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Linking Process Technology and Manufacturing Performance Under the Framework of Manufacturing Strategy

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1. Introduction

Performance improvement is the goal of any manufacturing firms. A bunch of manufacturing practices are involved as suggested in the manufacturing strategy model. These include technologies, human resources and comprehensive programmes such as total quality management (TQM) and pull production. As a result, the linkage among various practices and performance are very complicated. Previous research in this field may have some limitations. The following part will review these limitations using TQM and AMT (Advanced Manufacturing Technology) as an example and argue the necessity of using structural equation modeling to deal with multiple variables.

First, most previous research on practice-performance linkage assumes that all practices directly contribute to the performance. Therefore, the conceptual models are mostly a one-layer model. The data analysis methods are mostly simple correlation or multiple correlation. The methodology is basically exploratory. The assumption of this research argues that practices may not all be directly correlated with performance. There may be several layers from practices to performance. Therefore, a comprehensive model based on path analysis or structural equation modeling is needed to investigate the practice-performance relationship. To specify the path-analysis model, a conceptual model is needed. In this research the conceptual framework from manufacturing strategy will be used.

Second, in previous research, the measures of practices vary from one single question to a set of questions which are grouped into a construct. It is not so common to develop constructs in AMT-performance research yet. The definition and classification of AMT are not consistent. Beaumont et al (2002) measure AMT in terms of direct (fabrication and assembly), indirect (engineering and design) and administrative (information management). Dasa and Narasimhan (2001) divided AMT into manufacturing technologies and design technologies. However, the classification of AMT is not consistent with technical definition (Groover, 1987; Goetsch, 1990; Singh, 1996; Kotha and Swamidass, 1998). In this research, AMT will be classified according to technical definition of computer integrated manufacturing (CIM).

In summary, practice-performance linkage has been mostly studied by simple or multiple correlation analysis in single areas such as technology or quality. In modern manufacturing companies, both practices as input and manufacturing performance as output are getting more and more complicated. Therefore, the relationship must be a complex one. This paper reports the research which aims to investigate this complex practice-performance linkage in a path-analysis model. The research is based on the manufacturing strategy framework. The idea is consistent with complex performance. Complex performance is described by Lewis and Roehrich (2009) in terms of the interaction between infrastructural complexity (e.g. buildings, enabling facilities, hardware) and transactional complexity (e.g. performance involving high degrees of embedded knowledge).

The paper is structure in five sections. In section two, literature on all types of practice and performance will be reviewed under the framework of manufacturing strategy and a set of hypotheses will be formulated. In section three, methodological issues such as data collection, operationalisation, validity and reliability tests and data analysis method will be described. In section four, the results will be presented. In section five, the results will be discussed and implications for practice and future research will be explored. In the final section, the research will be concluded; limitation and future research will be discussed.

2. A conceptual model and hypotheses formulation

2.1 The conceptual framework under manufacturing strategy

Manufacturing strategy is regarded as the manner in which the business unit deploys its manufacturing resources (Hayes and Wheelwright, 1984) and effectively uses its manufacturing strengths (Swamidass and Newell, 1987; Riis, 1992) to complement the business strategy. One of the themes in manufacturing strategy deals with various linkages or alignment among business objectives, manufacturing missions, manufacturing practices and performance. This paper aims to explore the relationship between manufacturing practices and performance. The key variables are practices and performance. The related variables include performance, structural decisions, infrastructural decisions, technology, and organization. The contents and possible relationships among the variables are illustrated in figure 1 and will be elaborated below.

2.2 Manufacturing performance

Under manufacturing strategy theory, manufacturing practices may not directly contribute to business performance such as market share and profitability. Their immediate contribution should be those at manufacturing levels such as cost reduction, quality improvement and shortening throughput time. Therefore, in manufacturing strategy research, business performance and manufacturing performance are distinguished (Tunalv 1991, McDermott and Stock, 1999, Sun and Cui 2002, Beaumont et al, 2002). These manufacturing performance dimensions, if being well aligned with business competitive objectives, will contribute to the achievement of business performance (Dasa and Narasimhan, 2001, Sun and Cui 2002). Therefore, there should be a corresponding relationship between manufacturing performance, manufacturing missions and business objectives. So in this research on practice-performance linkage, the performances refer to manufacturing performance. In manufacturing strategy research, manufacturing

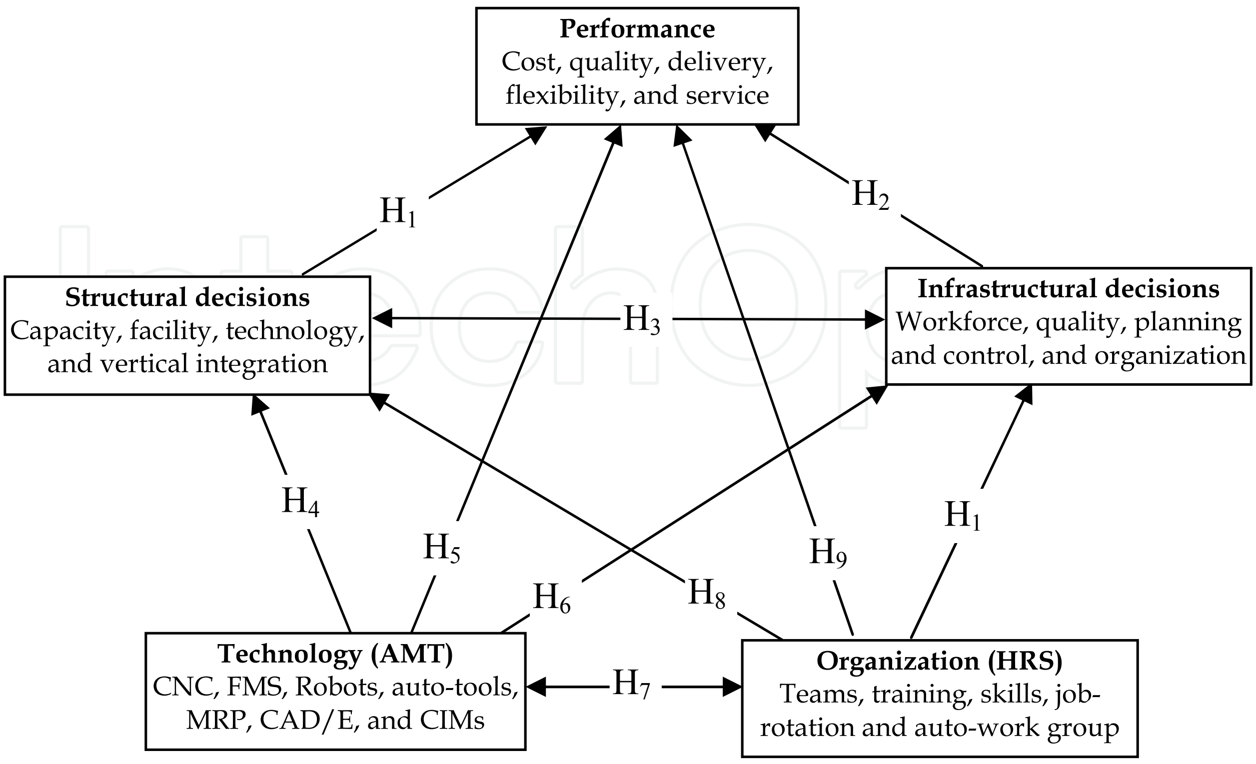

Fig. 1. A conceptual model for studying practice-performance linkage

performance should be corresponding to manufacturing missions/tasks which cover cost, quality, delivery, flexibility and service (Skinner 1969, Wheelwright 1984, Kim and Arnold 1996 etc.). The service often refers to customer satisfaction. Based on the alignment and corresponding theory, manufacturing performance can also be divided on into these five categories.

