An empirical taxonomy of advanced manufacturing technology

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Abstract *An empirical advanced manufacturing technology (AMT) taxonomy with three groups was identified from cluster analysis. The analysis was based on a survey of Swedish metal-working industries and 324 relevant responses were received (response rate of 38 percent). The first group, "the traditionalists" is characterised by firms of relatively small size with low levels of investments in AMT. "The hard integrators" emphasise computerised transactions between sub-units and processes to a larger extent than the investment in administrative, design and manufacturing technologies. "The high investors" group contains relatively large firms that have invested in most technologies and have computerised their transactions significantly more than both the other groups. Companies with heavy investments in AMT had developed the infrastructure (worker empowerment, improvement programmes and organisational design) and maintenance (prevention and integration) aspects to a greater extent than low investors. They also performed better.*

Introduction

The old production paradigm of mass production has long given way to a new one based upon more flexible and advanced manufacturing technologies (AMT) and organisational arrangements with a different basis for competitiveness. The overall potential of AMT is great, and several problem issues in manufacturing could be solved through increased use of it. Introduction of new products can occur more frequently through use of computer-aided design and manufacturing (CAD/CAM), since the design lead times may be shortened. Flexible manufacturing systems (FMS) and automated materials handling systems reduce set-up times and other interruptions so that products flow more smoothly and faster through the plant. More responsive computer-based systems, such as electronic data interchange (EDI), can react quicker to information fluctuations and result in more accurate production planning and integrated supply chains. Integrated production control systems, such as manufacturing resource planning (MRP II) and enterprise resource planning systems (ERP), reduce inventories and raw materials, work-in-progress and finished goods. Tighter control and flexible manufacturing smooth flow through plant, make the flow more predictable and cut the overall throughput time, allowing accurate delivery performances to be achieved. Improvements in overall quality may be achieved through automated inspection and testing, better production, information and the more accurate delivery performances.

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AMTs are used for design, manufacturing or administrative activities. Investment in one or several technologies should be associated with simultaneous investment in supportive mechanisms, such as changed work organisation and preventive maintenance policies. An approach that structures the field of AMT and describes the patterns of AMT investment and associated support mechanisms would improve the general understanding of AMTs and could support successful implementation. The objective of this paper is to identify a taxonomy of AMT users among Swedish metal-fabricating companies and to describe how the groups of companies differ in terms of technology, but also in manufacturing strategy, environmental uncertainty, infrastructure, maintenance and performance.

Boyer *et al.* (1996) developed the only other taxonomy of AMTs that has been found. In contrast to this North American work, the taxonomy developed in this paper is based on a survey of Swedish metal working companies and includes one more AMT dimension. Swedish companies have by tradition somewhat different organisational design compared to the average US company (Hofstede, 1991) and it is therefore interesting to compare the findings of this study with those conducted in the USA.

Literature review and generation of hypotheses

A conceptual review of previous research on AMT is conducted to identify variables that describe an empirical AMT taxonomy.

AMT configurations

AMT is used as a term to describe a variety of technologies that use computers to control or monitor manufacturing processes. It includes computer-aided design/computer-aided manufacturing (CAD/CAM), computer-aided process planning (CAPP), robotics, group technology, flexible manufacturing systems (FMS), electronic data interchange (EDI), office automation, computerised numerical control machines (CNC), automated material handling systems, bar coding, decision support systems, enterprise resource planning systems (ERP) and many other forms of factory automation and control, that can provide cost-efficient flexibility and flow in manufacturing.

Several authors have structured the AMT field into three groups. Kaplinsky (1984), Lei and Goldhar (1991) and Meredith (1987) used the dimensions design, manufacture and integration. In this paper, a similar definition presented by Adler (1988) is used:

- *Design.* The dimension of AMT includes computer-assisted drafting, design and engineering. The focus of AMTs is on the design of products and processes.
- *Manufacturing.* Computer-controlled processes in the fabrication/assembly industries; automatic materials handling; automatic storage and retrieval systems. The focus of AMTs is on the actual manufacturing and physical transformation of the products.

- *Administrative*. Computerised accounting, inventory control systems and shop-floor tracking systems. This dimension focuses on tracking operations.

Boyer *et al.* (1996) identified four homogeneous groups of firms, according to their relative emphasis on design, manufacturing and administrative technologies. One of the groups had low investments in design, manufacturing and administrative technologies. Another distinct group invested heavily in design-related AMTs, but had low investments in both manufacturing and administrative-based technologies. A third group had relatively large investments in most technologies. The last group had highest investments in all technology types. There were no significant differences between the groups regarding profitability.

Hard integration, or technical integration, is another important component of AMT application that tells how well implemented the technologies are. It may be realised through computer-integrated transactions between functions, for example between marketing, engineering, production and maintenance, or between processes, such as CAD data directly linked to Computer-Aided Process Planning (CAPP), CAD data directly controlling Computerised Numerical Control (CNC) machines, robots or Flexible Manufacturing Systems (FMS), parts data from CAD linked to Manufacturing Resource Planning (MRP II) software, production schedules generated by MRP II controlling production equipment, various robots or computer-controlled machines linked to computerised material handling devices, etc.

We propose that it is possible to identify distinct AMT clusters, in accordance with the findings of Boyer *et al.* (1996), and that the groups of companies are very similar, whether the data come from Swedish or North American companies. Unlike Boyer *et al.* (1996) we combine the three types of technologies, presented by Adler (1988), with two levels of hard integration when identifying AMT typologies.

Manufacturing strategy and environmental uncertainty

AMT may be used to alter the rules of competition in industries, in effect creating an environment in which the firm has a competitive edge based on its use of AMTs. In this environment the firms can frequently introduce new production processes and products with large numbers of varieties and features. They are, thereby, competing simultaneously along all manufacturing capability dimensions, leading to advantages in terms of speed, low cost and high variety. Work-in-progress and changeover time are becoming shorter through simplified change of tools, dies and product variants. Faster speed can also be gained through integrating design activities and manufacturing. Greater product variety can be derived from flexible and modular production set-up, but also from the use of group technology and flow oriented layouts. Mass customisation results from “smarter” production technology, that is tailored to the needs of specific designs and customers. The fact that there is less downtime required to shift between families of products or components can result in greater productivity.

The competitive possibilities of AMTs discussed above deal with flexibility and we state the hypothesis in accordance with the belief that AMT is most appropriate in dynamic environments where flexibility is a key element of the manufacturing strategy:

H1: Companies in dynamic environments, where flexibility is an important competitive capability, invest more heavily in AMTs than companies in stable environments.

Infrastructure

Direct labour with high technical competence and high skill level within the entire organisation most likely results in motivated and empowered labour and improved labour/management relations. These infrastructural aspects (e.g. worker empowerment, improvement programmes and organic organisational structure) are especially important for the realisation of flexible organisations and AMT success, and there is a growing consensus that organisations with empowered personnel, continuous improvement programmes and organic structures are more likely to realise the full potential of AMT investments (e.g. Chung, 1991; McLachlin and Piper, 1991; Dean *et al.*, 1992; Saraph and Sebastian, 1992; Maffei and Meredith, 1994; Sun and Gertsen, 1995; Chen *et al.*, 1996; Chen and Small, 1996; Dawson, 1996; Lei *et al.*, 1996; Co *et al.*, 1998; Wong and Ngih, 1997). However, research findings also suggest that the relationship between organisation structure, infrastructure and AMT benefits ascribed to AMTs are as much an outcome of infrastructure as of AMTs. Zammuto and O'Connor (1992), for example, summarised a study of 50 automobile plants and showed that plants using traditional technology often outperformed those with AMTs. Bessant and Lamming (1987) estimated that the relative contribution of organisational and human changes to gained benefits during AMT implementation to be between 40 and 70 percent.

