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Technical Note

Toward a taxonomy of manufacturing flexibility dimensions

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Abstract

Researchers agree on the importance of manufacturing flexibility but are somewhat divided on the dimensions of this important construct. This paper seeks to find a middle-ground by working toward a generally acceptable taxonomy of manufacturing flexibility dimensions. The authors build on extant literature and propose a theoretically grounded operationalization of the manufacturing flexibility construct. Operational measures of manufacturing flexibility dimensions are identified and tested on a sample of 240 manufacturing firms. Results indicate good support for the theorized taxonomy.

Keywords: Manufacturing; Flexibility; Measurement; Empirical research

1. Introduction

Academicians and practitioners agree that the pressures of global competition will continue to grow in the twenty-first century. Barring some differences in terminology, the consensus is that the major competitive arenas will be cost, quality, and responsiveness, where responsiveness refers to flexibility and speed (Olhager, 1993). Most managers agree that cost and quality will continue to be competitive arenas for a firm. However, they also note that these are not enough to compete effectively in the marketplace. Flexibility to respond appropriately to changes in the competitive environment will be essential if a firm is to succeed in this increasingly global marketplace. It is therefore incumbent on managers and researchers to strive for a better understanding of the flexibility construct.

The manufacturing flexibility construct is not as well understood as are the cost or quality constructs. We know that the cost of a product is a function of direct labor, direct materials, and allocated overhead. Consequently, most firms have a reasonably accurate understanding of the cost of producing their products. The quality of a product is specifically defined when the firm identifies the characteristics that define product quality in the mind of the customer. Firms measure those characteristics and compare the data with predetermined standards to assess the degree of conformance between the quality characteristics and the design specifications. Thus, one can conceivably determine whether a product has met a predetermined standard of quality.

Flexibility, on the other hand, is not determined quite so easily. Most researchers in the area of manufacturing flexibility agree on a workable defini-

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tion of manufacturing flexibility. However, we notice significant variation in perspectives when we try to break down manufacturing flexibility into its dimensions, elements, and measures.

1.1. Objectives of the study

Gerwin notes that, ''operationalizing flexibility is ... the single most important research priority'' (1993, p. 405) for researchers in the area of manufacturing flexibility. However, only a few studies have operationalized this constructs, and even fewer studies have attempted to validate/refine such operationalizations based on empirical evidence. The objective of this paper is to develop a theoretically-grounded and empirically-tested operationalization of the manufacturing flexibility construct. The development builds on extant literature and results in a set of dimensions and elements of the manufacturing flexibility construct. We use data collected from 264 manufacturing firms to assess the validity of our operationalization.

2. Manufacturing flexibility

Most studies on manufacturing flexibility provide implicitly or explicitly stated definitions of the manufacturing flexibility construct. Some representative definitions are presented below.

- The ability to change or react with few penalties in time, effort, cost, or performance (Upton, 1994).
- The ability to implement changes in the internal operating environment in a timely manner at a reasonable cost in response to changes in market conditions (Watts et al., 1993).
- In the short run, flexibility means the ability to adapt to changing conditions using the existing set and amount of resources. In the long run, it measures the ability to introduce new products, new resources and production methods, and to integrate these into the existing production system (Olhager, 1993).
- The ability to respond effectively to changing circumstances (Gerwin, 1987; Gupta and Gupta, 1991).
- The capacity of a manufacturing system to adapt successfully to changing environmental conditions and process requirements. It refers to the ability of the production system to cope with the instability induced by the environment (Swamidass, 1988).

There is considerable commonality in these definitions of manufacturing flexibility. Specifically, they all describe manufacturing flexibility as the ability of the manufacturing function to react to changes in its environment. In addition, most of the definitions make some reference to the time such adjustments might take, the cost of the adjustments, and the effort required. This is consistent with Upton's (1995) observation that each dimension of manufacturing flexibility can be represented by two elements: the *range* of adjustment on the dimension, and the *mobility* of the adjustment on the dimension. We will elaborate on these elements later. For now, we present a working definition of manufacturing flexibility that encompasses the components common to most definitions found in the literature: Manufacturing flexibility is a multidimensional construct that represents the ability of the manufacturing function, to make adjustments needed to react to environmental changes without significant sacrifices to firm performance. Such adjustments are typically in the range of outputs and/or the mobility to respond to change.

2.1. Dimensions of manufacturing flexibility

There is general agreement among researchers that manufacturing flexibility is a multidimensional concept. However, they differ on what the underlying dimensions should be. Sethi and Sethi (1990) suggest 11 dimensions of manufacturing flexibility, Gupta and Somers (1996) identify nine, whereas Gerwin's (1993) taxonomy consists of seven dimensions. Some dimensions identified by researchers are strategic in nature. Examples include diversification of the product line, product innovation, responsiveness to customer specifications, and strategic adaptability. Others are tactical in nature. Examples might include accommodating variations or shortages in components or raw materials and adjusting job routing to bypass a disabled machine or process. Watts et al. (1993) address this hierarchical nature of manufacturing flexibility dimensions when they note that some dimensions are ''primary,'' whereas others are ''secondary.'' They note that the secondary dimensions may be components subsumed under the primary dimensions. In this paper, the unit of analysis is the manufacturing function of the organization, sometimes called the factory, plant, or production function of the firm. At this level of aggregation, the dimensions of interest are the ''primary'' dimensions. Hence, it is preferable that we focus on these primary dimensions, and not cloud our analysis with overlapping secondary dimensions.

