ELSEVIER

Journal of Operations Management 17 (1998) 23–37

JOURNAL OF OPERATIONS MANAGEMENT

Explaining manufacturing technology use, firm size and performance using a multidimensional view of technology [1]

Paul M. Swamidass [a,*], Suresh Kotha [b]

[a] Thomas Walter Center for Technology Management, Tiger Drive, Room 104, Auburn University, AL 36849-5358, USA
[b] School of Business Administration, 328 McKenzie Building, University of Washington, Seattle, WA 98195, USA

Received 22 April 1995; accepted 27 October 1997

Abstract

This study examines the relationships among the variables Advanced Manufacturing Technology (AMT) use, Firm Size, and Performance in US manufacturing firms using a multidimensional definition of AMT. The study's four major findings are based on empirical analyses of survey data collected from 160 manufacturing firms. First, evidence indicates that there are at least four dimensions of AMT including: Information Exchange and Planning Technology (IEPT), Product Design Technology (PDT), High-Volume Automation Technology (HVAT), and Low-Volume Flexible Automation Technology (LVFAT). This brings to light a key difference between the literature and the four empirically determined dimensions of AMT: empirical dimensions include two distinct dimensions for shop floor technology while most conceptual schemes do not. Second, AMT use across three of these dimensions increases linearly as firm size increases logarithmically; however, the use of some dimensions of AMT increase more rapidly with firm size than others. Third, AMT use does not show any direct impact on firm performance. Finally, firm size weakly moderates the AMT-performance relationship; perhaps, due to their superior resource base, larger firms are able to use AMTs more effectively.

Keywords: Advanced manufacturing technology (AMT); Product design technology (PDT); Information exchange and planning technology (IE)

1. Introduction

The use of advanced manufacturing technologies (AMTs) has not been fully understood although billions of dollars are invested in them each year. Investments are made each year in AMT because practitioners perceive a number of benefits attributed directly to their use, the top five benefits in descending order of the frequency of mention being: (1) reduced cycle-time; (2) market share growth; (3) progress towards zero-defects; (4) return on investment; and (5) focused production (Swamidass, 1996). Academic researchers view AMTs to be one of the key elements of integrated manufacturing, which is fast becoming an important source of sustained competitive edge for manufacturers in the nineties (Dean and Snell, 1991).

AMTs emerged when conventional manufacturing technology and computer-based control technology converged. AMTs include computer-driven technolo-

* Corresponding author. Tel.: +1-334-844-4333; fax: +1-334-844-1678; e-mail: swamidp@eng.auburn.edu

[1] Both authors contributed equally to this paper.

0272-6963/98/$ - see front matter
PII: S0272-6963(98)00016-3

gies such as computer-aided design (CAD), computer-aided-engineering (CAE), computer-aided-manufacturing (CAM), flexible manufacturing systems (FMS) and computer-aided process planning, among others (Dean and Snell, 1991).

The use of AMTs is associated with many benefits (Swamidass, 1996). First, the programmable capability of AMTs allows for manufacturing flexibility because users can switch machines from producing one kind of component to another instantly. Also, programs controlling a machine can be changed from one program to another by punching a few computer keys; the set-up costs for product changes are virtually zero. Such flexibility permits the production of a wide variety of products at low volumes without added cost or penalty. Second, AMTs permit functional integration by linking various functional departments' information systems, common data bases and shopfloor AMTs (Ettlie, 1984; Dean and Snell, 1991). Third, AMTs increase manufacturing productivity by embedding routine repetitive tasks into AMT hardware and software. This embedding reduces users' direct labor costs, rework costs, and work-in-process inventories (Zummato and O'Connor, 1992). Fourth, AMTs such as CAD can considerably improve white-collar productivity (e.g., product designers and engineers) by automating the product design process. Finally, process oriented AMTs such as FMS and CNC machines enable greater consistency in the manufacturing process by reducing the variance in the production process, thus enabling a firm to achieve superior product quality.

The objectives of the study are threefold. First, using empirical data, we attempt to validate a multidimensional concept of AMT that embodies both flexibility and information processing capabilities. Second, we investigate whether AMT use increases with firm size, just as conventional production technology increases with firm size (cf. Marsh and Mannari, 1981). Third, an implicit premise underlying all investments in AMT is that AMTs improve firm performance. This notion is central to the 'investment justification' research stream. Although AMTs are credited with many benefits pertaining to cost, quality and flexibility, the AMT-performance relationship remains largely unexamined using empirical data. Therefore, the empirical investigation of the relationship in this study is significant.

2. Theory and hypotheses

In this section, we address three distinct issues: the multidimensionality of AMT, the firm size and AMT use relationship, and the AMT use and performance relationship.

2.1. The multidimensionality of AMT

Historically, two to three decades ago, manufacturing technology research stressed mass production capability and the inherent inflexibility of the prevailing manufacturing technology (e.g., Woodward, 1965; Inkson et al., 1970; Child and Mansfield, 1972; Gerwin, 1981; Yasai-Ardekani, 1989). For example, Yasai-Ardekani (1989) (p. 136) used scaling procedures to measure 'the degree to which automated, continuous, fixed-sequenced activities are present' in a production process as a measure of technology. This 'explicitness of technology' (Gerwin, 1981) view of manufacturing technology has been widely researched as 'technological complexity' (Woodward, 1965), 'mechanization' (Blau et al., 1976), 'production continuity' (Child and Mansfield, 1972) and 'automicity' (Inkson et al., 1970). Foremost, this insufficiently developed *historical* view of technology is too limited for describing today's AMT because it stressed inflexibility and mass production. For additional discussions comparing conventional technology and AMT, see Lei and Goldhar (1990).

Over the past decade, flexibility has become the hallmark of emerging AMTs. Several conceptual schemes explain the notion of flexibility associated with AMTs (e.g., Goldhar and Jelinek, 1985; Swamidass, 1988; Dean and Snell, 1991; Gerwin and Kolodny, 1992; Parthasarthy and Sethi, 1992; Gerwin, 1993). Table 1 compares some emerging multidimensional views on AMT as proposed by three different researchers. The conceptual schemes in Table 1 are not necessarily tested and established by empirical data but they are useful guides for conducting empirical studies, and they are useful inputs to the development of future conceptual schemes. Rosenthal's scheme was proposed in the early eighties when the flexibility aspect of manufacturing technology was beginning to take shape.

