
Boyer et al. (1997)	AMTs	Infrastructure impact on effectiveness of AMT's	+[g]		+	+		General performance (ROA and profit), flexibility
Gupta et al. (1997)	AMTs	Measured AMT intensity in cross-sectional study and related it to performance as moderated by decentralization and formalization	+	–[h]				Work-in-process, unit manufacturing cost, delivery
Banker et al. (1996a)	Electro-mechanical assembly, capital intensive, labor intensive	Impact of high performance work teams on manufacturing on four different production lines, longitudinal. Team success on one of four lines	I[i]		I			Cost (productivity) and quality
Youndt et al. (1996)	Metal-working industry	Studied the link between the HR system (administrative vs. human capital enhancing) and performance contingent on manufacturing strategy. Found no connection between HR system and strategy				I	I	General performance relative to others
MacDuffie (1995)	Auto-assembly plants, capital and labor intense	Study of high commitment HR systems in assembly that is buffered or flexible need more training, teams and reward-based pay for flexible system	+		+	+	+	Cost (productivity) and quality
Maffei and Meredith (1995)	FMCs	Six in depth cases studies of operations infrastructure	+					Time, cost, quality, flexibility
Arthur (1994)	High technology integrated continuous process, steel mini-mills	Compared control vs. commitment HR systems. Commitment increased productivity, reduced scrap and reduced turnover	+		I	+		Cost (productivity), quality (scrap)
Kelley (1994)	(PA) Programmable automation — CNCs	Found that the more PA rather than conventional machines needed more decentralized work force. Labor-management teams decreased productivity	+		–			Cost (productivity)
Collins and King (1988)	CAD	Found that the more 'non-routine' the technology the more organic structure is needed	+	+				Quality and flexibility
Krafcik (1988)	AMTs	Found decentralized organization more productive than those with more AMT's	+	+				Cost (productivity)
Bessant and Lamming (1987)	FMSs	Organization impacts caused 40% of performance improvements before FMS's were implemented	+					Cost (productivity) and flexibility
Jaikumar (1986)	FMSs	International comparison of FMS used. Found US more efficient, less flexible than Japan			+	+		Time, cost, quality, flexibility

[a] Centralization.
[b] Formalization.
[c] Teams.
[d] Training.
[e] Incentives.
[f] Performance
[g] Positive relationship found.
[h] Negative relationship found.
[i] Inconclusive results.

Table 3
Literature summary of impact of management levers on firm performance

Cite	Technology	Description	C[a]	F[b]	TE[c]	TR[d]	IN[e]	P[f]
Adler et al. (1999)	Automotive assembly plants	Study of major model changes at a Toyota subsidiary to examine the tradeoff between flexibility and efficiency	+[g]	+		+		Efficiency, flexibility
Dow et al. (1999)	Australian manufacturers	Study of quality management practices and their contribution to plant performance	+		I[h]	I		Defects, warranty claims
Samson and Terziovski (1999)	Australian and New Zealand manufacturers	Study of quality management practices and organization performance				+		Defects, warranty claims, productivity, delivery, quality costs
Banker et al. (1996b)	Retailer study contingent on competitive intensity	Centralization based on ratio of supervisors to employees. More centralized, less impact of financial incentives on performance	+		I		+	General performance (sales and profits)
Delery and Doty (1996)	HR management in banking industry	Tested fit of employment system to bank strategy for its impact on performance. Inconclusive results, incentives strongly correlated to performance	I			I	+	General performance
Saleh et al. (1990)	Quality circles in auto-parts industry	Use of quality circles improved productivity and quality			+			Cost (productivity) quality
David et al. (1989)	Bank management	Tested technology (predictability, analyzability, and interdependence) structure fit. Found it is a better predictor than technology alone. Task unpredictability needs expertise and teamwork						Overall performance including quality and quantity of work
Campbell (1988)	Overview of training research	General impact of training on performance is positive						General performance impact
Pritchard et al. (1988)	Air force maintenance	Experiment with treatments on feedback, goal setting and incentives. Incentives influences performance positively					+	Cost (productivity)
Alexander and Randolph (1985)	Nursing unit field study	Study fit between Perrow's technology (uncertainty, instability, variability) and structure. Found fit between technology and structure better than structure or technology alone with performance. Mechanized structures fit routine technology	+	+				
Brass (1985)	Newspaper publishing company	Found job characteristics of autonomy and skill variety impact performance for high technology uncertainty	+			+		Cost (productivity), quality

[a] Centralization.
[b] Formalization.
[c] Teams.
[d] Training.
[e] Incentives.
[f] Performance
[g] Positive relationship found.
[h] Inconclusive results.

Fig. 1 is based on prior work in the domain of organization behavior and technology management. The technology-specific research used in motivating the following discussion is summarized in Table 2, while the empirical research on management levers and their performance impacts is summarized in Table 3.

The support for the base relationship in our model (Fig. 1) is provided by the work of, among others, Miller and Roth (1994) and Vickery et al. (1997). Miller and Roth (1994) showed that firms often focus on clusters of performance goals in an attempt to master certain performance goals that fit their strategy. Their 'Innovator' firms achieved high performance in lead time, flexibility, and high quality. These firms were flexibility focused, and their improvement programs included the use of sophisticated CAD systems and quick new product introductions. A similar study by Vickery et al. (1997) in the furniture industry also found that firms tended to group flexibility and speed together (the 'Delivery' performers).

There has been little current research that has provided an empirical foundation for specifically hypothesizing the impact of functionality as defined here on CAD process performance. The derivation of hypotheses regarding functionality is based primarily on the historical research of Woodward (1965). Research that builds upon her work has found that improvements in quality, flexibility and lead times occur in those operating environments where technology has high functionality (Chen and Adam, 1991; Badham, 1989; Collins and King, 1988; Alexander and Randolph, 1985). We would expect sophistication to have a similar impact. This leads to the statement of Hypothesis 1.

Hypothesis 1. Functionality and sophistication will be positively related to enhanced quality, flexibility and overall process performance.