Our initial task is to identify a parsimonious set of primary dimensions for manufacturing flexibility. We chose to use Gerwin's taxonomy as the starting point for our development. It is representative of most of the flexibility frameworks discussed in the literature, and for the most part, it focuses on ''primary'' dimensions of manufacturing flexibility. His seven dimensions of manufacturing strategy include: (1) *volume flexibility*, the ability to change the volume of output of a manufacturing process; (2) *materials flexibility*, the ability of the manufacturing system to accommodate uncontrollable variations in the materials and parts being processed; (3) *mix flexibility*, the ability of the system to produce many different products during the same planning period; (4) *modification flexibility*, the ability of the system to incorporate design changes into a specific product; (5) *changeover flexibility*, the ability of the system to adapt to changes in the production process; (6) *rerouting flexibility*, the ability to change the sequence of steps in the production process through which the product must progress; (7) *flexibility responsiveness*, the ability to adjust emphasis on the above flexibility dimensions given changes in the internal or external environment.

On viewing the first two dimensions, we note that as industries get more competitive, the ability of the manufacturing function to adjust the volume of output to meet market demand levels will increase. Thus, *volume flexibility* of the manufacturing system is clearly an important primary flexibility dimension. On the other hand, the second dimension, *materials flexibility*, has two components. The first is the ability of the system to handle inputs that are ''off-spec.'' The second component is the materials handling flexibility of the system itself. We believe that competitive pressure on suppliers to deliver quality products, and the increasing popularity of TQM routines that build supplier relationships, make off-spec inputs less of a problem for manufacturing firms. This has had the effect of diminishing the significance of the first component of material flexibility. However, the second component, *materials handling flexibility*, will continue to be an area of flexibility that is very much under the control of the firm and hence will be of interest to researchers and managers alike.

Our analysis of the seven dimensions also reveals some commonality. While volume flexibility and material handling flexibility are unique flexibility dimensions, mix flexibility and modification flexibility dimensions actually represent two perspectives on an underlying dimension that represents ''variety'' of new and existing products that the manufacturing system can produce. We call this *variety flexibility*. In addition, changeover flexibility and rerouting flexibility are two of several flexibility elements that reflect characteristics of the manufacturing ''process'' itself and are seen to represent a broader dimension that we call *process flexibility*. Finally, flexibility responsiveness is a category that reflects system mobility on each of the other dimensions and is what Upton (1994) called an element or sub-dimension of all manufacturing flexibility dimensions. We will come back to this element a little later in the paper. We suggest that the remaining six components of manufacturing flexibility can be parsimoniously represented on four dimensions: volume flexibility, variety flexibility, process flexibility, and materials handling flexibility.

We also note that two of these dimensions (volume flexibility and variety flexibility) are ''externally driven,'' toward meeting the market needs of the firm. The other two dimensions (process flexibility and materials handling flexibility) are ''internally driven,'' toward operational activities of the manufacturing function. This classification is in line with the generally accepted view that the ''dominant orientation'' of the firm (Hambrick et al., 1982; Galbraith and Schendel, 1983) can be described along two dimensions — one that is internally driven and another that is externally driven (Wheelwright, 1984).

In summary, the discussion presented above suggests that it is appropriate to view manufacturing flexibility dimensions as falling under two generalized categories: (1) externally-driven dimensions, and (2) internally-driven dimensions. Key externally-driven dimensions are volume flexibility and variety flexibility, while key internally-driven dimensions are process flexibility and materials handling flexibility. A more formal definition for each of the dimensions is presented in Table 1.

2.2. Manufacturing flexibility: integrating dimensions and elements

Implicit in the definitions of the four dimensions of manufacturing flexibility is the characterization of the extent or ''range'' of flexibility and also the agility or nimbleness of the firm to make the changes. Browne et al. (1984) were among the first to suggest the need to discuss the ability of a firm to operate within the broad parameters of a flexibility dimension. They used the term ''range of flexibility'' when discussing the degree of flexibility provided by a flexible manufacturing system. Swamidass (1988) reinforced this notion when he argued that manufacturing flexibility, when used properly, would result in a variety of products. However, he went one step further. He introduced the concept of ''speed,'' or mobility, when he stipulated that manufacturing flexibility could result in quicker changes in the product line. This quickness, or mobility is what Gerwin referred to as *flexibility responsiveness*, and is often measured in terms of time and cost (Gupta and Goyal, 1989). Gerwin (1993), and later Upton (1994), brought these concepts together when they argued that each dimension of manufacturing flexibility consisted of two elements, *range* and *mobility*. The greater the range of possible adjustments, the greater the flexibility. Also, the higher the mobility, the greater the flexibility.

To summarize, we identified four dimensions of manufacturing flexibility: *volume flexibility, variety flexibility, process flexibility,* and *materials handling flexibility*. We also note that each dimension has two elements: range and mobility. *Range* is the element that defines the extent of flexibility on each dimension. The element of *mobility* represents the firm's agility in making the changes on each dimension. Section 3 explains how the dimensions and elements were operationalized.