2.3 Action programmes based on structural and infrastructural decisions

Manufacturing action programs are often regarded as sets of decisions, that derive from the experience of a number of leading companies and that have proved to be successful (Schonberger, 1982; 1986; Hanson and Voss, 1993, Hanson *et al.*, 1994). They are the resources or functions that must be performed by manufacturing (Schroeder *et al.*, 1986). Because of the diversity of manufacturing decisions that must be made over time, Hayes and Wheelwright (1984) developed an organizing framework that groups them into two major categories, structural and infrastructural decisions. There is an essential agreement on this structure-infrastructure dichotomy in the literature (e.g., Leong *et al.*, 1990; Hill 1995, Tseng et al, 1999, Ng and Hung 2001). Structural decision category addresses the "bricks and mortar" decisions of capital spending. Examples of structural decisions include decisions on capacity, facility, the investment in technology, and vertical integration (Hayes and Wheelwright, 1984). Infrastructural decision category addresses more "tactical" issues, which affect the people and systems that make manufacturing work (Leong *et al.*, 1990). The infrastructural decisions may include decisions on workforce, quality, production planning and organization.

Corresponding to the above two decision areas, there are two types of action programmes. Those programmes supporting structural decisions such as increasing equipment and capacity are named as structural programmes. The programmes to support infrastructural decisions and choices are named as infrastructural programmes. Regarding contribution to performance, Hayes *et al*. (1988) suggested that infrastructure decisions were equally important as structure decisions. Performance improvement has been found positively correlated with infrastructural programs such as quality management programs, pull production systems, total productive maintenance (Cua, McKone and Schroeder, 2001), and supply chain management. Structural and infrastructural decisions are the two sides of the same manufacturing process. So they must be related to each other. Hayes *et al*. (1988) suggested that the distinction between structure and infrastructure was analogous to the distinction between computer hardware and software. The fixed, long-term and often unrecoverable investments of the firm in durable or facilities are analogous to computer hardware, while those that are more controllable by management are analogous to software. Based the contents and analysis of the two types of programmes, the following hypotheses are formulated.

H_1: Structural programs directly contribute to Performance.
H_2: Infrastructural programs directly contribute to Performance.
H_3: Infrastructural programs are positively related to Structural programs.

2.4 Technology

Under manufacturing strategy framework, technology is part of structural decisions. However, since technology has changed dramatically in the past decades years and it has very different features compared with other items such as capacity and facility etc, technology is treated separately and refers to Advanced Manufacturing Technologies (AMT).

AMT refers to those computer-aided technologies in information management, design, engineering and fabrication processes such as Computer Aided Manufacturing (CAM), Computer Aided Design (CAD) and Computer Aided Process Planning (CAPP). AMTs are the main technical components of Computer Integrated Manufacturing (CIM) systems. It is more than a group of advanced and automated technologies (Haywood, 1990). The main feature of CIM is the total integration of all manufacturing functions, including design, engineering, planning, control, fabrication, and assembly etc. through the use of computers. According to the CIM wheel model of the Society of Manufacturing Engineer (SME), there are one business and four technical components of a CIM system (Goetsch 1990). The four technical components are *planning and controlling*, *information resources management*, *product and process definition*, and *factory automation*. The four components and relevant AMTs involved have been described in details in literature (Groover, 1987; Goetsch, 1990; Singh, 1996; Kotha and Swamidass, 1998). The contents of the four components as well as their relationship with other variables will be analyzed below.

The factory automation component contains will directly influence the structural decision on the manufacturing process, especially the level of automation, new equipment implementation, capacity incensement and facility investment (Goetsch 1990, Bessant and Haywood 1988). In fact, the structural decision is called process choices in Hill's model (Hill

1995). Regarding the relationship between processes and AMT selection, there have been many similar models reported (Fix-Sterz et al 1987, p.11, Greenwood 1988, Lindberg 1990 p.12, Noori 1990, Ayres 1991, Parthasarthy & Sethi 1992). In general, for small batch and large variety job shop processes, standalone NC and MC will be suggested. For medium batch and variety, FMS is recommended. For large volume and few varieties, dedicated and automated lines are suggested. All these suggest that different processes may use different type of AMTs. In either case, the changes in process will require the changes in the technological dimensions. In other words, AMT is needed to support the implementation of structural programs for the purpose of updating manufacturing processes. The above reference leads to the fourth hypothesis.

H_4: The implementation of structural programs will be positively correlated with the utilization of manufacturing technologies.

The planning and controlling component includes such elements as planning/scheduling and controlling of facilities, materials, tools and shop floor activities. Hardware and software are available to automate each of the elements. Material Requirement Planning (MRP), as well as Manufacturing Resources Planning (MRP II), is an important concept with a direct relationship to CIM. Information resources management is the nucleus of CIM. Information, updated continually and shared instantaneously, is what CIM is all about. One of the major goals of this nucleus is to overcome the barriers that prevent the complete sharing of information among all other CIM components. The AMTs used for this purpose include Shared Databases (Shared DB), Wide Area Network (WAN), and Local Area Network (LAN). Planning and control is one of the key issues in infrastructural decision. However, it needs the support of technologies such as MRP and IT system. Re-engineering program is especially based on IT system implementation. The implementation of IT systems also needs the support of the relevant infrastructural changes. The above analysis leads to H_5.

H_5: The utilization of AMT is positively correlated with the implementation of infrastructural programs.

The need to achieve cost efficiency, quality, and flexibility is necessary, and has imposed a major challenge to the manufacturing industry in the nineties and beyond. AMT has been widely regarded as a new and valuable weapon to rise to the challenge proposed by the new market situation to manufacturing industries (Hunt, 1987; Noori, 1990). Therefore, AMT is widely regarded as the new weapon to improve manufacturing performance. This leads to the following hypothesis.

H_6: There is a positive relationship between technology utilization and manufacturing performance.

2.5 Organisational dimension

Workforce and organisation are part of the infrastructural decisions. However, the issue is different to other items such as quality, planning and control. Additionally, HRS and organisational issues have been studied intensively from AMT perspective. So the organisational issue is separated in the research. Since the scope of study is in manufacturing function, the organisation refers to work organisation on the shop floor.

