The Role of Hard and Soft Technologies in Improving Competitive Capabilities: The Case of Thailand

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ABSTRACT
Drawing on the resource-based view (RBV) of the firm, this study investigates the relationships between hard and soft technologies and multiple dimensions of competitive capabilities. To date, research in this area remains rare; therefore, this study extends prior research by offering evidence that begins to explain relative effects of hard and soft technologies on cost efficiency, quality, cycle time reduction, and flexibility. Using data from 186 manufacturing plants in Thailand, this study has found that hard technologies have a relatively stronger effect on flexibility, cost efficiency, and cycle time reduction, whilst soft technologies have a superior effect on quality. The results may be translated into specific implications for technology justification and capability creation and sustainability in response to intensified global competition.

Keywords: Just-in-Time, manufacturing technology, operations improvement, quality management, TQM, supply chain management

INTRODUCTION
Global competition has intensified the pressure on manufacturing plants to improve along multiple aspects of competitive manufacturing capabilities (Boyer & Lewis 2002). Based on the operations management (OM) perspective, competitive capability aspects of manufacturing include cost efficiency, quality, cycle time, and flexibility (e.g., Hayes & Wheelwright 1984; Droge, Jayaram & Vickery 2004). In order to achieve a high level of manufacturing capability, Swamidass (2003) highlights the important roles of hard, computerized technologies and soft technologies considered as critical resources. Hard, computerized technologies are a complex bundle of equipment, computer hardware and software, such as, computer-aided design (CAD), computer numerical control (CNC) machines, and robots. In contrast, soft technologies are manufacturing techniques and know-how, such as total quality management (TQM) and just-in-time (JIT) operations.

Although empirical studies have examined the linkage between hard and soft technologies and manufacturing capability, different groups of studies have reported the results, which are not definitive. One group of studies has focused on the relationship between organizational resources and a composite index of manufacturing performance or capabilities (e.g., Beaumont, Schroder & Sohal 2002; Challis, Samson & Lawson 2002; Das & Jayaram 2003; Dean & Snell 1996). Dean and Snell (1996) and Challis et al. (2002), for example, find that there is no direct effect of advanced manufacturing technologies (AMT) on manufacturing performance. Challis et al. (2002) examine significant direct effects of TQM and JIT on manufacturing performance, whilst Dean and Snell
(1996) report that only TQM produces significant results. Another group has emphasized the relationship between organizational resources and a specific aspect of manufacturing capabilities. Malhotra, Heine and Grover (2001) propose that hard technologies (i.e. CAD technology functionality and sophistication) enhanced flexibility, whereas Pagell and Krause (1999) assert that their company cases adopted AMT not to increase flexibility, but to improve quality and/or to decrease lead times or costs. Patterson, West and Wall (2004) report that neither TQM nor JIT accounts for sufficient variance in subsequent productivity to be statistically significant, whilst AMT (hard technologies) is related to subsequent productivity.

It seems that the latter group has been supported by the resource-based view (RBV) of the firm, arguing that different dimensions of capabilities require specific configurations of resources. Ketokivi and Schroeder (2004) propose that, based on the premise that each practice-performance model may be unique, the organizational determinants of high conformance quality may be different from those of flexibility; hence, a regression (or equivalent) model that combines the two dependent variables into one is likely mis-specified. Ward and Zhou (2006) point out that many studies have explored hard or soft technologies for improving manufacturing capabilities; however, the empirical evidence provides little guidance to managers needing to make a reasoned choice about the merits of pursuing these two kinds of technologies. Therefore, this paper aims to address these relatively neglected areas presented above by focusing on a major research question: what are the relative effects of hard and soft technologies on multiple aspects of manufacturing capabilities (cost efficiency, quality, cycle time reduction, and flexibility)? Swink and Nair (2007) suggest that this is an important question as many manufacturing firms have sunk enormous amounts of capital into investments in hard technologies over the last three decades. The study on this area may be translated into specific implications for technology justification and capability creation and sustainability.

