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Flexibility configurations: empirical analysis of volume and product mix flexibility

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Abstract

In this paper we address flexibility and investigate the relationship between volume and product mix flexibility. One view of flexibility is that of being a capability in itself; another view is that of flexibility as an enabler, providing the manufacturing system with properties on which other competitive capabilities are built. In this research the latter view of flexibility is used, where flexibility acts as a second order competitive criterion. The aim is to differentiate between two dimensions of flexibility important to the manufacturing value chain, i.e. volume and product mix flexibility, and to investigate how different flexibility configurations are related to various manufacturing practices. A clustering research approach is used to identify groups of companies based on flexibility configurations. The groups are then analyzed with respect to characteristics and impact on operational performance. For the empirical investigation, we use empirical data from the High Performance Manufacturing (HPM) study, including three industries and seven countries – a total of 211 plants. We find that flexibility configurations based on high or low levels of volume and mix flexibility combinations show significant differences both in terms of operational performance, and in terms of emphasis put into different flexibility source factors.

Keywords: Empirical research; Flexible manufacturing; Operations management; Survey; Value chain.

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1. Introduction

Increased competition, global markets, and more challenging customers are all ingredients of today's business environment and contributors to higher uncertainty and variability. Manufacturing flexibility has been proposed to handle or mitigate the effects of these challenges [1,2]. Manufacturing flexibility is an important element of a firm's operations strategy, as being one of the main competitive priorities commonly used [3]. This view makes flexibility a goal in itself. Another view of flexibility is as an enabler; a means providing the capability to respond quickly to shifts in the market [4]. In this study we take the latter perspective, with manufacturing flexibility as an enabler that provides the manufacturing system with properties on which other capabilities are built.

Although manufacturing flexibility is recognized as important, the value of flexibility has been difficult to establish empirically. However, there are case studies concerned with the evaluation of flexibility using mathematical modeling; see [2, 5, 6]. Still, Dreyer and Grønhaug [7] claim that empirical research on manufacturing flexibility is still lagging. Then again, performance metrics such as overall profitability and return on assets are related to the company as a whole and thus distorted by other functions within the company. To better assess the actual impact from manufacturing flexibility on the performance of the manufacturing function, the use of operational performance have been proposed [8, 9].

While past research informs about how manufacturing firms can successfully achieve a certain type of flexibility, there are few insights for understanding how different types of flexibility can be simultaneously achieved within a manufacturing plant and its supply chain [10]. In a recent case study, Salvador et al. [10] found that a few approaches used to increase volume flexibility actually negatively affected mix flexibility and vice versa. They also observed that, to some extent, volume and mix flexibility may be achieved synergistically. They identified a need for large-scale empirical research. This paper fills this gap by providing an empirical study of the interrelationships among volume and product mix flexibility.

The purpose of this empirical study is threefold: (i) we aim to investigate how volume flexibility and product mix flexibility are interrelated. For flexibility configurations based on high or low levels of volume and product mix flexibility, we aim to (ii) analyze the impact on operational performance and (iii) analyze the source factors that firms use to establish high levels of volume and/or mix flexibility. We link the flexibility source factors to the strategic flexibility approaches by Gerwin [1] for how to cope with uncertainty; i.e. proactive and adaptive approach. In doing so, we answer Gerwin's [1] call for applied flexibility research aimed at managerial application and problem-solving that makes academic operations management research more relevant and accessible to managers.

The paper is organized as follows. We first review the literature on manufacturing flexibility related to our purpose, before presenting our conceptual model. We then describe the research methodology and the empirical study. Finally, we present the results and discuss managerial and research implications.

2. Perspectives on flexibility

In this section, we review the related literature. General overviews and reviews of manufacturing and supply chain flexibility can be found in Sethi and Sethi [11], DeToni and Tonchia [12], D'Souza and Williams [13], and Stevenson and Spring [14]. Here we review literature on output flexibility, the impact on performance, flexibility source factors, and strategic flexibility approaches, before combining these in the research model.

2.1. Output flexibility

In recent years, flexibility has received much attention from both academics and practitioners as a source of competitive advantage. The competitive environment has seen a major transformation the last decades, from the relative stability of the 80's to today's intense global competition with e.g. shorter product life cycles [15]. Flexibility is a complex, multidimensional concept and is defined on a meta level as the ability to adapt to environmental change [16]. Upton [17] added "…with little penalty in time, effort, cost or performance" bringing efficiency into the picture. We define those penalties in terms of cost, quality and delivery performances. It is well established that flexibility can be viewed in many perspectives; the two most widely cited being volume flexibility and product-mix flexibility [9,10,18,19,20]. For example, Chen et al. [18] stated that: "Depending upon the competitors' penetration, firms can be faced with drastic changes in product mix and/or volume. In the environment of volatile demand, firms' profitability lies in the extent to which they can neutralize the effects of these demand uncertainties. Consequently, firms with both volume flexibility and mix flexibility incorporated in their manufacturing systems can respond better to this aspect of environmental uncertainty." Further, D'Souza and Williams [13] defined four dimensions of manufacturing flexibility, and found that volume and variety are "mainly externally driven" towards meeting the needs of the market. Upton [21] viewed this as external flexibility, i.e. what the customer sees (capabilities). We therefore focus on volume and (product) mix flexibility in this study and refer to them as output flexibility types; cf. [22,23,24]. Volume flexibility is defined as the ability to change the level of output of a manufacturing process [1,13]. It demonstrates the competitive potential of the firm to increase production volume to meet rising demand and to keep inventory low as demand falls [1]. Product-mix flexibility in general refers to the ability of the manufacturing system to cope with changes in the product mix [5]. Berry and Cooper [25] defined it as the ability to produce a broad range of products or variants with presumed low changeover costs.