4.1. *Moderation effect of the management levers*

Recent research by MacDuffie (1995), Youndt et al. (1996), and Banker et al. (1996a) has grouped management techniques or levers into two groups. The first group is referred to as 'control' or 'administrative' human resource management. It includes the use of more formalization and centralization, less need for training and teams, and outcome-based incentives. The second group is called 'human capital enhancing' or high commitment management and utilizes less formalization, more autonomy, more teamwork and training, and group or process-based incentive plans. The control type management is found to be more effective where the environment is more structured, as in an automated context. The human capital enhancing management is better in more variable work environments, such as those where highly functional or sophisticated technology is present. These are the basic premises and arguments used in presenting our next set of hypotheses that are related to the moderating effect of management levers on performance.

4.1.1. *Relationship between organization structure and performance*

Research on organization structure's influence on technology performance generally infers that more decentralized management with less formalization will enhance employee performance in environments with more advanced technologies (Boyer et al., 1997; MacDuffie, 1995; Maffei and Meredith, 1995). Current research shows that while the relationship between technology and performance may not be significant in the absence of the influence of decentralization and less formalization, it will be significant when these conditions exist. This is attributed to the employee's ability to make decisions quickly as required in the use of technology in a dynamic environment (Boyer et al., 1997; Gupta et al., 1997; Karuppan, 1997; Liden et al., 1997; Collins and King, 1988), and provides support for a moderating influence. Older, well-known studies by Woodward (1965) and Collins et al. (1988) also provide support for the use of a more decentralized management system with less formalization in environments where there is increased technological uncertainty. In general, 'human capital enhancing systems' with higher worker autonomy and less formalization work better than the bureaucratic systems of the past (Arthur, 1994; MacDuffie, 1995; Youndt et al., 1996). This leads to the following hypothesis.

Hypothesis 2. The relationship between functionality and sophistication with quality, flexibility and overall performance will be (a) strengthened by higher levels of decentralization, and (b) strengthened by lower levels of formalization.

4.1.2. Relationship between the use of teams and performance

The literature on the use of teams does not present consistent results, and its linkage to performance appears to be very much contingent upon the environment in which they are employed. A study of quality circle teams found their use positively correlated to productivity and quality improvements (Saleh et al., 1990), while Katz et al. (1995) found that the use of teams negatively impact costs. Banker et al. (1996a) could not find a relationship between use of teams and performance in retailing and sales context. Yet team use in the context of ‘high commitment systems’ in complex technological environments has been shown to improve productivity, quality, and general firm performance (Boyer et al., 1997; MacDuffie, 1995; Jaikumar, 1986).

In a more traditional manufacturing environment the impact of teams has been inconclusive (Dow et al., 1999; Banker et al., 1996a; Arthur, 1994;), suggesting that use of teams is probably a moderator in the technology–performance relationship. As has been pointed out by others, successful use of teams is highly contingent upon the environment where they are employed (Banker et al., 1996a). A more technically complex environment, one where there is increased functionality and sophistication, would indicate a need for teams. In contrast, a simplified, more simplified process would require less teamwork. This leads to Hypothesis 3.

Hypothesis 3. The relationship of functionality and sophistication with quality, flexibility and overall process performance will be strengthened by the use of teams.

4.1.3. Relationship between the extensiveness of training and performance

The research on the use of training is much more cohesive. In the context of a technically complex manufacturing environment, more training was shown to enhance performance over firms that used less training (Boyer et al., 1997; MacDuffie, 1995; Arthur, 1994). But there are a few studies showing training’s impact to be insignificant in affecting performance (Dow et al., 1999; Delery and Doty, 1996; Youndt et al., 1996). In these studies there was no technology influence, which brings up the proposition that training is not *always* better. Even a manufacturing study (Youndt et al., 1996) where the technology is standard, did not find a relationship between training and performance, again leading to the conclusion that training would be more likely to strengthen performance in a technologically advanced environment (increased functionality or sophistication) rather than a simpler one. This reasoning leads to Hypothesis 4.

Hypothesis 4. The relationship of functionality and sophistication with quality, flexibility and overall process performance will be strengthened with increased levels of training.

4.1.4. Relationship between the equity of incentives and performance

The influence of incentives on performance “depends heavily on the circumstances” (Guzzo et al., 1985, p. 285). The meta-analysis research by Doucouliagos (1995) found equitable incentive programs to be positively related to performance. Although there is not much related research in the manufacturing arena, there is some evidence that incentives are correlated with improved performance. Based on organizational research studies it can be proposed that if incentives are equitable, employees will be motivated to improve their individual performance (Karuppan, 1997; Banker et al., 1996b; Delery and Doty, 1996; Pritchard et al., 1988). This leads to Hypothesis 5.

Hypothesis 5. The relationship between functionality and quality, flexibility and overall process performance will be strengthened with greater use of equitable incentives.

This research proposes that by examining the impact of each human capital enhancing management lever individually rather than collectively, their interactions with technology attributes can be better examined. This provides a first step in evaluating the issue of the ‘fit’ of types of management with technology for most effective performance at the process level.

5. Methodology

The development of measures of constructs is a complex process. In order to reduce the sources of measurement, sampling and statistical error, the procedure set forth by Churchhill (1979) was used to develop and purify the measurement instrument. In order to present a test instrument that is clear, accurate and valid, extensive pre-testing of this survey was conducted before it was finalized. Currently used and validated measures were obtained for the management levers. The research on technology has not provided the concise definition of technology attributes at the technology–process level of analysis as was needed here. Therefore, many of the items presented to measure technology functionality and sophistication were derived from an extensive review of the literature and through interviews with experts in this field. Along with the purification process and pre-testing of survey items, a Q-sort technique was used for examination of construct convergent validity (Moore and Benbesat, 1991). Field interviews and pre-testing were subsequently used to further develop the items. Administration of the pre-test survey instrument to 14 CAD respondents revealed that the instrument needed very few modifications. Some rewording was done to attribute items of technology in order to add clarity. The resulting items used in the survey instrument after these rigorous purification processes are shown in the Appendix A.

5.1. Data collection

In order to obtain broad-based information on the use of CAD, a mailed survey methodology was chosen rather than the case study approach that is often used in technology research (Adler et al., 1999; Maffei and Meredith, 1995; Orlikowski, 1992). While case study research is used to explore construct definitions and generate hypotheses, survey research allows testing of hypotheses and theory building. The survey research in technology effectiveness in manufacturing firms has been limited to a few studies, often with intra-firm or intra-organization selection of respondents (Adler et al., 1999; MacDuffie, 1995; Kelley, 1994; Tyre and Hauptman, 1992). This limits the generalizability of the results. Since our research is being performed as a process level study over a wide variety of firms, it provides a contribution to the fairly limited population of empirical work on technology effectiveness.

