Dynamic Flexibility—Operational Definition, Measurement & Analysis

Baohua Qin[1,2]
1 Department of Information Operations and Technology Management
College of Business Administration, University of Toledo
2 College of Economics and Management
Yanshan University, Qinhuangdao, China
EMAIL: linda_qin2000@yahoo.com

Abstract: Although flexibility has been researched for about 30 years, the conceptual understanding of flexibility is still limited. There is no operational definition of flexibility which can facilitate measuring the construct and further verify the endeavor of the companies on improving it. This paper analyzes the dimensions and measurement of flexibility using systems theory from dynamic perspectives. Four dimensions i.e., range of variety, response time, adjustment cost and variance of performance, are presented. Based on the analysis of the relationship of these dimensions, the measurement of flexibility is discussed. Finally, a comprehensive operational definition of dynamic flexibility is presented. The purpose of this paper is to take the area at least one step further towards a clearer understanding and valid measurement of flexibility.

Keywords: Flexibility, Dimension, Measurement, Operational Concepts

I. Introduction

"In recent years, time-based competition has grown more important. When consumer demand is prone to large and unpredictable shifts, the firm that adapt most quickly to these shifts will gain and advantage (Hill, 2003)." In an ever-changing environment with greater uncertainty (Huber, 1984; Doll & Vonderembse, 1991) where consumers demand more and more customized products with quicker response time (Stevenson & Spring, 2007), manufacturers have to enhance flexibility across the value chain to achieve competitive advantage (Zhang et al., 2003). Flexibility is important in meeting customer demands and improving responsiveness (Fisher et al., 1994; Vickery et al., 1999) and has been described as a strategic capability (Krajewski et al., 2005; Stevenson & Spring, 2007). Hayes and Wheelwright (1984) consider flexibility to be one of the dimensions of a business' competitive strategy along with price, quality, and dependability (Sethi & Sethi, 1990). Slack(1983) consider flexibility in terms of utilizing it to improve manufacturing performance—especially in terms of dependability of delivery, productivity of resources and availability of products.

II. Confusions regarding the definition

According to the literature, several typical definitions of flexibility are in table 1.

Table 1 Typical definitions of flexibility

Author	Definition
Upton, 1994	Flexibility is the ability to change or adapt with little penalty in time, cost, effort of performance.
Upton, 1995	Organizations cope with environmental uncertainty by creating flexible capabilities to satisfy changing customer needs without significant disruption, excessive cost, extended time or lower performance.
March & Simon, 1958	Through an organizational science lens, flexibility is the firm's ability to suffer limited change without severe disorganization.
Benjaafar, 1994, Gerwin, 1989, Gupta & Buzacott, 1989	Flexibility is seen as an adaptive mechanism allowing organizations to effectively compete despite the volatility of their operating environments.
Zhang et al., 2002	The organization's ability to meet an increasing variety of customer expectations while keeping costs, delays, organizational disruptions and performance losses at or near zero.
Gupta & Somers, 1992	The ability of a manufacturing system to cope with changing circumstances or instability caused by the environment.

The definitions above explain certain characteristics of flexibility from different angles; to certain degree, they present the authors' deep understandings of the construct.

They do make sense and easy to be accepted. But are they operational? There is much confusion comes out which can be delivered by questions listed below:

1) We can find a common character of the definitions is that they used key adjective words to give the limitation to the situations, such as 'little', 'significant', 'excessive', 'severe', 'at or near zero'. We know more flexibility accompanies 'little' time, effort, etc. But, How much is 'little'? What degree should it be that we can judge it as 'sever'?If we do increase the variety of customer's needs that the organization can meet but with certain increase of cost or time, or if we increase our response speed to a great extent but with much increase of cost, can we say that the system has lost its flexibility? What does flexibility exactly mean?

2) We often say that this organization is flexible, while the other is not flexible. Is flexibility a 'have it or not' virtue of a system or a continuous measurement of a character of a system? In other words,Does every subject have flexibility to a certain degree or only so-called 'good' subjects possess such virtue?

3) We usually say that one system is more flexible than others. And many times we need to prove that the flexibility has increased to justify our investment on increasing it.How do we judge which is more flexible? How can we measure flexibility? What are the dimensions of flexibility and their relationship? When we measure flexibility, what issues should we pay attention to?

4) We often want to increase flexibility. Upton (1994) mentioned that both flexibility and quality are laudatory attributes, but is flexibility the higher the better?

5) Is flexibility static? How do we understand the dynamic character of flexibility?

6) Is flexibility internal or external? Can we use internal disturbance level to measure internal flexibility?