2.2. Flexibility and performance

According to Lau [26], flexibility has become one of the most important factors in achieving a competitive advantage. However, in order to remain competitive achieving higher degrees of flexibility must not come with a loss of productivity and quality [27]. This was also recognized in the latter part of Upton's [21] definition of flexibility: "…..without incurring high transition penalties or large changes in performance outcomes." Over the last two decades, several studies have provided evidence for the relationship between flexibility and performance in manufacturing. Swamidass and Newell [28] and Vickery et al. [29] found significant positive relationships between manufacturing flexibility and financial performance. Gupta and Somers [30] found significant positive relationships between manufacturing flexibility and growth performance, which was also found by Vickery et al. [29]. More specifically, Vickery et al. [31], Suarez et al. [32], and Jack and Raturi [33] have shown that volume flexibility has a positive impact on a firm's performance. On the other hand, Feigenbaum and Karnani [22] found no relationship between volume flexibility and return on assets. Kekre and Srinivasan [34] provided some empirical support for the benefits of mix flexibility by demonstrating that a broader product line is associated with higher market share and profitability. Zhang et al. [20] found evidence for the positive effects from mix flexibility on customer satisfaction, and Das [35] observed significant positive effects on manufacturing cost reduction and delivery performance. Thus, empirical testing of the impact of flexibility on operational performance is relatively sparse. There seems to be no previous survey testing volume and mix flexibility simultaneously on operational performance measures, which would help to clarify these interrelationships.

2.3. Flexibility source factors

Flexibility dimensions such as product mix flexibility can be achieved through different flexibility means or source factors [19,36]. Upton [21] viewed this as internal flexibility, i.e. what the firm can do in terms of competencies. In Table 1, we list combinations of source factors and flexibility types such as that source factors are explicitly related to volume and mix flexibility, based on sources in the literature that are concerned with two or more combinations of flexibility source factors and output flexibility types.

Gerwin [37] focused on workforce and equipment and related characteristics for these to volume and mix flexibility, and other flexibility types. Slack [38] discussed the implications of resources on flexibility types, e.g. process technology and labor versus volume and mix flexibility. Chen et al. [18] referred to volume and mix flexibility as marketing-based flexibility which can be supported by advanced manufacturing technologies, excess capacity or labor flexibility. Gerwin [1] discussed methods for delivery flexibility and related these to e.g. volume and mix flexibility. Olhager [19] mapped a variety of flexibility source factors (setup time, excess capacity, modular product design and multi-skilled labor) to volume and/or mix flexibility. Suarez et al. [32] investigated 31 printed circuit-boards, and found empirical support for certain practices related to production technology, production management techniques, supplier and subcontractor relationships, human resource management, and product development process on volume and mix flexibility. Jack and Raturi [33] described internal sources of volume flexibility as slack production capacity, inventory buffers and labor flexibility. Olhager and West [39] developed a framework for deploying market-related competitive priorities into output flexibilities and further into flexibility source factors, such as modular product design, setup times, multi-purpose process technology, slack capacity, and multi-trained employees, and applied it in a case study. Zhang et al. [20] focused on volume and mix flexibility as flexible manufacturing capabilities and studied how these are developed by flexibility manufacturing competencies and also how these affect customer satisfaction. Chang et al. [40] studied e.g. how manufacturing technology advancements, multi-skilled workforce and manufacturing/design collaboration relate to mix and volume flexibility. Schmenner and Tatikonda [41] updated the Gerwin [37] paper, discussing various flexible and proactive approaches, and found that these are complementary rather than in conflict. Chandra et al. [2] studied the enterprise-level benefits of manufacturing flexibility in a case study, and found that overtime and slack capacity affects both volume and mix flexibility. Sawhney [23] reported on the results of a field study of 10 printed circuit board fabricators, and proposes a transformation framework for how internal flexibility can be used to develop output flexibility. The rigid flexibility model presented by Collins and Schmenner [42] was investigated in an empirical study by da Silveira [43], focusing on approaches that contribute to simplicity (such as platform designs and modularization) or discipline (such as quality program, total preventive maintenance, and workforce development) in building flexibility for market responsiveness. Yang et al. [44] studied the interrelationships among new product, product mix, and volume flexibility in as case study, finding that reserve capacity and change-over time affect volume flexibility and that design for manufacturing (DFM) participation affects product mix flexibility. Salvador et al. [10] investigated factors enabling or hindering the simultaneous pursuit of volume and mix flexibility, and found that DFM, chase approaches to capacity addition, and workers training programs improved volume flexibility at the expense of mix flexibility, while synergies existed between volume and mix flexibilities for setup-time reduction. Note that the finding on DFM contradicts the results by Yang et al. [44]. Finally, Hutchison and Das [9] listed capabilities to achieve mix flexibility: manufacturing processes that can produce a wide range of products, workforce flexibility, quick changeover times, and the ability to quickly introduce and produce new products. Thus, many sources are based on conceptual models, and there are relatively few empirical studies concerned with how output flexibility is built up by flexibility source factors.

2.4. Strategic flexibility approaches

Gerwin [37] contrasted the "flexible" factory which attempts to adapt to realized uncertainty versus the "proactive" one which attempts to control its uncertainty through advance planning. Today, a factory is "flexible" in part because it is "proactive"; for example, the proactive factory's advances in removing waste, incorporating new technologies, and moving information to where it can be used best (e.g. via enterprise resource planning systems) have certainly diminished the time and cost of being flexible, and this enhances the degree of flexibility in the process [41]. In a later paper, Gerwin [1] proposed four generic flexibility strategies labeled adaptation, redefinition, banking, and reduction, that use proactive or defensive (flexible) approaches to managing uncertainty. Narasimhan et al. [8] extended the Gerwin [1] framework by adding execution competence and flexibility competence. Execution competence was defined as the ability of a firm to convert its flexibility capabilities into tangible, firm-level performance outcomes that can affect its competitive success, while flexibility competence was defined as the ability of a firm to convert or exploit investments in advanced manufacturing technologies and strategic sourcing initiatives to develop manufacturing flexibilities [8]. The ideas by Gerwin [1,37] highlight that flexibility can be both adaptive, reacting to the changes in the environment (the traditional use of flexibility), and proactive, trying to reduce the need for flexibility. Slack [45] observed that managers seek to limit the need to be flexible, and calls this a "flexibility avoidance strategy", which relates to the proactive approach by Gerwin [1,37]. A similar proposition is the rigid flexibility model that is based on simplicity and discipline; cf. [42,46]. The practices related to simplicity and discipline include design for manufacturability, preventive maintenance, modular design, and quality management processes, i.e. the flexibility source factors linked to the proactive approach in Table 1. However, they do not specifically relate these source factors to volume or mix flexibility. Sawhney [23] observed that flexibility can be utilized proactively and not only as a coping mechanism against uncertainty, and proposed that these should be used simultaneously to analyze the opportunities and uncertainties along the value chain.