Purposive sampling procedures were used for data collection (Thompson, 1992), whereby the first step is to identify a population from which the sampling frame can be identified. A sample of potential CAD users was drawn from membership listing for various automotive and equipment manufacturing organizations including Equipment Manufacturers Institute (EMI), American Gear Manufacturers Association (AGMA), Society of Automotive Engineers (SAE) and The Outdoor Power Equipment Industry (OPEI), as well as the Harris Directory (1995). The firms selected have SIC codes in the 3500 and 3700 categories and include automotive, truck and bus, construction machinery, agricultural and recreational vehicle industries. Research has shown these groups have a proportionately large amount of use of CAD technologies (Montagno et al., 1995). The second step involved identifying and removing non-manufacturing firms. The third step was to locate the appropriate respondents within the firms inside of the sampling frame.

A cover letter explaining the nature of the research and a sample benchmarking report was included to encourage participation in this research. The recipient, usually a plant manager or general manager or higher, was encouraged to forward the survey to the appropriate 'key informant' within their firm. These 'key informants' were usually the CAD manager or a manager of design engineering. They were offered a customized report that benchmarked their responses to those of the other respondents within the vehicular industry as an incentive to respond. After 3 weeks a follow-up letter was sent to non-respondents encouraging participation. Two weeks subsequent to the follow-up letter, a third mailing was sent to non-respondents. This process was repeated three times over, separated by a period of a few months each. In order to insure that the technology has been in place long enough to evaluate its effectiveness, only responses for systems that had been in place for at least 6 months were used. Overall, this resulted in 143 CAD responses out of a sample frame of 581, yielding a reasonable response rate of 24.6%.

In order to assess non-response bias, research precedent is to compare the profiles of the early and late respondents (Venkatraman, 1989). Research has shown late respondents profiles tend to match those of non-respondents. In this case, the early respondents were those that responded within 2 weeks for each of the three mailings. Late respondents were all other respondents for each mailing. The differences between all early and late respondents, as well as those between

Table 4
CAD technology measures construct validity

Item		Factor analysis		
			Two factor model	
		ITC[a]	Loading factor 1	Loading factor 2
Functionality **(Cronbach $\alpha = 0.83$)**				
C1	This CAD system allows the design of a wide variety of parts or products	0.46	**49**	11
C2	This CAD system has a lot of extra features and is not just a basic system	0.74	**75**	34
C3	This CAD system has just about any feature we could want	0.82	**73**	25
C4	This CAD technology has a lot of features compared to available CAD technologies	0.81	**82**	30
Sophistication **(Cronbach $\alpha = 0.92$)**[b]				
C5	In terms of its hardware?	0.79	24	**79**
C6	In terms of its electronics and use of information technology?	0.81	18	**83**
C7	In terms of all of its features?	0.87	33	**85**
C8	In terms of its placement on a state-of-the-art timeline	0.81	47	**76**

[a] Item-to-total correlations.

[b] Position your CAD system on a continuum as to whether it is based on standard, well-known technology or on new technological developments.

different temporal stage of data collection were tested using the Chi-Square test of independence. No significant differences were found between respondents for industry type, size of firm, and technology type. The resulting data was then used for all further analysis.

6. The construct validation process

Internal consistency of the measures was assessed using Cronbach's alpha, while tests for convergent and discriminant validity were conducted using exploratory factor analysis. The coefficient alpha's for functionality and sophistication construct were sufficiently high (0.83 and 0.92, respectively) and indicate high levels of internal consistency. These inter-item correlations and alpha values are shown in Table 4. Exploratory factor analysis was conducted as the next step in establishing discriminant validity for technology constructs. Using the Varimax (orthogonal) rotation method resulted in a two factor model that explained 95% of the variance. Convergent validity of the functionality construct was further evaluated by observing its correlation with and objective measure of functionality that is based on a list of the number of major features plus some minor features possessed by the CAD technology. The correlation between this objective measure and the proposed perceptual measure was 0.47 with a significance level of 0.0001, thereby providing strong evidence of the convergent validity of the construct.

The measures for the management levers were adapted from prior research as discussed earlier and are briefly examined here for construct validity using the same techniques as those used for technology attributes. Table 5 provides a summary of the results of the coefficient alpha analysis and factor analysis for the formalization and decentralization measures, while Table 6 contains the results for teams, training and equity of incentives. The coefficient alpha for all management lever constructs met the minimum 0.7 criterion, and in most cases was above 0.80.

The management levers are previously developed measures that were modified somewhat to apply to the CAD process level environment. The unidimensionality criterion was examined in this research through exploratory factor analysis. A five-factor model using all management lever items clearly indicated five unidimensional factors with no cross-loadings. The organizational structure variables, formalization and decentralization were also factor analyzed with a two-factor model. There were clean loadings onto two factors, with no formalization items significantly loading onto centralization, and vice versa. Item O7,

Table 5
Structural management lever measures and construct validity[a]

Item	Item description	ITC[a]	Factor analysis: Loading factor 1	Factor analysis: Loading factor 2
Formalization **(Cronbach $\alpha = 0.82$ (0.80))**[a]				
O1	Comprehensive rules exist for all routine procedures and operations with regard to CAD usage	0.61	***78***[a]	21
O2	Whenever a situation arises in the CAD area, we have procedures to follow in dealing with it	0.61	***78***	16
O3	When rules and procedures exist in the CAD area, they are in written form	0.52	***61***	8
O4	There are significant penalties for CAD designers for violating procedures	0.53	***61***	8
O5	The CAD designer's job has an up-to-date job description	0.62	***60***	−20
O6	The job description for the CAD designer's job contains all of the duties performed by individual CAD designers	0.61	***58***	−24
O7	The actual job duties are shaped more by a specific job description than by the CAD designer	0.28[b]	27	−27
Decentralization **(Cronbach $\alpha = 0.71$)**				
O8	CAD designers are involved in decisions related to the investment of new technology in their area	0.48	−7	***57***
O9	CAD designers work autonomously with little or no management guidance	0.29	18	*37*
O10	CAD designers have a high degree of participation in the adoption or change of organization policies affecting their area	0.53	−30	***61***
O11	CAD designers have a high degree of participation in hiring and staffing decisions	0.47	−18	***51***
O12	CAD designers determine their own workflow, scheduling or order of tasks	0.62	−3	***71***
O13	CAD designers are rarely involved in day-to-day decisions on product design issues (reverse score)	0.25	−4	40

[a] Item-to-total correlations; italic numbers denote the significant loading. Alpha value in parenthesis indicates before item(s) were dropped.
[b] Indicates item dropped.

dealing with the actual job duties being shaped by the job description rather than the designer, was not significantly linked to the formalization factor. It was also weak in the reliability test. Therefore, in order to improve the internal consistency of the construct item O7 was dropped. Items Pay6 and Pay7, dealing with the width of the pay range across CAD designers, were highly insignificant in relation to all other items in the equity of incentives construct. These items were also dropped from further analysis.