Several conceptual studies (e.g. Meredith, 1987; Parthasarthy and Sethi, 1992; Twigg *et al.*, 1992) and at least one empirical study (Boyer *et al.*, 1997) have indicated the importance of infrastructural issues for successful implementation of AMTs. Boyer *et al.* (1997) studied the interaction between the adoption of advanced manufacturing technologies and investments in infrastructure through a survey. They concluded that firms that invested in both AMTs and infrastructure performed better than firms which only invested in one or the other. They further found that infrastructural investments have a stronger relationship with performance for firms with high investments in AMTs than for those with low investments.

It is clear that an organisation's infrastructure is important for companies with heavy AMT investments, but it should also be important for those with low AMT investments. We state the hypothesis in accordance with the research indicating that increased emphasis on infrastructure is necessary in AMT companies:

H2: Companies with heavy investments in AMTs emphasise infrastructural aspects to a greater extent than companies without heavy AMT investments.

Maintenance

The availability of the ever more automated manufacturing systems is critical for achieving the goals of tied-up capital, throughput time, flexibility and quality. Total Productive Maintenance (TPM) was developed during the 1970s to help the Japanese industry avoid costly "breakdown maintenance" and instead achieve high availability and strong manufacturing capability (Yamashina, 1995). TPM is a company-wide maintenance system that aims to maximise the overall availability and quality rates of equipment, through autonomous operator-maintenance teams working to continuously improve the production processes and decrease the downtime losses, speed losses and defect losses (Nakajima, 1988). Such preventive and manufacturing-integrated maintenance should be important in companies with heavy investment in AMT. The hypothesis is stated in accordance with this belief:

H3: Companies with heavy investments in AMTs emphasise maintenance aspects to a greater extent than companies without heavy AMT investments.

Performance

AMTs differ from earlier technologies in their capacity to increase organisational flexibility because they are programmable, allowing them to produce a wide array of different parts or products in small volumes by changing software instead of replacing hardware (Zammamuto and O'Connor, 1992). Not all AMT necessarily leads to increased flexibility, though, but some is designed to increase speed, sometimes at the expense of flexibility. Another type automates what were previously human operations, for example assembly. The operational role of AMT is often seen as an instrument for achieving economies of scale in small batches (Chen and Small, 1996). For mass production firms, the greater flexibility and speed provided by AMTs could result in economies of scope (Goldhar and Jelinek, 1983). In the marketing role AMTs provide the basis that enables firms to exploit competitive advantages fostered by the technology. Mass production firms are expected to gain a competitive edge through their ability to provide a wider range of products at their usual rates of efficiency. Small batch producers can, on the other hand, enhance their process efficiencies while maintaining or improving product flexibility. Chen and Small (1996) state further that the strategic role of AMT has been related to improving the firm's ability to cope with environmental uncertainty, but that it has also been viewed as an important factor in the overall improvement of industrial performance. We state the hypothesis in accordance with the belief of a positive effect of AMT investment:

H4: Companies with heavy investments in AMTs are performing higher than companies with low investments in AMTs.

Research design

Figure 1 describes the research design of this paper. In the first step, an AMT taxonomy with distinct groups of companies based on the dimensions design technology (AMTDES), manufacturing technology (AMTMFG), administrative technology (AMTADM), computer-based transactions of data between sub-units (HINT1) and computer-based transactions of data between processes (HINT2) are identified through cluster analysis. In the second step, the identified clusters are described and compared in terms of context, manufacturing strategy, environmental uncertainty, infrastructure, maintenance and performance.

Methodology

The methodological considerations discussed here concern selection of population, selection of sample, selection of scales, questionnaire construction, pilot testing, mailing the survey, and ensuring high reliability and validity. The software package SPSS was used for all statistical analyses.

Sample

Data was collected during the first half of 1998. The goal was to receive at least 200 usable responses, because the statistical techniques (e.g. factor analysis, cluster analysis, ANOVA) require approximately that number of responses (Hair *et al.*, 1998). Response rates from similar studies in the USA, Australia,

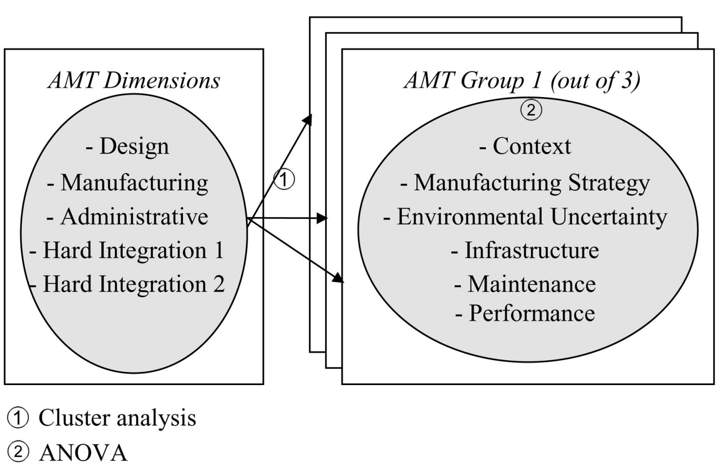

Figure 1. The research design

New Zealand and Singapore vary from about 10 (e.g. Co *et al.*, 1998) to 40 percent (e.g. Dean *et al.*, 1992, Boyer *.et al*, 1997), with a median response rate around 20 percent (e.g. Sohal *et al.*, 1996; Small and Chen, 1997). A previous survey to maintenance managers in Sweden (Jonsson, 1997) resulted in a response rate of about 40 percent, which indicates that the achievable rate may be higher in Sweden, compared to the studies in other countries. Calculating with similar response rates it was necessary to send out between 500 and 1,000 questionnaires.

The metal-working industries (US SIC 33-37/European SIC 27,28,29,31,35; primary metals, fabricated metals, machinery except electrical, electric and electronic equipment and transportation equipment) are considered to be the industries that most heavily invest in AMTs (e.g. Dean *et al.*, 1992; Boyer *et al.*, 1996). To exclude small plants without the necessary resources to invest in AMTs, only plants with more than 50 employees were included in the sample. Addresses were obtained from the database of the Swedish Postal Services. It contained 892 addresses of production managers in such plants. The survey was pre-tested, adjusted according to the feedback and sent to the 892 production managers.

Three weeks after the first questionnaire was mailed a follow-up letter was sent to those who had not answered. All respondents were promised a summary of the study. A total of 324 usable responses was received (response rate of 36 percent, based on the original selection of 892 cases). To check the reliability of the answers provided by the respondents it is appropriate to obtain a second response from another individual in the plant. The questionnaire sent to the production managers included a section where they were asked to name another individual within the organisation who could answer the same question: 85 first-respondents gave names to other informants and a new copy of the questionnaire was sent to them. Altogether 47 responses were received from this sample, resulting in a second-response rate of 56.5 percent.