Table 1
The four dimensions of manufacturing flexibility

Category 1: Externally-driven flexibility dimensions	
1. Volume flexibility	This dimension of flexibility represents the ability to change the level of output of a manufacturing process
2. Variety flexibility	This dimension represents the ability of the manufacturing system to produce a number of different products and to introduce new products. Researchers have suggested the use of product mix and product modification as components of this dimension of manufacturing flexibility
Category 2: Internally-driven flexibility dimensions	
3. Process flexibility	This dimension represents the ability of the system to adjust to and accommodate changes/disruptions in the manufacturing process. Examples of these changes/disruptions found in the literature are, machine breakdowns, changes in the production schedules, or job sequencing
4. Materials handling flexibility	This dimension represents the ability of the materials handling process to effectively deliver materials to the appropriate stages of the manufacturing process and position the part or the material in such a manner as to permit value adding operations

3. Operationalizing the dimensions and elements of manufacturing flexibility

To operationalize our taxonomy for manufacturing flexibility, we began by identifying relevant measures for each of the flexibility dimensions in the extant literature. It is not our intention, at this time, to provide an exhaustive list of all such measures. The measures discussed in Sections 3.1–3.4, however, are the ones that we believe are the most representative of the literature. We observed that many of the measures found in the literature were originally created to support theoretical model developments. Few were developed to operationalize and test these models. To that extent measures may not have been stated explicitly. Nonetheless, they provide a starting point for the investigation. Consequently, we have attempted to classify earlier operationalizations of the manufacturing flexibility construct based on the dimension and element that they addressed.

We note that, although many measures have been suggested, not all of them explicitly focused on the range or the mobility element of the dimension. Hence, where a single measure seems to address both elements, we modified the measure so that it was directed toward only one element. For example, the dimension of volume flexibility might have been measured by the variation in quantity of output a system produces. Since it is possible to achieve wide ranges of variation if profitability is not a factor, the measure of the range element was appropriately altered to control for profitability. In general, some range elements may include references to cost, time, or profitability. However, these references are inserted to improve the quality of the range measure by controlling for mobility.

We used Gupta and Somers' (1992) review of the literature on manufacturing flexibility as a baseline for operationalizing the four dimensions. Their work was one of the first attempts that used empirical evidence to associate measurement items with specific underlying dimensions of manufacturing flexibility. Building on their work and other existing developments on the dimensions of manufacturing flexibility, we isolated measures that represent the range or the mobility element of the corresponding dimension. Details of the selection process are presented below. A summary of the operationalizations of each manufacturing flexibility dimension is presented in Table 2. In addition, the table presents measures recommended by Gupta and Somers (1996). As Table 2 reveals, there is considerable agreement between the two sets of items. We have also provided the sources of the measures used by both this study and that of Gupta and Somers.

3.1. Volume flexibility measures

3.1.1. Range

Measures of this element of the volume flexibility dimension are well documented in the literature. Browne et al. (1984) suggest that this element be measured as the smallest volume a system can produce without significantly effecting firm profitability. Gerwin (1987), on the other hand, offers two approaches. One is the ratio of average volume fluctuations to total capacity, and the other is an average of volume fluctuations over time. Sethi and Sethi (1990) recommend that one measure could be the range of output over which a firm can operate profitably.

We note that, although each of the above approaches seems to address the range of volume flexibility from different perspectives, they all involve the determination of output levels at which the firm operates profitably. In fact, operationalization of the range element of volume flexibility is the least controversial flexibility dimension in the literature. Thus, we are comfortable using a single measure for volume flexibility that is both straightforward and objective, and we offer the following:

- The range of output volumes at which the firm can run profitably.

3.1.2. Mobility

Fewer treatments of manufacturing flexibility address the issue of mobility as it pertains to volume flexibility. Those that do, however, are consistent in their use of ''time'' and ''cost'' as critical components for the mobility element of volume flexibility. Falkner (1986) recommends that constancy of per-unit manufacturing cost over different levels of output can be used as a measure of the mobility element. Two approaches are suggested by Carter (1986). One is the time required to double the output of a system in a given time period, and the other is the cost of doubling the system's output. Sethi and Sethi (1990) place a quantitative limitation on the range of volume when they suggest using the time required to change volume of output by 20%. Because of the practical limitations of acquiring time and cost data for a quantum change in manufacturing output (e.g., 20%), we believe that generalized measures would be more appropriate. We therefore propose the following measures:

- Time required to increase or decrease output.
- Cost of increasing or decreasing volume of output.