The conceptual schemes in Table 1 for classifying AMT have common themes and tend to agree on

Table 1
Competing multidimensional views of AMT

Adler (1988)	Rosenthal (1984)	Warner (1987)
Types of automation	Grouping of technologies	AMT classifications
(1) Design automation	(1) Computer-aided design group	(1) Shop floor technologies with intelligence
(2) Manufacturing automation	(2) CAD/CAM group	(2) Product oriented technologies
(3) Administrative/control technologies	(3) Computer-aided manufacturing group	(3) Information and control technologies
	(4) Factory management and control group	

three common technology types: (1) design related technologies; (2) process related shop floor technologies; and (3) information and control related technologies. These classifications not only consider the flexibility aspects of AMT but also the inherent information processing capabilities of AMTs (i.e., information and/or control technologies). However, for the purpose of this study, we incorporate other views on technology dimensions (Kaplinsky, 1983; Kotha, 1991) to redefine information and control related technologies (item 3 above) into two separate dimensions, namely: (1) logistics/planning related technologies, and (2) information exchange technologies. Later, field data is used to test the four-dimensional model proposed as follows.

(A) *Product Design Technologies (PDT)*. This dimension includes technologies such as CAD, CAE and automated drafting technologies that focus primarily on product definition, design, and related information processing functions.

(B) *Process Technologies (PT)*. This dimension encompasses technologies such as CNC, CAM, FMS, and programmable controllers that focus on the process related aspects in manufacturing; these technologies are used on the shop floor, and generate process related information from the factory floor. Further, these technologies can be linked to product related technologies for reciprocal communication.

(C) *Logistics / Planning Technologies (LPT)*. This dimension covers technologies that control and monitor the material flow from the acquisition of raw materials to the delivery of finished products, and the related counterflows of logistical information. It includes both the hardware and software for production scheduling systems, shop floor control systems, and Material Requirements Planning (MRP) systems.

(D) *Information Exchange Technologies (IET)*. This dimension helps facilitate the storage and exchange of information among process, product, and logistics technologies identified above. Technologies that include common databases, data transfer protocols, and intra- and inter-factory networks are essential to this dimension.

The technologies that make up the multiple dimensions of AMT can be *easily integrated electronically with each other and with the rest of the organization*. This integrative capability makes AMT different from conventional manufacturing technologies and, therefore, a reinvestigation of known relationships between AMT use and firm size, and AMT use and performance is significant.

To facilitate the empirical investigation of these relationships in this study we develop two hypotheses in the next sections. Hypothesis 1 addresses AMT use and firm size, and Hypothesis 2 addresses AMT use and performance.

2.2. Technology use and size

It has been noted by researchers that size is a contextual or enabler variable in the use of AMT (Ettlie, 1984) and that it is common for small manufacturers to lag behind larger manufacturers in implementing new technologies (Howard, 1990). Other researchers have reported this phenomenon for more than two decades (see Kimberly, 1976; Yasai-Ardekani, 1989). With the arrival of AMTs in recent years scholars show renewed interest in the subject. Recently, Mansfield (1993) found that very large firms tend to use FMS, an expensive form of AMT. He explained that (p. 154):

> There are many reasons why large firms began using flexible manufacturing systems more rapidly

than small ones. They have more resources and are better able to take the risks than their smaller rivals. A flexible manufacturing system often costs several million dollars, and specialized engineering personnel are required to introduce and operate such a system...

Meredith (1987) (p. 255) notes that the reasons for adopting AMT in larger firms are different from the reasons for adopting them in small firms. While the theme of his paper was that small firms have several potential reasons for investing in AMT, he cites the following popularly accepted reasons why larger firms use AMT:
1. large firms are able to afford the often extreme expense of these computerized manufacturing technologies, and the cost of the failure should the investment fail;
2. large firms are likely to have the skills and human resources it takes to understand, implement, and manage such technologies; and
3. large firms have the product-line depth and breadth to benefit from using these technologies.

The previous discussions show that AMT use may increase with firm size just as conventional technology use was known to increase with firm size. In this study, our focus is to confirm this relationship using a large sample of US discrete products manufacturers. Additionally, given our multidimensional view of AMT, we wish to investigate if the use of all dimensions of AMT increase with firm size.

2.2.1. Measurement of firm size

In previous empirical studies, firm size has been frequently measured in terms of employment (Munro and Noori, 1988; Collins et al., 1989). Evidence in the literature shows that conventional technology use increases with firm size, measured as the logarithm of employment (Kimberly, 1976; Yasai-Ardekani, 1989). In other words, the relationship between conventional technology use and size is non-linear. In order to reevaluate the relationship in the context of AMT, this study maintains employment as the measure of size and tests the following hypothesis.

Hypothesis 1: The use of all dimensions of AMT will grow linearly as size grows logarithmically.

2.3. AMT use and performance

The adoption and use of AMTs in modern manufacturing is viewed as critical to improved performance and a pathway for exploiting market opportunities (e.g., Jaikumar, 1986; Meredith, 1987; Dean and Snell, 1991; Gerwin and Kolodny, 1992; Parthasarthy and Sethi, 1992). Moreover, the role played by AMTs in achieving sustainable competitiveness through flexibility, delivery, cost, and quality has been widely discussed (Hayes and Wheelwright, 1984; Schroeder et al., 1986; Swamidass, 1988; Leong et al., 1990). Further, the literature on AMT 'investment justification' is based on the premise that AMT use leads to superior performance via improved competitive ability (Swamidass and Waller, 1991; Parsaei and Mital, 1992).

A recent study based on 1042 US manufacturing plants reports that smaller plants (less than 100 employees) use 5.4 AMTs while larger plants use 9 different AMTs. Further, larger plants report a ROI of 14.7%, while small plants report a ROI of 11.5% (Swamidass, 1997). Given this evidence, we argue that the superior performance of larger plants is partly due to the increased use of AMTs by such plants. We also argue that, while size has an independent effect on performance, it also moderates or enhances the effect of technology on performance because: (1) larger plants have the resources to hire and train expensive skilled labor and professionals for the purpose of exploiting these technologies; and (2) larger firms have a wider product range to more completely exploit today's AMTs. Thus,

Hypothesis 2: Size moderates the relationship between AMT use and performance.