The profile of the sample and respondents is shown in Table I. The median company has 100 to 199 employees, six to ten main competitors and has implemented ISO 9001. The sample has a bias toward plants in the fabricated metal industry and plants with 50 to 99 employees. However, this corresponds well to the population. The response rates differ between industries, but the individual response rates of the industries are not critical, since the definitions of the industries are rather similar (several of the responding plants could belong to two or more of the surveyed industries). The sample should therefore be reasonably representative of the general distribution of plants within the metal-fabricating industries.

Reliability

Reliability is an evaluation of measurement consistency. It ensures the ability to replicate the study, and high reliability is a prerequisite for establishing validity of the study. Three tests of reliability were carried out:

	Sample	Responses received	Percent of total	Expected responses	Response rate
Industry code					
27. Primary metal	95	34	10.5	34	6.8
28. Fabricated metal	573	149	46.0	208	26.0
29. Machinery, except electrical	145	76	23.5	53	52.4
31. Electronic equipment	50	36	11.1	18	72.0
35. Transportation equipment	29	28	8.6	10	96.6
99. Other	0	1	0.3	0	0
Total	892	324	100	324	36.3
No. of employees					
50-99	423	127	41.4	146	30.0
100-199	237	99	32.2	82	41.8
200-499	151	49	16.0	52	32.4
> 500	81	32	10.4	28	39.5
Total	892	307	100.0	307	34.4
No. of main competitors					
1		15	4.9		
2-5		117	37.7		
6-10		86	27.7		
>10		92	29.7		
Total		310	100.0		
ISO 9000					
Not implemented		67	20.7		
ISO 9001		178	54.9		
ISO 9002 or ISO 9003		79	24.4		
Total		324	100.0		

Table I. Sample profile and test of non-respondent bias

(1) non-respondent bias;

(2) inter-item reliability within the scales; and

(3) inter-rater reliability between multiple respondents.

The *non-respondent* bias arises from the difference between those who respond to the survey and those who do not. To estimate this bias the following measures were taken:

(1) analysis of the reasons given for the non-respondents not answering the questionnaire; and

(2) comparing respondents and non-respondents regarding contextual factors (industry members and company size).

In the covering letter the respondents were requested to send back the questionnaire even if they did not intend to answer it, indicating their reason for not answering. In addition some non-respondents were contacted by telephone. Altogether 101 explanations of non-respondents were received. The reasons for not answering varied between; that there was no available time to fill in the questionnaire; the respondent had not enough knowledge to answer the questions; the addressee had quit and did not work at the plant any more; the questionnaire was not relevant to answer because the individual had received two copies of it; the questionnaire was irrelevant because the company had no production; and several other reasons. About half of them indicated that the questionnaire was not relevant, because the plant did not have any manufacturing (see Table II). If this was true for the entire sample, the relevant sample size would be 622 and the response rate 52 percent. After adjusting the selection size with the 46 cases without manufacturing and the two surveys sent to people in the same organisation the selection size is not larger than 844, and the corresponding response rate is 38 percent. Consequently, the response rate is at least 38 percent, but the true rate is most likely considerably higher.

It is important to have a high response rate. Several operations management studies have been published with response rates around 20 percent or lower, and such studies are highly unreliable with results difficult to generalise (Flynn *et al.*, 1990). The present response rate of at least 38 percent is in the lower range of acceptability, but the non-respondents analysis indicates that the rate should be good enough.

The contextual differences between respondents and non-respondents presented in Table I were tested using Chi-square statistics. No significant difference could be found at the $p < 0.05$ level between respondents and non-respondents regarding industry code or plant size (number of employees).

The questionnaire contained about 150 individual variables. These were combined in 32 summated scales. Most questions were based on seven-point Likert scales (see Appendix, section A). A summated scale is the mean of a set of questions that measure the same underlying construct, and consequently the scores of summated scales also range between one and seven. By using the average response to a set of related variables, the measurement error that might occur in a single question will be reduced. Another benefit of the summated scale is that it represents the multiple aspects of a concept in a single measure and allows more exact distinctions to be made between respondents. There exist very few established scales in the area of operations management. Most existing scales were developed in the USA, were quite new and had not been used frequently. Most scales in the questionnaire were not new, but adopted from previous studies. We therefore expected high degrees of inter-item reliability within the scales. In one sense all scales were new, though, since

Table II. Reasons for non-response

Reasons for non-response	Frequency	Percent
No production	46	45.5
No available time	32	31.7
Addressee has quit	6	5.9
Not enough knowledge	3	3.0
Sent to two persons	2	2.0
Other reason	12	11.9
Total	101	100.0

they had never before been translated into Swedish. This is why some of the existing scales were changed due to the reliability and validity tests (Tables III to VII).

Cronbach's coefficient alpha is the most widely used measure for testing inter-item reliability when using scales of individual measures (Sakakibara *et al.*, 1993). It measures the internal consistency within a particular scale, by calculating an average of the correlation coefficient of each item within a scale with every other item, as weighted by the number of items within a scale. Values of 0.70 or higher are considered acceptable, with 0.60 acceptable for new scales (Flynn *et al.*, 1990, Hair *et al.*, 1998). The reliability analysis indicated slightly better reliability if some items were removed from existing scales. Removal of items from WEMP, SOFTINT and HINT1 were also supported by the test for construct validity (see next section on "Validity"). Therefore, five items were removed from these scales. All scales, except for ENVIR, AMTDES, QDIFF and FOCUS showed acceptable levels of Cronbach's Alpha for established scales. The reliability of ENVIR was above the minimum of 0.60 and since it has shown acceptable (or close to acceptable) levels of reliability in previous studies (Swamidass and Newell, 1987; Boyer *et al.*, 1997) its inter-item reliability is considered appropriate here as well. (The scale, however, is not used in its aggregated form in this study. See next section on "Validity".) AMTDES, QDIFF and FOCUS were quite new scales (developed by Boyer *et al.*, 1996) that contained only three items. Because the alpha has a positive relationship to the number of items in the scale it will automatically get lower alphas for these scales than for scales with more items. The reliabilities of AMTDES and QDIFF were very close to 0.70. The corresponding figure of FOCUS was as low as 0.54, but it should be compared to the alpha of 0.60 for new scales, since the original scale (Boyer *et al.*, 1997) only contained two items. Based on the above analysis the internal consistency of all scales, except for FOCUS, was considered acceptable. However, the alpha of FOCUS was close to acceptable and the scale is therefore included in the analysis.