2.5. Combining strategic flexibility approaches, flexibility source factors and output flexibility types

Gerwin [1,37] suggested that some flexibility source factors are typically associated with either of the two strategic approaches to flexibility; proactive and adaptive. Total preventive maintenance (TPM), statistical process control (SPC), and DFM are considered sources for proactively mitigating uncertainty, while setup time reduction, advanced manufacturing technology, and slack capacity are adaptive flexibility sources. In reviewing the literature we find support for two additional flexibility source factors, i.e. modular product design and multi-trained employees. The first can be associated with a proactive strategic approach to flexibility, in that a modular product design can reduce demand uncertainty since the product is defined within pre-determined limits [39,41]. The second can be considered as an adaptive strategic approach to flexibility since the multi-training competence is used once demand uncertainty is observed [19,20,23,37,38,39,40]. In Table 1 we list sources in the literature that relate flexibility source factors to particular output flexibility types, i.e. volume and/or product mix flexibility.

Table 1. Relationships in the related literature between flexibility source factors, and volume and mix flexibility.

Approach to mitigate uncertainty	Flexibility source factors	Output flexibility type	Selected references
Proactive	Total preventive maintenance	Volume	[1,43]
		Mix	[1,43]
	Statistical process control	Volume	[1,43]
		Mix	[1,43]
	Design for manufacturing	Volume	[1,39,40,41,43]
		Mix	[1,9,39,40,41,43]
	Modular product design	Volume	[39,41,43]
		Mix	[19,32,39,41,43]
Adaptive	Setup time reduction	Volume	[1,10,39,44]
		Mix	[1,9,10,19,32,38,39]
	Advanced manufacturing technology	Volume	[1,9,20,32,39,40]
		Mix	[1,9,18,19,20,32,37,38,39,40]
	Slack capacity	Volume	[1,2,9,10,18,19,33,37,38,39,44]
		Mix	[1,2,19,39]
	Multi-trained employees	Volume	[10,18,19,20,24,33,37,38,39,40,43]
		Mix	[9, 19,20,24,33,37,38,39,40,43]

The ways that the various approaches lead to volume and mix flexibility are manifold. The discussion below only provides examples based on the sources in Table 1, and is not an exhaustive list of relationships. TPM helps to keep the resource availability at a high level, facilitating the access to the production resources when flexibility is needed. Similarly, SPC helps to keep the production process in control by checking that good parts are produced, thus eliminating quality problems when having to exercise flexibility. DFM guides the product development process to make sure products can be produced efficiently. The fourth proactive approach is modular product design offering the customer a wide selection of product configurations and combinations, based on a limited set of modules that can be efficiently produced.

Setup time reduction improves the capacity availability for both volume and mix flexibility purposes, allowing for reduced lot sizes, producing at a lower capacity utilization rate, and increasing total production, or a combination thereof. Advanced manufacturing technology aims at utilizing technological advances and automation for high levels of flexibility, e.g. through flexible manufacturing systems. Slack capacity provides extra capacity availability that can be used for quick increases in production volumes and for extra setups, even for resources with non-negligible setup times. Finally, multi-trained employees can handle a variety of products and can increase the capacity at work centers that need temporary relief. The adaptive approaches clearly address flexibility as a property of the manufacturing system, which can be utilized once the needs occur.

Table 1 shows that the adaptive approaches to flexibility dominate the literature, and that there are few examples that treat proactive approaches to flexibility. The latter is at least partially explained by that many scholars have regarded the proactive approach as a form of robustness rather than as a form of flexibility. However, there are some exceptions that treat these characteristics and practices as flexibility source factors; cf. [1,9,32,39,40,41,43].

3. Research methodology

The logic behind the research methodology is to investigate the relationships between levels of flexibility and operational performance, and also the relationships between flexibility source factors and levels of output flexibility. We thus investigate different combinations of the perspectives presented in the previous section. The design is conceptually depicted in Figure 1. From left to right, the model distinguishes between proactive and adaptive approaches to flexibility, and considers four source factors in each (cf. Table 1). Furthermore, four flexibility configurations are based on the levels of mix and volume flexibility; the two main types of output flexibility. Finally, the model considers the impact on operational performance, in terms of cost, quality, on-time delivery, and delivery speed.

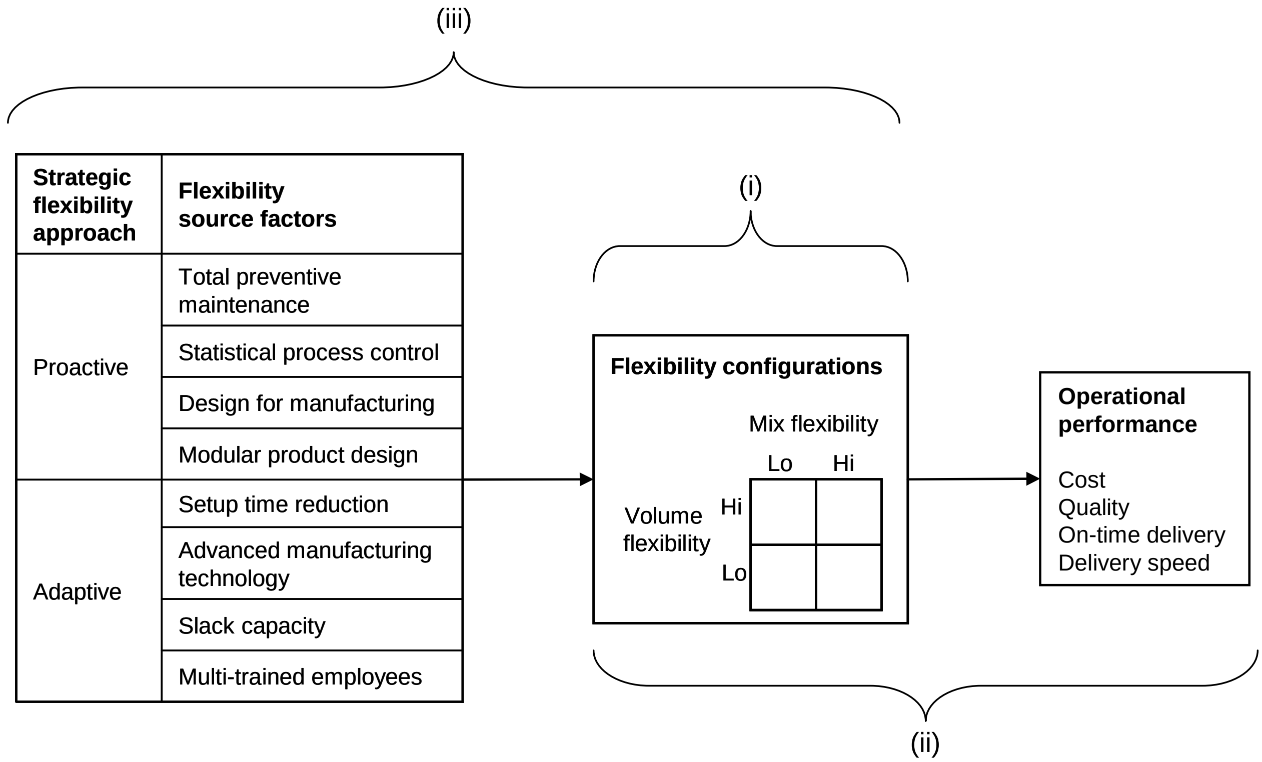


Figure 1. Conceptual model describing the relationships between strategic flexibility approaches, flexibility source factors, flexibility configurations and operational performance.