3. Method

3.1. Sample

The data for the study were collected through a mail survey of manufacturing firms listed in the 1990 *Compustat* Compact Disclosure Database. [2]

[2] *Compustat*, database. Standard and Poor's Corporation, Englewood, CO.

Firms selected for this study conformed to Standard Industrial Classification (SIC) codes 34 to 39: fabricated metal products; industrial nonelectrical machinery; electronic and other electric equipment; transportation equipment; instrumentation and related products; and miscellaneous manufacturing.

We selected firms from these industries for the following reasons. First, firms in these discrete products/parts manufacturing industries (SIC 34–39) are users of AMTs of interest to this study (cf. US Department of Commerce, 1988; Dean and Snell, 1991; US Department of Commerce, 1991; Dean et al., 1992; Swamidass, 1994; Ward et al., 1994). Second, these industries comprise the back bone of the manufacturing sector of our economy. For example, the total sales of the firms listed under SIC codes 34–39 account for over 40% of the sales of the US manufacturing sector (US Department of Commerce, 1988). Third, these *discrete products* manufacturing industries are reasonably homogenous in their manufacturing; they are however, substantially different from *process* (e.g., oil refineries and chemicals) industries. Finally, based on our goal to obtain a large sample, and our goal to keep the industries relatively homogenous (from a production perspective), this group of six industries was a reasonable compromise that accomplished both our goals.

The unit of analysis was the strategic business unit (SBU) and the questionnaires were mailed to SBU managers. Out of the 1652 firms listed under the SIC classification 34–39, questionnaires were sent to 851 firms with complete information in the database but excluded holding companies and those located outside the US; 31 firms declined to participate citing company policy, and 22 questionnaires were undeliverable. The first set of survey questionnaires, along with a letter indicating the purpose of the survey, was mailed out during the first week of October 1990. This step was followed up with a second mailing approximately six weeks later. This left questionnaires in the hands of 798 potential respondents.

In our cover letter, we asked that the survey be completed by a top level executive in charge of manufacturing and/or technology in the firm, or the top executive in the business unit in the case of businesses with multiple units. In our sample, forty

Table 2
Industries and respondents[c]

SIC code	Industry description	No. of responses	% of responses	Questionnaires mailed to	% of total mailed
34	Fabricated Metal Products	11	7.4	63	7.4
35	Industrial Machinery and Equipment	36	28.3	259	30.4
36	Electronic and Other Electric Equipment	33	25.9	239	28.1
37	Transportation Equipment	9	7.0	57	6.7
38	Instruments and Related Products	32	25.2	188	22.1
39	Miscellaneous Manufacturing Industries	6	4.7	45	5.3
Other[a]		33	–	–	–
Total		160	100%[b]	851	100%
Respondents					
1	Chairman/CEO/COO	26	16.3		
2	Presidents	36	22.5		
3	Senior VP/Executive VP/VPs	49	30.6		
4	Directors/General Managers	16	10.0		
5	Others	33	20.6		
Total		160	100%		

[a]Respondents who failed to disclose the identity of their firms.
[b]Excluding 'other'.
[c]Table 1 indicates the number of firms participating in the study and their distribution across the various SIC groupings. The industrial affiliation of the firms is based on the information provided by the respondents and from information in the data base. If the SIC classification for a firm could be determined, because some respondents failed to identify themselves or their products, the firm was classified as 'other.'

percent (40%) of the respondents were CEOs or presidents, and a total of approximately seventy (70%) of the respondents held titles such as Vice-Presidents or higher (see Table 2).

Approximately 10% of the 851 firms, randomly selected, were sent two questionnaires, each to be filled out by a different senior manager in the firm. Out of the 86 firms that received two questionnaires, only 17 returned both questionnaires. The two responses, from each of these 17 firms, were used to conduct interrater agreement as explained below. In sum, 177 completed responses were received ($177/798 = 22.2\%$) including the seventeen firms that returned two responses. This response rate is comparable to mail surveys involving top management (Hitt et al., 1982; Dean and Snell, 1991). In cases of multiple responses from the same firm, only the response from the more senior official was included in the analysis. Overall, 160 responses were used in subsequent analyses.

3.2. Interrater agreement

Since interrater agreement analysis provides a measure of reliability for the questionnaire responses of our study, we carried out such an analysis using the multiple responses from the 17 firms using the procedure followed by Shortel and Zajac (1990). Given that there were 17 responses on 19 items, there were 323 (i.e., 17×19) possible matches for comparisons. Six responses were missing which left 317 responses for comparison. Our findings indicated that 136 responses were identical, and 98 other responses were within one interval on the 5-point scale. Thus, 74% (i.e., $234/317$) of the responses from two different individuals in the same firm were within one interval or less. The two responses from the 17 firms on the 6 performance measures were also checked for interrater reliability. Out of the possible 102 (i.e., 17×6) matches, 93 (91%) were identical or within one interval on the 5-point scale. Since there are no preset acceptable levels for this kind of analysis, we treated this to be satisfactory (cf. Shortel and Zajac, 1990).

4. Non-response and industry bias

A Chi-square test indicated that there was no statistically significant difference between the distribution of industries in the 851 firms receiving the questionnaires and the distribution of industries among the respondents in Table 2; this test confirms that non-respondent firms introduce no particular industry bias into the study. In Table 3, we report additional comparisons between responding firms and non-responding firms; the data for non-responding firms come from the *Compustat* Compact Disclosure database. The *t*-statistics in the table are not significant, which is interpreted to mean that non-response bias is not a factor.

4.1. Measurement and variables

4.1.1. Technology use

The questionnaire to assess ‘technology use’ was developed and refined as follows: (1) nearly all items in the questionnaire were adapted from published work (e.g., US Department of Commerce, 1988) to ensure construct validity; (2) preliminary drafts of the questionnaire were discussed with academic scholars to assess the content and construct validity prior to pilot testing; and (3) a pilot test was conducted with a group of 5 firms whose inputs were used to improve the clarity, comprehensiveness and relevance of the research instrument and to check for content and construct validity. The section of the questionnaire on ‘technology use’ included 19 items

Table 3
A test for non-response bias

Characteristics	Respondents	Non-respondents	*t*-Value	Significance
No. of employees	2808 (17533)[a]	2008 (7307)	0.432	ns
5-Year income growth	25% (59%)	13% (43%)	1.349	ns
5-Year sales growth	35% (61%)	33% (85%)	0.427	ns

[a]Standard deviations reported in parentheses.