Plenty of previous research was found on the changes in human resources in association with single AMTs. Lee and Leonard (1990) discovered that the Automated Guided Vehicle (AGV) in a small batch-manufacturing environment altered the nature of human work. Saraph and Sebastian (1992) reviewed many previous studies and concluded that the failure of AMT is mainly due to the implicit or explicit neglect of critical human resource factors. Gerwin and Kolandy (1992, p.215) said that AMT invites a wide range of changes in human resources management and practices. They further suggested that human resources development should be integrated with the design of new technologies in the manufacturing environment. Samson, Sohal and Ramsay (1993) argue that human resources issues such as commitment, involvement, the acceptance of changes, culture, work and skills should be considered for the successful implementation of AMT. According to these previous studies, the human resources suitable for AMT are characterised by lower division of labour, frequent job rotation, stable employment, active employees' participation, loose first-line supervision, more training, team-based work organisation, group-based incentive system (Sun 2001). Based on the requirement of the development in HRS and organisational dimension for AMT implement, the following hypotheses can be formulated.

H_7: The utilization of AMT is positively correlated with the adoption of new form of work organization.

The most influential research on organizational structure and technology was made by Woodward (1965) at Imperial College in England. The very original research was conducted through a survey of 203 British manufacturing firms (p.8). Woodward's research was carried out at the level of the work organization in the production department. The samples are purely industrial companies. Woodward found that type of production, i.e., the structural decision area, was related to a specific type of organizational structure. The found that production process was the most important factor deciding the organizational structure. The number of levels in the management hierarchy, the span of control of first-line supervisors, and the ratio of managers and supervisors to other personnel were all affected by the type of the employed production technology. Besides, the success or effectiveness of the organizations was related to the "fit" between processes and organizational structure. The successful firms of each type were those that had the appropriate structured technical systems. The theory leads to hypothesis H9.

H_8: The adoption of new work organization is positively correlated to the implementation of structural action programs.

HRS and organization is part if infrastructural decision area, there it is of course related to the infrastructural decisions and relevant action programmes to support the decision. For example, teams work, employee involvement and suggestions have been proved to be a necessary part of quality management program. Employee involvement in terms of suggestions and participation are associated with quality management activities such as quality circles and communication. Research has shown that job enrichment and task characteristics such as skill variety and autonomy are directly associated with higher work quality and employee satisfaction (Kopelman, 1986). Self-managing work teams typically produce positive results in terms of quality and costs (Beekun, 1989; Sundstrom, 1990). Teams are also proved to be useful for new product development (Sobek II et al, 1998). Therefore, it is natural to formulate hypothesis H_9 and H_{10}.

H_9: The autonomous working organization is positively correlated with performance.

H_{10}: The adoption of autonomous working organization is positively correlated with the implementation of infrastructural programmers.

The relevant variables and would-be relationships are illustrated in the conceptual model as shown in figure 1. The ten hypotheses will be tested in several models.

3. Empirical data

3.1 Questionnaire and data collection

The data for this research are from the International Manufacturing Strategy Survey (IMSS). The project was initiated by London Business School and Charlmes University of Technology in 1992. IMSS is an international research network consisting of 20 countries and 600 companies around the world, including developed countries, i.e. USA, Japan, British, Germany, and developing countries, i.e. China, Argentina, Mexico. The participant companies are in the metal products, machinery and equipment industry, i.e. the international Standard Industry Classification (ISIC) 38. For details regarding IMSS project, please refer to the book by Lindberg et al., 1998.

The research reported in this paper is based on the data from the third round of IMSS survey. Data collection methods varied from country to country. In some countries, sample selection was at the coordinators' convenience, and others used random sampling. Phone contact was followed in most of the participating countries, except for the Netherlands. The questionnaires were forwarded to participating companies via mailing, fax or on-site interview. In those countries where English is not used, the questionnaire was translated into local native languages. Participating countries sent their data to the coordinator who forwarded the final database to all participants. When this research is conducted, 282 sets of data are available.

IMSS questionnaire covers four aspects of manufacturing practices and strategies. In this research those questions that are related to practice and performance are selected. In the practice part, there are three sections, namely, technology, organization and improvement programs. The section on organization contains questions on suggestions, training, skills, teams, and job rotations. The performance section contains questions related to quality, flexibility, delivery, cost and customer satisfaction. These questions are listed in the Appendix.

3.2 Method for validity and reliability tests

Validity and reliability tests cover content validity, construct validity and reliability. *Content validity* refers to whether the items in a scale represent the contents of a theoretical construct. The content validity is based on literature review, research experiences, and case studies. The contents of technology, organization, improvement programmes and performance have all been reviewed and discussed in literature review section.

Reliability refers to the internal consistent of the items within a scale that aims to measure a theoretical construct. The most commonly used test method is internal consistency (Saraph, Benson, and Schoeder, 1989; Flynn, Schroeder and Sakakibala, 1994; Nunnally, 1978). It is estimated by using Cronbach's alpha. Peterson's (1994) summary of Cronbach coefficient shows that a value above 0.7 was thought to be sufficient in most of the situations. However, in the early stage of a research where the construct had not been well tested in previous studies, Nunnally (1967) recommended a level above 0.5 be acceptable.

Construct validity refers to whether a scale is an appropriate operational definition of an abstract variable or a construct (Nunnally 1978). It is established through the use of principal factor analysis. Factor analysis (de Vaus 1993) groups variables (i.e., single questions) into factors based on their common correlation. Those variables that are correlated with each other will be grouped together. Such a group of variables is called a factor. The grouping is based on the rotated loading coefficients. The threshold of the loading coefficients is related to the size of the sample. For example, Flynn, Schroeder and Sakakibala (1994) claim that for a sample of 100, the loading of 0.19 and 0.26 indicate significance at the 0.05 and 0.01 levels, respectively. This is based on the seminal work by Cohen (1988), who suggested that in 'soft' behavioral and management research, an effect size of 0.3 is often encountered (p.95). Based on Cohen's argument, de Vaus (1993) suggested a rule of thumb as follows: if its rotated loading coefficient is more than 0.30, then a variable will be included in the corresponding factor; if the loading coefficients for all the factors are more than 0.3, then the variable will be grouped according to the largest coefficient and conceptual analysis. As the sample size of this study is 250 (180 plus 71), with a 95% confidence level and an effect size of 0.3, the statistical power of this sample is larger than 0.95 (Cohen, 1988, p.102), which is high enough to identify inherent statistical relationships.

3.3 Construct measurement

All the questions used in this research are coded and corresponding to the questionnaire in the appendix.

3.3.1 Manufacturing performance and the latent variable

Manufacturing performance is directly measured by asking the respondents to indicate the amount of change of the performance dimensions over the past three years, with 1=strongly deteriorated and 5=strongly improved. According to the classification of manufacturing mission and performance under manufacturing strategy, five constructs/dimensions are formulated as shown in table 1. All the constructs passed validity and reliability tests. Additionally, a second level factor analysis of the five performance dimensions produces a valid and reliable performance scale. This means that a latent variable of performance exists.

3.3.2 Technology constructs and the latent variables

Based on the classification in literature, AMT is divided onto four constructs, namely, fabrication (NC, MC and FMS) assembly, design (CAD/E), information technology (IT) and integrated manufacturing with automated materials transportation and inspection. Confirmative factor analysis revealed that the FMS and NC, MC are separated into two factors which are named standalone automation and FMS, respectively. Other items passed the factor analysis. Finally five AMT constructs are identified. Their validity and reliability tests are list in table 2. Additionally, a second level factor analysis of the five technological dimensions produces a valid and reliable technology scale. This implies that there exist a latent variable of technology.