Figure 1 also highlights the three parts of the purpose of this study. We start by investigating the levels of flexibility of manufacturing plants in order to identify groups based on different flexibility configurations (cf. *(i)* in Figure 1). We then compare the different configurations with respect to the impact on operational performance (cf. *(ii)* in Figure 1), to investigate whether higher levels or specific types of flexibility lead to better performance. Thirdly, we investigate whether there are differences in emphasis put on certain proactive and adaptive flexibility source factors across configuration (cf. *(iii)* in Figure 1). The results of these three analyses are presented in sections 4.1, 4.2, and 4.3, respectively.

3.1. Data and sample

The data used in this study come from the third round of the High Performance Manufacturing (HPM) project. HPM is a systematic international study of manufacturing plants initiated in 1989 under the name World Class Manufacturing. It was initiated in response to the growing awareness that some manufacturing plants are better than others, along many dimensions of operational performance. The aim of the project is to investigate high performing plants in order to understand the practices and principles behind superior performance. Third round data were collected in 2005 by independent research groups in the seven countries: Austria, Finland, Germany, Japan, South Korea, Sweden and USA. Both authors are part of the HPM project and are responsible for collecting and managing the Swedish data.

Throughout the HPM project three industries have been targeted: electronics, machinery and automotive suppliers. The three industries were originally chosen to represent a variety in product characteristics and competition. A stratified sampling design was used to obtain an approximate equal number of plants for each industry-country combination. In return for participating, each plant was provided with a detailed profile of its own manufacturing operations and benchmark data in its industry. With this approach, the third round of the HPM project yielded a response rate of 65 % (calculated as the percent of the plants contacted by the research team that returned the surveys). The sample totalled 211 manufacturing plants across the seven countries and three industries. A description of the sample is provided in Table 2. The sample represents a mix of small and large plants with a median size of 379 employees. The typical plant in the sample is 34 years old and manages nine different product families. In general, the sample exhibits high variety and seems appropriate for investigating the research questions raised in this paper.

Table 2. Description of sample.

Number of plants				
	Industry			
Country	Electronics	Machinery	Auto suppliers	Total
Austria	10	8	4	22
Finland	14	6	10	30
Germany	9	13	19	41
Japan	10	11	13	34
South Korea	10	10	11	31
Sweden	7	10	7	24
United States	9	11	9	29
Total	69	69	73	211

3.2. Measures

The HPM database is comprehensive and encompasses several areas of manufacturing strategy. The questionnaire consists of both perceptual and objective measures of practices and performances. In this study, all practice and performance measures are perceptual; see the Appendix for details on the survey questionnaire. The levels of flexibility and operational performance are related to the competition within the industry, implying an implicit standardization of responses with respect to industry. To minimize possible country effects, all performance metrics are standardized with respect to country prior to all analysis by relating each individual score to the mean of its country. Specifically, the sample was split into country sub-samples, and standardized scores were computed for each sub-sample.

To capture the levels of flexibility we used perceptual measures of manufacturing flexibility. Within the HPM database there were readily available measures of mix and volume flexibility. The plant managers were asked to indicate the levels of flexibility on a 5-point scale compared to the competition in their industry (from “superior” to “poor, low end of industry”) on the two types of flexibility; volume and mix.

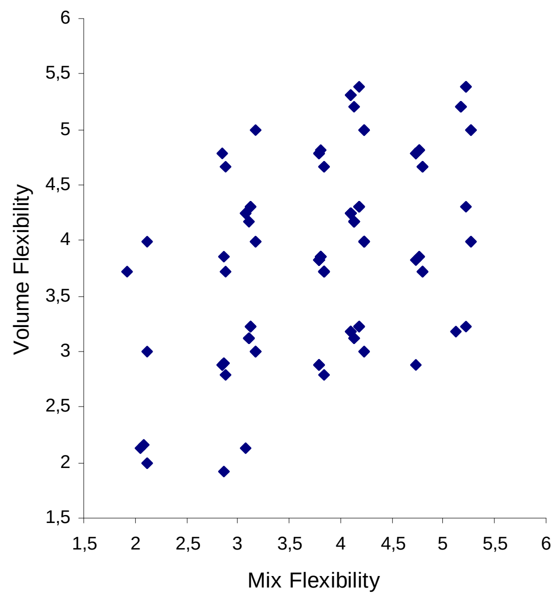
The performance dimensions were captured within the HPM data using perceptual measures. The plant managers were asked to indicate on a 5-point scale how their plant performed along the different dimensions of operational performance, compared to the competition in their industry (from "superior" to "poor, low end of industry"). The dimensions used in this study are unit cost of manufacturing, conformance quality, on-time delivery and delivery speed.

All flexibility source factors were captured as constructs where the measurement items are formatted using 7-point Likert-type scales. For each practice, the respondents were asked to indicate to what extent statements concerning practice implementation applied to their plant, from 1 = "strongly disagree" to 7 = "strongly agree". To assess the reliability of the measures we computed Cronbach's reliability alpha for all practices. The alphas were all clearly above the typical cut-off point 0.70 [47], except for slack capacity (SLC) which had value 0.629. Still, we retain SLC, since it is considered a major source for creating flexibility. A complete account on specific measurement items, respondents, and corresponding Cronbach's alpha is included in the Appendix.

