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Defining Manufacturing Flexibility: A Research Prerequisite

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**DEFINING MANUFACTURING FLEXIBILITY:
A RESEARCH PREREQUISITE**

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ABSTRACT

In the 21st century, manufacturers face an increasingly uncertain external environment with the cumulative effect of changes in customer requirements, global competition, and technological advancement. Thus, in addition to quality, cost and time, flexibility has become an important competitive weapon for manufacturing companies. In the manufacturing flexibility field, understanding, classifying and measuring manufacturing flexibility is very important to researchers and practitioners alike as the concepts, as expressed in the literature, are at best vague and at worst, confusing. This paper reviews the definition, classification, and measurement of manufacturing flexibility and in so doing attempts to identify the most appropriate definitions, classifications and measurements that can be used in a study concerned with manufacturing flexibility management. The selection process consists of the synthesis and critical evaluation of the concepts put forward in the extant literature. As a consequence of this process four primary flexibility dimensions are identified: volume, variety, process, and material handling. In addition two lower order attributes of flexibility are identified as providing the most likely means of measuring manufacturing flexibility: the number or range of options at a given time, and the mobility or the ease with which an organisation moves from one state to another.

Keywords: Manufacturing flexibility, Volume flexibility, Variety flexibility, Process flexibility, Material handling flexibility.

INTRODUCTION

In the 21st century, manufacturers are facing an increasingly uncertain external environment with a cumulative effect of changes in customer requirements, global competition, and technological advancement. As a consequence, flexibility is now regarded by most manufacturing organisations as one of their most important competitive weapons, besides quality, cost and time.

Understanding the definition, classification and measurement of manufacturing flexibility is very important to researchers and practitioners in manufacturing management. The ambiguities and inconsistencies in the concept of manufacturing flexibility make the understanding of the subject difficult. Thus it has been suggested that the management of manufacturing flexibility could be understood, measured and managed better if the vagueness that surrounds it was removed, and researchers and practitioners had a framework which clarified the issues (Upton, 1994). This might include the basic structures for defining, characterising and measuring flexibility.

In the following sections this paper will identify the main issues concerning researchers and practitioners with particular emphasis on defining, classifying and measuring flexibility. Through a process of synthesis and a critical evaluation of the published literature, the principal flexibility dimensions required to conduct research in manufacturing flexibility management will be identified and defined, as will the most likely means of measuring them.

DEFINING MANUFACTURING FLEXIBILITY

There have been many definitions for the term manufacturing flexibility. The flexibility concept can be translated into the production context as 'the ability to take up different positions', or alternatively, 'the ability to adopt a range of states' (Slack, 1983, p. 7). Gupta and Goyal (1989, p. 120) use the definition of "the ability of a manufacturing system to cope with changing circumstances or instability caused by the environment", whilst, manufacturing flexibility is defined by Upton (1994, p. 73) as "the ability to change or react with little penalty in time, effort, cost, or performance".

Looking to more recent definitions, among others, Swamidass (2000, p. 399) offers a definition of manufacturing flexibility as "the capacity of a manufacturing system to adapt successfully to changing environmental conditions as well as changing product and process requirements".

Zhang et al. (2003, p. 178) regard manufacturing flexibility as "the ability of the organisation to manage production resource and uncertainty to meet various customer requests".

The above definitions emphasise some important points. First, flexibility is used to accommodate uncertainty, usually in the form of changes emanating from both the internal and external environment, e.g. changes in product design or customer requirements. Second, flexibility refers to the capability of a manufacturing system to manage its resources in order to adapt successfully to these changes. Therefore, manufacturing flexibility could be defined as: the ability of manufacturing organisations to manage their resources in order to cope with environmental uncertainties, and to be able to produce variability in product outputs.

There are also some manufacturing concepts that are similar to flexibility. However, whilst they are not mutually exclusive concepts, they do differ in a number of important aspects. Spring and Dalrymple (2000) review the literature covering manufacturing strategy, flexibility and agile manufacturing concepts. Consequentially, they make the following distinction between each concept:

- *Flexibility* - the capacity to deploy or re-deploy production resources efficiently as required by changes in the environment.
- *Total flexibility* - the ability to deliver high-quality product tailored to each customer at mass-production prices.
- *Agility* - the ability to alter any aspect of the manufacturing enterprise in response to changing market demands.
- *Flexibility/agility* - an ability to adapt rapidly and with constant coordination in an environment of constant and rapid change.