Code	Factors and items	1	2	3	4	5	Performance
	1. Quality:						0.64
D21	Manufacturing conformance	0.74					
D22	Product quality and reliability	0.72					
	2.Flexibility:						0.39
D24	Volume flexibility		0.88				
D25	Mix flexibility		0.63				
	3. Delivery:						0.78
D28	Delivery speed			0.73			
D29	Delivery reliability			0.88			
	4. Cost:						0.55
D213	Labor productivity				0.67		
D214	Inventory turnover				0.52		
D215	Capacity utilization				0.62		
D27	5. Service (customer satisfaction):					/	0.69
	Extraction Sums of Squared Loadings						
	Total	1.73	1.94	2.67	1.89	/	1.9
	% of Variance	38.64	54.23	43.46	39.45	/	40
	(Cronbach's α)	0.70	0.77	0.71	0.63	/	0.60

Table 1. Manufacturing performance constructs

	Factors and items	1	2	3	4	5
	1. Integrated manufacturing:					
BT15	Robots	.712				
BT16	Automated guided vehicles (AGVs)	.602				
BT17	Automated storage-retrieval systems (AS/RS)	.721				
BT19	Computer-aided in inspecting/testing/ tracking	.666				
	2. CAD/E:					
BT110	CAD; CAE		.817			
BT111	CAD-CAE-CAM-CAPP		.807			
BT112	Eng'g DB, Product Data Management systems		.654			
	3. IT and MRP:					
BT23	Purchasing and supply management			.884		
BT21	Material management			.867		
BT22	Production planning and control			.786		
BT24	Sales and distribution management			.760		
BT25	Accounting and finance			.730		
BT113	LAN-WAN/ Intranet / Shared databases/Internet			.551		
	4. Standalone automation:					
BT13	CNC-DNC				0.80	
BT12	Machining centers				0.77	

	Factors and items	1	2	3	4	5
BT14	Automated tool change - parts loading/unloading				0.75	
BT11	Stand-alone/NC machines				0.66	
	5. FMS:					0.63
	Extraction Sums of Squared Loadings					
	Total	1.83	1.75	3.66	2.23	/
	% of Variance	45.79	58.25	59.43	55.76	/
	% of Variance	45.79	58.25	59.43	55.76	/
	(Cronbach's α)	0.60	0.64	0.86	0.74	/

Table 2. Factor analysis of technologies by CFA

3.3.3 Organsiation construct and a representative partial model

The organization part contains ten questions. Some of them were deleted since they are not relevant. Corresponding to literature review on HRS development, questions on training, skills, working in teams and job rotation are selected. Since the constructs for HRS development as discussed in the paper are not as common as AMT constructs, explorative factor analysis is used to explore all the items. It is found that the two questions related to training do not significantly related to other items. Scanning the data revealed that the data on training may have something wrong. Maybe due to different training systems, there are quite many data that are not explainable at all. For example, annual training hours are more than 10,000 hours. So questions on training are neglected. A question on labour union cooperation is also deleted since it is not a common question for all participating countries. The rest questions are analyzed and produce 3 factors which are named, working in teams, autonomous working group and suggestions, and skills and job rotation. The validity and reliability tests are shown in table 3. The construct "auto work org. & suggestions" does not pass the reliability test. Its Cronbach alphas is only 0.39, less than the minimum threshold of

Code		F1	F2	F3
		Team	Skills & rotation	Auto work org. & suggestions
B06a	Team in fabrication	**0.90**	0.15	0.06
BO6b	Team in assembly	**0.90**	-0.01	0.12
BO9	Multiple skills	0.03	**0.86**	0.12
BO10	Job rotation	0.10	**0.86**	-0.01
BO5	Suggestions	-0.06	0.00	**0.87**
C512a	Auto work org.	0.30	0.13	**0.67**
	Rotation Sums of Squared Loadings:			
	Total	1.72	1.51	1.24
	% of Variance	28.59	25.10	20.60
	Cumulative %	28.59	53.69	74.30
	Cronbach's α	0.80	0.67	*0.39<0.5*

Note: ** significant at the level of p=0.01, * significant at the level of p=0.05

Table 3. Factor analysis of human resources items by EFC

0.05. The construct is not accepted. Instead, the two items "auto work org." and "suggestions" are treated as separate variables. So there are four variables in transitional dimension, namely, autonomous working organization, suggestions, working in team and skills and rotation.

The second level factor analysis of the four variables does not produce a valid and reliable scale. Therefore these four factors cannot be treated as a latent variable in data analysis. Based on the correlation analysis, it is found that "autonomous working organization" is correlated with all other three variables and no other correlation relationships exist. So this variable will be used as a representative variable of organizational dimension while other three are linked to the representative one. In fact, the measure of autonomous working organization is a quite representative since it covers knowledge of employees, delegation, training, improvement and autonomous teams. Details will be shown it the specified models in figure 2, 3, and 4.

3.3.4 Structural and infrastructural programmes

The programmes used in this research refer to a major project aimed at producing considerable changes in the company's management practice and organization. There are fourteen improvement action programs listed in the questionnaire. These programmes cover many aspects of manufacturing improvement. However, based on manufacturing strategy framework, improvement activities can be divided into structural and infrastructural areas. Based on this concept, the programmes are divided into two groups, namely structural and infrastructural programmes as shown in table 4. These two groups of programmes both pass the validity and reliability tests as shown in table 4. This indicates that companies do no implement action programme individually, rather in a coherent and systematic way. The validity and reliability tests imply that there exist a latent variable of structural programs and a latent variable of infrastructural programs.

Code		Component	Component
	Structural programmes:		
C53A	Process automation	.767	
C51A	Updating process equipment	.763	
C511A	Equipment productivity	.667	
C58A	Process focus	.634	
C52A	Expanding manufacturing capacity	.528	
	Infrastructural programmes:		
C59A	Pull production		.717
C513A	New product development		.713
C510A	Quality improvement		.687
C56A	Restructuring supply strategy		.623
C57A	Outsourcing		.582
C514A	Environmental compatibility		.490
	Extraction Sums of Squared Loadings:		
	Total	2.296	2.46
	% of Variance	45.928	41.06
	Cumulative %	45.928	41.06
	Cronbach's α	0.69	0.77

Table 4. Factor analysis of action programmes by CFA

3.4 Structural Equation Modeling (SEM) and model fitness test

In this study, structural equation modeling (SEM) is used to test the hypothesis as well as the fitness of the whole model. SEM is a method that can be used to establish relationships among multiple variables. It has several advantages over simple correlation, such as considering the collinearity effect. It can also include any possible relationships among a set of variables. SEM is applied in the following procedures.