(Table 4) and together they cover almost the entire domain of AMTs employed in discrete manufacturing; this ensures construct validity.

We asked each respondent to indicate how frequently a particular technology was used in his or her firm. The usage attributed to AMTs was measured using five point Likert-type scales (1 = not used, 3 = used often, and 5 = used extensively). The questionnaire defined, 'used often' as 'these technologies are used at least once a week,' and 'used extensively' as 'these technologies are used on a daily basis.'

4.1.2. Size and performance

Business-unit size was measured using employment figures provided by respondents. The questionnaire section on 'performance' measurement contained six items: after-tax return on total assets; after-tax return on total sales; net profit; market share gains relative to competition; sales growth relative to competition; and overall performance rating. Respondents were asked to rate their business units on these six items using Likert-type scales (1 = top 20% to 5 = lowest 20%). Combinations of these items have been used successfully by previous researchers (Swamidass and Newell, 1987; Venkatraman, 1989).

4.1.2.1. Validity. To check the validity of perceptual performance measures, we conducted a correlation analysis between selected objective external measures included in the *Compustat II* database with self-reported perceptual data on performance for 20% of the firms randomly selected ($n = 32$) from our sample of 160 firms. Specifically, correlation analysis was conducted between standardized values of return on assets and return on sales for the industry

Table 4
Results of factor analysis—advanced manufacturing technologies

	Technology items	Mean	SD	IEPT	PDT	HVAT	LVFAT
				I	II	III	IV
T16	Local Area Network for Factory Use	2.23	1.63	**0.76**	0.18	0.31	−0.08
T13	Computers used for control on Factory Floor	2.93	1.66	**0.66**	0.21	0.10	0.30
T15	Local Area Network for Technical Data	2.55	1.66	**0.63**	0.37	0.23	−0.20
T12	Computers for Production Scheduling	3.87	1.44	**0.59**	0.43	−0.09	0.28
T19	Electronic Data Interchange	2.21	1.57	**0.57**	−0.03	0.31	0.40
T14	MRP I and MRP II Systems	3.37	1.72	**0.49**	0.46	0.10	0.27
T17	Intercompany Networks	1.95	1.51	**0.47**	0.04	0.42	0.34
T3	Automated Drafting Technologies	3.08	1.66	0.15	**0.84**	0.07	0.00
T1	Computer Aided Design (CAD)	3.60	1.65	0.26	**0.81**	0.04	0.22
T2	Computer Aided Engineering (CAE)	2.91	1.64	0.07	**0.77**	0.28	0.14
T11	Computer Aided Quality Control Performed on final products	2.62	1.74	0.04	0.32	**0.73**	−0.04
T10	Computer Aided Inspection Performed on incoming or in process material	1.97	1.48	0.04	0.19	**0.70**	0.29
T6	Robots Others Than Pick and Place	1.24	1.13	0.36	−0.06	**0.61**	0.24
T5	Pick and Place Robots	1.64	1.46	0.21	0.02	**0.57**	0.16
T18	Manufacturing Automation Protocol	1.37	1.08	0.50	0.08	**0.57**	0.23
T8	NC/CNC	2.17	1.81	0.13	0.18	0.11	**0.83**
T9	Programmable Controllers	2.42	1.70	0.02	0.05	0.23	**0.67**
T4	CAD/CAM	1.94	1.51	0.32	0.39	0.22	**0.53**
T7	FMC/FMS	1.93	1.59	0.44	0.11	0.34	**0.44**
	Eigenvalue			7.30	1.90	1.30	1.20
	Percentage of variance explained			38.60	10.20	7.10	6.30

SD: Standard deviation; IEPT: Information exchange and planning technology; PDT: Production design technology; HVAT: High-volume automation technology; LVFAT: Low-volume flexible automation technology.

from the *Compustat* and self-reported values for the sample of 32 firms; the result showed a correlation of 0.72 and 0.82, respectively; we consider this acceptable.

5. Results and discussion

5.1. Four technology factors

The first step in our analysis was a factor analysis of the responses to the 19 technology use items to establish meaningful patterns (i.e., factors) in the data; a principal factor analysis solution with varimax rotation was obtained. Four significant factors (i.e., eigenvalue > 1) emerged from this analysis. Technology items that exhibited factor loadings greater or equal to ± 0.4 on at least one factor were then used to label the factors (cf. Kim and Mueller, 1986). The use of four factors in our subsequent analyses is consistent with the guidelines provided by Carmine and Zeller (1979) (p. 60).

Results of the factor analysis are presented in Table 4. Some items (e.g., computers used for production scheduling, electronic data interchange, MRP I and MRP II, manufacturing automation protocol, and FMC/FMS) show moderate loading on more than one factor. Since several items show strong loadings on each factor in Table 4, the independence and distinctiveness of the four factors are not compromised by a few items showing moderate loadings in more than one factor. Further, we used factor scores as measures for technology factors (i.e., technology dimensions), where each factor measure is the sum of the weighted raw scores for all the 19 items in the technology instrument (Table 4), the weights employed being the factor loading of each item on the appropriate factor. This means that the factor measures are not based *entirely* on items with factor loadings greater than ± 0.4.

In Table 4, the seven items that load on Factor 1 include: local area network for factory use (T16); computers used for control on factory floor (T13); local area network for technical data (T15); computers for production scheduling (T12); electronic data interchange (T19); MRP I and MRP II systems (T14); and intercompany networks (T17). Factor 1 consists of technologies that are related to information exchange (e.g., intercompany and intra-company networks; electronic data interchange) and those that assist in production planning and control (e.g., MRP I and MRP II systems). Therefore, we call this the Information Exchange and Planning Technology (IEPT) factor. Factor 1 represents the technologies essential to the integration of other technologies and functions in the organization. This factor being an integrating factor, it enhances or multiplies the benefits of individual AMTs used by functional areas such as manufacturing, design, planning and control, et cetera, through the process of integration. *This empirically determined dimension IEPT combines LPT and IET dimensions of the conceptual model proposed earlier*.