Table 2
Operationalization of the flexibility construct

Manufacturing flexibility measurement items used in this study		Gupta and Somers' (1992) list of manufacturing flexibility measures	
		Items	Original source
Volume flexibility			
Range	The range of output volumes at which the firm can run profitably is high	The range of volumes in which the firm can run profitably	Sethi and Sethi (1990)
		The capacity (e.g., output per unit time) of the system can be increased when needed with ease	Sethi and Sethi (1990)
Mobility	Cost required to increase or decrease output is high	Cost of doubling the output of the system	Carter (1986)
		Cost of delay in meeting customer orders	Abadie et al., (1988)
		Shortage cost of finished products	Abadie et al., (1988)
	Time required to increase or decrease output is high	Time required to increase or decrease production volume by 20%	Sethi and Sethi (1990)
		Time that may be required to double the output of the system	Carter (1986)
Variety flexibility			
Range	A large number of different products are produced by the manufacturing facility	Size of the universe of parts the manufacturing system is capable of producing without adding major capital equipment	Chatterjee et al. (1984)
		Number of different part types or range of sizes and shapes that the system can produce without major setups	Gerwin (1987)
	A large number of new products are produced each year	Number of new parts introduced per year	Jaikumar (1984)
Mobility	The time required to introduce new products is high	Time required to introduce new products	Sethi and Sethi (1990)
	The cost of introducing new products is high	Cost required to introduce new products	Sethi and Sethi (1990)
Process flexibility			
Range	A typical machine can perform a number of different operations without requiring a prohibitive amount of switching *time*	Number of different operations that a typical machine can perform without requiring a prohibitive *time* in switching from one operation to another	Sethi and Sethi (1990)
	A typical machine can perform a number of different operations without requiring prohibitive switching *costs*	Number of different operations that a typical machine can perform without requiring a prohibitive *cost* in switching from one operation to another	Sethi and Sethi (1990)
Mobility	Time required to switch from one product mix to another is high	Time required to switch from one part mix to another	Browne et al. (1984)
	Cost required to switch from one product mix to another is high	Cost required to switch from one part mix to another	Browne et al. (1984)
		Cost of the production lost as a result of expediting a preemptive order	Brill and Mandelbaum (1989)
		Changeover costs between known production tasks within the current production program	Warnecke and Steinhilper (1982)
Materials handling flexibility			
Range	The material handling system is designed to link every machine with every other machine on the shop floor	The material handling system can link every machine to every other machine	Chatterjee et al. (1987)
		The ratio of the number of paths the material handing systems can support to the total number of paths	Sethi and Sethi (1990)

Table 2 (*continued*)

Manufacturing flexibility measurement items used in this study		Gupta and Somers' (1992) list of manufacturing flexibility measures	
		Items	Original source
Materials handling flexibility			
	The material handling system can move every part for proper positioning and processing through the manufacturing facility	The ability of materials handling systems to move different part types for proper positioning and processing throughout the manufacturing facility	Sethi and Sethi (1990)
Mobility	Inventory cost as a percentage of total production cost is high		Gupta and Goyal (1989)

3.2. Variety flexibility measures

3.2.1. Range

This measure addresses the range of existing and new products produced by the manufacturing system. A measure of the existing range of products as offered by Carter (1986) is the extent to which the existing product mix can be changed while maintaining efficient production. As a measure of the range of new products, Dixon (1992) suggests a straightforward measurement of the number of new products or the number of new samples produced. This measure is similar to Gerwin's (1987) suggestion of using the number of product innovations and the number of design changes as a measure. However, new products represent new designs. Discussions with product design engineers led us to conclude that the distinction between new product introduction and the modification of existing products is very indistinct. Exactly when does a product undergoing design changes become a new product? We have tried to avoid that quagmire by making the simplifying assumption that new product introductions can also be used as an are an appropriate surrogate for product modification/innovation. We therefore offer the following measures for the range element of the variety dimension:

- The number of different products produced by the manufacturing facility.
- The number of new products produced per year.

3.2.2. Mobility

As with volume flexibility, the measures of the mobility component of variety flexibility also fall into the time and cost categories. Sethi and Sethi (1990) recommend that the time and cost to introduce new products be used as measures. Abadie et al. (1988) offer a somewhat more ambiguous measure: the cost of delay in meeting customer orders. Carter (1986) suggests a less direct way to measure variety mobility. He proposes the measurement of the robustness of production efficiencies. We chose Sethi and Sethi's operationalization because it was straightforward and parsimonious. As with the range items, our mobility items also focus on new products. Hence we offer the following measures:

- Time required to introduce new products.
- Cost of introducing new products.

3.3. Process flexibility measures

3.3.1. Range

The research has highlighted several components of the manufacturing process that necessitate process flexibility. Those discussed in the literature include, machine breakdown, rerouting or resequencing of jobs, and changes in the master schedule (Browne et al., 1984; Chatterjee et al., 1984; Gerwin, 1987; Das and Nagendra, 1993). No matter what the cause, the underlying determinant of process flexibility is the ability of machines, or machine centers, to perform their operations uninterrupted. If cost and or time were unlimited, almost any process could generate a high degree of flexibility. Of course, this is not the case. Hence, we chose to use two measures that are similar to Sethi and Sethi's (1990) global measures of the range of process flexibility:

- Number of operations a machine can perform without incurring prohibitive switching times.
- Number of operations a machine can perform without incurring prohibitive switching costs.

3.3.2. Mobility

Sethi and Sethi (1990) suggest using the time required to add one unit of production capacity as a measure of the mobility element of process flexibility. They also suggest using the cost of switching from one operation to another, and the procedural ease with which such changes can be made. Brill and Mandelbaum, (1989) recommend measuring the cost of production lost as a result of expediting a preemptive order. Warnecke and Steinhilper (1982) suggested using the costs incurred when switching between one production program and other known alternatives. Browne et al. (1984), however, suggested using the time and cost involved in switching from one part mix to another. It seems to us that the latter suggestion is the most direct and straight forward. In addition, it would be the easiest for operations managers to assess. Since we are interested in flexibility at the factory level, we chose to use a global measure that captures the production program as a whole, and offer the following measures of the mobility element of process flexibility:

- Time required to switch from one product mix to another.
- Cost required to switch from one product mix to another.