Thailand has been considered as the context of this study for three reasons. Firstly, according to the special issue of Production and Operations Management (POM), researchers have been increasingly interested in the issue of operations management in emerging economies (Iyer, Lee & Roth 2008). Secondly, in terms of its importance for the regional and world economies, Thailand, one of emerging economies, has been considered as an important production platform and the regional
headquarters for many multinational companies (Ferguson 1997; Grewal & Tansuhaj 2001; Intarakumnerd, Chairatana & Tangchitpiboon 2002). Finally, up to date, empirical studies, which use a resource-based view framework to examine operations management issues and focus on firms’ resources in the context of emerging economies, remains rare (Hoskisson, Eden, Lau & Wright 2000; Mills, Platts & Bourne 2003; Williamson 1999).

THEORETICAL DEVELOPMENT AND HYPOTHESES

Drawing on the resource-based view (RBV) of the firm, the research framework, which represents the relationships between hard and soft technologies and multiple aspects of manufacturing capabilities, is shown in Figure 1. The RBV is the umbrella term academics use to describe how a company’s resources drive its performance (Collis & Montgomery 1995). Grant (1991) concludes that, on their own, few resources are productive; and productive activity requires the cooperation and coordination of teams of resources. A capability is the capacity for a team of resources to perform some task or activity. While resources are the sources of a firm’s capabilities, capabilities are the main sources of its competitive advantage. The RBV examines these resources, such as hard and soft technologies, as inputs into production process (Grant 1991; 2005; Hitt, Ireland & Hoskisson 2007). With regard to the relationship between resources and capabilities, the types, the amounts, and the qualities of the resources available to the firm have an important bearing on what the firm can do (i.e. the firm’s capability(s)) because they place constraints upon the range of organisational routines that can be performed and the standard to which they are performed (Grant 1991). This means different types of capabilities would require specific type, amount, and quality of the resources. It is also implied that different firms that own different types, amounts, and qualities of the resources would perform differently. Next, the relationships of hard and soft technologies and four aspects of manufacturing capabilities (cost efficiency, quality, cycle time, and flexibility) will be discussed.

Figure 1 Research framework

Hard technologies and manufacturing capabilities

In this study hard, computerized technologies are defined as a complex bundle of equipment, computer hardware and software used in related activities in manufacturing (Swamidass 2003). Hard,
computerized technologies can also be considered as three interrelated aspects as suggested by previous studies (e.g., Adler 1988; Boyer, Ward & Leong 1996). Firstly, *design technologies* comprise of computer-aided design (CAD), computer aided engineering (CAE), and computer-aided process planning (CAPP). Secondly, *processing technologies* include computer-aided manufacturing (CAM), real-time process control systems, computer numerical control (CNC) machines, and robots. Thirdly, *administrative (planning) technologies* consist of electronic mail (e-mail), manufacturing resource planning tool (MRPII), and enterprise resource planning (ERP). Hard technologies are also referred to as programmable automation (PA) (Collins, Ryan & Matusik 1999), advanced manufacturing technology (AMT) (Boyer et al. 1996; Kotha & Swamidass 2000), and flexible automation (FA) (e.g., Adler 1988; Parthasarthy & Sethi 1992; 1993).

However, primary benefits of hard technologies have been debatable. Sohal (1994) reports that the benefits of hard technologies identified as most important at the time of the assessment from Australian and the UK respondents are “improved quality”, “reduced costs”, “increased throughput” and “increased flexibility”. However, others (e.g., Boyer, Leong, Ward & Krajewski 1997; Gold 1982; Meredith 1987) argue that hard technologies are primarily designed to provide increased manufacturing flexibility with relatively little diminution of other dimensions. Nevertheless, Das (2001) argues that flexibility may not be an explicit goal of manufacturing technology investments.