An initial model is specified and assessed by examining the whole model fit and individual parameter significance. Multiple criteria will be used to evaluate the whole model fitness (Hu and Bentler, 1999; Kaplan, 2000; Byrne, 2001), goodness of Fit Index (GFI) (Jöreskog & Sörbom, 1984), comparative fit index (CFI) (Bentler, 1990) and root mean square error of approximation (RMSEA) (Hu and Bentler, 1998; MacCallum and James, 2000). Rule of thumb recommended by scholars regarding the fit indexes is used to evaluate the model fit. Generally, GFI and CFI value above 0.9 are regarded as a good fit; RMSEA value less than 0.05 indicates good fit and value between 0.05-0.08 (Browne and Cudeck, 1993) represents reasonable fit. For normed Chi Square, Carmines and McIver (1981) recommended the value be below 3, but a value up to 5 also represents a reasonable fit (Wheaton et al., 1977; Marsh and Hocevar, 1985). If the model doesn't fit well, it should be re-specified. Those items whose path loading coefficients are insignificant ($\alpha>0.05$) should be deleted for further test. In case all the measure coefficients are significant ($\alpha<=0.05$), the item with smallest coefficient is deleted. The process should be one by one gradually. The process ends when the whole model satisfies all the fitness criteria and all individual measurement coefficients are significant. The evaluation criteria and standards are summarized below:

- Coefficients for all paths are significant at 0.05 level
- χ^2/df: <3 good fit, 3- 5 reasonable fit
- GFI and/or CFI: 0.9-0.95 good fit, > 0.95 superior fit
- RMSEA: <0.05 good fit, 0.05- 0.08 reasonable

4. Results

The data analysis includes the test of four models. The first model (model-1) is based the conventional simple correlation. The second model (model-2) is based on multiple correlation with performance as dependent variable and four practices as independent variable. The third model (model-3) is based on the conceptual model in figure 2, i.e., all the hypotheses paths being included. The last model (model-4) will be the model deleting the no-significant paths gradually, if any. The testing results of the four models are summarized in table 5 and presented in details below.

4.1 Model 1 based on simple correlation

In model-1, each pair of the five variables are linked separately and simple bivariate correlation is calculated. The result is shown in table 5, the column of model-1. The result shows that all the correlation coefficients are significant. Based on the results from model-1, all the hypotheses should be accepted.

Hypotheses and paths			Model-1	Model-2	Model-3	Model-4
			Simple correlation	Multiple correlation	SEM (Initial)	SEM (Final)
H_1	Structural programs	→ Performance	0.00 ✓	0.01 ✓	0.44 ×	0.01 ✓
H_2	Infrastructural programs	→ Performance	0.00 ✓	0.01 ✓	0.92 ×	/
H_3	Infrastructural programs	→ Structural programs	0.00 ✓	/	0.00 ✓	0.00 ✓
H_4	Technology	→ Structural programs	0.00 ✓	/	0.04 ✓	0.00 ✓
H_5	Technology	→ Infrastructural programs	0.00 ✓	/	0.00 ✓	0.00 ✓
H_6	Technology	→ Performance	0.00 ✓	0.35 ×	0.64 ×	/
H_7	Auto work org.	→ Technology	0.00 ✓	/	0.00 ✓	0.00 ✓
H_8	Auto work org.	→ Structural programs	0.00 ✓	/	0.89 ×	/
H_9	Auto work org.	→ Performance	0.00 ✓	0.71 ×	0.28 ×	/
H_{10}	Auto work org.	→ Infrastructural programs	0.00 ✓	/	0.00 ✓	0.00 ✓
SEM Model fitness indexes			n/a	X^2=858 X^2/df=3.15 CFI=0.95 RMSEA=0.088	X^2=516 X^2/df=1.94 CFI=0.98 RMSEA=0.06	X^2=518 X^2/df=1.92 CFI=0.98 RMSEA=0.057
Model fitness test (Figure)			n/a n/a	Not (Cf., Fig.2)	Not (Cf., Fig.3)	Yes (Cf., Fig.4)

Note: ✓: significant with $p<0.05$, ×: not significant with $p>0.05$, /: the path was not specified or deleted due to insignificance

Table 5. The path significance (p) and model fitness tests of the four models

4.2 Model 2 based on multiple correlation

However, simple correlation does to take collinearity into consideration. This is proved by the test of model-2, which is based on multiple correlation. Model-2 is specified with performance as dependent variable and the four practice variables as independent simultaneously. The SEM model fitness test shows that only two paths are significant while two others are not significant as shown in table 5, the column of model-2. Different results can be observed in the two models. According to the SEM principle, as long as there is a non-significant path, the whole model does not fit well and no conclusion should be drawn. The reason is that the interrelations among the four practice variables have not been considered yet. This interrelationship may influence the relationship among practice and performance, as will be illustrated in the model-3 and 4.

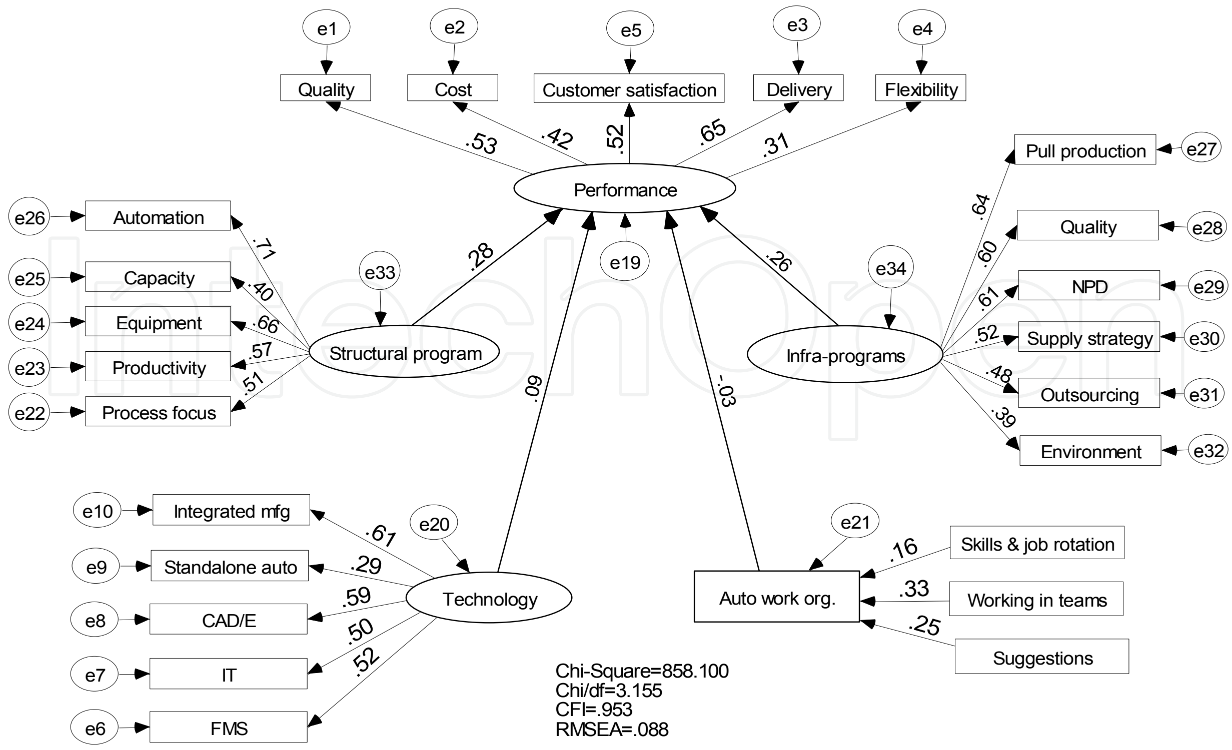

Fig. 2. The test of model-2 based on the multiple correlation principle

4.3 Mode-3 & 4 based on SEM

Model-3 is specified based on the conceptual model (cf., figure 1) of manufacturing strategy and incorporates all the possible hypotheses among the five variables. It is the initial specified model for testing. The test result of model-3 is shown in the column of model-3 in table 5. The details are shown in figure 3. The test shows that five paths are not significant. Obvious differences can be found between model-2 and model-3. In model-2, the paths for H1 and H2 are significant but not significant in model-3. According to the SEM principle, as long as there are non-significant paths, the whole model does not fit well and no conclusion can be drawn.