Baker (1996) explains the real difference between flexibility and agility, i.e. the level of application of the concept. According to him, whilst agility places greater focus on the strategic levels, flexibility is usually associated with the operational level. Moreover, agility implies both range and response dimensions (concepts discussed later), whilst flexibility can be one or the other, or both. Flexible operations are needed in order to provide agility at the organisational and business network levels (Baker, 1996).

MANUFACTURING FLEXIBILITY CONSTRUCTS

Many studies have been undertaken with the aim of extending our understanding of the nature of flexibility and its measurement. Beach et al. (2000) provide an extensive review of the literature in this area, examining many of the issues surrounding the concept of manufacturing flexibility, including the taxonomies used and the means of measuring flexibility.

To date, there is no consensus regarding the classifications and definition of flexibility and its constituent elements. Those developed by Slack (1983), Browne et al. (1984), Gerwin (1987), Sethi and Sethi (1990), and Hyun and Ahn (1992) show there are many that are not unique and sometimes show redundancy. The lack of a homogeneous view of manufacturing flexibility, and the lack of consensus on the terms used to describe it, complicate our understanding of the different notions of manufacturing flexibility and their measurement (Swamidass, 1988). Furthermore, researchers have still to reach an agreement on the definitions used to describe some of the most basic terms

A case in point is the term used to describe the constituent elements of flexibility. These have been described variously as flexibility 'types', 'dimensions', and 'kinds'. Taking into consideration this difficulty, Ramasesh (2000) has suggested that a distinction be made between manufacturing flexibility types and manufacturing flexibility dimensions, thus: "manufacturing flexibility types", refers to a few aggregate broader concepts or the aggregate notions of manufacturing flexibility. Whereas "manufacturing flexibility dimensions" applies to a large number of specific, more narrowly defined types of flexibility, or the specific attributes or constituent notions of manufacturing flexibility. For the purpose of clarity, the above definition will be adopted throughout this paper. However, the reader should be aware that many of the researchers cited herein may have used a different nomenclature when describing their own work.

Among the earliest flexibility classification systems is the one suggested by Browne et al. (1984). In the early 1980s many new manufacturing facilities were labelled Flexible Manufacturing System (FMS) and as a consequence, some confusion emerged about what constituted a FMS. To overcome this, Browne et al. (1984) developed a taxonomy that defined and described eight dimensions of flexibilities. These are: machine, process, product, routing, volume, expansion, operation, and

production flexibility. This classification has been used extensively by other researchers, such as Sethi and Sethi (1990). Indeed, Gupta and Goyal (1989) found the categories proposed by Browne et al. to represent "the most comprehensive" classification.

Slack (1983) describes the concept of manufacturing flexibility as an operation's ability to take up different positions or to adopt a range of states, and the ease with which a system moves from one state to another, in terms of time and cost. Building on this reasoning, he proposed that manufacturing flexibility dimensions could be further divided into three lower order attributes: the range of states a system could adopt, the cost of making the change, and the time necessary for the change. Manufacturing flexibility, according to him, has five dimensions: product, product mix, quality level, volume, and delivery. Later, Slack (1987) sought managers' views on manufacturing flexibility at the total manufacturing level. The empirical evidence showed that all the identified dimensions of flexibility were important, except for quality. The quality dimension was subsequently eliminated due to lack of support amongst the sample for the notion that companies might want to vary the quality of their products.

Hyun and Ahn (1992) classify the various dimensions of manufacturing flexibility according to three perspectives: the system view, the environment-associated view, and the decision-hierarchy view. The first corresponds to the organisational structure of a firm, characterised by its functional flexibilities, i.e. machine, routing, control and worker flexibility. The second relates to characteristics of internal and external environments surrounding manufacturing activities. Flexibility dimensions under this category are expansion, product, mix, volume and programme. The third refers to the decision hierarchy, and has three main dimensions: long-term, mid-term and short-term.