3.4. Materials handling flexibility measures

3.4.1. Range

The literature offers a few suggestions for the measurement of materials handling flexibility. This dimension is generally described as the firm's ability to move parts and/or materials through a process in an effective and efficient manner. Sethi and Sethi (1990) argue that the ratio of material handling paths to total number of processing paths would measure the range of materials handling flexibility. Chatterjee et al. (1984) suggest a measure of this element might be the extent to which the material handling system can link every machine to all other machines. In addition, Sethi and Sethi (1990) recommend using the ability of the material handling system to move different parts for proper positioning and processing through the system as a measure. Consequently, the range element can best be measured in terms of the materials handling systems ability to support alternative paths of movement through the various stages of a process. We therefore suggest the following measures culled from previous operationalizations found in the literature:

- The materials handling system is designed to link every machine with every other machine on the shop floor.
- The materials handling system can move every part for proper positioning and processing through the system.

3.4.2. Mobility

The literature does not suggest ways to measure the ''mobility'' element of materials handling flexibility. While this finding was at first a mystery, further thought provided a plausible explanation. While the range of materials handling flexibility pertains to the scope of materials handling options available to link equipment in the factory, the mobility element would relate to the time, cost, or efficiency of altering the material handling system to meet changing process needs. For example, assume that for various reasons, the jobs scheduled in a particular process have to be resequenced. This places demands on the materials handling system to move the jobs according to a new set of routings than were first planned. The efficiency with which the material handling system was able to accommodate the alternative materials handling paths, would be an indicator of its mobility. Viewed differently, the mobility of the material handling system will be inversely related to inventory build-up in the system. Hence, inventory cost as a percentage of production cost provides, at least in part, an indicator of the agility of the materials handling system. Given the paucity of operationalizations of this element, we chose to use this as our measure. Hence, we offer the following:

- Inventory cost as a percentage of total production cost.

4. Analysis and results

4.1. Method

The primary objective of our statistical analysis is to confirm whether the data set behaves as the theory suggests it should. If the data did behave as theorized, it would provide evidence of the appropriateness of the operationalization of the flexibility construct. Three statistical techniques were used during the analysis. First, correlations between the items that operationalized each of the four dimensions of manufacturing flexibility were assessed. Our theoretical development suggests that in each category, we should find higher correlation *among* the variables within each of the two elements (''range'' and ''mobility'') of a dimension and we should find lower correlations among variables *across* elements. The

Table 3
Measurement items and scales

Theoretical premise		Measurement items		Scale				
Dimension	Element	Symbol	Description	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
Volume flexibility	Range	Vol1	Range of output volumes at which the firm can run profitably is high	1	2	3	4	5
	Mobility	Vol2	Time required to increase or decrease output volume is high	1	2	3	4	5
		Vol3	Cost incurred to increase or decrease output volume is high	1	2	3	4	5
Variety flexibility	Range	Vri1	A large number of different products are produced by the manufacturing facility	1	2	3	4	5
		Vri2	A large number of new products produced every year	1	2	3	4	5
	Mobility	Vri4	The time required to introduce new products is high	1	2	3	4	5
		Vri5	The cost of introducing new products is high	1	2	3	4	5
Process flexibility	Range	Pr1	A typical machine can perform number of different operations without requiring a prohibitive amount of switching time	1	2	3	4	5
		Pr2	A typical machine can perform a number of different operations without requiring a prohibitive amount of switching cost	1	2	3	4	5
	Mobility	Pr3	Time required to switch from one part-mix to another is high	1	2	3	4	5
		Pr4	Cost required to switch from one part mix to another is high	1	2	3	4	5
Materials handling flexibility	Range	Mat1	The material handling system id designed to link every machine with every other machine on the shop floor	1	2	3	4	4
		Mat2	The material handling system can move every part for proper positioning and processing through the manufacturing facility	1	2	3	4	5
	Mobility	Mat3	Process inventory cost as a percentage of total production cost is high	1	2	3	4	5

second step of the analysis required that we cross-check our results using Cronbach's α. This would allow us to further assess whether the items in each element ''hang together.''

As a final step of the analysis, we propose to test the match between the theoretical model and the data by undertaking a confirmatory factor analysis for each dimension to assess the extent of separation across the elements. The existence of high loadings on the appropriate factors and non-significant loading on the other factor(s) along with a high level of variation explained by the model would be a positive signal. The existence of low factor loading, multiple factor loadings, or low levels of explained variance in the model are indicators of poor ''fit'' between the data set and the theory.

4.2. Data set

The current study is part of an ongoing stream of research that focuses on the manufacturing flexibility of firms. The database consists of 240 firms that responded to a pretested mailed questionnaire containing the items that related to manufacturing flexibility. Table 3 provides details on the items and the measurement scale. A 5-point Likert-type scale was used. Respondents were asked to circle the position on the scale that best represented their manufacturing function's position relative to that of their competitors.

Firms were selected from the 1996 Directory of Texas Manufacturers, compiled by the Bureau of Business Research, in Austin, TX. Questionnaires were mailed to the CEO or Head of Operations at 995 firms in August, 1997. Two follow-up mailings were undertaken. The final response rate was 24.1%. To check for non-response bias, the sample was split into two groups: early and late respondents. A test for equality of means indicated no differences on three variables that were not part of the variables-of-interest. Specifically, we looked at the years that the respondent had been with the firm, and two performance variables: Cost (cost of production per unit output relative to the competition) and quality (number of customer complaints about product quality.) We chose to include performance variables because we expect that they will eventually be important ''dependent'' variables in future research on manufacturing flexibility. In all three cases the results were not significant (significance levels were 0.22, 0.905, and 0.55, respectively). This suggests that late responses were not different from early responses, and it leads us to believe that non-response bias may not be a significant issue.