Nevertheless, there is more evidence supporting that hard technologies have contributed not only to greater flexibility, but also improved quality, lowered costs, and reduced cycle time. While their informational capacity enables the storing of computer programs, recording of machine and worker performance, and feedback about the process itself (Zuboff 1988). Hard technologies, therefore, result in quicker retooling and set-up, greater diversity of work methods, and economies of scope (Goldhar & Jelinek 1983; Zammuto & O’Connor 1992). Ward and Zhou (2006) confirm that integrated production control systems, such as MRP I and II, 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. Previous literature supports that hard technologies may allow
production of widely varied or customized products with greater precision, speed, and efficiency (Boyer & Lewis 2002; Corbett & Van Wassenhove 1993). Accordingly, we hypothesise:

- **Hypothesis 1a.** Hard technologies are positively associated with cost efficiency.
- **Hypothesis 1b.** Hard technologies are positively associated with quality.
- **Hypothesis 1c.** Hard technologies are positively associated with cycle time reduction.
- **Hypothesis 1d.** Hard technologies are positively associated with flexibility.

**Soft technologies and manufacturing capabilities**

Although literature examines the importance of hard technologies, which are considered as externally acquired resources, in determining manufacturing capabilities as presented in the previous sections, the RBV argues that most of these technologies are governed by weak appropriability regimes which are easily accessible in the market, or from the stock of public knowledge (Christensen 1996; Nair & Swink 2007). Since these technologies are often obtained from independently owned technology firms (Cohen & Zysman 1988), imitation is easy. Barney (1999) points out that some organisational resources should not be sourced and must be built internally. These internally developed resources evolve into the core competencies of a firm (Prahalad & Hamel 1990) that are inimitable and can potentially deliver long-term comparative advantage (Teece, Pisano & Shuen 1997). In contrast to externally acquired resources (hard technologies), internally developed resources typically take long periods of time to develop, and are often path dependent and idiosyncratic (Teece et al. 1997).

Examples of internally developed resources discussed in the literature include workforce organization and training (Bresnahan et al. 2002) and production skills (Rothaermel & Hill 2005). These internally developed resources, hence, are referred to as soft technologies.

In the present study, *soft technologies* refer to manufacturing techniques and know-how, which represent operating policies in the areas of JIT and TQM. Recent literature suggests that JIT and TQM are among the most sustainable management philosophies to have been adopted for decades and still continue to add value to company performance (Dangayach & Deshmukh 2001; Ian, Mohamed & Mohd 2002; Vokurka, Lummus & Krumwiede 2007). Many authors have found difficulty in precisely listing the practices that comprise JIT and TQM because of the extensive
overlap between the two philosophies (Flynn, Sakakibara & Schroeder 1995). Dean and Snell, for instance, pointed out that “like just-in-time, total quality involves a few relatively simple central concepts and an amorphous array of peripheral associated practices” (1991: 778).

Therefore, Flynn et al.’s (1995) approach of considering the interested practices was adopted in this study. It represents unique JIT and TQM practices, and common infrastructural (overlapping) practices. Drawing from previous studies relating to JIT and TQM (e.g., Cua et al. 2001; Flynn et al. 1995; Matsui 2007; Mehra & Inman 1992; Sakakibara et al. 1993), the interested aspects of the soft technologies construct include just-in-time (JIT) operations, process management, customer focus, workforce management, and supplier management. As Flynn et al.’s (1995) suggestion, we do not suggest that either set of unique practices, which are used in isolation, leads to effective performance. Rather, we advocate that each practice is complementary to each other.