Factor 2 includes the three technology items, CAD (T1), CAE (T2) and automated drafting technologies (T3). This factor is made up of technologies that are common to the design and engineering function within a manufacturing firm. Therefore, it is labeled the Product Design Technology (PDT) factor because *it conforms to the PDT dimension proposed earlier*. The five technology items–computer-aided quality control performed on final products (T11), computer-aided inspection performed on incoming or in-process materials (T10), robots other than pick and place (T6), pick and place robots (T5), and manufacturing automation protocol (T18)–load on Factor 3. These five technologies have a common feature. Their use reduces direct labor cost in repetitive, labor-intensive operations in large volume production. Although inspection and quality control are labor-intensive, automation of this process cannot be cost-justified unless large volume production is involved. Robots included in the factor are commonly used in assembly lines where high volume production occurs. Thus, we labeled this factor High-Volume Automation Technology (HVAT).

Technologies that load high on Factor 4 include NC/CNC machines (T8), Programmable Controllers (T9), CAD/CAM (T4), and FMC/FMS (T7). This group of technologies represents extremely flexible manufacturing automation that enables a firm to make quick process and product changes essential for low volume (and high variety) manufacturing. Consequently, this factor is labeled Low-Volume Flexible Automation Technology (LVFAT). *HVAT and LVFAT are both part of Process Technology (PT) in the conceptual model proposed earlier*.

5.2. Empirical and conceptual dimensions of AMT

In Section 2, based on a review of literature, we proposed a four-dimensional model of AMT. This model is partially validated by the field data used in our analyses. Upon comparing the empirically obtained model and the proposed model, three items are notable: (1) both models acknowledge a Product Design Technology (PDT) dimension, (2) the Logistics/Planning Technologies (LPT) and Information Exchange Technologies (IET) in our proposed model are combined into one IEPT dimension in the empirical model, which validates Adler's (1988) Administrative dimension that has been studied by other researchers (Boyer et al., 1996), and (3) the Process Technologies (PT) dimension in our proposed model splits into the two dimensions HVAT and LVFAT in the empirical model; that is, empirical evidence tells that *all shop floor technologies should not be lumped into one AMT dimension*.

While process related shop floor technologies are treated as a single dimension in most conceptual schemes, we see that the empirical data in this study distinguishes between low volume, flexible shop floor technologies and high volume shop floor technologies. This is an important finding because the conceptual literature appears to write off the role of high-volume, automation technologies in AMT either due to inadequate understanding or due to the prevailing enthusiasm for low-volume, flexible automation technologies. This study reminds us that high volume production and associated AMTs such as robots and automated inspection form an important dimension of AMT. Thus, based on this study, we are able to refine the various conceptual schemes of AMT in Table 1. The empirically established four-dimensional model of AMT becomes a validated alternative to conceptual schemes proposed in the literature. In the following sections, additional analyses are reported which increase our understanding of the four empirically determined dimensions of AMT.

5.3. Size and AMT use

5.3.1. Industry effects

Before we investigated the relationship between size and AMT use, we tested for industry effects. We utilized MANOVA method using the four technology factors and the six industries represented here (SIC 34–39) to test for industry effects; this analysis showed industry effect was not significant based on *Hotellings* (0.251, $P < 0.159$) and *Wilks* (0.764, $P < 0.165$) statistics. Therefore, industry type was not controlled for in subsequent analyses. One reason we did not find industry type effect in our sample may be due to the preselection of industries to ensure some degree of homogeneity in the sample.

Zero order correlations among the variables are in Table 5. According to this table, correlations between firm size and AMT factors, except for PDT, are positive and significantly ($P < 0.05$) associated with size. In other words, except for PDT, *AMT use is lower in firms of smaller size than in firms of larger size*. This finding partially confirms Hypothesis 1.

5.3.2. Rate of change in AMT use

To express in another form how the use of AMT increases with size, we estimated the slopes of the lines expressing the relationship between size and the four AMT factors using simple regressions. These models were estimated with AMT factors as the dependent variables and firm size (log of employ-

Table 5
Pearson's zero order correlations

		1	2	3	4	5
1	Information Exchange and Planning Technology	1.00				
2	Product Design Technology	0.019	1.00			
3	High Volume Automation Technology	−0.008	0.018	1.00		
4	Low Volume Process Automation Technology	0.004	−0.023	−0.017	1.00	
5	Size (Log of employment)	0.349***	0.173	0.306***	0.475***	1.00

* $P < 0.10$; ** $P < 0.05$; *** $P < 0.01$.

ment) as the independent variable. The linear regression models and the results of the regression estimate of slopes are: Technology $\text{Factor}_i = a_i + \beta_i(\log$ of employment)... $i = 1, 2, 3$ and 4.

Regression results (sample size was 127 in all equations; cases with missing values were dropped):

Size vs. IEPT (Factor 1), slope	0.35 ($P < 0.001$)
Size vs. PDT (Factor 2), slope	0.17 (not significant)
Size vs. HVAT (Factor 3), slope	0.31 ($P < 0.001$)
Size vs. LVFAT (Factor 4), slope	0.48 ($P < 0.001$)

The following conclusions are based on the above models:

1. The use of IEPT, HVAT, and LVAT increases with size (slopes of 0.35, 0.31, and 0.48).
2. The use of LVFAT (slope = 0.48) grows more rapidly than IEPT (slope = 0.35) or HVAT (slope = 0.31).

Hypothesis 1 states that the use of all dimensions of AMT will grow linearly as firm size increases logarithmically. The above findings support the hypothesis for three out of the four dimensions of AMT. Further, these findings also lend support to the argument that AMT is multidimensional because at least three orthogonal dimensions of AMT show significant and unique relationships with firm size.

5.3.3. PDT and size

The PDT dimension does not grow with size as hypothesized. This finding may be explained by the widespread use of CAD technology (one of the items constituting the PDT factor) in plants of all sizes (US Department of Commerce, 1991; Swamidass, 1996). For example, Swamidass (1994), based on a sample of 1042 plants, found that CAD is used by 84.2% of all plants in the US and by 95% of the larger plants (employment > 99). Thus, our finding concerning PDT is validated by other independent studies.

5.3.4. LVFAT and size

Our study shows that LVFAT use grows faster than other dimensions with increase in firm size. This may be due to the generally capital intensive nature of items such as FMS that make up this factor. Mansfield (1993) reported that FMS is *not found in small firms but is found only in very large firms* with over 10,000 employees. This may explain the stronger relationship between this factor and size than any other technology factor. Thus, our findings regarding LVFAT validate Mansfield's finding and *vice versa*. External sources validating PDT and LVFAT related findings, in sum, *validate our multidimensional conceptualization of AMT as well*.