In the next step, the non-significant paths are removed one by one GRADUALLY and the model is tested again. The principle for removing non-significant paths should follow the principle from the least non-significant to the next least non-significant each by each. The reason is that removing one of the paths may change the path significance of other remaining paths. In this case, the path for H2 (p=0.92) should be removed from the model first. Then the path for H8 (p=0.89) is removed. The process continues until all the remaining paths are significant and the whole model fits well. Finally a model-4 is obtained as shown in figure 4. In this model, all the paths are significant and the whole model passes the fitness test as well. Therefore, conclusion can be drawn from model-4.

According to the results from model-4, it can be found that among the 10 hypotheses, four hypotheses are rejected and six are accepted, as shown the column of model-4 in table 5 as well as figure 5. Hypotheses 1, 3, 4, 5, 7 and 10 are accepted, while hypotheses 2, 6, 8 and 9 are rejected.

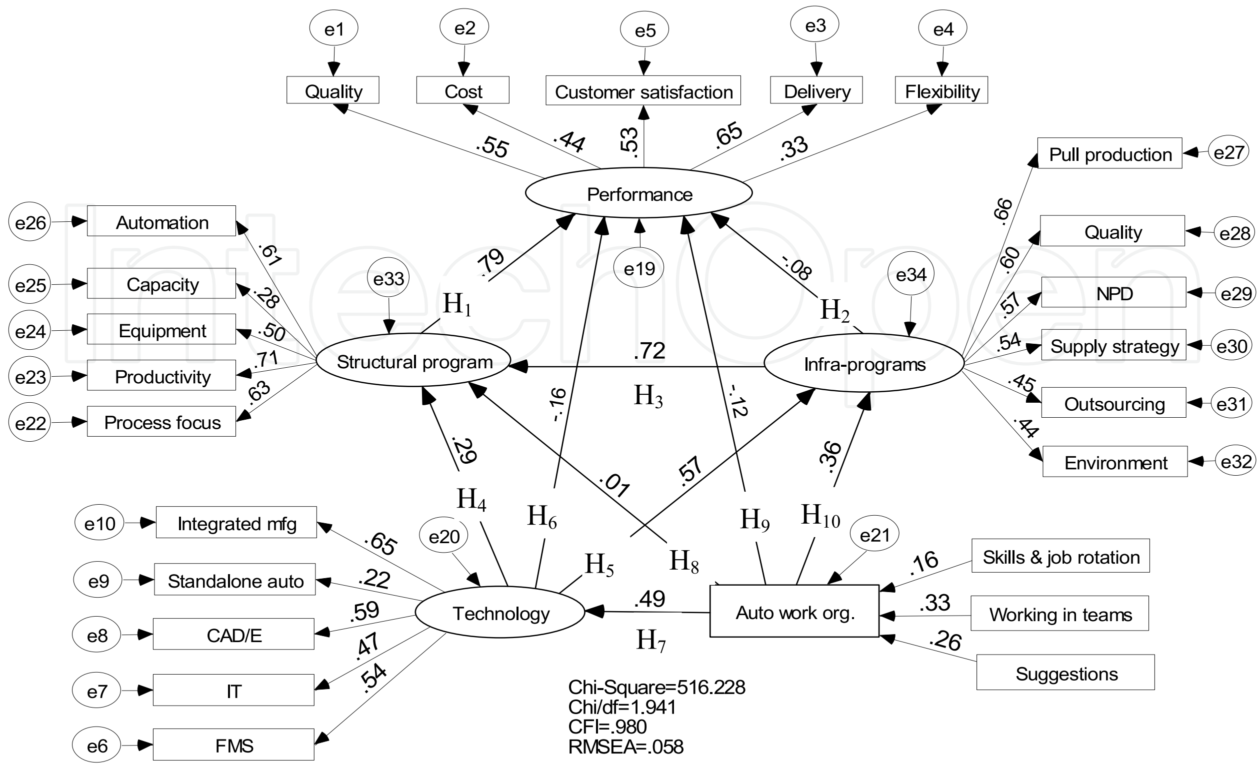

Fig. 3. The specified model (model-3) and test result

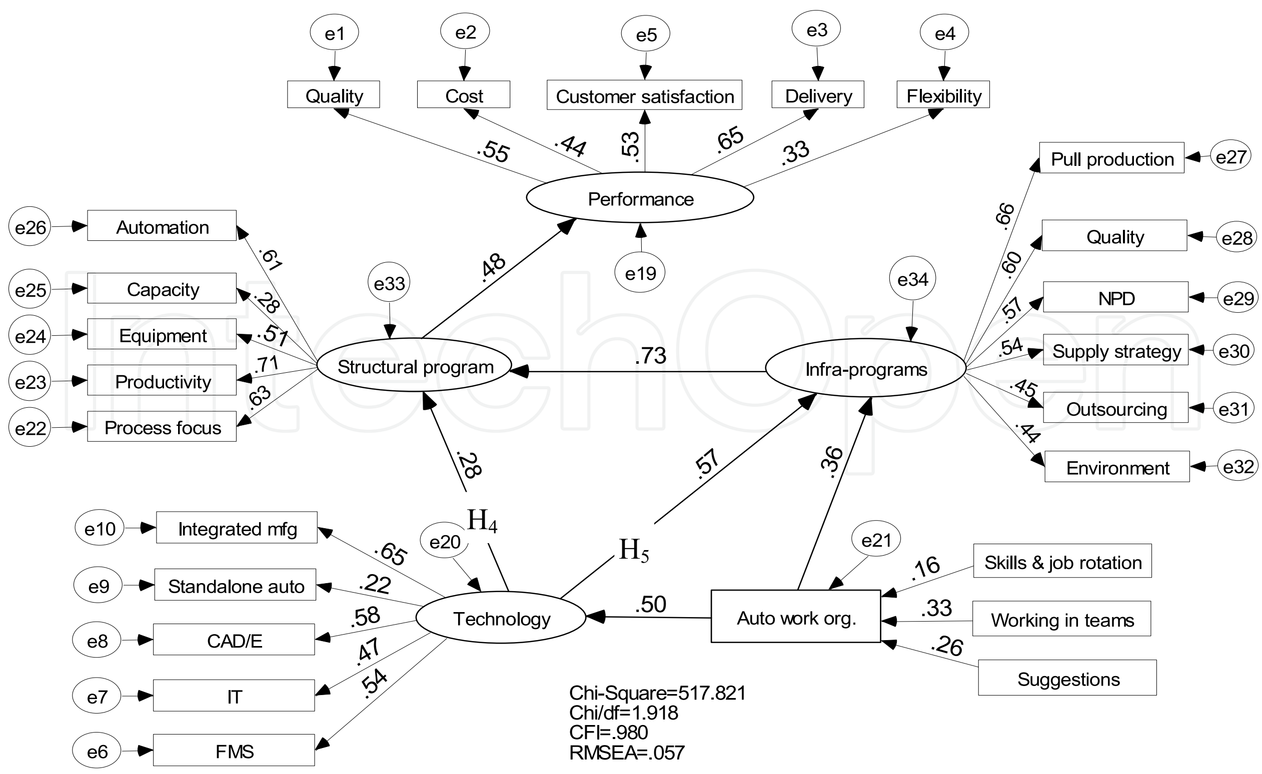

Fig. 4. The modified model (model-4) by gradually deleting no-significant paths

5. Discussions and implications

The research finds that structural programs are the only practice that directly contributes to manufacturing performance, while other three dimensions such as infrastructural programs, technology and organization contribute indirectly through structural programs. The research results trigger the following discussions.

5.1 Manufacturing process is the core

This research reveals that the improvement programs that are related to the physical process directly contribute to manufacturing performance. The structural programs work on the manufacturing process. Therefore, the process is the core and direct factor that explains manufacturing performance. This can be supported by another stream of structural research on quality management. The research based on the USMBQA framework is also a structural model and produced very valid and reliable research results. For most of the research based this model, process management is directly correlated with performance (Kaynak, 2003, Meyer and Collier 2001, Pannirselvam and Ferguson 2001, Wilson and Collier 2000). The implication is very clear. To improve the manufacturing performance, it is critical to improve the manufacturing process.

5.2 Infrastructure is the basis

It is surprising that infrastructural programs like quality management, full production etc do not directly contribute to manufacturing performance. This is opposite to many previous studies on the relationship between quality management and performance. However, if looking at the research models in previous research, it will be possible to explain the difference. In previous research, only part of the programs is investigated and other relevant factors such as structural programs are ignored. When simple correlation or multiple correlation is used in this research, the infrastructural programs are found to be positively correlated with performance (cf., model-1 in table 5). Then the conclusion will be different.

The explanation is that infrastructural programs are useful. However, they do not contribute directly to performance but through the structural programs. The path loading between infrastructural to structural programs is very high (0.73) and very significant (p=0.001). These infrastructural programs are for the establishment of infrastructure. They support the manufacturing structural technical process. The finding implies that whatever infrastructural programs to be implemented, the evaluation may not be whether it directly contributes to performance, but the requirement of the process or programs related to the structural side of the process.

5.3 Technology and organization are useful, but not directly contributing

Technology is not found to be directly correlated with performance. In the past 20 years, AMT has been widely used by manufacturing companies all-over the world. However, world-wide research found that not all AMT perform as expected. Some AMTs performs "satisfactory", but did not produce the full benefits. Other AMTs perform well on the shop floor level, while the business performances of the companies were not improved (Voss, 1988). All these problems have caught the attention of both researchers and practitioners.