4. Results

4.1. Flexibility configurations

Based on the actual levels of volume and mix flexibility, we can identify four different configurations: (i) plants that have high levels of both flexibility types, (ii, iii) plants that have a high level of one of the flexibility types and a low level of the other, and finally (iv) plants that have low levels of both mix and volume flexibility. We use the statistical mean values for partitioning plants into the configuration groups. For mix flexibility the values range from 1.921 to 5.277 with a mean value of 3.915 and for volume flexibility the corresponding range is between 1.062 and 5.387 with 3.906 as the mean value. The distribution of standardized values of manufacturing flexibility is reported in Figure 2a, and the four groupings is shown in Figure 2b. The four groups are labeled Low Flex, Mix Flex, Vol Flex and High Flex according to their levels of flexibility; cf. Table 3.



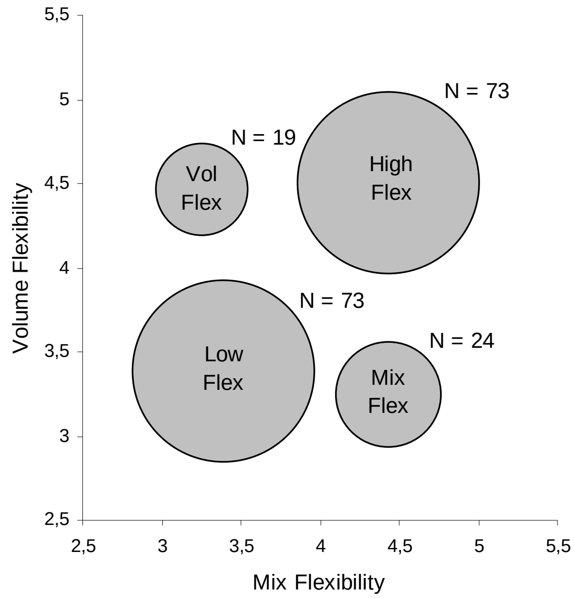


Figure 2a and b. a (left): Distribution across levels of flexibility, b (right): Configuration centres and group sizes.

Table 3. Levels of flexibility and sizes of the groups.

	Low Flex	Mix Flex	Vol Flex	High Flex
Number of observations	73	24	19	73
Mix flexibility mean value	3.398	4.439	3.259	4.437
Volume flexibility mean value	3.380	3.247	4.461	4.499

The results suggest that some firms are more flexible than others; the two major groups are the High Flex and Low Flex groups. The flexibility configurations also reveal that volume and mix flexibility are indeed two different types of output flexibility, since different combinations can be observed. We therefore analyze whether there are significant differences between the four groups, describing how high levels of flexibility can be attained and whether this will have a positive impact on operational performance.

4.2. The impact on operational performance

In order to establish the competitive value of manufacturing flexibility we contrast the groups across operational performance dimensions, based on pair-wise t-tests for the mean differences between the *a priori* determined groups (Low Flex, Mix Flex, Vol Flex and High Flex); cf. Table 4.

Table 4. Difference between groups in operational performance dimensions.

	Low Flex	Mix Flex	Vol Flex	High Flex
Cost performance	2.886 [a, c] (0.842)	3.146 (0.917)	3.458 [c] (1.015)	3.402 [a] (0.874)
Conformance quality	3.719 [c, d] (0.639)	3.957 (0.766)	4.037 [d] (0.774)	3.969 [c] (0.669)
On-time delivery	3.656 [a, c] (0.826)	3.610 [b, d] (0.952)	4.128 [c, d] (0.871)	4.154 [a, b] (0.772)
Delivery speed	3.553 [a] (0.726)	3.482 [b] (1.005)	3.815 [d] (0.826)	4.162 [a, b, d] (0.733)

Mean values (standard deviations); 5-point scale ranging from "Poor, low end of industry" to "Superior" (compared to competitors).

a,b = mean difference significant at 0.01 level

c = mean difference significant at 0.05 level

d = mean difference significant at 0.10 level

The two groups with high levels of volume flexibility (Vol Flex and High Flex) perform significantly better on cost than the Low Flex group. This result is very interesting since cost efficiency and flexibility are usually regarded to be subject to trade-offs; cf. [23,48]. Conformance quality is also significantly better in these groups compared to the Low Flex group. On-time delivery seems to be the outcome of having high levels of volume flexibility since the Vol Flex and High Flex groups significantly outperform the other two groups. Finally, the High Flex group is dominant on delivery speed and performs significantly better than all other groups.

In general, it seems that volume flexibility is the type of manufacturing flexibility that is most important for achieving higher operational performance. This is especially true for cost, quality and on-time delivery. Since High Flex dominates Vol Flex in terms of delivery speed performance one can conclude that the part of High Flex that is associated with mix flexibility is also important for achieving good delivery speed. Delivery speed is the only measure where High Flex plants perform significantly better than Vol Flex plants. The High Flex group significantly outperforms the Low Flex group on all four operational performance measures, while the Vol Flex group significantly outperforms the Mix Flex group on one dimension; on-time delivery. We can thus conclude that high levels of flexibility are indeed associated with better operational performance and thus contribute to the competitive value for the plant.

4.3. Comparing practices between groups

Once the competitive value of manufacturing flexibility is established we turn our focus to assessing the flexibility source factors that help to create high levels of manufacturing flexibility. In particular we want to explore if there are differences in the levels of implementation of different flexibility source factors as identified in previous sections. Again, we use pair-wise t-tests to establish differences between the groups. The results are reported in Table 5.

Table 5. Differences in practices between flexibility configurations.

Approach	Source factor	Low Flex Mean (St.dev.)	(Rank)	Mix Flex Mean (St.dev.)	(Rank)	Vol Flex Mean (St.dev.)	(Rank)	High Flex Mean (St.dev.)	(Rank)	Rank sum (Overall ranking)
Proactive	TPM	4.538 [a] (0.775)	(5)	4.560 [c, f] (0.631)	(6)	4.950 [f] (0.808)	(6)	4.902 [a, c] (0.656)	(4)	21 (5)
	SPC	4.816 (0.907)	(4)	4.666 (0.966)	(5)	5.036 (0.824)	(5)	4.754 (0.902)	(6)	20 (4)
	DFM	5.313 (1.187)	(1)	5.636 (1.197)	(1)	5.429 (1.238)	(3)	5.595 (1.035)	(1)	6 (1)
	MOD	4.489 [c] (0.841)	(6)	4.746 (0.784)	(4)	4.586 (0.914)	(7)	4.788 [c] (0.887)	(5)	22 (6)
Adaptive	STR	4.481 [a, f] (0.740)	(7)	4.534 [c] (0.766)	(7)	5.087 [a, c] (0.620)	(4)	4.712 [f] (0.718)	(7)	25 (7)
	AMT	4.827 [a, b] (0.719)	(3)	5.101 [c, f] (0.717)	(3)	5.535 [b, c] (0.570)	(2)	5.397 [a, f] (0.748)	(2)	10 (3)
	SLC	3.636 [f] (0.895)	(8)	3.788 (0.677)	(8)	4.086 [c, f] (1.003)	(8)	3.565 [c] (0.892)	(8)	32 (8)
	MTE	5.274 [d] (0.632)	(2)	5.254 [c] (0.503)	(2)	5.681 [c, d, e] (0.618)	(1)	5.353 [e] (0.554)	(3)	8 (2)