Our sample of respondents consisted primarily of senior level managers. There were 57 Presidents or CEOs, 76 General Managers or VPs of Operations, 45 Manufacturing Plant Managers, 27 manufacturing/operations managers and 35 other senior managers in the sample. A typical respondent had been with the firm for an average of about 14.5 years (standard deviation 9.3 years), suggesting that they should be very knowledgeable about firm-specific issues. The SPSS statistical package was used to analyze the data set.

5. Results

Correlational analysis of all variables used in the study indicated no situations of multi-collinearity. As a precursor to our investigation of each manufacturing flexibility dimension, we felt it necessary to investigate the interdependence between the theoretically-configured dimensions and elements of manufacturing flexibility. If our theoretical developments are correct, the variable loadings on an eight-factor solution should be fairly representative of the eight-component theoretical taxonomy. The eight-factor solution that resulted from the data analysis is presented in Table 4. We note that the solution that unfolded was identical to the one that was predicted. In addition, the eight-factor solution explained 87.4% of the variation. This provided encouraging prima facie evidence of the appropriateness of our instrument in operationalizing what we theorized to be relatively independent dimensions of manufacturing flexibility. In Section 5.1, we will assess the operationalizations of each of the dimensions of manufacturing flexibility.

5.1. Volume flexibility

The correlation matrix for the items representing volume flexibility indicates significant correlation between the two mobility items (Table 5). They also

Table 4
Range and mobility elements of manufacturing flexibility in the data set
Eight-factor solution: rotated component matrix (variance explained: 87.4%).

Type of flexibility variables that loaded on the factor	Variable	Factor loadings							
		1	2	3	4	5	6	7	8
Process range	Pr1	0.94							
	Pr2	0.94							
Process mobility	Pr3		0.93						
	Pr4		0.92						
Variety mobility	Vri3			0.91					
	Vri4			0.90					
Materals handling range	Mat1				0.91				
	Mat2				0.90				
Volume mobility	Vol2					0.87			
	Vol3					0.89			
Variety range	Vri1						0.85		
	Vri2						0.86		
Materials handling mobility	Mat3							0.99	
Volume range	Vol1								0.99

exhibit good separation (low correlation) from the ''range'' item. Cronbach's α for the two mobility items was at an acceptable level (0.76) for this type of exploratory research (Cronbach αs for the scale exceeded the 0.5 criterion generally considered adequate for exploratory works).

Results from the factor analysis of the three items using the entire sample set of 240 observations are

Table 5
Volume flexibility
Variation explained by the two-factor model — all firms: 87.4%; make-to-stock firms: 90.3%; make-to-order firms: 85.7%.

Correlation analysis and coefficient α ($n=240$)

Element	Measures		Vol1	Vol2	Vol3 ($n=240$)	Coefficient α
Range	Range of output volumes at which the firm can run profitability is high	Vol1	1.000			na
Mobility	Time required to increase or decrease output volume is high	Vol2	0.015	1.000		0.76
	Cost incurred to increase or decrease output volume is high	Vol3	−0.070	0.619**	1.000	

Factor analysis

Element	Measures	All firms ($n=240$) Factor loadings		Make-to-stock firms ($n=101$) Factor loadings		Make-to-order firms ($n=139$) Factor loadings	
Range	Vol1	0.998		0.993		0.999	
Mobility	Vol2		0.900		0.922		0.886
	Vol3		0.897		0.907		0.885

** Correlations significant at the 0.01 level (two-tailed).

also presented in Table 5. As per Nunnally's (1978) recommendation, only factor loadings that are greater than 0.40 are presented and used for analysis in this and subsequent factor analyses. The theorized two-factor model explained a significant portion (87.4%) of the variation in the data set. In addition, factor loadings are high and mirror the theorized pattern. This suggests that it is appropriate to conceptualize the volume flexibility dimensions as being independent underlying elements. To further determine if the results are not sample-specific, we ran the factor analysis independently on two subsets of firms in the database. The first subsets consisted of 101 firms that were primarily ''make-to-stock'' businesses. The second subset consisted of 139 ''make-to-order'' businesses. The item in the questionnaire that allowed us to create the two sub-groups read: ''Yours is predominantly a (A) Make-to-order business: Products are generally customized to customer requirements, or (B) Make-to-stock business: Products are made to standard specifications.'' The results of the factor analysis for each sub-group were very similar to those obtained for the entire set of 240 firms (Table 5). This further supports the two-factor operationalization of volume flexibility.

5.2. Variety flexibility

Correlation analysis indicated significant correlations ($r = 0.519$) between the ''range'' items (vri1 and vri2). The coefficient α was 0.68. Results of the correlation between the ''mobility'' items (vri3 and vri4) was also significant ($r = 0.715$). Coefficient α was a healthy 0.83. The correlation matrix for the four variety flexibility items is provided in Table 6.

Results of the factor analysis of the four variety flexibility items using the entire sample set of firms are also presented in Table 6. The two-factor model explained 80.9% of the variation in the data. In addition the factor loadings were high, and fell out in the predicted pattern. Table 6 also provides results of the factor analysis run on the two subsets of observations (101 make-to-order firms and 139 make-to-stock firms). The similarities of factor loadings, and

Table 6
Variety flexibility
Variation explained by the two-factor model — all firms: 80.9%; make-to-stock firms: 81.8%; make-to-order firms: 80.7%.