Extensive literature supports the relationships between soft technologies and multiple aspects of manufacturing capability. Swamidass (2003) examines that statistical quality/process control (SQC/SPC) considered as a process management tool applies the laws of probability and statistical techniques for monitoring and controlling the quality of a process and its output. Thus, SQC/SPC can be used to reduce variability in the process and, in turn, improve quality. Flynn et al. (1995) explain that the importance of an open relationship with customers (i.e. customer focus) provides an input to the product design process by facilitating clarification of the customers’ needs and desires and, therefore, promotes quality. According to ‘the Theory of Swift, Even Flow’, which is very much in tune with JIT operations, Schmenner and Swink (1998) examine that the creation of efficient equipment layouts highlight flows and often increase the speed by which a product is made; smaller lot size of materials to process increase speed flows or reduce variation, or both. Schmenner and Swink (1998) further explain that with a pull system, smooth flow is more assured and thus cannot flood the operation with work-in-process inventory, and because work-in-process inventory levels are capped by the number of containers or spaces permitted, throughput times are assured to be low. Workforce management practices, such as employee involvement and empowerment, eventually lead to improved quality, productivity, and efficiency (Dean & Bowen 1994; Spencer 1994). Gerwin (1987) and Raturi and Jack (2004) note that flexibility demands multi-skilled workers who can be
utilized elsewhere in the factory when volume is reduced, and that the equipment has high and/or adjustable capacity limits when volume is increased. Flynn et al. (1995) explain how the supplier relationship is also expected to be directly related to process flow management, because purchased materials and parts are dominant sources of process variability and, in turn, quality performance. Petroni and Bevilacqua (2002) report that the close relationship with suppliers helps manufacturing companies modify existing products more quickly and economically; and, therefore promote flexibility. Accordingly, we hypothesise:

**Hypothesis 2a.** Soft technologies are positively associated with cost efficiency.

**Hypothesis 2b.** Soft technologies are positively associated with quality.

**Hypothesis 2c.** Soft technologies are positively associated with cycle time reduction.

**Hypothesis 2d.** Soft technologies are positively associated with flexibility.

**RESEARCH DESIGN**

**Sample and procedures**

Data was collected through a questionnaire. Following previous empirical studies (e.g., Koste, Malhotra, & Sharma 2004; Swink & Nair 2007), the manufacturing plant was chosen as the unit of analysis for this study. The companies participating in this study were selected from a database provided by the Department of Industrial Work, Ministry of Industry, Thailand. Upon selection, each company was sent a questionnaire, and asked to pass it to the senior manager who had responsibilities and who possessed information about the firm’s manufacturing (Gupta & Chen 1997). In total, 186 useable questionnaires were returned, constituting a 14% response rate (186/1,327). The data were checked for bias using correlations of responses between early and late respondents based on industry sector and size of revenue. The chi-square tests on both categories did not indicate any significant difference between the two groups of respondents.

In the sample, the greatest proportion of the respondents comes from automotive industry (31.1%), followed by fabricated metal (30.1%), machinery and equipment (24.2%), and electronics, computers, and electrical appliances industries (13.4%). Almost half of the sample was made up of small to medium sized companies and the remaining 49.5% of firms employed more than 200 people.
The majority of responses were from top management (i.e. CEO/vice president of manufacturing and plant managers) (47.9 %), followed by manufacturing/operations managers (30.6%), and other positions that are relevant to operations, e.g., quality managers, production engineers (17.7%).

**Measures**

By following Kotha and Swamidass’s (2000) procedure, the questionnaire was developed and refined. As discussed earlier, the *hard, computerized technologies* construct comprising of three aspects (design, processing, and administrative technologies) and measures were adopted from Boyer et al. (1996; 1997). The measures of the *soft technologies* construct, which is represented by JIT operations, customer focus, process management, workforce management, and supplier management, were derived from previous studies (Cua et al. 2001; Flynn et al. 1995; Matsui 2007; Prajogo & Sohal 2006). The four constructs of manufacturing capabilities (*cost efficiency, quality, cycle time reduction, and flexibility*) and their measures are derived from previous studies (Ahire et al. 1996; Droge et al. 2004; Jacobs, et al. 2007; Rosenzweig, Roth & Dean 2003; Zhang, Vonderembse & Lim 2003). The questionnaire items used to operationalise the key constructs are presented in Table 1, 2, and 3.