One of the most widely accepted classification systems was developed by Sethi and Sethi (1990). This surveys the literature on manufacturing flexibility over the previous 10 to 20 years and through reasoned argument identifies eleven dimensions of manufacturing flexibility as well as the means of measuring and evaluating them. Interestingly, the eleven dimensions are developed from the eight original dimensions of Browne et al. (1984), the additional three dimensions that emerged from their synthesis of the literature were: material handling, programme, and market flexibility.

More recently, D'Souza and William (2000) have attempted to develop a generally acceptable taxonomy of the manufacturing flexibility construct. Their study is based on the taxonomy built by Sethi and Sethi (1990), Gupta and Somers (1992) and Gerwin (1993). A sample of manufacturing companies was used to identify the operational measures of manufacturing flexibility. The results provide support for the proposed taxonomy. Two generalised categories of manufacturing flexibility emerge as externally and internally driven. The externally driven manufacturing flexibility dimensions are volume and variety flexibility, while the internally driven manufacturing flexibility dimensions are process and material handling flexibility.

Having various dimensions of manufacturing flexibility, a manufacturing company must identify the dimension(s) it most needs (Adler, 1988; Gerwin, 1993; Upton, 1995b). Furthermore, a comparison of the specific aspects of flexibility that are leveraged and emphasised is also thought to be necessary (Koste and Malhotra, 2000) as trade-offs may occur between the different dimensions. Indeed, relationships are thought to exist among the various flexibility dimensions, e.g. between machine and process flexibility (Boyer and Leong, 1996). Furthermore, certain flexibility dimensions have been found to be more important than the others; specifically, machine, labour, mix, new product and modification (Abdel-Malek et al., 2000; Braglia and Petroni, 2000; Koste and Malhotra, 2000).

MEASURING MANUFACTURING FLEXIBILITY

One area in manufacturing flexibility where researchers have experienced particular difficulties is in evaluating and measuring flexibility. The cause of the difficulties are said to be due to a number of factors (Slack, 1983; Upton, 1995; Narain et al., 2000): manufacturing flexibility is a measure of potential rather than actual performance; the concept lacks a coherent and detailed classification and is multidimensional in nature.

Difficulties encountered in measuring manufacturing flexibility are fundamentally based on the fact that the measurement must depend on factors such as the degree of uncertainty in the environment, management objectives, and machine capabilities (Gupta, 1993). From consideration of these nebulous factors it is clear why researchers have experienced some difficulty in defining the manufacturing flexibility concept and why measuring manufacturing flexibility as proved so problematic.

Research into the measurement of manufacturing flexibility can be classified according to the ways researchers have defined flexibility, and the approaches used in measuring it (Gupta and Goyal, 1989). These approaches are based on economic consequences, performance criteria, multi-dimensional approach, petri-nets approach, decision theory approach, and information theory approach.

It is quite possible that the difficulties of measuring flexibility are being exacerbated by the multifarious ways in which the subject is being approached. Therefore, Gupta and Somers (1992) have beseeched researchers and practitioners to choose a standard measurement. The measurement should be adequately reliable and valid, in order to bridge the gap between theory and empirical observation (Vokurka and O'Leary, 2000). Gupta and Somers (1992) review the literature, particularly on manufacturing flexibility measurement, and develop an instrument for measuring and analysing manufacturing flexibility. They use empirical evidence to associate measurement items with specific underlying dimensions of manufacturing flexibility.

The measurement of manufacturing flexibility in the extant literature can be classified according to three attributes. First, the number of options or range at a given time (Slack, 1983; Gerwin, 1993; Upton, 1994; Koste and Malhotra, 1999). Second, the mobility or the ease with which the organisation moves from one state to another (Slack, 1983; Upton, 1994; Koste and Malhotra, 1999). The mobility attribute uses both the time and cost of making changes as an assessment because of the interrelatedness of these two elements. Third, the uniformity or the similarity of performance outcomes within the range (Upton, 1994; Koste and Malhotra, 1999)

These attributes were suggested instead of other indicators based on physical units, because of the lack of agreement on the relationships between dimensions and higher order types, and the inconsistency in approach. According to Gerwin (1993), the most common measurement approach in practice is to count the number of options at a given time. This approach actually represents the ability to take up different positions in the production context (Slack, 1983). Thus, one production system is more flexible than another if it is capable, for example, of producing a wide range of products. This also reflects the range in which the production resource can be managed to meet various customer requests. The production

resource might involve, for example, workforce, machines, and technology.