Correlation analysis and coefficient α ($n = 240$)

Element	Measures		Vri1	Vri2	Vri3	Vri4 ($n = 240$)	Coefficient α
Range	A large number of different products are produced by the manufacturing facility.	Vri1	1.000				0.68
	A large number of new products are produced every year.	Vri2	0.519**	1.000			
Mobility	The time required to introduce new products is high.	Vri3	−0.044	0.074	1.000		0.83
	The cost of introducing new products is high.	Vri4	−0.047	0.050	0.0715**	1.000	

Factor analysis

Element	Measures	All firms ($n = 240$) Factor loadings		Make-to-stock firms ($n = 101$) Factor loadings		Make-to-order firms ($n = 139$) Factor loadings	
Range	Vri1	0.872		0.866		0.881	
	Vri2	0.870		0.856		0.868	
Mobility	Vri4		0.925		0.935		0.917
	Vri5		0.926		0.941		0.915

** Correlations significant at the 0.01 level (two-tailed).

explained variance (81.8% for the make-to-stock group and 80.7% for the make-to-order group) confirmed the two-factor model and further supports our operationalization of the variety flexibility dimension.

5.3. Process flexibility

Results of the correlation analysis have been presented in Table 7. Correlations among the variables that were theorized to hang together are significantly higher than other bivariate correlations in the matrix ($r = 0.851$ for the range items and $r = 0.816$ for the mobility items). The coefficient αs for the corresponding elements support this finding (0.92 for range items and 0.90 for the mobility items).

Results of the factor analysis (Table 7) confirm the appropriateness of the two-factor solution. The models (full sample and subsets) explained a high level of the variation in the data sets (91.7% for the full sample, 92.7% for make-to-stock firms, and 91.2% for make-to-order firms). In addition, appropriately high loadings are observed on each factor that matched theorized relationship. This is true not only for the entire sample set of 240 observations but also for the sub-samples suggesting a rather robust instrument for measuring process flexibility.

5.4. Materials flexibility

We had identified two items (mat1 and mat2) that operationalize the ''range'' of materials flexibility and one item (mat3) that operationalize its ''mobility'' component. Results of correlation analysis of these variables are presented in Table 8. As indicated in the table, intra-group correlations is high for the range items ($r = 0.662$) and the corresponding Cronbach α is near 0.8 for the range items. In addition the across-group correlations are low; suggesting good separation between the two sets of items.

Table 7
Process flexibility
Variation explained by the two-factors model — all firms: 91.7%; make-to-stock firms: 92.7%; make-to-order firms: 91.2%.

Correlation analysis and coefficient α ($n = 240$)

Element	Measures		Pr1	Pr2	Pr3	Pr4 ($n = 240$)	Coefficient α
Range	A typical machine can perform a number of different operations without requiring a prohibitive amount of switching *time*	Pr1	1.000				0.92
	A typical machine can perform a number of different operations without requiring prohibitive switching *costs*	Pr2	0.851**	1.000			
Mobility	Time required to switch from one product mix to another is high	Pr3	0.253**	0.215**	1.000		0.90
	Cost required to switch from one product mix to another is high	Pr4	0.258**	0.227**	0.816**	1.000	

Factor analysis

Element	Measures	All firms ($n = 240$) Factor loadings		Make-to-stock firms ($n = 101$) Factor loadings		Make-to-order firms ($n = 139$) Factor loadings	
Range	Pr1	0.957		0.964		0.953	
	Pr2	0.951		0.961		0.944	
Mobility	Pr3		0.945		0.955		0.939
	Pr4		0.944		0.940		0.947

** Correlations significant at the 0.01 level (two-tailed).

Table 8
Materials flexibility
Variation explained by the two-factor model — all firms: 88.7%; make-to-stock firms: 87.9%; make-to-order firms: 89.3%.

Correlation analysis and coefficient α ($n = 240$)

Element	Measures		Mat1	Mat2	Mat3 ($n = 240$)	Coefficient α
Range	The material handling system is designed to link every machine with every other machine on the shop floor.	Mat1	1.000			0.80
	The material handling system can move every part for proper positioning and procession through the manufacturing facility.	Mat2	0.662**	1.000		
Mobility	Process inventory cost as a percentage of total production cost is high.	Mat3	0.037	0.015	1.000	na

Factor analysis

Element	Measures	All firms (n = 240) Factor loadings		Make-to-stock firms (n = 101) Factor loadings		Make-to-order firms (n = 139) Factor loadings	
Range	Mat1	0.911		0.899		0.916	
	Mat2	0.910		0.897		0.916	
Mobility	Mat3		0.997		0.98		1.000

** Correlations significant at the 0.01 level (two-tailed).

Results of the factor analysis in Table 8 indicate that a two-factor solution explains 88.7% of the variation in the data set. In addition the factor loadings reflect the pattern that was theorized. Similar factor loading patterns and similar levels of explained variances were noted for the two subgroups of firms (87.9% for the make-to-stock group and 89.3% for the make-to-order group). While the explained variance was slightly higher for the make-to-order firms, the difference was marginal at best. Hence, we conclude that our operationalization of the two-factor model for materials flexibility is appropriate.