Scales ranging from 1-7; cf. Appendix.

a,b = difference significant at 0.01 level

c,d,e = difference significant at 0.05 level

f = difference significant at 0.10 level

The results in Table 5 can be interpreted in two different ways; horizontally, the emphasis of a certain source factor for different flexibility configuration, and vertically, the level of implementation of practices for a certain flexibility configuration. TPM and SPC are both means that aim to enhance the availability and reliability of the manufacturing process, thus reducing the variability in process times. The results for TPM speak in favor of volume flexibility. High Flex plants put more effort into total productive maintenance than both Low Flex and Mix Flex plants do, and Vol Flex plants have the highest mean value, even higher than the High Flex group (although not significantly). The efforts put into SPC are similar across all four groups. Low Flex plants put more effort into SPC than High Flex plants, indicating that stricter process control may even restrict mix flexibility to some extent. DFM and modular product design (MOD) are both related to the product, aiming to facilitate swift configuration and manufacturing of products. We cannot detect any differences in the use of DFM between the groups, while modularity of products is significantly more emphasized among High Flex plants than among Low Flex plants. In general, there are few significant differences among the flexibility configurations for proactive approaches.

The plants focusing on volume flexibility (Vol Flex) put significantly more effort into setup time reduction than Low Flex and Mix Flex plants. Advanced manufacturing technology is significantly more emphasized by Vol Flex and High Flex than the other two groups. The Vol

Flex group uses slack capacity the most, even significantly more than both High Flex and Low Flex plants. The results on MTE are very interesting since the practice is significantly more emphasized by Vol Flex plants than by any of the other plants, even including the High Flex group. In general, there are many significant differences among the flexibility configurations for adaptive approaches, indicating that these are the primary sources for differentiation between the types (mix and volume) and levels (low and high) of flexibility.

The top three practices for any configuration are DFM, advanced manufacturing technology (AMT) and multi-trained employees (MTE). DFM is top ranked for all groups except for the volume flexible plants, where it ranks third. The top practice for the plants focusing on volume flexibility is multi-trained employees. Most interestingly, these three practices relate to three different “p” areas: product, process and personnel. This result suggests that flexibility is created by a mix of practices, and not by a single source factor.

When comparing the proactive and adaptive approaches, Table 5 indicates that there are numerous (twelve) significant differences between the four flexibility configurations for the adaptive approaches, while only two of the four source factors in the proactive approach show significant differences, and then only for four comparisons. Thus, adaptive approaches seem to be a differentiator between how volume and mix flexibility competences are acquired, while the proactive approaches are practiced more equally across all four flexibility configurations. Especially, the Vol Flex group needs high levels of all four adaptive source factors, even higher than the High Flex group. This is especially true for slack capacity and multi-trained employees, since the Vol Flex plants require significantly higher levels than the High Flex plants. Of the proactive source factors, TPM is significantly more used for volume flexibility (than for mix flexibility). The Vol Flex group has the highest score for six of the eight factors, while the High Flex group is the main user of modular product design and the Mix Flex group for design for manufacturing. This result suggests that DFM and modular designs are most important for mix flexibility, while the others mainly build volume flexibility competence. The Low Flex group scores the lowest on six of eight factors, and significantly lower on these factors than the High Flex group or the Vol Flex group. This shows that low utilization of these eight approaches leads to lower levels of flexibility, while high levels of implementation lead to high levels of flexibility, primarily for volume flexibility.

5. Concluding remarks

In this paper, we have used flexibility configurations to show the operational value of manufacturing flexibility. We also analyzed the effects of various practices, both proactive and adaptive, on the development of flexibility. We find that the flexibility configurations based on high or low levels of volume and mix flexibility combinations, show significant differences both in terms of operational performance, and in terms of emphasis put into different flexibility source factors. Since there are some significant differences between the firms focusing on volume flexibility versus those that focus on mix flexibility, we can conclude that there are indeed differences between mix and volume flexibility, and it is not only a question of high versus low levels of flexibility.

We find that plants exhibiting high levels of flexibility generally perform better than those showing low levels of flexibility, on all four operational performance measures: cost, conformance quality, on-time delivery, and delivery speed. The volume flexible plants generally perform better than mix flexible plants, but the difference is only significant for on-time delivery. Volume flexibility seems to be the key ingredient in high flexibility plants, but for delivery speed it seems to be more important to be both volume and mix flexible, since the high flexibility plants perform significantly better than the plants that are only volume flexible.

The findings have implications for both practitioners and researchers. To gain managerial insights we have targeted manufacturing practices that are hands on and broadly applicable in order to provide practical guidelines for flexibility development for manufacturing value chain operations. In this paper, we have answered Gerwin's [1] call for flexibility research aimed at providing managerial guidelines for developing manufacturing flexibility, as well as the call by Salvador et al. [10] for large-scale empirical testing of mix flexibility, volume flexibility and their interaction. We also addressed Upton's [21] observation that one of the major causes for unsuccessful flexibility development efforts is the inability to identify "which factors most affect it (flexibility)". In general, Table 5 indicates the relative importance of practices for volume and mix flexibility. The top three practices for both volume and mix flexibility are design for manufacturing, multi-trained employees, and advanced manufacturing technology, referring to flexibility competencies related to the product, the process and the personnel. This indicates that flexibility is not achieved through a single factor; rather it is created through a mix of flexibility source factors. When comparing volume and mix flexibility, the volume flexible plants show higher levels of practices of TPM, SPC, setup time reduction, AMT, slack capacity, and multi-trained employees, while mix flexible plants show higher levels of DFM and modular product design, both related to the product-process interface. Thus, all adaptive approaches are utilized to a higher extent for volume flexibility. The result for setup time reduction is interesting, since the empirical study shows that this practice is significantly higher for volume flexible plants than for mix flexible plants. The results support the finding in the case study by Salvador et al [10] that slack capacity and worker training improve volume flexibility. The results also support the finding in the case study by Yang et al. [44] that DFM is more related to mix flexibility (but not significantly compared to volume flexibility).