The performance measures for the outcomes of the technology–process are endogenous variables. All of the performance items were drawn from the taxonomy presented by Safizadeh et al. (1996), but using the work of Collins and King (1988) were specifically changed to represent process level indicators for CAD systems. The constructs for quality and flexibility are commonly used in manufacturing research, but the specific item development for CAD is new. The exploratory factor analysis shown in Table 7 provided an interpretable, two factor solution that explained 97% of the variance. Item P11 (drawing quality) was removed from the quality construct since it did not yield significant correlations with other quality items and also did not load significantly on any factor. The three performance factors, flexibility, quality, and overall CAD performance provide constructs that demonstrate internal consistency with Cronbach alpha reliabilities of 0.77, 0.81, and 0.81, respectively, and high item-to-total correlations. Using the criterion of

Table 6
Infrastructural management lever measures and construct validity[a]

Item	Item description	ITC[a]	Factor loadings 1	2	3
Use of teams in product design **(Cronbach α = 0.89)**					
TE1	CAD designers are involved in formal product design teams that are organized for new product exploration or introduction	0.48	**60**	0	−8
TE2	CAD designers are involved in temporary teams that form to solve problems or accomplish specific goals	0.65	***74***[a]	15	15
TE3	CAD designers frequently work in teams with members from a variety of areas (marketing, manufacturing, etc.)	0.71	***78***	14	6
TE4	CAD designers are involved in teams that form to solve problems	0.73	***81***	25	13
Training in product design **(Cronbach α = 0.90)**					
TR1	How extensive is the training process for CAD designers?	0.80	9	**84**	12
TR2	How much priority is placed on training CAD designers?	0.77	8	**83**	18
TR3	How much money is placed on training CAD designers?	0.83	5	**88**	15
TR4	How formal or structured is the training process?	0.78	12	**83**	0
TR5	What percentage of designers received training this last year?	0.59	12	**58**	13
TR6	On the average, how many hours of formal training does a typical CAD designer receive per year?	0.74	14	**75**	−8
TR7	How may different kinds of training programs are available for CAD designers to attend?	0.54	10	**59**	3
TR8	Do you feel training is viewed as a cost or an investment?	0.34	6	**41**	11
Equity of incentives **(Cronbach α = 0.84 (0.76))**[a]					
PAY1	How would you rate pay levels in the product design area compared to other firms?	0.64	1	9	**79**
PAY2	How would you rate pay levels in the product design area relative to past years?	0.58	0	15	**72**
PAY3	The wages in our product design area are not very competitive with the industry	0.57	14	13	**74**
PAY4	To what extent are CAD designers paid what they are worth compared to others in this work unit?	0.62	12	6	**69**
PAY5	How much emphasis is placed on paying CAD designers what they would be paid on similar jobs in other companies?	0.60	11	9	**69**
PAY6	To what extent do differences in pay across CAD designers represent a difference in their contribution?	0.35	1	4	**34**
PAY7	How wide is the range in pay across CAD designers?	0.13[b]	10	8	**12**
PAY8	How closely is pay tied to individual performance?	0.45[b]	−7	−4	**52**

[a] Item-to-total correlation; italic numbers denote significant loading. Alpha value in parenthesis indicates before item(s) were dropped.
[b] Indicates item dropped.

a 0.4 loading as significant (Hatcher, 1994), all items have a simple factor structure where they load onto only one factor except in one instance. In this instance, the item for flexibility, the ability to customize products has a 0.43 loading on the quality construct, but 0.68 loading on flexibility. The higher loading on flexibility is theoretically sound, therefore this item is acceptable.

We have thus far shown that constructs belonging to the TEM model (Fig. 1) have demonstrated acceptable construct validity and reliability. A summary of the results of the construct validation process is shown in Table 8, while the correlations between constructs are shown in Table 9. These constructs will now be used to examine the hypothesized relationships.

7. Discussion of results and findings

Hierarchical linear regression was used to examine the relationships between the technology attributes and performance. Results in Table 10 show that the primary hypotheses for functionality (Hypothesis 1) were supported for both quality and flexibility. As

Table 7
CAD performance measures[a,b]

Item	Performance measures	ITC	Factor analysis		
			Loading factor 1	Loading factor 2	Loading factor 3
Flexibility **(Cronbach α = 0.80)**					
P1	Design speed	0.49	56[c]	7	33
P2	Speed of introducing new products into production	0.55	57[c]	22	18
P3	Ability to produce more variety in designs	0.65	67[c]	36	9
P4	Ability to customize products per design specifications	0.66	68[c]	43[c]	20
P5	Ability to make design changes easily	0.57	63[c]	11	5
Quality **(Cronbach α = 0.81)**					
P6	Quality of design presentations	0.56	18	63[c]	0
P7	Features shown on design	0.66	12	72[c]	34
P18	Design conformation to engineering specifications	0.51	17	54[c]	16
P9	Design quality as perceived by the customer	0.65	22	72[c]	13
P10	Product quality as perceived by the customer	0.63	26	69[c]	35
Overall process performance **(Cronbach α = 0.81)**					
P12	Rate the overall performance of CAD based on corporate performance criteria	0.69	13	16	76[c]
P13	Rate the overall performance of CAD compared to similar technology by your competitors	0.69	15	30	68[c]
Not used					
P11	Drawing quality				

[a] Extent to which process improvements have been achieved as a result of this CAD system, relative to its anticipated performance goals; 1: significantly lower; 3: as expected; 5: significantly higher.
[b] Bold numbers denote Cronbach alpha for construct.
[c] Significant loading.

proposed, increasing levels of technology functionality enhanced performance in quality and flexibility, as proposed, explaining 13 and 10%, of the variance, respectively. Finally, there was very high support for the relationship between functionality and overall process performance, with an explained variation of 38.5%.