5.4. Performance and AMT use

To study the effect of AMT use on performance, we undertook moderated regression analyses with size as our moderator variable. First, we analyzed the responses to the six performance items in our questionnaire by a principal factor solution using varimax rotation. The first factor termed *profitability* in Table 6 explains nearly 68% of the variance in performance while growth factor explains only 20% of the variance. In all subsequent analyses, we used the

Table 6
Factor analysis—performance measures

No.	Items and descriptions	Factor no. 1, profitability	Factor no. 2, Growth
P2	After tax returns on total sales	**0.9488**	0.1669
P1	After tax returns on total costs	**0.9398**	0.1435
P3	Net profit positions relative to competition's	**0.8804**	0.2992
P6	Overall firm performance/success	**0.7281**	0.5271
P5	Sales growth positions relative to competition's	0.1978	**0.9282**
P4	Market share gains relative to competition's	0.2184	**0.9127**
	Eigenvalue	4.06	1.22
	Percent of variance explained (Total = 88.1%)	67.8%	20.3%

factor score for the profitability factor as the measure of performance. All regression models using the growth factor as the dependent variable were non-significant. This may be because the growth factor explains only a small proportion of the variance; only additional studies could confirm this. The regression models developed with the profitability factor as the dependent variable are reported in Table 7.

Model 1 is our base model, where profitability is the dependent variable and all four AMT factors are independent variables. The resultant R^2 is 0.05 with a significance of $P < 0.06$ (see Table 7). The R^2 being very small, we conclude that the relationship is negligible. In Model 2, we repeat the analysis by including size as an additional independent variable. This substitution improves the regression R^2 to 0.16. Using the test procedure recommended by Mendenhall et al. (1993) (p. 595), we find Models 1 and 2 differ significantly from each other (i.e., $F = 15.96$; $P < 0.01$). Thus, Model 2 reveals that size is strongly associated with profitability ($\beta = 0.286$, $P < 0.05$). This result is also consistent with the findings of other researchers (e.g., Buzzell and Gale, 1987; Cool and Schendel, 1987).

In Model 3, we investigate the interaction effects between size and the four AMT factors in the regression model. Consequently, the products of size and the AMT factors (i.e., four independent variables) are added to the model as additional independent variables. The inclusion of interaction effects increases the R^2 value for the model from 0.16 to 0.20, but further tests indicate that Model 3 is only marginally different from Model 2 (i.e., $F = 2.05$, $P < 0.10$). Therefore, we conclude that our *results marginally support Hypothesis 2*, which states that size moderates the relationship between AMT use and performance. Although, this finding is not very conclusive, this new finding has not been reported in the literature before. This effect is worthy of further investigation in search of a more conclusive finding.

It is notable in Model 3 that the interaction of size with IEPT has a negative effect on performance. This may be explained by the fact that Information Exchange and Planning Technologies (IEPT) such as

Table 7
Regression analysis: size as a moderator variable

	Dependent variable: profitability		
	Model 1	Model 2	Model 3
Independent variables			
Constant	0.013 (0.101)	−1.66* (0.427)	−1.72** (0.489)
Technology factors			
Information exchange and planning technology (IEPT)	0.119 (0.103)	−0.065 (0.109)	0.559 (0.398)
Product design technology (PDT)	0.119 (0.098)	0.021 (0.095)	0.387 (0.318)
High volume automation technology	0.204** (1.06)	0.065 (1.05)	−1.02 (0.352)
Low volume flexible automation (LVFAT)	0.17* (0.093)	−0.058 (0.104)	−0.703* (0.371)
Size		0.286** (0.071)	0.294** (.0489)
Interaction terms (technology and size)			
Size × IEPT			−0.103* (0.062)
Size × PDT			−0.061 (0.053)
Size × HVAT			0.028 (0.059)
Size × LVFAT			0.099* (0.055)
Adjusted R^2	0.05*	0.16**	0.20**
Incremental R^2		0.11***	0.04*
F-value	2.39	5.41	4.04
Significance	< 0.05	0.001	0.001
Sample size (n)	110	110	110

* $P < 0.10$; ** $P < 0.05$; *** $P < 0.01$. Standard errors are in parentheses.
Models 1 and 2 are statically different; $F = 15.96$, $P < 0.01$; Models 2 and 3 are statically different; $F = 2.05$, $P < 0.10$.
Cases with missing values were dropped.

MRP, MRP II, and computers in production scheduling, which constitute IEPT have been in use in larger firms from the late sixties. Since then, larger firms have gone through several generations of IEPT technologies, each with its own advancements. Smaller firms, however, may be first time investors in IEPT as recently as the nineties. Hence they may see much bigger gains in performance due to investments in IEPT than larger firms, who may realize only marginal performance gains.

To summarize, the major results of this study are as follows:
1. The shop floor AMT factor has two distinct dimensions: one advancing high volume production and the other advancing low volume flexible production,
2. AMT use is associated with firm size,
3. Firm size is associated with performance,
4. AMT use is not directly associated with performance, and
5. Size weakly moderates the relationship between AMT use and performance.

5.4.1. Limitations

First, in our analyses involving regression models, the independent variables (i.e., technology factors) and dependent variables (i.e., performance measures) were based on responses provided by the same respondent. This situation can lead to response/response bias. Although, we are aware of this risk we have tried to reduce its effects, if any, by reverse scaling the questions for measuring performance; larger values in the technology scale meant greater use, while larger values in the performance scale meant inferior performance. Further, our validation of perceptual performance data reported by respondents with objective data from *Compustat II* database gives us some assurance that the dependent variable is not significantly biased. While this test does not directly address the question of response/response bias, it compares the dependent variable against external criteria to lend credibility to the dependent variable measure.

Second, given that our ratio of items (i.e., 19 for technology) to the number of observations (i.e., 160) is less than 10 (i.e., 8.4) recommended by Nunnally (1978), it is possible that the stability of the factor loadings may be weakened.

6. Conclusion and implications

The purpose of this study was to examine the relationships among AMT use, firm size and performance in the discrete products manufacturing industries using a multidimensional operationalization of AMT; this purpose has been accomplished. There are several important findings. First, the results of our empirical analyses confirm and refine a multidimensional view of AMT. Second, *we found that the positive relationship between size and advanced manufacturing technology is a function of the AMTs considered*. For example, PDT use was not affected by firm size, but LVFAT (e.g., FMS, CNC technologies) use increased more sharply with firm size compared to the use of other dimensions of AMT (based on the four slopes reported earlier).