For researchers, this study adds detail to the analysis of the relationships between flexibility source factors, output flexibility types and the impact on operational performance. The results of the study show that specific flexibility configurations have distinctly different effects on operational performance of the manufacturing value chain.

References

[1] Gerwin, D., 1993. Manufacturing flexibility: A strategic perspective. *Management Science* 39(4), 395-410.

[2] Chandra, C., Everson, M., Grabis, J., 2005. Evaluation of enterprise-level benefits of manufacturing flexibility. *Omega* 33(1), 17-31.

[3] Boyer, K.K., Leong, G.K., 1996. Manufacturing flexibility at the plant level. *Omega* 24(5), 495-510.

[4] Slack, N., 1983. Flexibility as a manufacturing objective. *International Journal of Operations and Production Management* 3(3), 4-13.

[5] Bengtsson, J., Olhager, J., 2002a.Valuation of product-mix flexibility using real options, *International Journal of Production Economics* 78(1), 13-28

[6] Bengtsson, J., Olhager, J., 2002b. The impact of the product mix on the value of flexibility. *Omega* 30(4), 265-273.

[7] Dreyer, B., Grønhaug, K., 2004. Uncertainty, flexibility, and sustained competitive advantage. *Journal of Business Research* 57(5), 484-494.

[8] Narasimhan, R., Talluri, S., Das, A., 2004. Exploring flexibility and execution competencies of manufacturing firms. *Journal of Operations Management* 22(1), 91-106.

[9] Hutchison, J., Das, S.R., 2007. Examining a firm's decisions with a contingency framework for manufacturing flexibility. *International Journal of Operations and Production Management* 27(2), 159-180.

[10] Salvador, F., Rungtusanatham, M., Forza, C., Trentin, A., 2007. Mix flexibility and volume flexibility in a build-to-order environment: synergies and trade-offs. *International Journal of Operations and Production Management* 27(11), 1173-1191.

[11] Sethi, A.K., Sethi, S.P., 1990. Flexibility in manufacturing: a survey. *International Journal of Flexible Manufacturing Systems* 2(4), 289-328.

[12] De Toni, A., Tonchia, S., 1998. Manufacturing flexibility: a literature review. *International Journal of Production Research* 36(6), 1587-1617.

[13] D'Souza, D.E., Williams, F.P., 2000. Towards a taxonomy of manufacturing flexibility dimensions. *Journal of Operations Management* 18(5), 577-593.

[14] Stevenson, M., Spring, M., 2007. Flexibility from a supply chain perspective: definition and review. *International Journal of Operations and Production Management* 27(7), 685-713.

[15] Barnes-Schuster, D., Bassok, Y., Anupindi, R., 2002. Coordination and flexibility in supply contracts with options. *Manufacturing & Service Operations Management* 4(3), 171-207.

[16] Gupta, Y.P., Goyal, S., 1989. Flexibility of manufacturing systems: concepts and measurements. *European Journal of Operational Research* 43(2), 119-135.

[17] Upton, D.M., 1994. The management of manufacturing flexibility. *California Management Review* 36(2), 72-89.

[18] Chen, I.J., Calantone, R.J., Chung, C-H., 1992. The marketing-manufacturing interface and manufacturing flexibility. *Omega* 20(4), 431-443.

[19] Olhager, J., 1993. Manufacturing flexibility and profitability. *International Journal of Production Economics* 30-31, 67-78.

[20] Zhang, Q., Vonderembse, M.A., Lim, J-S., 2003. Manufacturing flexibility: defining and analyzing relationships among competence, capability, and customer satisfaction. *Journal of Operations Management* 21(2), 173-191.

[21] Upton, D.M., 1995. What really makes factories flexible?, *Harvard Business Review* 73(4) 74-84.

[22] Fiegenbaum, A., Karnani, A., 1991. Output flexibility – A competitive advantage for small firms. *Strategic Management Journal* 12(2), 101-114.

[23] Grubbstrom, R.W., Olhager, J., 1997. Productivity and flexibility: fundamental relations between two major properties and performance measures of the production system. *International Journal of Production Economics*, 52, 73-82.

[23] Sawhney, R., 2006. Interplay between uncertainty and flexibility across the value-chain: towards a transformation model of manufacturing flexibility. *Journal of Operations Management* 24(5), 476-493.

[25] Berry, W.L., Cooper, M.C., 1999. Manufacturing flexibility: methods for measuring the impact of product variety on performance in process industries. *Journal of Operations Management* 17(2), 163-178.

[26] Lau, R.S.M., 1996. Strategic flexibility: a new reality for world-class manufacturing. *SAM Advanced Management Journal* 61(2), 11-15.

[27] Ahmed, P.K., Hardaker, G., Carpenter, M., 1996. Integrated flexibility – key to competition in a turbulent environment. *Long Range Planning* 29(4), 562-571.

[28] Swamidass, P.M., Newell, W.T., 1987. Manufacturing strategy, environmental uncertainty and performance: A path analytic model. *Management Science* 33(4), 509–524.

[29] Vickery, S.K., Dröge, C., Markland, R.E., 1997. Dimensions of manufacturing strength in the furniture industry. *Journal of Operations Management* 15(4), 317-330.

[30] Gupta, Y.P., Somers, T.M., 1996. Business strategy, manufacturing flexibility, and organizational performance relationships: a path analytic approach. *Production and Operations Management* 5(3), 204-233.

[31] Vickery, S., Calantone, R., Dröge, C., 1999. Supply chain flexibility: an empirical study. *The Journal of Supply Chain Management* 35(3), 16-24.

[32] Suarez, F.F., Cusumano, M.A., Fine, C.H., 1996. An empirical study of manufacturing flexibility in printed circuit board assembly. *Operations Research* 44(1), 223-240.

[33] Jack, E.P., Raturi, A., 2002. Sources of volume flexibility and their impact on performance. *Journal of Operations Management* 20(5), 519-548.

[34] Kekre, S., Srinivasan, K., 1990. Broader product line: a necessity to achieve success? *Management Science* 36(19), 1216-1231.

[35] Das, A., 2001. Towards theory building in manufacturing flexibility. *International Journal of Production Research* 39(18), 4153-4177.

[36] Gong, Z., Hu, S., 2008. An economic evaluation model of product mix flexibility. *Omega* 36(5), 852-864.