Regarding the second attribute (mobility), cost and time are popular measurements for flexibility, as they are in other organisational performances contexts. A production system which moves smoothly, quickly and cheaply from one state to another should be considered more flexible than a system which achieves the same change, but at greater cost or time (Slack, 1983). Cost and time also can be regarded as the resistance elements of flexibility (Slack, 1987). They constrain the response of the system to move from one state to another, and manifest the difficulty of making a change.

Since the third attribute (uniformity) represents the consistency of performance measurement, it can be assessed through efficiency, productivity, quality, and processing times (Koste and Malhotra, 1999). They suggest that a less flexible manufacturing system will exhibit peaks in performance outcomes, whereas a flexible manufacturing system is one in which such a performance measure is invariant with the position it occupies within the range (Upton, 1994).

SELECTING THE STUDY DIMENSIONS AND ATTRIBUTES

The selection of the manufacturing flexibility dimensions and attributes to be used in this study involved reviewing the dimensions identified in the most recent research on manufacturing

flexibility and a construct developed from what has been considered to be the most comprehensive synthesis of manufacturing flexibility.

To select the flexibility dimensions, the recent work involving empirical research into manufacturing flexibility found in the literature was analysed (D'Souza and Williams, 2000; Koste and Malhotra, 2000; Jack and Raturi, 2002; Petroni and Bevilacqua, 2002; Zhang et al., 2003). The flexibility dimensions and the rationale behind their selection are as shown in Table 1.

Four dimensions of flexibility: volume, variety, process, and material handling flexibility, appear to be particularly popular dimensions. According to D'Souza and Williams (2000), they are a parsimonious set of primary dimensions for manufacturing flexibility. Indeed, one of the dimensions, i.e. volume flexibility, is considered to be a key contributor to an organisation's competitive strategy (Jack and Raturi, 2002).

These four dimensions were also among the flexibility dimensions proposed by researchers, as discussed in the previous section. The operationalisation for these four dimensions has been developed by D'Souza and Williams (2000). As the starting point they used Gerwin's (1993) taxonomy to define the flexibility dimensions. For the flexibility measurement, they used Gupta and Somers' (1992) work. Table 2 outlines the flexibility dimensions and their associated uncertainty, as suggested by Gerwin (1993).

TABLE 1: FLEXIBILITY DIMENSIONS STUDIED IN RECENT EMPIRICAL RESEARCH

Research	Flexibility dimensions	Reasons for choosing dimensions
D'Souza and Williams (2000)	Volume, variety, process, and material handling	Parsimonious set of primary dimensions for manufacturing flexibility
Koste and Malhotra (2000)	Machine, labour, mix, new product, and modification	Chosen for two primary reasons. First, flexibility dimensions frequently discussed in flexibility research. Second, appear to be most relevant to automotive industry.
Jack and Raturi (2002)	Volume	Key competitive strategy.
Petroni and Bevilacqua (2002)	Machine, process, product, routing, volume, expansion, and layout	Combination of dimensions proposed in literature.
Zhang et al. (2003)	Machine, labour, material handling, routing, volume, and mix	Machine, labour, material handling, and routing flexibility represent flexible manufacturing competence. Volume and mix flexibility represent flexible manufacturing capability.

The flexibility dimensions suggested by Gerwin (1993) are: mix, modification, volume, changeover, rerouting, material flexibility, and flexibility responsiveness. Mix, modification, and volume flexibility are externally driven. The uncertainty associated with these dimensions is either from market and customer demand, in terms of product variety, product innovation and product quantity. Changeover, rerouting, and material are internally driven. The uncertainty associated with these dimensions is either from the production input or production environment, in terms of product specification, machine downtime and material characteristics.

The comparison between Gerwin's original dimensions and the D'Souza and Williams' (2000) new dimensions is presented in Table 3. The rationale behind the changes proposed by D'Souza and Williams (2000) is explained below.