**Table 1, 2, and 3**

**DATA ANALYSIS**

The two-step process of analysis (Anderson & Gerbing 1988) with Lisrel 5.52 was employed to test our hypotheses. Firstly, we constructed a measurement model to conduct a maximum likelihood confirmatory factor analysis (CFA). As recommended by Graham (2009), we used the full-information maximum likelihood (FIML) methods. Subsequently, the fit of the CFA models was evaluated using two indices: the $\chi^2/df$ ratio and the Root Mean Square Error of Approximation (RMSEA) (Scientific Software International Inc. 2009) \(^1\). The criteria for model fit were set at $\chi^2/df < 3.00$ and RMSEA $< .08$ (Browne & Cudeck 1993; Kline 2005). The item loadings and the overall

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\(^1\) The raw data in the PRELIS system file (PSF) contains missing values in which case the Full Information Maximum Likelihood (FIML) method is invoked by defaults. Unlike in the case of Maximum Likelihood (ML), the Chi-square test statistic value for the Independence Model is not available in closed form and has to be computed by fitting the Independence Model to the data. Consequently, the measures of fit such as the NFI, NNFI, CFI, IFI, GFI, etc. cannot be computed when the model is fitted to the data (Scientific Software International, Inc. 2009).
models fit results (i.e. the three measures of hard technologies (see Table 1): $\chi^2 (df = 29) = 60.72$, $\chi^2/df = 2.09$, RMSEA = 0.077; the five measures of soft technologies (see Table 2): $\chi^2 (df = 314) = 510.66$, $\chi^2/df = 1.63$, RMSEA = 0.058; the four measures of manufacturing capabilities (see Table 2): $\chi^2 (df = 97) = 195.10$, $\chi^2/df = 2.01$, RMSEA = 0.074) suggest acceptable unidimensionality and convergent validity for the measures (Browne & Cudeck 1993; Hinkin 1995; Kline 2005). Cronbach’s alpha suggests satisfactory reliability of the constructs (Nunnally 1978). The results of the confirmatory factor analysis and the Cronbach’s alpha are presented in Table 1, 2, and 3.

As recommended by Podsakoff, MacKenzie, Lee, and Podsakoff (2003), we undertook Harman’s one-factor test and Lisrel confirmatory factor analysis to reduce and evaluate the magnitude of common method bias usually coming from the use of self-report data and single informant. Overall, these results suggested little threat of common method bias and provided support for the validity of our measures. As suggested by Venkatraman and Grant (1986) and Ahire et al. (1996), discriminant validity was established by conducting Confirmatory Factor Analysis (CFA) on each pair of the constructs in this study. With twelve constructs incorporated in this study, we conducted 20 chi-square tests. The values of $\Delta \chi^2$ for all tests confirm the discriminant validity of the constructs and lend further evidence towards the lack of common method variance.

With regard to the confirmatory factor analysis of the hard and soft technology constructs (see Table 4), the goodness-of-fit indices support the robustness of the model ($\chi^2 (df = 19) = 30.02$, $\chi^2/df = 1.58$, RMSEA = 0.056). The path coefficients (standardized solution) between all measures of hard and soft technologies and the two constructs are highly significant and the magnitudes are reasonably high, thus, demonstrating the convergent validity of the models (Anderson & Gerbing 1988).

The goodness-of-fit indices support the robustness of the structural model ($\chi^2 (df = 238) = 492.21$, $\chi^2/df = 2.07$, RMSEA = 0.076). The results provide evidence supporting all hypotheses.

**Hypothesis 1** predicted that hard technologies are positively associated with **cost efficiency (H1a)**, **quality (H1b)**, **cycle time reduction (H1c.)**, and **flexibility (H1d)**. The standardised beta coefficients are $\beta = 0.31 (p < 0.05)$, $\beta = 0.23 (p < 0.05)$, $\beta = 0.20 (p < 0.05)$, and $\beta = 0.31 (p < 0.05)$, respectively, providing support for H1. **Hypothesis 2** predicted that those soft technologies are positively associated
with cost efficiency (H2a), quality (H2b), cycle time reduction (H2c.), and flexibility (H2d). The
standardised beta coefficients are $\beta = 0.22 \ (p < 0.05), \beta = 0.38 \ (p < 0.05), \beta = 0.17 \ (p < 0.05), \beta = 0.20 \ (p < 0.05)$, respectively. Figure 2 presents the results of path analysis.