Third, we found that firm size is significantly associated with performance as reported in many previous studies (e.g., Buzzell and Gale, 1987; Cool and Schendel, 1987), but we failed to find a direct relationship between AMT use and performance. Our results indicate that once the effect of size on performance is controlled, the impact of AMT use on performance is small. This may be because of what many authors have observed: investments in AMT will pay off only when complementary variables such as infrastructure and strategy fit the investments in technology (Kimberly, 1986; Ward et al., 1994).

Fourth, firm size weakly moderates (enhances) the relationship between AMT use and performance. This finding means that size enhances the effective use of AMT perhaps due to larger firms' command of resources which gives them access to skilled operators and professionals who could get more out of these technologies. Further, the broader product line in large firms may contribute to better use of AMTs. This moderating effect of size deserves more conclusive investigations in the future.

Based on these findings, we address here two implications of the study as they pertain to: (1) the multidimensionality of AMT and business strategy; and (2) AMT use and performance relationship.

(1) *Implications for business strategy*. The multidimensionality of AMT has many implications for business strategy. Lei and Goldhar (1990) have discussed at length the value of different types of AMTs in accomplishing different business strategies.

This empirical work adds support to their discussions. As an illustration, the two generic strategies—low variety and high volume production, and high variety and low volume production (cf., Porter, 1980; Kotha and Orne, 1989)—can be implemented successfully using selected dimensions of AMT. In this illustration the former strategy will be best served by HVAT and the latter will be best served by PDT and LVFAT, while both strategies can benefit by employing IEPT. This illustration is intended to show that the multiple dimensions of AMT bring clarity to the discussion of the 'fit' between business strategy and the choice of AMTs because it is easier for researchers and practitioners to see how the distinctive characteristics of the four dimensions of AMT have features that complement generic strategic options open to firms. In other words, manufacturing firms can pursue generic strategic options that can then be backed up by well-matched AMT dimensions.

(2) *AMT use and performance*. We did not detect a direct relationship between AMT use and financial performance. How could this be explained? We offer two explanations for not detecting a direct connection between AMT use and *financial* performance even though investments in AMTs are routinely justified on the basis of estimated economic benefits.

First, strategic rather than financial benefits may be the primary reason for investing in AMTs. For example, Davis (1986) notes that economic justifications of AMT are questionable because although 'these technologies seldom save money; they provide new opportunities for making money.' Through lead-time reduction and improved quality, which are strategic, non-financial benefits of new technology, AMTs create new opportunities for businesses (cf. Meredith, 1987; Fiegenbaum and Karnani, 1991; Swamidass, 1994). Additionally, Majchrzak et al. (1986) (p. 121) note that firms incorporate computerized manufacturing technology, 'probably less out of a need to cut costs than out of a desire to take advantage of the opportunities' that these technologies will bring. The importance of strategic, non-financial benefits of AMTs are underscored by the finding that lead-time reduction was the most frequently cited benefit directly attributed to investments in 15 different technologies in a survey of 1042 manufacturers (Swamidass, 1994).

Second, Kimberly (1986) states that the effective use (i.e., with measurable benefits) of advanced manufacturing technology can be predicted by the following three factors in descending order of importance: (1) the firm's competitive strategy; (2) firm-vendor relations; and (3) the firm's ability to integrate AMT, structure and strategy. Since the link between AMT use and performance is a function of several other complementary factors, firms investing in AMT must pay considerable attention to the three items above for the effective use of AMTs.

Acknowledgements

We thank Arun Kumaraswamy, and two anonymous reviewers of JOM for their useful suggestions.

References

Adler, P.S., 1988. Managing flexible automation. California Manage. Rev. 20 (1), 35–56.
Boyer, K.K., Ward, P.T., Leong, G.K., 1996. Approaches to the factory of the future. An empirical taxonomy. J. Operations Manage. 14 (4), 297–314.
Blau, P.M., Falbe, C., McKinley, W., Tracy, K., 1976. Technology and organization in manufacturing. Administrative Sci. Q. 21, 20–40.
Buzzell, R.D., Gale, B.T., 1987. The PIMS Principle. Free Press, New York.
Carmine, E.G., Zeller, R.A., 1979. Reliability and validity assessment. Sage University series.
Child, J., Mansfield, R., 1972. Technology, size and organization structure. Sociology 6, 369–393.
Collins, P.D., Hull, F., Hage, J., 1989. Programmable automation technology, strategy, and organization: A profile of adopters. Krannert School, Purdue University, Lafayette, IN.
Cool, K., Schendel, D., 1987. Strategic group formation and performance: the case of US pharmaceutical industry, 1963–1982. Manage. Sci. 33 (9), 1102–1124.
Davis, D.D., 1986. Integrating technological, manufacturing, marketing, and human resource strategies. In: Davis, D.D., et al. (Eds.), Technological Innovation, Jossey-Bass, San Francisco.
Dean, J.W. Jr., Snell, S.A., 1991. Integrated manufacturing and job design. Acad. Manage. J. 34 (4), 776–804.
Dean, J.W. Jr., Yoon, S.J., Susman, G.I., 1992. Advanced manufacturing technology and organizational structure: empowerment or subordination?. Organizational Sci. 3 (2), 203–229.
Ettlie, J.E., 1984. Implementation strategy for discrete parts manufacturing innovations. In: Warner, M. (Ed.), In Microelectronics, Manpower, and Society, Gower Press, Brookfield, VT.