6. Discussion and conclusions

Gerwin (1993) identified the task of operationalizing the manufacturing flexibility construct as the single most important priority for researchers in this area. We have endeavored to answer Gerwin's call and to extend it a step further by empirically testing the operationalized dimensions of the manufacturing flexibility construct. The literature on manufacturing flexibility was reviewed and key theoretical developments were isolated. We then developed a parsimonious conceptualization and operationalization of manufacturing flexibility dimensions that is grounded in the manufacturing flexibility literature. To assess the appropriateness of our taxonomy, we operationalized and tested the taxonomy using empirical data from a sample set of 240 manufacturing firms. The value in our development lies in its ability to provide direction toward a generalizable taxonomy of manufacturing flexibility dimensions.

The results of the empirical analysis of the data set suggest that the operationalization is fairly robust, with dimensions and elements falling out as theoretically predicted in the entire sample as well as in two sub-samples of firms. These results are especially encouraging when one notes that the sub-samples represent firms that are known to be configurationally different. The make-to-stock firms use manufacturing processes that tend to be configured as ''line'' or ''continuous flow'' while the make-to-order firms have manufacturing processes that tend to be ''project-,'' ''job-shop-,'' or ''batch''-oriented. Despite their configurational differences, both groups of firms were successfully characterized using our operationalization of the manufacturing flexibility construct. This lends support to the generalizability of our operationalization across these types of manufacturing firms.

We believe that our taxonomy is useful in several respects. The parsimonious nature of the instrument makes it easy to implement. In addition, several researchers have noted that manufacturing flexibility may well be a critical competitive arena in the twenty-first century. Hayes and Upton (1998) argue that companies that use the operations function as an element in their competitive battles with other companies in their industry have discovered that such capabilities cannot be developed quickly. The exact organizational configuration that creates such flexibility has yet to be exactly determined. Greis and Kasarda (1997) suggest that a ''collective enterprise'' configuration might provide the broader range of resources, skills and technologies to adapt to market opportunities and provide the flexibility needed to compete effectively. Our conceptualization of manufacturing flexibility may be useful to researchers and practitioners as they strive to take advantage of a better understanding of manufacturing flexibility.

Configurational research on manufacturing flexibility has not been profuse. We believe that the existence of our integrative taxonomy could stimulate the search for robust manufacturing flexibility archetypes. Several important research questions exist in this areas. For example, is it possible to isolate a set of manufacturing flexibility archetypes that are generalizable across most manufacturing firms? If not, are there sub-sets of firms within from which such typologies can be developed. We have noted that our taxonomy of manufacturing flexibility dimensions is appropriate for both make-to-order and make-to-stock firms. But, will the flexibility archetypes also follow the same pattern? This is one of several ''content'' related questions that can be more readily addressed with an existing taxonomy of manufacturing flexibility dimensions.

The availability of a tested taxonomy of manufacturing dimensions should be good news for researchers who investigate manufacturing flexibility ''process'' issues. For example, we do not fully understand the process of configuring manufacturing flexibility. While researchers have implicitly postulated a direct linkage between environmental uncertainty and manufacturing flexibility, new evidence from the field of organizational theory suggests that such a portrayal may be an oversimplification. Our taxonomy allows researchers to evaluate these and other process relationships at the dimensional level.

6.1. Study limitations

We would like to conclude by noting that this study is exploratory in nature. We do not present this research as the definitive work on manufacturing flexibility dimensions. Rather, we hope it moves us a few steps closer to a comprehensive, yet parsimonious model. When this is done, the resulting model might or might not have elements common to those that we have identified in this paper. For example, our review of the literature uncovered a variety of frameworks, each of which included a different set of manufacturing flexibility dimensions. Which one is the best? All of them can be defended on a theoretical basis. We have tried to simplify our model by identifying four and only four dimensions: volume, variety, materials handling, and process. We acknowledge that this could be seen by some as a limitation of our research. We believe, however, that it provides an effective springboard for further research in the area.

We recognize that further research is needed. Subsequent efforts might result in a more comprehensive set of dimensions that are generalizable across a variety of industries. It is every researcher's prerogative to question the appropriateness of any model specification.

We hope that our integration will stimulate such efforts. For example, our data supports the appropriateness of isolating materials handling flexibility as a unique dimension. However, other researchers may want to investigate the alternate hypothesis that materials handling flexibility may be subsumed under the broad umbrella of process flexibility. If such is indeed the case, it would lead to an increased level of parsimony in the operationalization of the flexibility construct. Conversely, researchers may want to explore the alternate hypothesis that the operationalization may be under-specified, and that there are, indeed, other significant dimensions that need to be included in the operationalization.

We have used an instrument that was constructed recently and could benefit from refinements. Two area may warrant further research. First, one might want to consider improvements on the single-item operationalizations of the range element of volume flexibility and the mobility item of materials flexibility. Second, the range and mobility elements of the process construct did not show exceptionally good separation. This is probably due to the quality of the items used. We suggest that researchers attempt to develop items that provided better separation between these two elements of process flexibility.

Although the sample set is rather large, all the firms are from one state. We do not believe that geographical location is a significant factor in this study. However, the reader may want to consider this aspect into account when interpreting our findings. Finally, although several studies have found that information provided by the manager of the ''unit-of-analysis'' in the firm is acceptable for this type of research, such information does reflects the subjective judgement of the manager and should be treated with appropriate caution.

The operationalization that is developed and tested in this paper is an attempt to move toward a generally acceptable taxonomy of manufacturing flexibility dimensions. Although the results of our study are encouraging, we invite other researchers to further refine our operationalization and to delve deeper into its applicability in other organizational settings.

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