**Figure 2 Results of path analysis**

**DISCUSSION OF THE FINDINGS AND THEIR IMPLICATIONS**

The present study contributes to the OM research by investigating the role of hard and soft
technologies on improving cost efficiency, quality, cycle time reduction, and flexibility. It also shows
importance of both hard and soft technologies. As suggested by the RBV, this highlights the need for
balancing these two aspects of technologies. The results also indicate that different dimensions of
capabilities require specific configurations of resources. Flexibility, cost efficiency, and cycle time
reduction tend to heavily rely on hard technologies rather than soft technologies. Our finding that
flexibility can be an explicit goal of manufacturing technology investments is contradictory to
previous findings (e.g., Boyer et al. 1997; Das 2001). However, the results are relevant to others
studies (e.g., Gold 1982; Meredith 1987), which suggest that hard technologies are primarily designed
to provide increased flexibility. It could be explained that while its informational capacity enables the
storing of computer programs, recording of machine and worker performance, and feedback about the
process itself (Zuboff 1988), hard technologies’ flexibility, therefore, results in quicker retooling and
set-up, greater diversity of work methods, and economies of scope (Goldhar & Jelinek 1983;
Zammuto & O’Connor 1992). Therefore, the value of these technologies can be primarily assessed on
flexibility, cost efficiency and cycle time reduction (Adler 1988; Pagell & Krause 1999). However,
the results of this research indicate that quality heavily requires soft technologies. One possible reason
is that, by focusing more on soft aspects of technologies, such as being customer focused, maintaining
competent, reliable and flexible suppliers, and promoting employee participation in decision making
processes through training and empowerment, firms can achieve superior quality capability by
designing quality into products and by assuring in-process quality through the use of defect
prevention methods and control tools, as well as through judicious use of quality information such as
Moreover, it is worth noting that even though soft technologies represent practices (i.e. customer focus, process management, and supplier management) from the quality management area, our result indicates soft technologies have a significant role not only on improving quality performance (considered as a primary purpose for implementing quality management practices), but also reducing cycle times and cost and improving flexibility. As quality performance improves, cycle times are reduced because these is less time wastage (non-value-added time) resulting from rework of defective items (Flynn et al. 1995). The close relationship with suppliers helps manufacturing companies modify existing products more quickly and economically; and, therefore promote flexibility and cost efficiency (Petroni & Bevilacqua 2002).

The present study proposes a more realistic view of the relationships between hard and soft technologies and multiple aspects of manufacturing capabilities. Previous studies (see e.g., Beaumont et al. 2002; Challis et al. 2002; Das & Jayaram 2003; Dean & Snell 1996) combine multiple aspects of manufacturing capabilities into one composite variable only. By combining cost efficiency, quality, cycle time reduction, and flexibility into one composite variable, the meaningful implication that represents the relative effects of hard and soft technologies on these aspects of manufacturing capabilities would not be revealed. The present study supports the findings of Cua et al. (2001) and Ketokivi and Schroeder (2004) that different configurations of basic techniques and common practices affect specific aspects of capabilities. Furthermore, the present study also suggests that many companies are increasingly being motivated to compete with more than one aspect of capability as suggested by the cumulative perspective of capabilities (Ferdows & De Meyer 1990). Finally, in response to the question as to how much a firm should invest in hard and soft technologies, the results from this study suggests that it depends on which aspect(s) of capabilities a firm focuses on, in order to compete in the marketplace.
CONCLUSION, LIMITATIONS, AND FUTURE RESEARCH

Relying on the RBV, we propose a model that explains relative effects of hard and soft technologies on cost efficiency, quality, cycle time reduction, and flexibility. From the theoretical perspective, our study of 186 manufacturing plants in Thailand makes a valuable contribution to the OM literature. Our results support that different types of resources affect specific aspects of capabilities, and therefore provide a more realistic view of the relationships between hard and soft technologies and multiple aspects of manufacturing capabilities, when compared with previous studies that combine multiple aspects of manufacturing capabilities into one composite variable only. Additionally, our results support the RBV originally developed in advanced economies is applicable in an emerging economy, such as Thailand. Further research is recommended to test whether the theory can be applicable in other emerging economies.