[37] Gerwin, D., 1987. An agenda for research on the flexibility of manufacturing processes. *International Journal of Operations and Production Management* 7(1), 38-49.

[38] Slack, N., 1988. Manufacturing systems flexibility – an assessment procedure. *Computer-Integrated Manufacturing Systems* 1(1), 25-31.

[39] Olhager, J., West, M., 2002. The house of flexibility: using the QFD approach to deploy manufacturing flexibility. *International Journal of Operations and Production Management* 22(1), 50-79.

[40] Chang, S-C., Lin, R-J., Chen, J-H., Huang, L-H., 2005. Manufacturing flexibility and manufacturing proactiveness – empirical evidence from the motherboard industry. *Industrial Management & Data Systems* 105(8), 1115-1132.

[41] Schmenner, R.W., Tatikonda, M.V., 2005. Manufacturing process flexibility revisited. *International Journal of Operations and Production Management* 25(12), 1183-1189.

[42] Collins, R.S., Schmenner, R.W., 1993. Achieving rigid flexibility: factory focus in the 1990s. *European Management Journal* 11(4), 443-447.

[43] da Silveira, G.J.C., 2006. Effects of simplicity and discipline on operational flexibility: an empirical reexamination of the rigid flexibility model. *Journal of Operations Management* 24(6), 932-947.

[44] Yang, C.-L., Lin, C.H., Sheu, C., 2007. Developing manufacturing flexibility through supply chain activities: evidence from the motherboard industry. *Total Quality Management and Business Excellence* 18(9), 957-972.

[45] Slack, N., 1990. Flexibility as managers see it. In Warner, E., Wobbe, W., Brödner, P. *New Technology and Manufacturing Management.* John Wiley & Sons.

[46] Collins, R.S., Cordon, C, Julien, D., 1998. An empirical test of the rigid flexibility model. *Journal of Operations Management* 16(2-3), 133-146.

[47] Nunnally, J., 1978. *Psychometric Theory*. McGraw-Hill, New York, NY.

[48] Adler, P.S., Goldoftas, B., Levine, D.I., 1999. Flexibility versus efficiency? A case study of model changeovers in the Toyota Production System. *Organization Science* 10(1), 43-68.

Appendix: Survey Questionnaire

Levels of flexibility

Please indicate how your plant compares to its competition in your industry. Respondent: PM	
Variable	*Item*
MF	*Flexibility to change product mix*
VF	*Flexibility to change volume*
5-point scale: "Superior", "Better than average", "Average", "Equivalent to competition", "Poor, low end of industry"	

Operational performance

Please indicate how your plant compares to its competition in your industry. Respondent: PM	
Variable	*Item*
OP1	*Unit cost of manufacturing*
OP2	*Conformance to product specification*
OP3	*On time delivery performance*
OP4	*Fast delivery*
5-point scale: "Superior", "Better than average", "Average", "Equivalent to competition", "Poor, low end of industry"	

Flexibility source factors – manufacturing practices

TPM: Total Preventive Maintenance; α= 0.754; Respondents: PE, SP, PS

Variable	*Item*
TPM01	*Cleaning of equipment by operators is critical to its performance.*
TPM02	*Basic cleaning and lubrication of equipment is done by operators.*
TPM03	*Production leaders, rather than operators, inspect and monitor equipment performance (reverse coded).*
TPM04	*Operators inspect and monitor the performance of their own equipment.*

SPC: Statistical Process Control; α =0.901; DL, PE, QM

Variable	*Item*
SPC01	*A large percent of the processes on the shop floor are currently under statistical quality control.*
SPC02	*We make extensive use of statistical techniques to reduce variance in processes.*
SPC03	*We use charts to determine whether our manufacturing processes are in control.*
SPC04	*We monitor our processes using statistical process control.*

DFM: Design For Manufacturing; α = 0.738; PD

Variable	*Item*
DFM01	*New product design teams have frequent interaction with the manufacturing function.*
DFM02	*Manufacturing is involved at the early stages of new product development.*

MOD: Modular Product Design; α = 0.748; IM, PD, PE

Variable	*Item*
MOD01	*Our products are modularly designed, so they can be rapidly built by assembling modules.*
MOD02	*We have defined product platforms as a basis for future product variety and options.*
MOD03	*Our products are designed to use many common modules.*
MOD04	*We do not use common assemblies and components in many of our products (reverse coded).*

STR: Setup Time Reduction; α = 0.836; PC, IM, SP

Variable	*Item*
STR01	*We are aggressively working to lower setup times in our plant.*
STR02	*We have converted most of our setup time to external time, while the machine is running.*
STR03	*We have low setup times of equipment in our plant.*
STR04	*Our crews practice setups, in order to reduce the time required.*
STR05	*Our workers are trained to reduce setup time.*
STR06	*Our setup times seem hopelessly long(reverse coded).*

AMT: Advanced Manufacturing Technology; α = 0.793; PE, PM, PS

Variable	*Item*
AMT01	*We pursue long-range programs, in order to acquire manufacturing capabilities in advance of our needs.*
AMT02	*We make an effort to anticipate the potential of new manufacturing practices and technologies.*
AMT03	*Our plant stays on the leading edge of new technology in our industry.*
AMT04	*We are constantly thinking of the next generation of manufacturing technology.*

SLC: Slack Capacity; α = 0.629; PC, IM, SP

Variable	*Item*
SLC01	*We build time into our daily schedule to allow for machine breakdowns and unexpected productions stoppages*
SLC02	*We build extra slack into our daily schedule, to allow for catching up*

MTE: Multi-Trained Employees; α = 0.855; HR, SP, PS

Variable	*Item*
MTE01	*Our employees receive training to perform multiple tasks.*
MTE02	*Employees at this plant learn how to perform a variety of tasks.*
MTE03	*The longer an employee has been at this plant, the more tasks they learn to perform.*
MTE04	*Employees are cross-trained at this plant, so that they can fill in for others, if necessary.*
MTE05	*At this plant, each employee only learns how to do one job (reverse coded).*

7-point Likert-type scale from "1 = Strongly disagree" to "7 = Strongly agree"

Respondent legend

DL	*Direct labor*
HR	*Human resources manager*
IM	*Inventory manager*
PC	*Production control manager*
PD	*Member of product development team*
PE	*Process engineer*
PM	*Plant manager*
PS	*Plant superintendent*
QM	*Quality manager*
SP	*Supervisor*