Since the beginning of the 1980s, management of technology, especially implementation of AMT, has been a hot topic (Gerwin, 1982; Voss, 1988). The relationship between AMT and performance was investigated conceptually (Macbeth, 1989, p.71; Bishop and Schofield, 1989, p.44), by case studies (Sohal, 1996; Sun, Hjulstad and Frick, 1997) and by survey (Sun 2000, Small, 1998). Recent empirical research does not found that the use of AMT has direct impact on business or manufacturing performance (Swamidass and Kotha, 1998). The research by Beaumont et al (2002) intents to investigate AMT investment and performance in foreign-owned and Australian domestic companies. They did not conclude whether the AMT is significant related to performance. Sun (2000) found that little linear relationship exists between AMT and performance. The result from this research provides a reasonable explanation. Future research is needed to investigate the detail relationship between AMT and structural infrastructural action program. For example IT and supply chain management is one of the topic recently attracts researchers' attention.

5.4 Methodological implications

In this research, four different models are tested for the same set of hypotheses tests. Obvious differences are found among the four models. The differences have significant implications for selection of research methods on relationships among multiple variables. Simple correlation is simple and visual. However, its main limitation is the ignorance of the collinearity effects among variables. It can be used for identity or specify the preliminary model or explorative research at preliminary stage. Multiple correlation has the advantage of taking collinearity into consideration. However, it does not cover the interactions among the independent variables. If there are such interactions, multiple correlation results may not be reliable. Structural Equation Modeling (SEM) method is a good method since it covers collinearity effects and interactions among all the variables. As a result, it is more reliable for investigating relationships among multiple variables. More research on operations management, technology management and quality management are using more SEM to investigate multi-variant relationships (Kaynak, 2003, Meyer and Collier 2001, Pannirselvam and Ferguson 2001, Wilson and Collier 2000).

6. Conclusions, limitations and future research

The research in this paper has investigated the complex relationship among manufacturing practice and manufacturing performance. It is based on a structural model that incorporates all the possible linkages among practices and performance. The research may have the following contribution to the literature on practice-performance linkage. First, the research is based on the conceptual framework of manufacturing strategy, therefore, the model prevents from ignoring any possible linkages. Second, the data analysis is conducted with all available methods so that differences and limitations of simple and multiple correlation analysis are identified. Finally, the research produces several different results which are worthwhile to be considered in research in operations management.

The main message from this research is that not all practices may directly contribute to performance. It is the structural programmes that directly contribute to performance. Whatever other programs or technologies or organizational practices to be implemented, the final goal is to improve the manufacturing process. If the process is not improved, the contribution of other practices may not be realized.

Since the research aims to be comprehensive and holistic, the scope of the paper is pretty wide. The ten hypotheses may not be fully discussed conceptually. The implications are not fully explored for each sub-relationship. Page and words limitation may also contribute to this weakness. However, in future research which looks at a sub-relationship, for example, between technology and structural programs, the conceptual part should be enhanced.

Some of the sub-relationships have been well studied. For example, the relationship between technology and HRS/organization has been studied insensitively in the past decades. However, future research may include the following topics, the relationship between technology and structural programmes, the relationship between technology and infrastructural programs, as well as the relationship between structural and infrastructural programs.

The research provides a conceptual model and data analysis approach for investigating practice-performance relationships. Triangulation research based on the model is welcomed and appreciated to cross-proof the validity of the research method. Based on this method, a series of comparative studies can be conducted, for example, between mass and job-shop process, between Small and Media Enterprises (SME) and larger companies, and between developed and developing countries.