The relationship between sophistication and performance provided mixed results. The proposed

Table 8
Construct summary results for CAD ($n = 143$)[a]

Construct	Coefficient alpha	Number of items	Number of items removed	Comments
Functionality	0.83	4	0	
Sophistication	0.92	4	0	
Formalization	0.82 (0.80)	6 (7)	1	O7 not significant
Decentralization	0.70	5	0	
Use of teams	0.89	4	0	
Use of training	0.90	8	0	
Equity of incentives	0.84 (0.76)	6 (8)	2	Items PAY6 and PAY7 do not demonstrate convergent reliability or internal consistency
Performance–quality	0.81 (0.79)	5 (6)	1	P12 not significant
Performance–flexibility[b]	0.80 (0.78)	5 (3)	(2)	Added the two time items
Scale	0.66	3		

[a] Items in parentheses are values before items were dropped.
[b] Items were added due to addition of time items.

Table 9
Correlation matrix of validated constructs[a]

	Mean	S.D.	1	2	3	4	5	6	7	8	9	10
Functionality	0.75	0.20	1.00									
Sophistication	0.51	0.25	**0.58**	1.00								
Formalization	0.56	0.19	*0.19*	*0.18*	1.00							
Decentralization	0.53	0.15	0.02	0.08	0.06	1.00						
Team use	0.72	0.19	0.15	*0.18*	**0.27**	**0.41**	1.00					
Training	0.54	0.20	**0.47**	**0.41**	**0.43**	**0.22**	**0.30**	1.00				
Equity of incentives	0.58	0.14	0.11	0.06	0.15	0.06	0.15	*0.22*	1.00			
Quality performance	0.61	0.20	**0.34**	**0.31**	**0.24**	0.02	0.03	**0.43**	0.15	1.00		
Flexibility performance	0.66	0.16	**0.30**	**0.22**	0.02	0.10	0.04	**0.25**	0.10	**0.49**	1.00	
Process performance	0.73	0.17	**0.56**	**0.40**	*0.18*	0.08	0.12	**0.34**	*0.22*	**0.36**	**0.49**	1.00
Scale	0.55	0.16	**0.34**	**0.26**	**0.28**	**0.24**	*0.19*	*0.21*	0.10	*0.19*	0.04	0.15

[a] Bold numbers denote significance levels <0.01; italics numbers denote significance levels <0.05.

influence of sophistication of the CAD system on quality was supported, explaining 9.7% variation. The relationship between CAD sophistication and overall performance was also supported, explaining over 12% of the variation. On the other hand, the relationship between CAD sophistication and flexibility was only weakly supported at the five percent significant level and 4% explained variation. Scale was not a significant predictor for any of these models.

The significant impact of CAD technology functionality and sophistication on product design performance is encouraging for further process level research. Since technology alone has been shown to not influence performance in plant level studies (Swamidass and Kotha, 1998; Boyer et al., 1997), examination of the impact of CAD technology at the process level is encouraging. Examination of the management levers will provide further explanations on how these relationships can be improved. Tables 11–13 contain the results of the moderated and mediating regression results for the five management levers. Table 11 deals with CAD sophistication. Table 12 presents the results for CAD functionality, and finally Table 13 contains the results of the mediation analysis for the impact of training.

7.1. Testing Hypothesis 2: decentralization and formalization

Decentralization, had no interactions with the predictor variables, therefore was not a moderator in any relationship. The lack of significant findings here leads to the conclusion that neither centralization, nor the reverse, increasing decentralization, will enhance outcomes. These results imply that increasing the decentralization of authority in the product design process is not effective in improving CAD's impact on performance. This may be due to the nature of the CAD department functions, with designers being able to use their CAD workstation in a timely manner, without

Table 10
Test of primary hypotheses[a]

Technology attribute	Proposed relationship	Regression coefficient		
		Quality	Flexibility	Overall performance
Functionality	+	0.320 (13.6)**	0.290 (10.5)**	0.485 (38.4)**
Impact of scale		0.120 (0.1)	−0.084 (0.1)	−0.024 (0.0)
Sophistication	+	0.231 (9.7)**	0.138 (4.1)*	0.234 (12.4)**
Impact of scale		0.130 (1.0)	0.005 (0.0)	0.083 (0.6)

[a] Numbers in parentheses are the R^2 values (%).
** Significant at $p < 0.01$.
* Significant at $p < 0.05$.

Table 11
Results of regression analysis for sophistication as the predictor variable[a]

Dependent variables	Model 1[b]		Management lever	Model 2[c]				Model 3[d]					
	B_1	R^2		B_1	R^2	B_2	R^2	B_1	R^2	B_2	R^2	B_3	R^2
Flexibility	*0.138*	4.1	Formalization	0.133	4.0	0.000	0.0	−0.136	0.5	−0.262	1.6	*0.501*	4.2
			Decentralization	0.115	3.4	0.126	1.1	0.115	3.4	0.126	1.1	0.000	0.0
			Teams	0.122	3.4	0.000	0.0	−0.073	0.0	−0.103	0.5	0.267	3.4
			Incentives	0.122	3.2	0.172	2.0	−0.104	0.5	0.000	0.0	*0.374*	5.4
Quality	**0.231**	9.7	Formalization	**0.214**	9.7	*0.186*	3.5	0.267	0.3	0.235	1.0	**−0.100**	11.6
			Decentralization	**0.217**	9.7	0.051	0.1	**0.362**	9.7	−0.074	0.3	0.275	0.3
			Teams	**0.231**	10.1	−0.128	1.4	**0.231**	10.1	−0.128	1.4	0.000	0.0
			Incentives	**0.209**	8.7	*0.304*	5.2	−0.314	1.3	−0.095	0.1	**0.862**	14.7
Overall performance	**0.234**	12.4	Formalization	**0.221**	12.2	0.098	1.5	−0.016	0.0	−0.140	0.7	**0.43**	14.6
			Decentralization	**0.229**	12.4	0.064	0.3	**0.399**	12.4	−0.079	0.1	0.319	0.6
			Teams	**0.234**	12.7	0.036	0.2	0.000	0.0	−0.089	0.7	**0.322**	13.1
			Incentives	**0.201**	10.0	**0.277**	5.8	0.322	1.1	0.368	1.2	**−0.197**	13.7