Inter-rater reliability measures the correlation between the first and second respondents of the same plant. It indicates the degree to which two independent respondents of the same plant agree on the ratings to a specific scale. The test for inter-rater reliability was first presented by James *et al.* (1984) and has since then been used sporadically in operations management research (e.g. Dean and Snell, 1991; Snell and Dean, 1992; Boyer *et al.*, 1996; Boyer *et al.*, 1997). We had 47 plants with matched pairs of respondents. Out of the 36 scales, 24 (31 original and five scales derived from the validity analysis, see section on "Validity") showed significant correlations at the $p < 0.01$ level between first and second raters (see Table III) and the correlations of five scales were significant at the $p < 0.05$ level. Correlations of ENVIR, ENVIR1 and MDELIV were very close to the $p < 0.05$ level ($p = 0.055$, $p = 0.057$ and $p = 0.054$ respectively). ENVIR2, DEC, DEC1 and DEC3 were the scales with lowest correlation between first and second raters ($p = 0.113$, $p = 0.104$, $p = 0.318$ and $p = 0.326$ respectively). ENVIR and DEC are old scales, but are not used in their

Construct[a]	Name	Mean (SD)	Cronbach's alpha	Inter-rater reliability
Environmental uncertainty				
Environmental uncertainty [A]	ENVIR	3.45 (0.92)	0.63	0.337
Market uncertainty	ENVIR1	3.25 (1.18)	0.68	0.340
Political uncertainty	ENVIR2	4.22 (1.66)	NA	0.295
Business strategy [B]				
Quality differentiation	QDIFF	5.35 (0.80)	0.65	0.389**
Market differentiation	MDIFF	4.47 (1.18)	0.84	0.604**
Delivery differentiation	DELDIFF	5.94 (0.89)	NA	0.397**
Focus	FOCUS	4.53 (1.20)	0.54	0.473**
Price	PRICE	5.43 (0.95)	NA	0.467**
Manufacturing strategy [B]				
Manufacturing costs	MCOST	5.06 (0.93)	0.77	0.467**
Manufacturing delivery	MDELIV	5.86 (0.88)	0.79	0.293
Manufacturing quality	MQUAL	5.32 (1.11)	0.76	0.399**
Manufacturing flexibility improvement	MFLEX	4.64 (1.03)	0.83	0.372*
Advanced manufacturing technologies [C]				
Design technology	AMTDES	3.48 (1.63)	0.69	0.481**
Manufacturing technology	AMTMFG	2.85 (1.16)	0.73	0.640**
Administrative technology	AMTADM	3.21 (1.13)	0.77	0.575**
Hard integration 1 [D]	HINT1	3.92 (1.47)	0.86	0.562**
Hard integration 2 [D]	HINT2	3.23 (1.55)	0.83	0.746**
Infrastructural aspects				
Worker empowerment [E]	WEMP	5.64 (0.79)	0.89	0.443**
Small group problem solving [E]	GROUP	4.74 (1.37)	0.91	0.560**
Training [E]	TRAIN	4.70 (1.07)	0.80	0.671**
Quality leadership [F]	QLEAD	5.09 (0.97)	0.78	0.434**
Interfunctional besign process [F]	INTERFUN	4.57 (1.30)	0.81	0.473**
Decentralisation [B]	DEC	3.31 (0.67)	0.73	0.250
Decentralisation employment	DEC1	2.26 (0.79)	NA	0.150
Decentralisation planning	DEC2	3.67 (2.07)	NA	0.641**
Decentralisation operations	DEC3	3.72 (0.60)	0.78	0.148
Soft Integration [I]	SOFTINT	4.53 (0.99)	0.73	0.462**
Maintenance Management				
Preventive maintenance	PMAIN	4.62 (1.18)	NA	0.589**
Soft maintenance integration	SMAIN	5.84 (0.85)	NA	0.308*
Hard maintenance integration	HMAIN	3.05 (1.62)	NA	0.459**
Performance				
Profit [G]	PROFIT	4.72 (1.05)	0.90	0.445**
Growth [H]	GROWTH	4.88 (1.05)	NA	0.386*
Flexibility I [H]	FLEX1	3.60 (1.00)	0.74	0.392*
Flexibility II [I]	FLEX2	5.24 (0.87)	0.75	0.517**

Notes: The scale was developed by: [A] Dess and Beard (1984); [B] Miller and Vollmann (1984); [C] Boyer *et al.* (1996); [D] Dean *et al.* (1992); [E] Sakakibara *et al.* (1993); [F] Flynn *et al.* (1994); [G] Vickery *et al.* (1993); [H] Swamidass and Newell (1987); [I] Boyer *et al.* (1997); NA = not applicable; * significant at the $p < 0.05$ level; ** significant at the $p < 0.01$ level; Kolmogorov-Smirnov statistics, with a Lilliefors significance correction for testing normality, indicates significant univariate normality for all variables; [a] for scales used, see Appendix

Table III.
Constructs, scales and reliability coefficients

aggregated forms in this study (see next section on "Validity"). To further test the inter-rater reliability of the eight scales with *p*-values below 0.05, 95 percent confidence intervals for the differences between first and second raters were established. The intervals of all scales included zero (Table IV), indicating that the hypothesis that the mean difference between the first and second raters differs from zero cannot be rejected at the $p < 0.05$ level.

The combination of these two tests shows that there are high degrees of inter-rater reliability for all scales.

Validity

Validity indicates if the scale measures what it is supposed to measure. *Content validity* is a judgement by experts or is referenced in literature that a scale truly measures the concept for which it was designed. *Construct validity* indicates whether a scale provides an appropriate operational definition of an abstract or latent variable. To establish high degree of content and construct validity we have followed the recommendations of Flynn *et al.* (1990) to draw the scales directly from existing sources and to base new scales on extensive literature review. Most scales that were used had been tested and used in previous US studies. The scales were translated to Swedish which resulted in somewhat new scales. The entire questionnaire was pre-tested before it was sent out to the respondents. The formulations of several questions were changed and adjusted during this process.

Content validity is subjective in nature and can always be debated. Construct validity, on the other hand, can be tested in factor analysis. If a scale loads on more than one factor, then it measures more than one construct and should be split into two or more independent scales or the factors beyond the first should be eliminated as unwanted nuisance factors. The most common solution is to retain factors with eigenvalues greater than one and to remove items with factor loadings less than 0.4 (Sakakibara *et al.*, 1993).

Factor analysis by principal components was carried out for each scale. All scales, except ENVIR, DEC, WEMP, SOFTINT and HINT1, loaded on single factors. When deleting the critical items identified in the inter-item reliability tests (see Table III) WEMP, SOFTINT and HINT1 loaded on single factors. The validity of ENVIR and DEC, on the other hand, could not be improved to acceptable levels except by deleting one or two items. It was obvious that they

Scale	Lower limit	Upper limit
ENVIR	–0.24	0.47
ENVIR1	–0.43	0.44
ENVIR2	–0.57	0.97
DEC	–0.28	0.25
DEC1	–0.32	0.28
DEC3	–0.41	0.35
MDELIV	–0.33	0.24

Table IV. 95 percent confidence intervals for the difference between first and second raters measured multiple constructs (see Tables V and VI). One item was deleted from ENVIR and the scale was then split into two new scales. The first was named ENVIR1 and focused on the uncertainty among competitors and customers in the market environment. The second was named ENVIR2 and focused on uncertainty in the political environment, such as governmental regulations and political attitudes. One item was deleted from DEC and it was then split into DEC1 dealing with decisions about employment of workers, DEC2 on production planning and DEC3 dealing with operational decisions, such as resolution of internal labour disputes, machinery to be used and allocation of work between available workers.

After adjusting the scales according to the above factor analyses, all scales loaded on single factors. The eigenvalues were all larger than one and the individual item loadings exceeded 0.40, with many loading in the 0.70 to 0.90 range. These results indicate that every scale used in the analysis will have good construct validity. The results of the factor analysis are presented in Table VII.