7. Appendix: Questions

PT3. Please indicate to what extent your activity uses one of the following process types: (indicate percentage of total volume)

Process type	
one of a kind	***BPT3a*** %
batches	***BPT3b*** %
mass production	***BPT3c*** %
	100 %

T1. Please indicate to what extent the operational activity is performed using the following technologies:

		No use			High use	
Stand-alone/NC machines	***BT11***	1	2	3	4	5
Machining centres	***BT12***	1	2	3	4	5
CNC-DNC	***BT13***	1	2	3	4	5
Automated tool change - parts loading/unloading	***BT14***	1	2	3	4	5
Robots	***BT15***	1	2	3	4	5
Automated guided vehicles (AGVs)	***BT16***	1	2	3	4	5
Automated storage-retrieval systems (AS/RS)	***BT17***	1	2	3	4	5
Flexible manufacturing/assembly systems – cells (FMS/FAS/FMC)	***BT18***	1	2	3	4	5
Computer-aided inspection/ testing/ tracking	***BT19***	1	2	3	4	5
Computer aided design/engineering (CAD; CAE)	***BT110***	1	2	3	4	5

Integrated design-processing systems (CAD-CAE-CAM-CAPP)	***BT111***	1	2	3	4	5
Engineering databases, Product Data Management systems	***BT112***	1	2	3	4	5
LAN-WAN/ Intranet / Shared databases/Internet	***BT113***	1	2	3	4	5

T2. To what extent are the following management areas software supported through the use of Enterprise Resource Planning systems?

		No use			**High use**	
Material management	***BT21***	1	2	3	4	5
Production planning and control	***BT22***	1	2	3	4	5
Purchasing and supply management	***BT23***	1	2	3	4	5
Sales and distribution management	***BT24***	1	2	3	4	5
Accounting and finance	***BT25***	1	2	3	4	5
Human Resources management	***BT26***	1	2	3	4	5
Project Management	***BT27***	1	2	3	4	5
Other (please specify ***BT28a***)	***BT28b***	1	2	3	4	5

O1. At the end of the last fiscal year, in your business unit you had:
a. ___***BO1a1***___ employees in total, of which ___***BO1a2***___ were salaried employees,
b. ___***BO1b***___ % of salaried employees belonging to a union or similar workers associations.
c. ___***BO1c***___ % of employees in total who are temporary (i.e. not permanent) workers

O2. How many organizational levels do you have (plant manager to first-line supervisors)? ___***BO2***

O3. How many employees are under the responsibility of one of your line supervisors (on average)?
___***BO3a***___ in Fabrication ___***BO3b***___ in Assembly

O4. a. What proportion of your direct employees are payed on incentives? ___***BO4a***___ % employees
b. Among which (please select all relevant alternatives)
Work Group incentive ☐ **BO4b1, I**ndividual incentive ☐ **BO4b2,** Companywide incentive ☐ **BO4b3**

O5. To what extent are your employees giving suggestions for product and process improvement?

No suggestions			**High number of suggestions**	
1	2	3	4	5

O6. a. What proportion of your total work force work in teams? (*):
in Fabrication ***BO6a*** % in Assembly ***BO6b***_ %

O7. How many hours of training are given to new production workers? __***BO7***_____ hours per new worker

O8. How many hours of training per year is regularly given to regular work-force?
___***BO8***___ hours per employee

O9. How many of your production workers do you consider as being multi-skilled?(*)
BO9 % of total number of production workers.
(*) Note: A multi-skilled operator is skilled in several operational tasks.

O10. How frequently do your production workers rotate between jobs or tasks?

Never				**Frequently**
1	2	3	4	5

C5 This question explores the action programs * to which your company is now devoting high resource and innovation effort and on which is concentrated the management focus and commitment. Please indicate whether the program has been undertaken within the last three years. (* *By action program is meant a major project aimed at producing considerable changes in the company's management practices and organization)*

	Action programmes	**Degree of use last 3 years**
C51a	Updating your process equipment to industry standard or better	1 2 3 4 5
C52a	Expanding manufacturing capacity (e.g. buying new machines; hiring new people; building new facilities; etc.)	1 2 3 4 5
C53a	Engaging in process automation programs	1 2 3 4 5
C54a	Implementing Information and Communication Technologies and/or Enterprise Resource Planning software	1 2 3 4 5
C55a	Reorganizing your company towards e-commerce and/or e-business configurations	1 2 3 4 5
C56a	Rethinking and restructuring your supply strategy and the organization and management of your suppliers portfolio	1 2 3 4 5
C57a	Concentrating on your core activities and outsourcing support processes and activities (e.g. IS management, maintenance, material handling, etc.)	1 2 3 4 5
C58a	Restructuring your manufacturing processes and layout to obtain process focus and streamlining (e.g. reorganize plant-within -a-plant; cellular layout, etc.)	1 2 3 4 5
C59a	Undertaking actions to implement pull production (e.g. reducing batches, setup time, using kanban systems, etc.),	1 2 3 4 5
C510a	Undertaking programs for quality improvement and control (e.g. TQM programs, 6σ projects, quality circles, etc.)	1 2 3 4 5
C511a	Undertaking programs for the improvement of your equipment productivity (e.g. Total Productive Maintenance programs)	1 2 3 4 5
C512a	Implementing actions to increase the level of delegation and knowledge of your workforce (e.g. empowerment, training, improvement or autonomous teams, etc.)	1 2 3 4 5
C513a	Implementing actions to improve or speed-up you process of new product development through e.g. platform design, products modularization, components standardization, concurrent engineering, Quality Function Deployment, etc.	1 2 3 4 5

C514a	Putting efforts and commitment on the improvement of your company's environmental compatibility and workplace safety and healthy	1 2 3 4 5

D2. Please indicate the amount of change of the following performance dimensions over the last three years

		Strongly deteriorated		**No change**	**Strongly improved**	
Manufacturing conformance	***D21***	1	2	3	4	5
Product quality and reliability	***D22***	1	2	3	4	5
Product customization ability	***D23***	1	2	3	4	5
Volume flexibility	***D24***	1	2	3	4	5
Mix flexibility	***D25***	1	2	3	4	5
Time to market	***D26***	1	2	3	4	5
Customer satisfaction	***D27***	1	2	3	4	5
Delivery speed	***D28***	1	2	3	4	5
Delivery reliability	***D29***	1	2	3	4	5
Manufacturing lead time	***D210***	1	2	3	4	5
Procurement lead time	***D211***	1	2	3	4	5
Procurement costs	***D212***	1	2	3	4	5
Labor productivity	***D213***	1	2	3	4	5
Inventory turnover	***D214***	1	2	3	4	5
Capacity utilization	***D215***	1	2	3	4	5
Overhead costs	***D216***	1	2	3	4	5
Environmental performance	***D217***	1	2	3	4	5

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It is widely accepted that technology is one of the forces driving economic growth. Although more and more new technologies have emerged, various evidence shows that their performances were not as high as expected. In both academia and practice, there are still many questions about what technologies to adopt and how to manage these technologies. The 15 articles in this book aim to look into these questions. There are quite many features in this book. Firstly, the articles are from both developed countries and developing countries in Asia, Africa and South and Middle America. Secondly, the articles cover a wide range of industries including telecommunication, sanitation, healthcare, entertainment, education, manufacturing, and financial. Thirdly, the analytical approaches are multi-disciplinary, ranging from mathematical, economic, analytical, empirical and strategic. Finally, the articles study both public and private organizations, including the service industry, manufacturing industry, and governmental organizations. Given its wide coverage and multi-disciplines, the book may be useful for both academic research and practical management.