[a] Bold numbers denote $p < 0.01$; italic numbers denote $p < 0.05$; underlined numbers denote $p < 0.1$.
[b] $Y = \text{int} + B_1X$.
[c] $Y = \text{int} + B_1X + B_2Z$.
[d] $Y = \text{int} + B_1X + B_2Z + B_3XZ$, where X is the sophistication, Z the management lever and Y the dependent variable.

distraction of involvement in technology investment, hiring, determining what tasks to do and so on. Therefore, Hypothesis 2(a), that higher levels of decentralization will improve the functionality–performance and sophistication–performance relationships was not supported. Formalization also had no significant interaction effects in the relationship between CAD functionality and any performance measure (see Table 12). But it was influential in the relationship between sophistication and performance, as attested by

Table 12
Results of regression analysis for functionality as the predictor variable[a]

Dependent variables	Model 1[b]		Management lever	Model 2[c]				Model 3[d]					
	B_1	R^2		B_1	R^2	B_2	R^2	B_1	R^2	B_2	R^2	B_3	R^2
Flexibility	**0.29**	10.5	Formalization	**0.318**	12.5	−0.072	0.8	**0.159**	12.5	−0.305	0.8	0.303	0.4
			Decentralization	**0.284**	10.8	0.100	1.1	**0.284**	10.8	0.100	1.1	0.000	0.0
			Teams	**0.299**	11.1	−0.094	0.0	**0.298**	11.1	−0.017	0.0	0.000	0.0
			Incentives	**0.293**	10.6	0.093	0.6	**0.483**	10.6	0.313	0.2	−0.333	0.3
Quality	**0.366**	16.8	Formalization	**0.319**	14.5	0.147	2.4	**0.526**	14.5	0.451	2.4	0.395	0.5
			Decentralization	**0.316**	13.5	0.033	0.0	**0.916**	13.5	0.768	1.9	1.120	0.4
			Teams	**0.321**	12.9	−0.139	1.3	**0.552**	12.9	0.092	0.0	−0.333	1.5
			Incentives	**0.303**	13.3	*0.235*	3.0	−0.099	0.0	−0.249	0.7	**0.692**	16.8
Overall performance	**0.485**	38.4	Formalization	**0.511**	32.9	0.086	0.6	**0.035**	38.2	−0.566	2.2	0.832	1.7
			Decentralization	**0.466**	29.6	−0.023	0.0	**0.675**	29.6	0.258	0.3	−0.391	0.2
			Teams	**0.486**	30.1	0.018	0.0	**0.195**	30.1	−0.274	0.6	0.423	0.2
			Incentives	**0.423**	27.2	0.189	2.4	**0.606**	28.0	*0.387*	2.7	−0.269	0.2

[a] Bold numbers denote $p < 0.01$; italic numbers denote $p < 0.05$; underlined numbers denote $p < 0.1$.
[b] $Y = \text{int} + B_1X$.
[c] $Y = \text{int} + B_1X + B_2Z$.
[d] $Y = \text{int} + B_1X + B_2Z + B_3XZ$, where X is the functionality, Z the management lever and Y the dependent variable.

Table 13
Results of regression analysis for training as the mediating variable[a]

Dependent variables	Predictor variable	Model 1[b]		Model 2[c]				
		B_1	R^2	Management lever	B_1	R^2	B_2	R^2
Flexibility	Sophistication	*0.138*	4.1	Training	0.089	1.4	**0.163**	5.9
Flexibility	Functionality	**0.290**	10.0	Training	**0.271**	10.8	0.047	0.0
Quality	Sophistication	**0.231**	9.7	Training	0.120	2.2	**0.352**	18.3
Quality	Functionality	**0.320**	13.6	Training	0.154	2.7	**0.337**	19.8
Overall performance	Sophistication	**0.234**	12.4	Training	**0.168**	5.2	**0.222**	13.2
Overall performance	Functionality	**0.485**	38.4	Training	**0.394**	27.2	0.093	0.9
Flexibility	Training	**0.207**	6.0					
Quality	Training	**0.416**	19.2					
Overall performance	Training	0.095	0.9					
Training	Sophistication	**0.297**	15.2					
Training	Functionality	**0.471**	24.5					

[a] Bold numbers denote $p < 0.01$; italic numbers denote $p < 0.05$.
[b] $Y = \text{int} + B_1$ Predictor.
[c] $Y = \text{Int} + B_1$ Technology Attribute $+ B_2$ Training.

significant B_3 coefficients for all three performance measures (see Table 11). However, the effect size as seen by the R^2 values is much larger for quality and overall performance. In general, the increased levels of formalization improved sophistication's impact on performance. This is the *reverse* of the relationship hypothesized in Hypothesis 2. Perhaps when state of the art technology is acquired, formalized rules and procedures are more effective in exploiting capabilities. This concurs with another recent manufacturing study (Adler et al., 1999) It is also possible that larger organizations with more formal structure are the ones that can usually afford to adopt more sophisticated CAD systems. Therefore, Hypothesis 2(b) was also not supported.

7.2. Testing Hypothesis 3: use of teams

The only significant moderating influence of team use has is on the relationship between technology sophistication and overall performance (highly significant B_3 value in Model 3 shown in Table 11). Thus team use may have benefits that other direct process outcomes such as flexibility and quality, and the positive impact of teams on the use of sophisticated technology undoubtedly helps in understanding how such technology may be deployed. Once again, team use does not improve the performance of CAD technology with high functionality. The lack of impact on functionality and performance can be attributed to team use taking the designer away from their work stations. Apparently the team involvement as measured here does not affect functionality since it has little to do with enhancing the designers knowledge of the features of the system. Therefore, Hypothesis 3 was generally not supported, except in the case of sophistication's impact on overall performance. This implies that in general, having CAD designers work in teams (whether cross-functional, permanent or in new product design), will not improve quality or flexibility performance.