According to D'Souza and Williams (2000), the mix and modification flexibility dimensions represent two perspectives on an underlying dimension that represents 'variety' of new and existing products that a manufacturing system can produce. In addition, changeover and rerouting flexibility reflect characteristics of the manufacturing 'process' itself, and are seen to represent a broader dimension of process flexibility. Regarding flexibility responsiveness, they recommend that this dimension be considered an element or sub-dimension of all manufacturing flexibility dimensions.

Therefore, they suggest that while the flexibility responsiveness dimension is embedded in the other six dimensions, these six can be parsimoniously represented on four dimensions: volume, variety, process, and materials handling flexibility.

TABLE 2: TYPE OF UNCERTAINTY AND FLEXIBILITY DIMENSION

Type of uncertainty	Flexibility dimension
Market acceptance of kinds of products	Mix
Length of product life cycles	Modification
Aggregate product demand	Volume
Specific product characteristics	Changeover
Machine downtime	Rerouting
Characteristics of materials	Material
Changes in the above uncertainties	Flexibility responsiveness

Source: Gerwin (1993)

TABLE 3: COMPARISON OF FLEXIBILITY DIMENSIONS OF GERWIN (1993) AND D'SOUZA AND WILLIAMS (2000)

D'Souza and Williams (2000)	Gerwin (1993)	Reasons for re-dimension
Volume	Volume	
Variety	Mix, Modification	Represent 'variety' of new and existing products that manufacturing system can produce
Process	Changeover, Rerouting	Reflect characteristics of manufacturing 'process'
Materials handling	Material	

Source: D'Souza and Williams (2000)

Additionally, Sethi and Sethi (1990) had previously suggested that certain relationships might exist between various flexibilities dimensions (Figure 1). The construct indicates that 'component' flexibilities might contribute to the 'system' flexibilities, which in turn are may influence the 'aggregate' flexibilities. In this construct, material handling, process, and volume flexibility can be seen to be either components or system flexibilities, in our view, representing 'primary' dimensions. Product flexibility in Sethi and Sethi's (1990) construct refers to variety flexibility. This definition is also consistent with Gerwin's (1987) and Gerwin's (1993) mix flexibility. Product flexibility is also classified in Sethi and Sethi's (1990) construct as a 'system' flexibility.

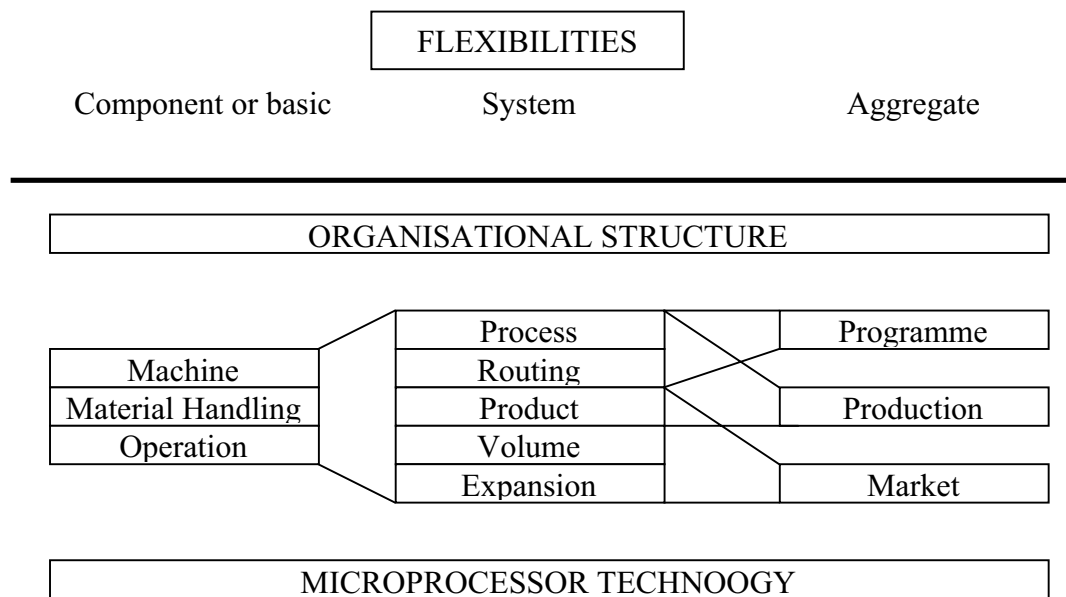
Therefore, the four flexibility dimensions of volume, variety, process and material handling flexibility are either component flexibilities or system flexibilities and thus represent a set of 'primary' dimensions, rather than aggregated flexibility or 'secondary' dimensions. At the level of the manufacturing function it is important for the study to focus on primary dimensions and not cloud the analysis with overlapping secondary dimensions (D'Souza and Williams, 2000). Thus the selection of the four manufacturing flexibility dimensions for this study is based on four justifications:

- They are a parsimonious set of primary dimensions for manufacturing flexibility (D'Souza and Williams, 2000).
- Process and material handling flexibility represent an internally driven flexible manufacturing capability.
- Volume and variety flexibility represent an externally driven flexible manufacturing capability.
- They are the dimensions most frequently discussed in the extant literature concerned with flexibility research.

Two attributes have been emphasised as the basis of measuring manufacturing flexibility. The first is the number of range or options at a given time, and the second is the mobility or the ease with which the organisation moves from one state to another.

These attributes were chosen because they represented the most common measurement approach used in practice. In the following section we consider Gupta and Somers' (1992) review of the literature on manufacturing flexibility and identify the most suitable means of measuring these two attributes for each of the flexibility dimensions selected for this study.

FIGURE 1: LINKAGES BETWEEN FLEXIBILITIES



Source: Sethi and Sethi (1990)

THE DEFINITION AND MEASUREMENT OF THE STUDY DIMENSIONS

The definition and measurement of the four flexibility dimensions: volume, variety, process, and material handling flexibility will be discussed here.

Volume flexibility

This dimension of flexibility is defined as the ability of the manufacturing system to change the volume or output of a manufacturing process (Sethi and Sethi, 1990). This ability is related to the ability to increase and decrease production to satisfy upward and downward changes in demand required by customers (Gerwin, 1993). The range element of volume flexibility might be assessed by the range of the production volume in which the firm can run profitably (Sethi and Sethi, 1990). The mobility element can be assessed by the cost of doubling the output of the system (Carter, 1986), or by the time required to increase or decrease the production volume (Sethi and Sethi, 1990).

Variety flexibility

This is the ability of the manufacturing system to produce many different products simultaneously and to incorporate new designs as needed. Variety flexibility represents mix flexibility and modification flexibility in Gerwin's (1993) taxonomy. While mix flexibility is the ability of the system to produce many different products during the same planning period, modification flexibility is the ability of the system to incorporate design changes into a specific amount (Gerwin, 1993). Other researchers, such as Browne et al. (1984), Sethi and Sethi (1990), and Upton (1994), regard variety flexibility in other terms, i.e. product flexibility, is defined as the ability to change over to produce new products.

This dimension of flexibility is related to the ability to offer varieties of products to customers in order to meet market requirements and to provide product innovation in encountering the length of product life cycles (Gerwin, 1993). Product flexibility is the most important dimension of flexibility according to a survey of managers from a wide variety of industries carried out by Abdel-Malek et al. (2000) due to its contribution to the achievement of product diversification and family marketing strategy.

To measure the range element of variety flexibility in terms of introducing new products, Chatterjee et al. (1984) suggest the use of the size of the universe of parts the manufacturing system is capable of producing without adding major

capital equipment. On the other hand, Gerwin (1987) suggests the use of the number of different part types that the system can produce without major set-ups. In terms of producing various types of products, Jaikumar (1984) recommends the use of the number of new parts introduced per year. Regarding the mobility element of variety flexibility, the time and cost required to introduce new products might measure this (Sethi and Sethi, 1990).

Process flexibility

This is the ability of the manufacturing system to adapt to changes in the production process. Examples of changes in the production process are machine breakdowns, changes in the production schedules, and changes in the sequence of steps through which the product must progress. This definition suggests that in order to adapt to these changes, there should be alternative routes to produce a part through the system.

Process flexibility is comprised of changeover flexibility and rerouting flexibility in Gerwin's (1993) taxonomy. Changeover flexibility is the ability of the system to adapt to changes in the production process, while rerouting flexibility might be defined as the ability to change the sequence of steps in the production process through which the product must progress Gerwin (1987).