On the practical front, the present study extends prior research by offering a more fine-grained empirical analysis, thereby offering evidence that begins to explain how hard and soft technologies contribute to multiple aspects of competitive capabilities. As many manufacturing firms have sunk enormous amounts of capital into investments in these technologies over the last three decades, therefore, our findings can be translated into specific implications for technology justification and capability creation and sustainability.

There are a few limitations of the study that present directions for future investigations in this domain. First, we have painted a rather static picture of the resource-capability relationship. Therefore, future research should consider the effects of interactive relationships between hard and soft technologies on manufacturing capabilities, and the use of longitudinal data, which would enable us to examine the stability of both resources and capabilities and to scrutinise the issue of causality in more detail. Second, as the scope of soft technologies used in this paper is limited to the areas of JIT and TQM, future research should investigate the effects of other soft resources, such as knowledge management and supply chain integration, on the hard technology-manufacturing capability relationship.
REFERENCES


* The path is significant at the 0.05 level.

Figure 2 Results of path analysis
### Table 1 Validity and reliability of the measures of hard technologies: design, processing, and administrative technologies

<table>
<thead>
<tr>
<th>Measures</th>
<th>Items</th>
<th>Loading paths</th>
<th>Cronbach’s alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design technologies</strong></td>
<td>Computer-aided design (CAD)</td>
<td>0.69</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>Computer-aided engineering (CAE)</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Computer-aided process planning (CAPP)</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td><strong>Processing technologies</strong></td>
<td>Computer-aided manufacturing (CAM)</td>
<td>0.72</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>Sophisticated robots</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Real-time process control systems</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Computerized numerical control machines (CNC)</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td><strong>Administrative technologies</strong></td>
<td>Electronic mail</td>
<td>0.66</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>Manufacturing resource planning (MRP II)</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enterprise resource planning (ERP)</td>
<td>0.64</td>
<td></td>
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</table>

$\chi^2 (df = 29) = 60.72, \chi^2/df = 2.09, \text{RMSEA} = 0.077$

Note: The respondents were asked to indicate the levels of investments of hard technologies implemented in their organization, which were considered in a grading sense from no investment (1) to heavy investment (5).

### Table 2 Validity and reliability of the measures of soft technologies: JIT operations, customer focus, process management, supplier management, and workforce management

<table>
<thead>
<tr>
<th>Measures</th>
<th>Items</th>
<th>Loading paths</th>
<th>Cronbach’s alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>JIT operations</strong></td>
<td>We use a kanban pull system for production control.</td>
<td>0.58</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>We have a small amount of work-in-process inventory.</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The layout of the shop floor facilitates low inventories and fast</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td></td>
<td>throughput.</td>
<td></td>
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<tr>
<td></td>
<td>Employees practice set-ups to reduce the time required.</td>
<td>0.53</td>
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</tr>
<tr>
<td></td>
<td>We usually complete our daily schedule as planned.</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td><strong>Customer focus</strong></td>
<td>We actively and regularly seek customer inputs to identify their</td>
<td>0.64</td>
<td>0.82</td>
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<tr>
<td></td>
<td>needs and expectations.</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Customer needs and expectations are effectively disseminated and</td>
<td>0.69</td>
<td></td>
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<tr>
<td></td>
<td>understood throughout the workforce.</td>
<td></td>
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<tr>
<td></td>
<td>We systematically and regularly measure customer satisfaction.</td>
<td>0.83</td>
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<td></td>
<td>We have an effective process for resolving customers’ complaints.</td>
<td>0.74</td>
<td></td>
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<tr>
<td></td>
<td>We always maintain a close relationship with our customers and</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td></td>
<td>provide them an easy channel for communicating with us.</td>
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<td></td>
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<tr>
<td><strong>Process management</strong></td>
<td>We design processes in our plant to be “fool-proof” (preventive-</td>
<td>0.69</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>oriented).</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>We have clear, standardized and documented process instructions which</td>
<td>0.78</td>
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<td>are well understood by our employees.</td>
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<tr>
<td></td>
<td>We make an extensive use of statistical techniques (e.g. SPC) to</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td></td>
<td>improve the processes and to reduce variation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The concept of the ‘internal customer’ (i.e. the next process down</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td></td>
<td>the line) is well understood in our company.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>We emphasize the continuous improvement of quality in all work</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td></td>
<td>processes.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 2 Validity and reliability of the measures of soft technologies: JIT operations, customer focus, process management, supplier management, and workforce management (continue)