7.3. Testing Hypothesis 4: extent of training

Training had a high correlation with sophistication and functionality. This is indicative of a potential mediating relationship, as a moderating relationship is not possible for constructs that are correlated with the predictor. Using the technique proposed by Baron and Kenny (1986), the relationships between each technology attribute and training, as well as those between training and performance, were examined. Table 13 contains the mediating regression models, all of which were significant with the exception of the training–overall performance relationship. The multiple regression models that include the predictor variables and training to predict performance are also shown in Table 13. Model 2 indicated a mediating relationship in four instances with the B_2 values for sophistication and functionality decreasing when training is added, along with a corresponding increase in the R^2 values.

The preceding analysis shows that training has a large mediating impact on the sophistication–quality relationship, whereby the explained variation improves significantly. A similar result is achieved between the functionality and quality model, improving explained variation from 14 to 20%. In general, training mediates sophistication–performance relationships across the board for all performance measures. This supports Hypothesis 4. These results imply that the extensiveness of training is an important component in CAD technology's effectiveness. Increased levels of CAD sophistication or functionality call for increased levels of training (more so for sophistication than functionality) since it results in improved quality of product design.

7.4. Testing Hypothesis 5: equity of incentives

Results in Table 11 show that equity of incentives significantly strengthens the relationship of sophistication with flexibility and quality. It was also significant in the relationship between functionality and quality, but with little explained variation (see Table 12). Therefore, there is mixed support for Hypothesis 5. Competitiveness of the wage package definitely enhances design quality performance, more so for sophisticated CAD systems than systems with high functionality. The examination of the influence of incentives to technology outcomes is not common in manufacturing research, but is increasingly supported in the management literature (Banker et al., 1996b; Delery and Doty, 1996; Snell and Dean, 1994). The process level approach used here supports increased examination of incentives and their influence on technology outcomes.

8. Conclusions

8.1. Management implications

The results of this cross-sectional study of vehicular firms using CAD systems provides some insight into the performance goals of the product design process, the effectiveness of the CAD system in attaining those goals, and the impact of five management levers on this relationship. The general findings of the primary models support the first part of this proposition, that technology functionality and sophistication significantly impact the effectiveness of CAD in attaining quality, flexibility, and overall process goals. The largest level of explained variation was between functionality and overall performance of the product design process at 38.5%. This is strong evidence that CAD systems with extensive features go a long way in helping the designers achieve their performance goals and create a competitive advantage in the product design process.

There were mixed results with respect to the influences of management levers on the CAD technology–performance relationship. Training helps in generally improving performance under a wide range of conditions. Overall performance for functional CAD systems is little affected by the use of management levers, perhaps because the purchase of the system with high functionality itself allows most of the benefits to be realized. Such is not the case with sophisticated CAD systems, where management levers play a more important role. Increased levels of formalization and use of teams improves overall performance of sophisticated CAD systems, while incentives have a mixed effect of increasing design quality and flexibility but not overall performance. Thus sophisticated systems have to be more proactively managed by retaining competent employees through competitive wage packages, increasing levels of formalization through increased rules and procedures, and providing opportunities for them to work and exchange ideas in team settings. Increased performance will otherwise not come from merely acquiring 'state of the art' CAD systems.

8.2. Theoretical implications

As expected, this research provides support for the 'fit' notion, which essentially posits that for any technology to be effective, a balance is needed between technology attributes and structural and infrastructural dimensions of the firm. Other researchers have proposed the notion of fit between technology, task and the individual and have found that 'fit' helps explain performance (Goodhue, 1998; Huselid, 1995; David et al., 1989). Differential impact of various management levers examined in our study was dependent on the level of 'fit' between these variables and technology attributes such as functionality and sophistication. As firms develop their individual distinctive competencies that set them apart from others, it is essential that they learn to balance the characteristics of their dominant technologies with the firm's organizational structure and social system.

This research differs from other technology research in that it provides the process level perspective which demonstrated that management levers will vary according to the technology attributes that are prevalent in the process. This provides a rich foundation of knowledge for process management and theory development at the technology–process level. It is a step toward defining the 'black box' that is labeled as technology, and how its features can be managed more effectively by measuring performance at the technology–process level.

8.3. Limitations

While our study provides valuable guidelines for the management of the CAD technology and contributes to the theory of fit between technology and its management, its results must be interpreted with caution and in the context in which the study was conducted. As with any study of its kind, only cross-sectional data was collected, thereby precluding any interpretation of the temporal effects of managing technologies. Even though several of the variables were found to be significant, low R^2 values in some cases suggests that other variables of practical and theoretical interest may exist within this context, but which were not modeled in this study. Finally, our recommendations hold in general for managing CAD systems, and their validity for other manufacturing related technologies must be independently affirmed through additional studies.

8.4. Recommendations for further study

We have shown that effectiveness of the technological system can be studied at the process level. Our technology effectiveness model (TEM) provides a starting point in this inquiry. Hopefully, other researchers will use the structure and results of this study to extend our knowledge of technology management into other areas as well. Additional measures of process effectiveness need to be rigorously developed, since that would represent a major contribution to the field. In addition, attitudes of the user about the technology have been theorized to impact job satisfaction, commitment, morale, job turnover, and perhaps ultimately performance (Dow et al., 1999; Goodhue, 1998; Campion and McClelland, 1991; Saleh et al., 1990). The human side of the equation is an important one and cannot be overlooked. These factors should be incorporated into the technology effectiveness model for future testing in the manufacturing domain. Only then can we begin to holistically understand how better utilization of human capital, organizational structures, and the technological system can occur.

8.5. Some concluding thoughts

While we created the theoretical foundations for studying the impact of any technology at the process level, the selection of the CAD technology as a focus of this study was highly appropriate since its use and technological importance is growing. Worldwide user spending on CAD and related technologies such as CAD and CAM has grown to US$ 6.2 billion in 1999, an increase of almost 17% over 1998 (CAE, 1999). This technology's effectiveness continues to improve with advancements in information technology, thereby allowing the CAD systems to accomplish more in shorter time periods. This has led to significant reductions in product development cycle times. Through increased responsiveness to customer needs, firms are able to maintain a competitive advantage. Correspondingly, what we have learned in this research about the management of CAD technology will improve CAD's impact on the product development process. Firms can also potentially benefit from the enhanced understanding of the management of technology that this research provides, and in turn lead to world class organizations that define the standards of excellence well into the next millenium.