Criterion-related (predictive) validity assesses the relationship between scores on a predictor scale and an objective outcome criterion. The performance measures of PROFIT and GROWTH were the only measures that were measured subjectively as well as objectively. The other items had no fully objective answers

Table V. Factor analysis by principal components and Varimax rotation – ENVIR

Item	Component 1	Component 2
ENVIRa	0.79	*
ENVIRb	0.66	*
ENVIRc	0.83	*
ENVIRd	*	0.87
ENVIRe	*	0.88
ENVIRf	*	*

Note: * Factor loadings less than 0.40

Table VI. Factor analysis by principal components and Varimax rotation – DEC

Item	Component 1	Component 2	Component 3
DECa	*	0.78	*
DECb	*	0.73	*
DECc	0.64	*	*
DECd	0.52	*	*
DECe	*	*	0.46
DECf	*	*	0.83
DECg	*	0.45[a]	*
DECh	0.52	*	*
DECi	0.83	*	*
DECj	0.76	*	*
DECk	0.65	*	*

Note: * Factor loadings less than 0.40; [a] item deleted based on inter-item reliability test

Table VII. Results of construct validity analysis

Scale	Item number 1	2	3	4	5	6	7	8	9	Eigen value
ENVIR1	0.79	0.70	0.85							1.83
ENVIR2	0.89	0.89								1.60
AMTDES	0.69	0.88	0.72							1.77
AMTMFG	0.55	0.60	0.61	0.61	0.69	0.43	0.67	0.59	0.55	3.07
AMTADM	0.64	0.65	0.58	0.50	0.60	0.72	0.73	0.50		3.09
DEC1	0.85	0.85								1.45
DEC2	0.72	0.72								1.04
DEC3	0.70	0.65	0.63	0.78	0.69	0.70				2.88
WEMP	0.82	0.74	0.76	0.70	0.78	–[a]	0.84			3.61
GROUP	0.93	0.93	0.89							2.54
TRAIN	0.77	0.79	0.83	0.77						2.50
QLEAD	0.69	0.77	0.71	0.75	0.72					2.65
INTERFUN	0.73	0.79	0.87	0.81						2.56
PROFIT	0.91	0.92	0.90							2.50
GROWTH	0.94	0.94								1.75
FLEX1	0.74	0.56	0.85	0.84						2.29
FLEX2	0.70	0.79	0.83	0.71						2.30
SOFTINT	–[a]	0.54	0.60	0.78	0.71	–[a]	0.66	0.62		2.58
HINT1	0.77	–[a]	–[a]	0.80	0.77	0.67	0.72	0.70		3.28
HINT2	0.71	0.77	0.78	0.80	0.78	0.78				3.56
PMAIN	0.84	0.84								1.40
SMAIN	0.88	0.88								1.56
HMAIN	0.91	0.91								1.65
QDIFF	0.64	0.72	0.74	0.53	0.61					2.12
MDIFF	0.60	0.74	0.77	0.72	0.80	0.81				3.32
DELDIFF	0.90	0.90								1.63
FOCUS	0.69	0.70	0.78							1.57
PRICE	0.78	0.78								1.24
MCOST	0.61	0.75	0.88	0.84						2.42
MDELIV	0.87	0.84	0.81							2.12
MQUAL	0.86	0.81	0.79							2.02
MFLEX	0.70	0.72	0.71	0.74	0.74	0.78				3.21

Note: [a] Item removed during the reliability and validity analyses; NA = not applicable

and were therefore followed up with more or less subjective scales. The correlations between the subjective and objective measures are 0.198 ($p < 0.01$) for PROFIT and 0.218 ($p < 0.01$) for GROWTH. This indicates that the subjective performance measures should be reliable predictors of the objective measures.

Findings

Identifying the taxonomy

Cluster analysis was employed to identify the AMT types from the variables AMTDES, AMTMFG, AMTADM, HINT1 and HINT2. The variables are correlated (Pearson coefficient for bivariate correlation varies between 0.35 and 0.54 for all pairs of variables), but these levels of collinearity are expected, since the variables measure related constructs and it should therefore not create problems in the forthcoming analysis.

Ward's minimum variance cluster method was used to identify outliers and form appropriate numbers of clusters. When forming 30 clusters of the 302 valid cases (the cases with answers to all five AMT variables), two clusters contained only one case, while no cluster contained two cases. The two cases in the single clusters were identified as outliers and deleted from the database, and a new hierarchical cluster analysis, based on the remaining cases, was conducted. A rule of thumb says that the number in any cluster should be limited to between $n/30$ to $n/60$, where n is the number of cases (Lehmann, 1979). Thus, according to this criterion the number of clusters should be between five and ten. Another criterion says that there should be pronounced increases in the tightness of the clusters. Small changes of the clustering (agglomeration) coefficient when conducting hierarchical cluster analysis indicate that fairly homogeneous clusters are being merged, and joining two very different clusters results in a large percentage change in the coefficient (Hair *et al.*, 1998). For our data, the two and three cluster models provided the best fit. The coefficient is changed by 51 percent when moving from two to one cluster and by 24 percent when moving from three to two clusters. The three cluster model was considered most appropriate, since it may be a more interesting base for further comparison between the groups, and since it is closer to the minimum of five clusters suggested by the first criterion.

Non-hierarchical cluster analysis with seed points from the hierarchical results (the cluster centres) were used to "fine-tune" the results and present the final clusters. The final cluster centres, generated from the non-hierarchical analysis, (see Table VIII) and the number of group members were slightly adjusted compared to the hierarchical analysis. To check for stability of the cluster solution, a second non-hierarchical analysis was performed, this time allowing the procedure to collect seed points randomly. The cluster sizes are comparable (but not exactly equal), and the cluster profiles are very similar between the two models. The final cluster solution (i.e. from the first non-hierarchical cluster model) is therefore considered consistent.

	Clusters			
Variables	Traditionalists $n = 92$ Mean (SD)	Hard integrators $n = 115$ Mean (SD)	High investors $n = 93$ Mean (SD)	F-statistics
AMTADM	2.30 (0.78)	3.27 (0.90)	4.11 (0.94)	98.2
AMTDES	2.45 (1.12)	2.90 (1.05)	5.37 (0.88)	222.6
AMTMFG	1.90 (0.67)	2.79 (0.85)	3.89 (0.89)	138.4
HINT1	2.54 (1.12)	4.38 (1.11)	4.77 (1.03)	111.6
HINT2	1.65 (0.82)	3.71 (1.14)	4.60 (1.30)	135.2

Note: *F*-statistics are derived from one-way ANOVA. All variables are significantly different at the $p < 0.001$ level. Scheffe's pairwise comparison procedure indicates that all pairs of groups on all the five variables are significantly different at the $p < 0.05$ level

Table VIII.
Clusters and AMT variables

We compared the clustering variables by group means using a one-way ANOVA test. Scheffe's pairwise comparison test was used to identify significant differences between individual pairs of groups on each of the five individual variables. Both tests indicated significantly different means between all groups and pair of groups on all five variables (Table VIII). Consequently, the result indicates that each cluster is distinct from each other.

The three identified AMT groups were named "traditionalists", "hard integrators" and "high investors". They have almost the same number of members (ranging from 92 to 115). The interpretation of the meaning of the three groups is given below.

Cluster 1 – traditionalists. The first cluster was labelled "traditionalists", because it had the least investments in all AMT variables of the three groups. The cluster means varied between 1.65 and 2.54, where "4" indicated moderate investment in administrative (AMTADM), design (AMTDES) and manufacturing (AMTMFG) technologies; some transactions of data between sub-units accomplished through computers (HINT1); and 50 percent of the transactions between processes accomplished through the use of computer equipment (HINT2). Consequently, the traditionalists rely more on non-computerised and automated equipment. Compared to the other two groups, the traditionalists show especially low level of hard integration (HINT1 and HINT2).