<table>
<thead>
<tr>
<th>Measures</th>
<th>Items</th>
<th>Loading paths</th>
<th>Cronbach’s alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier management</td>
<td>Our suppliers are certificated, or qualified, for quality.</td>
<td>0.54</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>We have long-term arrangements with our suppliers.</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Our suppliers deliver to us on short notice.</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td></td>
<td>We can depend upon on-time delivery from our suppliers.</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Our suppliers are linked with us by a pull system.</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>Workforce management</td>
<td>Employees receive training to perform multiple tasks.</td>
<td>0.43</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>Employees are cross-trained at this plant so that they can fill in for others if necessary.</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>During problem solving sessions, we make an effort to get all team members’ opinions and ideas before making a decision.</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Many problems have been solved through small group sessions.</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Problem solving teams have helped improve manufacturing processes at this plant.</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Employee teams are encouraged to try to solve their problems as much as possible.</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Employees inspect the quality of their own work.</td>
<td>0.61</td>
<td></td>
</tr>
</tbody>
</table>

$\chi^2 (df = 314) = 510.66, \chi^2/df = 1.63, \text{RMSEA} = 0.058$

Note: The respondents were asked to indicate to what extent they agree or disagree that each statement applies to their organisation. All items were considered in a grading sense from strongly disagree (1) to strongly agree (5).

### Table 3 Validity and reliability of the measures of manufacturing capabilities

<table>
<thead>
<tr>
<th>Measures</th>
<th>Items</th>
<th>Loading paths</th>
<th>Cronbach’s alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost efficiency</td>
<td>Low production cost</td>
<td>0.71</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>Competitive pricing</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Production efficiency</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inventory turnover</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>Quality</td>
<td>Product durability</td>
<td>0.68</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>Product reliability</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Product performance</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overall product quality as perceived by the customer</td>
<td>0.76</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conformance to specifications</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td>Cycle time reduction</td>
<td>Procurement lead time</td>
<td>0.78</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>Manufacturing lead time</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delivery speed / Customer lead-time</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td>Flexibility</td>
<td>Easily change the production volume of a manufacturing process.</td>
<td>0.68</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>Build different products in the same plants at the same time.</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Changeover quickly from one product to another.</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Easily modify products to a specific customer need.</td>
<td>0.58</td>
<td></td>
</tr>
</tbody>
</table>

$\chi^2 (df = 97) = 195.10, \chi^2/df = 2.01, \text{RMSEA} = 0.074$

Note: The respondents were asked to indicate the levels of manufacturing capabilities that were considered in a grading sense from much worse than the organization’s primary competitor (1) to much better (5).
Table 4 The measurement models of hard and soft technologies

<table>
<thead>
<tr>
<th>Constructs</th>
<th>Measures</th>
<th>Loading paths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard technologies</td>
<td>Design technologies</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>Processing technologies</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Administrative technologies</td>
<td>0.85</td>
</tr>
<tr>
<td>Soft technologies</td>
<td>JIT operations</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>Customer focus</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>Process management</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>Supplier management</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>Workforce management</td>
<td>0.67</td>
</tr>
</tbody>
</table>

$\chi^2 (df = 19) = 30.02, \chi^2/df = 1.58, \text{RMSEA} = 0.056$