This dimension of flexibility, according to Browne et al. (1984), Sethi and Sethi (1990), and Sarker et al. (1994), refers to the ability to produce a set of part types using several ways. Process flexibility is associated with the ability to produce items according to product specification required by customers, and to ensure product availability at the time it is required by customers, regardless of disruptions and changes in the production process.

The average number of possible ways in which a part type can be processed in the given system is one way to measure the range element of process flexibility (Chatterjee et al., 1984). On the other hand, according to Browne et al. (1984), the cost and time required to switch from one part mix to another might provide the mobility element of process flexibility.

Material handling flexibility

Material handling flexibility is the ability of the material handling system to transport different materials between various processing centres over multiple paths (Sethi and Sethi, 1990). The larger the material handling flexibility, the better the machines can be supplied with materials, thus the

flexibility of the machines, and consequently the flexibility of the processes are not hindered by the limitations of the material handling system (Tempelmeier and Kuhn, 1993).

The way the material handling system is designed by linking every machine with every other machine might provide the assessment of the range element of material handling flexibility (Chatterjee et al., 1984). Sethi and Sethi (1990) suggest the ratio of the number of paths the

material handling system can support to the total number of paths possible. Zhang et al. (2003) suggest the mobility element related to material handling flexibility could be measured by considering the cost and time required to change the material handling system between parts.

The definition and proposed means of measurement for these four flexibility dimensions are summarised in Tables 4 and 5, respectively.

TABLE 4: DEFINITION OF FLEXIBILITY DIMENSIONS

Flexibility Dimension	Flexibility Definition	Literature
Volume	Ability of manufacturing system to change volume or output of manufacturing process	Gerwin (1987), Sethi and Sethi (1990)
Variety	Ability of manufacturing system to produce many different products simultaneously and to incorporate new design	Browne et al. (1984), Gerwin (1987), Sethi and Sethi (1990), Upton (1994)
Process	Ability of manufacturing system to adapt to changes in production process including to change sequence of steps through which product must progress	Gerwin (1987), Sethi and Sethi (1990), Sarker et al. (1994)
Materials handling	Ability of material handling system to transport different materials between various processing centres over multiple paths	Sethi and Sethi (1990)

TABLE 5: MEASUREMENT OF FLEXIBILITY DIMENSIONS

Flexibility Dimension	Flexibility measurement	Literature
Volume	The range of production volumes The ability to economically increase or decrease production volume The ability to quickly increase or decrease production volume	Sethi and Sethi (1990) Carter (1986) Carter (1986), Sethi and Sethi (1990)
Variety	The variety of products that can be produced simultaneously The ability to develop new products each year The ability to economically change from producing one product to another The ability to quickly change from producing one product to another	Chatterjee et al. (1984), Gerwin (1987) Jaikumar (1986) Sethi and Sethi (1990) Sethi and Sethi (1990)
Process	The different routes that can be used to produce a part type The ability to economically change the sequence of steps in the production process The ability to quickly change the sequence of steps in the production process	Chatterjee et al. (1984) Browne et al. (1984) Browne et al. (1984)
Material handling	The different part types the material handling system can handle The ability of the material handling system to link different processing centres The material handling changeovers between parts can be done economically The material handling changeovers between parts are quick	Sethi and Sethi (1990) Chatterjee et al. (1984) Zhang et al. (2003) Zhang et al. (2003)

CONCLUSIONS

There can be no doubt that manufacturing flexibility is a complex, multidimensional concept that has evolved over the years. Many studies have been conducted in this area, mainly in addressing the theory and practice of manufacturing flexibility management and its measurement, yet agreement on these issues remains elusive. Nevertheless, while there is no consensus about the classification and measurement of flexibility and its constituent elements, it is important from a research perspective to adopt a flexibility construct prior to study in order to remove the ambiguities and inconsistencies that currently surround the concept of manufacturing flexibility.

The four flexibility dimensions selected for this study of manufacturing flexibility management are: volume, variety, process, and material handling

flexibility. The definition and measurement of these flexibility dimensions were developed from the published works of Gupta and Somers (1992), Gerwin (1993), and D'Souza and Williams (2000). The flexibility attributes chosen as the basis of the measurement were based around Upton's (1994) range and mobility attributes.

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