Cluster 2 – hard integrators. The hard integrators had the second highest group means for all variables. It was the largest group (n = 115) and relied on AMT and hard integration to a medium level. It was difficult to conclude anything about the importance of AMT for the single companies within this group. They knew about most technologies and had to some extent invested in them. However, hard integration, both in terms of computerised transactions between sub-units and processes, was emphasised to a larger extent than the investment in administrative, design and manufacturing technologies. The level of hard integration was high, even when compared to the high investors. Administrative technology was their most important AMT. This indicated that the generalists may use computers to make the supportive processes more efficient, rather than to increase the capacity of the primary manufacturing processes.

Cluster 3 – high investors. They have invested in most technologies and have computerised their transactions significantly more than both the other groups. The scores were, however, only slightly higher than "4", which indicates only a modest level of investment in AMT. The group contained as many as one third of the cases, and if more than three clusters had been chosen, a group with more extreme AMT investments could perhaps have been identified. The high investors were still distinct from the other groups in terms of AMT, and it should therefore be appropriate to use this group as the "high-tech" group in the forthcoming analyses of this paper.

The five variables representing the use of AMT succeeded in generating a taxonomy reasonably consistent with that identified by Boyer *et al.* (1996). Our three groups corresponded pretty well to three of their groups. We did not identify a group focusing on design technology and since Boyer *et al.* did not include hard integration in their analysis they could not identify such a group emphasising hard integration.

The AMT context

The context in which the surveyed firms exist was measured in terms of industry code, number of competitors and number of employees. Chi-square tests could not reveal any significant difference between the three AMT groups regarding industry or number of competitors. This is not very surprising, since the five industries included are very close to each other. However, one-way ANOVA indicates that the groups differ significantly in size ($F = 11.3$), and Scheffe's pairwise test at the $p < 0.05$ level showed that the group with high investments in AMT had significantly more employees than the other two groups. The mean number of employees was 602, compared to 123 in the traditionlist and 194 in the hard integrators groups. It is quite natural that firms that can afford to invest heavily in AMT are larger than the other firms. We had still expected larger firms in the group with investments in hard integration, but the size of the firms in this group was not significantly larger than the group with low overall AMT investments.

Uncertainty and strategy

AMT is considered important in a turbulent and dynamic business environment, where the organisation's competitive advantage is achieved through differentiation rather than low cost. At the functional level (e.g. manufacturing), flexibility should be the most important capability but most capabilities are critical. Table IX indicates that there are no significant differences between the market and political environments of the three groups of firms. What is even more surprising, though, is that the traditionalists showed the highest means for both environmental measures. These results indicate that the uncertainty is not critical for investing in AMT (or perhaps that the actual measures do not measure the environmental uncertainty correctly. The questions ask for "perceived" and not "actual" uncertainty).

Another reason for investing heavily in AMT should be to enhance flexibility and to fulfil business and manufacturing strategies that require multiple capabilities rather than single ones. It is, however, difficult to observe any clear relationship between business strategy, manufacturing capabilities and investment in AMT in the present analysis (Table IX). Regarding the business strategies of the three groups, delivery differentiation is the most important strategy for all three groups, and price is ranked second for traditionalists and hard integrators, and third for high investors. The emphasis on differentiation and focus is significantly larger for hard integrators and high investors than for traditionalists, but the emphasis on price does not differ significantly between the groups. Thus, the results only vaguely indicate that the price strategy has greater importance for traditionalists than for the other two groups.

Table IX. Strategy, organisation, maintenance and performance by AMT groups

Variables	Clusters 1. Traditionalists Mean (SD)	2. Hard integrators Mean (SD)	3. High investors Mean (SD)	*F*-statistics
Environmental uncertainty				
Market environment (ENVIR1)	*3.34* (1.22)	3.21 (1.17)	3.19 (1.10)	0.4
Political environment (ENVIR2)	*4.47* (1.65)	4.02 (1.67)	4.15 (1.71)	1.5
Business strategy				
Quality differentiation (QDIFF)	4.94 (0.79) [2,3]	5.46 (0.72) [1]	*5.64* (0.60) [1]	23.7**
Market differentiation (MDIFF)	3.97 (1.23) [2,3]	4.65 (1.12) [1]	*4.79* (1.02) [1]	13.6**
Delivery differentiation (DELDIFF)	5.62 (1.01) [2,3]	6.04 (0.82) [1]	*6.14* (0.75) [1]	9.4**
Focus (FOCUS)	4.19 (1.22) [3]	4.57 (1.12)	*4.86* (1.08) [1]	7.7**
Low price (PRICE)	5.25 (1.09)	5.47 (0.83)	*5.56* (0.89)	2.7
Manufacturing capabilities				
Manufacturing costs (MCOST)	4.73 (1.02) [2,3]	5.12 (0.85) [1]	*5.30* (0.84) [1]	9.6**
Manufacturing delivery (MDELIV)	5.53 (1.01) [2,3]	5.97 (0.79) [1]	*6.09* (0.75) [1]	11.1**
Manufacturing quality (MQUAL)	4.85 (1.22) [2,3]	5.52 (0.95) [1]	*5.56* (1.02) [1]	13.1**
Manufacturing flexibility (MFLEX)	4.28 (1.11) [2,3]	4.75 (0.93) [1]	*4.89* (0.86) [1]	10.1**
Infrastructural aspects				
Worker empowerment (WEMP)	5.23 (0.85) [2,3]	5.72 (0.66) [1]	*5.96* (0.68) [1]	23.8**
Self managed groups (GROUP)	4.00 (1.52) [2,3]	4.90 (1.11) [1]	*5.25* (1.14) [1]	24.0**
Training (TRAIN)	4.28 (1.03) [2,3]	4.62 (0.98) [1,3]	*5.19* (0.90) [1,2]	20.6**
Quality leadership (QLEAD)	4.73 (1.10) [2,3]	5.17 (0.84) [1]	*5.29* (0.93) [1]	8.9**
Interfunctional design (INTERFUN)	3.97 (1.31) [2,3]	4.71 (1.13) [1]	*5.08* (1.13) [1]	20.3**
Decentralisation employment (DEC1)	3.54 (0.62) [2,3]	3.75 (0.57) [1]	*3.87* (0.58) [1]	7.5**
Decentralisation planning (DEC2)	2.09 (0.67) [3]	2.25 (0.81)	*2.46* (0.85) [1]	5.2**
Decentralisation operations (DEC3)	3.51 (2.25)	3.87 (2.72)	3.61 (0.84)	0.8
Soft integration (SOFTINT)	4.05 (0.97) [2,3]	4.58 (0.89) [1]	*4.86* (0.87) [1]	18.8**

(continued)

Table IX.