Fiegenbaum, A., Karnani, A., 1991. Output flexibility-a competitive advantage for small firms. Strategic Manage. J. 12, 101–114.
Gerwin, D., 1981. Relationships between structure and technology. In: Nystrom, P.C., Starbuck, W. (Eds.), Handbook of Organizational Design, Vol. 2, pp. 3–38.
Gerwin, D., 1993. Manufacturing flexibility: a strategic perspective. Manage. Sci. 39 (4), 395–410.
Gerwin, D., Kolodny, H., 1992. Management of advanced manufacturing technology: Strategy Organization and Innovation, John Wiley and Sons, New York.
Goldhar, J.D., Jelinek, M., 1985. Computer Integrated Flexible Manufacturing: Organizational, Economic, and Strategic Implications, Interfaces, May–June, pp. 94–105.
Hayes, R.H., Wheelwright, S.C., 1984. Restoring our competitive edge: Competing through manufacturing, Wiley, New York, NY.
Hitt, M.S., Ireland, R.D., Palia, K.A., 1982. Industrial firms' grand strategy and functional importance: moderating effects of technology and uncertainty. Acad. Manage. J. 25 (2), 265–298.
Howard, R., 1990. Can small business help countries to compete? Harvard Business Rev., November–December, pp. 88–103.
Inkson, J.H.K., Pugh, D.S., Hickson, D.J., 1970. Organization context and structure: an abbreviated replication. Administrative Sci. Q. 15, 318–329.
Jaikumar, R., 1986. Postindustrial manufacturing. Harvard Business Rev., November–December, pp. 69–76.
Kaplinsky, R., 1983. Automation: the technology and society, Longmans, London.
Kim, J., Mueller, C.W., 1986. Factor analysis: statistical methods and practical issues. Sage University paper series on quantitative applications in Social Sciences.
Kimberly, J.R., 1976. Organizational size and the structuralist perspective: a review, critique, and proposal. Administrative Sci. Q. 21, 571–597.
Kimberly, J.R., 1986. The organizational context of technological innovation. In: Davis, D.D., et al. (Eds.), Technological Innovation, Jossey-Bass, San Francisco.
Kotha, S., 1991. Strategy, manufacturing structure, and advanced manufacturing technologies. Best Paper Proceedings, National Conference of the Academy of Management, pp. 293–297.
Kotha, S., Orne, D., 1989. Generic manufacturing strategies: a conceptual synthesis. Strategic Manage. J. 10 (3), 211–231.
Lei, D., Goldhar, J.D., 1990. Multiple niche competition: the strategic use of CIM technology. Manufacturing Rev. 3 (3), 195–206.
Leong, G.K., Snyder, D., Ward, P., 1990. Research in process and content of manufacturing strategy. OMEGA 18 (2), 109–122.
Majchrzak, A., Nieva, V.F., P.D., Newman, 1986. Adoption and use of computerized manufacturing technology: A national survey. In: Davis, D.D., et al. (Eds.), In Technological Innovation, Jossey-Bass, San Francisco.
Mansfield, E., 1993. The diffusion of flexible manufacturing systems in Japan, Europe and the United States. Manage. Sci. 39 (2), 149–159.
Marsh, R.M., Mannari, H., 1981. Technology and size as determinants of the organizational structure of Japanese factories. Administrative Sci. Q. 22, 33–57.
Mendenhall, S., Reinmuth, J.E., Beaver, R.J., 1993. Statistics for Management and Economics, Duxbury Press, Belmont, CA.
Meredith, J.R., 1987. The strategic advantages of new manufacturing technologies for small firms. Strategic Manage. J. 8 (3), 249–258.
Munro, H., Noori, H., 1988. Measuring commitment to new manufacturing technology: integrating technology push and marketing pull. IEEE Trans. Eng. Manage. 3 (1), 63–70.
Nunnally, J.C., 1978. Psychometric theory, McGraw-Hill, New York, NY.
Parsaei, H.R., Mital, A., 1992. Economics of advanced manufacturing systems, Chapman & Hall, London.
Parthasarthy, R., Sethi, S.P., 1992. The impact of flexible automation on business strategy and organizational structure. Acad. Manage. Rev. 17 (1), 86–111.
Porter, M.E., 1980. Competitive Strategy: Techniques for Analyzing Industries and Competitors. The Free Press, New York.
Rosenthal, S.R., 1984. Progress toward the 'factory of the future'. J. Operations Manage. 4 (3), 203–229.
Schroeder, R.G., Anderson, J.C., Cleveland, G., 1986. The content of manufacturing strategy: an empirical study. J. Operations Manage. 6, 405–415.
Shortel, S.M., Zajac, E.J., 1990. Perceptual and archival measures of Miles and Snow's strategic types: comprehensive assessment of reliability and validity. Acad. Manage. J. 33 (4), 817–832.
Swamidass, P.M., 1988. Manufacturing Flexibility. Monograph #2, Operations Management Association, Plano, TX.
Swamidass, P.M., 1994. Technology on the Factory Floor II. Monograph, National Association of Manufacturers, Washington, DC.
Swamidass, P.M., 1996. Benchmarking manufacturing technology use in the United States. In: Gaynor, G.H. (Ed.), In the Handbook of Technology management, McGraw-Hill, New York.
Swamidass, P.M., 1997. Practices and performance of small and larger US manufacturers: Issues and implications. In Manufacturing Modernization: Learning from evaluation practices and results, Georgia Tech Economic Development Institute, Atlanta, GA.
Swamidass, P.M., Newell, W.T., 1987. Manufacturing strategy, environmental uncertainty and performance: a path analytical model. Manage. Sci. 33 (4), 509–524.
Swamidass, P.M., Waller, M., 1991. A classification of the approaches to planning and justifying new manufacturing technologies. J. Manufacturing Sys. 29 (3), 181–193.
US Department of Commerce, 1988. Manufacturing Technology, 1988. A Bureau of Census Report, US Government Printing Office, Washington, DC.
US Department of Commerce, 1991. Manufacturing Technology: Factors Affecting Adoption 1991, A Bureau of Census Report, US Government Printing Office, Washington, DC.
Venkatraman, N., 1989. The concept of fit in strategy research: towards a verbal and statistical correspondence. Acad. Manage. Rev. 14 (3), 434–444.

Ward, P.T., Leong, G.K., Boyer, K.K., 1994. Manufacturing proactiveness and performance. Decision Sci. 25 (3), 337–359.

Warner, T., 1987. Information technology as a competitive burden, Sloan Manage. Rev., Fall, pp. 55–61.

Woodward, J., 1965. Industrial Organization: Theory and Practice, Oxford Univ. Press, London.

Yasai-Ardekani, M., 1989. Effects of environmental scarcity and munificence on the relationship of context to organizational structure. Acad. Manage. J. 32, 131–156.

Zummato, R.F., O'Connor, E.J., 1992. Gaining advanced manufacturing technologies' benefits: the roles of organizational design and culture. Acad. Manage. Rev. 17 (4), 701–728.