Appendix A

Unless otherwise noted, all scales were Likert scales as follows: 1 = strongly disagree, 2 = moderately disagree, 3 = silghtly disagree, 4 = neither agree nor disagree, 5 = slightly agree, 6 = moderately agree, 7 = strongly agree

Perceptual Measures of Functionality:

- This CAD technology allows the design of a wide variety of parts or products.
- This CAD system has a lot of extra features and is not just a basic system.
- This CAD technology has just about any feature we could want.
- This CAD technology has a lot of features compared to available CAD technologies.

(Source: Collins and King, 1988; Robertson and Allen, 1993; De Sanctis and Poole, 1994)

Features of CAD Systems – Objective Measure

1. Modeling Method:
   - 1.1. 2 dimensional modeling.
   - 1.2. 3 dimensional wire frame modeling.
   - 1.3. 3D auto meshing.
   - 1.4. 3 dimensional solids modeling.
2. Networking Features:
   - 2.1. CAD system configuration is mainframe based, PC based, or UNIX work station based.
   - 2.2. File sharing.
   - 2.3. Networking Ability.
   - 2.4. Associativity.
3. Drawing Features:
   - 3.1. Animation.
   - 3.2. Exploded view.
   - 3.3. Sketching ability.
   - 3.4. Visual Parametric editing.
   - 3.5. Easy conversion from 3D to 2D views.

Sophistication Measures

For the following statements, position your CAD system on a continuum as to whether it is based on standard, well known technology or on new technological developments:

(1 = based on standard technology, 4 = based partially on new technological developments, 7 = based predominantly on new technological developments)

- In terms of its hardware.
- In terms of its electronics and use of information technology.
- In terms of all of its features.
- In terms of its placement on a state of the art timeline.

(Source: Souder and Shrivastava, 1985)

Formalization Measures

- Comprehensive rules exist for all routine procedures and operations with regard to CAD usage.
- Whenever a situation arises in the CAD area, we have procedures to follow in dealing with it.
- When rules and procedures exist in the CAD area, they are in written form.
- There are significant penalties for CAD designer for violating procedures.
- The CAD designer's job has up-to-date job description.
- The job description for the CAD designer's job contains all of the duties performed by individual CAD designers.
- The actual job duties are shaped more by the CAD designer than by a specific job description (reverse coded).

(Source: Hage and Aiken, 1967; Delery and Doty, 1996)

Decentralization Measures

- CAD designers are involved in decisions related to the investment of new equipment and technology. CAD designers work autonomously with little or no management guidance.
- CAD designers have a high degree of participation in the adoption or change in the organization policies affecting their area.
- CAD designers have high degree of participation in hiring and staffing decisions.
- CAD designers determine their own workflow, scheduling or order of tasks.
- CAD designers are rarely involved in day-to-day decisions on product design issues (reverse score).

(Source: Arthur, 1992; Majchrzak and Cotton, 1988; Hage and Aiken, 1969; Lawrence and Hottenstein, 1995).

Extent of the Use of Teams Measures

- CAD designers are organized into formal product design teams that are organized for new product design or introduction.
- CAD designers are involved in temporary teams that form that form to solve problems or accomplish specific goals.
- CAD designers frequently work in teams with members from a variety of areas (marketing, manufacturing, etc.) to introduce new products.

- CAD designers are involved in teams that form to solve problems.

(Source: Flynn et al., 1994; Arthur, 1994; MacDuffie, 1995)

Extent of Training Measures for CAD

- How extensive is the training process for CAD designers? (1 = not extensive, 7 = very extensive)
- How much priority is placed on training CAD designers? (1 = very little, 7 = a great deal)
- How much money is spent on training CAD designers? (1 = very little, 7 = a great deal)
- How formal or structured is the training process? (1 = very unstructured, 7 = very structured)
- What percentage of designers have received training this last year? (1=0%, 4=60%, 7 = 100%)
- On average, how many hours of formal training does a typical CAD designer receive per year? (1 = 0, 4 = 21–30, 7 = 50+)
- How many different kinds of training programs are available for CAD designers to attend? (1 = very few, 4 = moderate variety, 7 = a wide variety)
- Do you feel training is viewed as cost or an investment? (1 = viewed as cost, 2 = viewed as investment)

(Source: Snell and Dean, 1992)

Equity of Incentives Measures

- How would you rate pay levels in this work unit compared to other firms? (1 = low, 4 = same, 7 = high)
- How do you rate the pay levels in this work unit relative to past years? (1 = low, 4 = same, 7 = high)
- The wages in our product design area are not very competitive with the industry (1 = completely true, 4 = some are competitive, some are not, 7 = completely false)
- To what extent are CAD designers paid what they are worth compared to others in this work unit? (1 = very little, 4 = moderate, 7 = a great deal)
- How much emphasis is placed on paying CAD designers what they would be paid on similar jobs in other companies? (1 = very little, 4 = moderate amount, 7 = a great deal)
- To what extent do differences in pay across CAD designers represent differences in their contribution? (1 = very little, 4 = moderate amount, 7 = a great deal)
- How wide is the range in pay across CAD designers? (1 = not closely, 4 = somewhat closely, 7 = very closely)
- How closely is pay tied to individual performance? (1 = not closely, 4 = somewhat closely, 7 = very closely)

(Source: Snell and Dean, 1994)

Flexibility and Quality performance measures used a scale of 1 = results were significantly lower than expected, 3 = results were as expected, 5 = results were significantly higher than expected.

Performance Measures – Flexibility

- Ability to customize product per design specs.
- Ability to produce more variety in designs.
- Ability to make design changes easily.
- Design speed.
- Time to introduce new products into production.

(Source: Collins and King, 1988; Boyer et al., 1997; Georgantzas and Shapiro, 1993)

Performance Measures – Quality

- Quality of design presentations.
- Features shown on design.
- Design conformance to engineering specifications.
- Product quality as perceived by the customer.
- Drawing quality.

(Source: Collins and King, 1988; Boyer et al., 1997; Georgantzas and Shapiro, 1993)

Performance Measures – Overall CAD Process

How would you rate the overall performance of this CAD technology:

- Based on corporate performance criteria?
- Based on performance of similar technology by your competitors?

(Scale 1 to 5 Very poor, poor, average, good, very good)
(Source: Boyer et al., 1997)

Scale Measures

- Please state the approximate replacement value of the hardware and software only for this system.
- How many work stations are there in this CAD system?

- The size of this CAD system is large in comparison to other CAD technologies available in the industry.

(Source: Sethi and King, 1994; Kelley, 1994)

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