Variables	Clusters 1. Traditionalists Mean (SD)	2. Hard integrators Mean (SD)	3. High investors Mean (SD)	*F*-statistics
Maintenance management				
Preventive maintenance (PMAIN)	4.26 (1.16) [2,3]	4.56 (1.08) [1]	*5.04* (1.13) [1]	11.5**
Soft maintenance (SMAIN)	5.38 (0.91) [2,3]	5.96 (0.75) [1]	*6.15* (0.67) [1]	25.0**
Hard maintenance (HMAIN)	1.76 (1.15) [2,3]	3.34 (1.42) [1,3]	*3.99* (1.35) [1,2]	69.2**
Performance				
Profitability (PROFIT)	4.45 (1.11) [3]	4.64 (0.99) [3]	*5.05* (1.00) [1,2]	6.4**
Growth (GROWTH)	4.61 (1.08) [3]	4.83 (0.98)	*5.18* (1.02) [1]	6.6*
Flexibility (FLEX1)	3.53 (1.03)	3.63 (0.97)	*3.66* (1.00)	0.4
Flexibility (FLEX2)	5.05 (0.88) [3]	5.26 (0.86)	*5.40* (0.84) [1]	3.4*

Notes: Numbers in brackets [ ] indicate the group numbers from which this group is significantly different at the $p < 0.05$ level. Scheffe's pairwise test of means was used for identifying pairwise differences. Numbers in italics indicate the highest group mean for that variable.
** Significant difference at the $p < 0.01$ level

The four manufacturing capabilities; cost, delivery, quality and flexibility, are all emphasised more by the hard integrators and the high investors than by the traditionalists. The means of all capabilities are highest for the high investors and lowest for the traditionalists, indicating that high investors emphasise most capabilities to greater extent than do traditionalists, with hard integrators somewhere in between. Delivery was ranked first in all groups, but what was more remarkable was that manufacturing flexibility had the lowest priority in all groups. A reason for the lack of relationships may be that the three AMT groups contain both high and low performing firms. Maybe only high performing firms have considered fully the importance of flexibility.

Infrastructural aspects

Research has indicated that worker empowerment and improvement programmes are the most important factors for achieving AMT success. The results of the ANOVA tests (Table IX) indicate that the high investors and hard integrators emphasise these variables to a greater extent than do the traditionalists and that the high investors emphasise TRAIN to a significantly greater extent than do the hard integrators. Consequently, investment in infrastructure is related to AMT investment, even though the difference between hard integrators and high investors is only modest. Greater differences are expected between high and low performing AMT users.

It was indicated that high performing AMT users most likely require organic organisations, characterised by decentralised work organisation with informal and integrated information channels. ANOVA tests show that there are only small differences between the groups regarding their organisational structure (Table IX). The level of decentralisation of operational decisions does not differ between the groups, while the high investors have decentralised more decisions about employment of workers and production planning, and emphasised soft integration to a significantly greater extent than have the traditionalists.

Maintenance management

Maintenance management is measured in terms of preventive maintenance, soft maintenance integration and hard maintenance integration. For firms with high AMT investments the availability of equipment is critical for success, and consequently maintenance of the equipment should be highly prioritised. The statistical tests (Table IX) verify that this is the case. All three measures are significantly higher for high investors compared to traditionalists and HMAIN is significantly higher for high investors compared to hard integrators. Consequently, preventive maintenance has high priority and direct labour employees are responsible for and carry out a large part of the inspection, quality and preventive maintenance activities in the production processes of AMT companies.

Performance

Several benefits of AMTs are highlighted in the literature, and flexibility is one of the most frequently mentioned, but overall competitiveness and profitability are other broader benefits. Table IX shows that the overall performances of the organisations were measured in terms of the relative profitability, growth and flexibility compared to the competitors. PROFIT is measured in terms of the relative level of return on investment (ROI) and return on sales (ROS) compared to their competitors. GROWTH is measured as the relative market share growth, sales growth and growth in ROI compared to their competitors. These measures should be relevant indicators of overall performances in most organisations. The measures are derived from Vickery *et al.* (1993) and Swamidass and Newell (1987). Flexibility is an important goal for firms with high AMT investments. The two flexibility measures are identified from Swamidass and Newell (1987) and Gerwin (1987).

The relative profitability was significantly higher for the high investors compared to both the other groups. Flexibility, which was considered to be an important performance measurement for organisations competing on differentiation strategies and emphasising flexibility capabilities, and growth were emphasised to largest extent by the high investors, but they only differed significantly from the traditionalists. Thus, the results indicate that AMT investments in themselves can generate high performance. These findings are interesting, but so far we do not know whether the better performances are results of the high AMT investments, the different organisational design, the emphasis on preventive maintenance, or of a combination of these. The different infrastructural and maintenance approaches of the clusters will most likely, in themselves, affect the performances. The analysis is based on a comparison between firms with different levels of AMT investments, no matter whether they are high or low performing. It is still possible to be a high performer without AMT investment, and consequently all three groups contain firms with high and low performances. The underlying causes for achieving the potential benefits in the organisations may, on the other hand, differ between firms with various levels of AMT investments.

Conclusions and comments

An empirical AMT taxonomy with three groups was identified. The traditionalists were characterised by firms of relatively small size with low levels of investments in AMT. The hard integrators emphasised computerised transactions between sub-units and processes to a larger extent than the investment in administrative, design and manufacturing technologies. The high investors group contained relatively large firms that have invested in most technologies and had computerised their transactions significantly more than both the other groups. The data was collected from five industry codes spread evenly between the three groups.

The differences between the business and manufacturing strategies of the three groups were not as significant as expected. Delivery differentiation was the most important business strategy for all groups and the relative importance of price was greater only for the traditionalists compared to the other groups. The high investors emphasised all manufacturing capabilities to larger extent than the other groups. These findings indicate that firms with heavy AMT investments are better prepared to compete with complementary capabilities than those with low levels of AMT investments.

Analysis also revealed that high AMT investors emphasised infrastructure (worker empowerment, improvement programmes and organisational design) and maintenance (prevention and integration into manufacturing) to greater extents than the other groups. Training and hard maintenance integration were especially important for hard integrators compared to both other groups. These findings verified the hypotheses stated. What was even more interesting, though, was that high AMT investors performed better than low-tech companies. Boyer *et al.* (1996), in their study of US companies, found no significant differences in terms of performances between high and low AMT users. The difference between the results could be of a cultural nature, i.e. the organisational culture in the average Swedish company may be better prepared for technology investment than that in the average US company. It could also be of technological nature, i.e. what is considered to be heavy AMT investments in Sweden is perhaps only modest investment in the USA. Therefore, heavy investors in the USA need greater change in infrastructure to be successful.

The analyses conducted were mostly descriptive in nature, and did not look for cause-and-effect relationship between underlying variables and high performance. It was indicated that companies with heavy AMT investments perform better than those without, but it was also indicated that they emphasise infrastructural and maintenance aspects to a greater extent than other companies. We therefore do not know which of infrastructure, maintenance and technology leads to competitive advantage and high performance. To fully understand the role of AMTs in Swedish companies it would be valuable to study the importance of infrastructure and preventive maintenance for companies to achieve the potential benefits of AMT.

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Appendix. Scales used

A. Advanced manufacturing technology

1. AMTDES; AMTMFG; AMTADM

Indicate the present amount of investment your manufacturing plant has in the following activities (seven-point Likert scale from "no investment" to "heavy investment"; AMTDES: b,c,d; AMTMFG: a,e,f,g,h,l,m,n,o; AMTADM: i,j,k,p,q,r,s,t).

a. Computer-aided manufacturing (CAM)

b. Computer-aided design (CAD)

c. Computer-aided engineering (CAE)
d. Computer-aided process planning (CAPP)
e. Robotics
f. Real-time process control systems
g. Group technology (GT)
h. Flexible manufacturing systems (FMS)
i. Electronic mail
j. Electronic data interchange (EDI)
k. Office automation
l. Computerised numerical control machines (CNC)
m. Automated material handling systems
n. Environmental control systems
o. Barcoding/automatic identification
p. Knowledge-based systems
q. Decision support systems
r. Material requirements planning (MRP)
s. Manufacturing resource planning (MRP II)
t. Activity-based accounting system

2. HINT1
To what extent are transactions of data between the following pairs of sub-units accomplished through computers or other computer-based technologies (seven-point Likert scale from "no transaction" to "all transactions")?

a. Marketing and engineering
b. Finance and engineering
c. Accounting and engineering
d. Personnel and engineering
e. Marketing and manufacturing
f. Accounting and manufacturing
g. Finance and manufacturing
h. Personnel and manufacturing

3. HINT 2
Please indicate the extent to which data transactions between the following pairs of processes are accomplished in your plant through the use of computers or computerised equipment (seven-point Likert scale from "no (0 percent) transaction computer-integrated" to "completely (100 percent) computer-integrated").

a. Design and production process planning (i.e. CAD data directly linked to CAPP)
b. Design and production (i.e. CAD data directly controlling production equipment such as CNC machines, robots or FMS)
c. Design and resource planning (i.e. parts data from CAD linked to MRP software)
d. Process planning and shopfloor production

e. Production planning and shopfloor production (i.e. production schedules generated by MRP controlling production equipment)
f. Between manufacturing equipment (i.e. various robots or computer-controlled machines linked by computerised material handling devices)

B. Environmental uncertainty(ENVIR)

Rate the predictability of the following items regarding your major product line (seven-point Likert scale from "always predictable" to "never predictable"; ENVIR1: a to c; ENVIR2: d to f).

a. Actual users of your products
b. Competitors for your supply of raw materials/parts
c. Competitors for your customers
d. Government regulations controlling your industry
e. Public's political view/attitude towards your industry
f. Your relationships with trade unions

C. Manufacturing capabilities

For your manufacturing plant, how important is the ability to (7 point Likert scale from "not important" to "absolutely critical"; MCOST: a,b,c,d; MDELIV: n,o,p; MQUAL: e,f,g; MFLEX: h,i,j,k,l,m).

a. Reduce inventory
b. Increase capacity utilisation
c. Reduce production costs
d. Increase labour productivity
e. Provide high performance products
f. Offer consistent, reliable quality
g. Improve conformance to design specifications
h. Make rapid design changes
i Adjust capacity quickly
j. Make rapid volume changes
k. Offer a large number of product features
l. Offer a large degree of product variety
m. Adjust product mix
n. Provide fast deliveries
o. Meet delivery promises
p. Reduce production lead time

D. Infrastructure

1. WEMP

Indicate the degree of emphasis which your manufacturing plant places on the following activities (seven-point Likert scale from "no emphasis" to "extreme emphasis").

a. Giving workers a broader range of tasks
b. Giving workers more planning responsibility
c. Giving workers more inspection/quality responsibility

d. Changing labour/management relationships
e. Improving direct labour motivation
f. Improving direct labour training

2. GROUP
Please answer the following questions regarding production teams in your manufacturing plant (seven-point Likert scale from "strongly disagree" to "strongly agree").

a. Our plant forms teams to solve problems
b. In the past three years, many problems have been solved through team efforts
c. During problem solving sessions, all team members' opinions and ideas are considered before making a decision

3. TRAIN
Please answer the following questions regarding employee skills and training in your manufacturing plant (seven-point Likert scale from "strongly disagree" to "strongly agree").

a. Direct labour undergoes training to perform multiple tasks in the production process
b. Employees are rewarded for learning new skills
c. Our plant has a high skill level, compared with our industry
d. Direct labour technical competence is high in this plant

4. QLEAD
Please indicate your level of agreement or disagreement with the following statements (7 point Likert scale from "strongly disagree" to "strongly agree").

a. All major department heads within our plant accept responsibility for quality
b. Plant management provides personal leadership for quality improvement
c. The top priority in evaluating plant management is quality performance
d. All major department heads within our plant work to encourage just-in-time production
e. Our top management strongly encourages employee involvement in the production process

5. INTERFUN
Please indicate your level of agreement or disagreement with the following statements (seven-point Likert scale from "strongly disagree" to "strongly agree").

a. Direct labour employees are involved to a large extent (on teams or consulted) before introducing new products or making product changes
b. Manufacturing engineers are involved to a great extent before the introduction of new products
c. There is a great deal of involvement of manufacturing and quality people in the early design of products, before they reach the plant
d. We work in teams, with members from a variety of areas (marketing, manufacturing, etc.) to introduce new products

E. Organizational structure
1. DEC
Which is the lowest level in your company that has the authority to make the following decisions (DEC1: a,b; DEC2: e,f; DEC3: c,d,h,i,j,k).

(1) GM = general manager or above
(2) PM = plant or divisional manager
(3) DM = departmental manager
(4) SUP = first-level supervisor
(5) SHOP = shop level

a. Number of workers required
b. Whether or not to employ a worker
c. Resolution of internal labour disputes
d. Amount of overtime to be worked at shop level
e. Delivery dates and priority of orders.
f. Production plans to be worked on
g. Dismissal of a worker
h. Methods of personnel selection
i. Method of work to be used
j. Machinery or equipment to be used
k. Allocation of work among available workers

2. SOFTINT
Rate the extent of usage of the following linkage mechanisms in coordinating efforts between different functional areas such as engineering, manufacturing, marketing, etc. (7 point Likert scale from "no emphasis" to "extreme emphasis").

a. Direct contact
b. Physical proximity
c. Electronic mail
d. Liaisons
e. Secondment
f. Cross functional project teams
g. Permanent project teams
h. Matrix organisation

F. Maintenance management
1. PMAIN
Please indicate your level of agreement or disagreement with the following statements (seven-point Likert scale from "strongly disagree" to "strongly agree").

a. Preventive maintenance has high priority in the production process
b. Direct labour employees are responsible for and carry out a large part of the preventive maintenance in the production process

2. SMAIN
Indicate the degree of emphasis which your manufacturing plant places on the following activities (seven-point Likert scale from "no emphasis" to "extreme emphasis").

a. Giving workers more inspection/quality responsibility
b. Giving the workers more responsibility for the efficiency of the machinery/equipment (downtime, speed and quality losses)

3. HMAIN
To what extent are transactions of data between the following pairs of sub-units accomplished through computers or other computer-based technologies (seven-point Likert scale from "no transaction" to "all transactions")?

i. Maintenance and engineering
j. Maintenance and manufacturing

G. Performance
1. GROWTH and PROFIT
For your major product line, indicate your position with respect to your competitors on the following dimensions for the last two years (seven-point Likert scale from "significantly lower" to "significantly higher"; GROWTH: a,b,d; PROFIT: c,e).

a. Market share growth
b. Sales growth
c. Return on investment (ROI)
d. Growth in ROI
e. Return on sales (ROS)

2. FLEX1
For your major product line, rate your manufacturing plant's position on the following dimensions (seven-point Likert scales - questions a and b from "least frequent in industry" to "most frequent in industry"; questions c and d from "narrowest range in industry" to "widest range in industry").

a. New products introduction
b. Introduction of new production processes
c. Product varieties
d. Product features

3. FLEX2
For your major product line, rate your manufacturing plant's relative position for each of the following types of manufacturing flexibility (seven-point Likert scale from "less than competitors" to "more than competitors").

a. Volume
b. Mix
c. Changeover
d. Modification