7) There are many types of flexibility presented in the previous literature (See figure1); many of them overlapped with each other. There is no clear understanding of the relationship among the types. Some researchers consider the methods of improving system flexibility such as machine flexibility as one type of system flexibility (Zhang, etc , 2002), which causes confusions. So we ask:

What is the relationship of these "types" of flexibility? Is there a reasonable and operational framework which can tell different levels and relationships among them more clearly?Flexibility can be understood, measured and managed better when its vagueness is removed (Upton, 1994). This paper tries to mitigate some of the confusions mentioned above.

III. Dimensions of Flexibility

There are many different opinions about the dimensions of flexibility. Slack and Correa emphasize range and response flexibility (Slack & Correa, 1992), and give three dimensions, range, cost and time (Slack N. , 1983); Upton (1994) added "uniformity" and identified three distinct 'elements', i.e., range, mobility, and uniformity. Here 'element' is what we mentioned 'dimension'. Leeuw & Volberda (1996) suggested variety, rapidity and procedures. Sethi & Sethi(1990) mentioned variety and response. Currently there is convergent opinion about the dimensions of flexibility, i.e., range, mobility and uniformity. Based on these valuable contributions, this paper will try to improve the understanding of the dimensions.

Range

Flexibility of a system means its adaptability to a wide range of possible environments that a system may encounter (Sethi & Sethi 1990). Slack (1983) define range flexibility as "the total envelope of capability or range of states which the production system or resource is capable of achieving." Flexibility of a company refers to the extent that a company can adapt to its changing circumstance. The circumstance includes all the components of a firm's outside circumstance, such as customers, competitors, suppliers, partner companies, market, government regulations, communities, labor markets or suppliers, technology, and financial organizations, which could affect a company's operations. One important dimension of flexibility is the range of variety of the circumstance, i.e., how many different circumstances a system can adapt to. The more variety, the more flexible a system is. Based on Upton (1994)'s framework of analysis (see figure 10 in the later part), to facilitate analysis of flexibility, it is better for us to focus on one content of flexibility such as changing product requirement instead of all kinds of complicate uncertainties of circumstance. To simplify the analysis, this paper only consider the flexibility of the company system to adapt to the changing requirements of the customer, which is currently the uncertainty that the companies attach the most importance to. The underlying theory which supports our analysis of flexibility can be generalized to all kinds of uncertainties of the circumstance.

The range dimension of flexibility should consider two factors:

- **number of different requirements**
- **degree of difference**

Assuming the amount of different requirements are the same, the system which can adapt to the requirements with greater difference will be considered more flexible. So range is the function of "number" and "degree of difference".

Range=f (number, degree of difference) (1)

Response Time

Now we come to the point of how we measure 'easiness' dimension of flexibility. How easily the system moves from one state to another is important in terms of cost, time or organizational disruption (Slack, 1983). There are debates in the research area about whether time and cost should be considered as separated dimensions of flexibility. Our opinion is that we should separate mobility into different dimensions, i.e., 'response time' and 'adjustment cost'. Respond time means how long a system needs to respond to the change of circumstance. The shorter the response time, the quicker the response speed, and the higher the degree the system's flexibility is. Machine changeover times, new product lead time, and purchasing lead time, can all be considered as response time (Slack, 1983). We separate time and cost as two different dimension because although time and cost have certain correlation and they both have negative correlation with flexibility, they are not always consistent with each other. Sometimes, we may take a longer time to adjust the system to the new requirement but with less cost. For example, to make a new product, we may use a less skilled worker to make it. Although we need more time to finish it, but the cost might be less than if we use an expert.

Adjustment Cost

From the analysis above, we have known that 'cost' is also one important factor of flexibility. But we should not confuse 'adjustment cost' with 'cost of building the flexibility' when analyzing flexibility.

- **Adjustment cost (AC)--the cost to make adjustments based on the "current system" to meet the customer's requirement.**
- **Cost of building the flexibility (CB)--the cost of building the flexibility into a system**

The two costs are totally different. They are separated by the point of time when "current system" was developed or by the point of time when the status of the system becomes our focused status. Here, "current system" should be understood broadly. It does not only mean a particular existing system; it also means the particular 'state' of a system that we focus on. In this way, "focused system" might be a stricter term than "current system". Based on systems theory, system is changing dynamically. The states of a system should be regarded as a variable depending on time which is continuous (see figure 1). At different points in time, the state of a system is different. Any state of a system can be considered as "current system" if it is the system's state that we focus on. So,

- **"Adjustment cost" (AC) means based on current system (focused state of a system), in order to meet the requirement of the customer, how much extra cost should be spent on the "current" (focused) system.**

When we mention the ease of the adjustment, i.e., the mobility of the system, we mean the "adjustment cost" instead of other costs. The lower the adjustment cost, the higher the flexibility.

- **"Cost for building the flexibility" (AC) occurs ahead of adjustment cost. It includes the cost spent on creating system flexibility before the point of time of our focused (current) system. We can improve the flexibility of the system by spending more on building the flexibility of the system and hence decrease the later additional cost needed (adjustment cost) when**

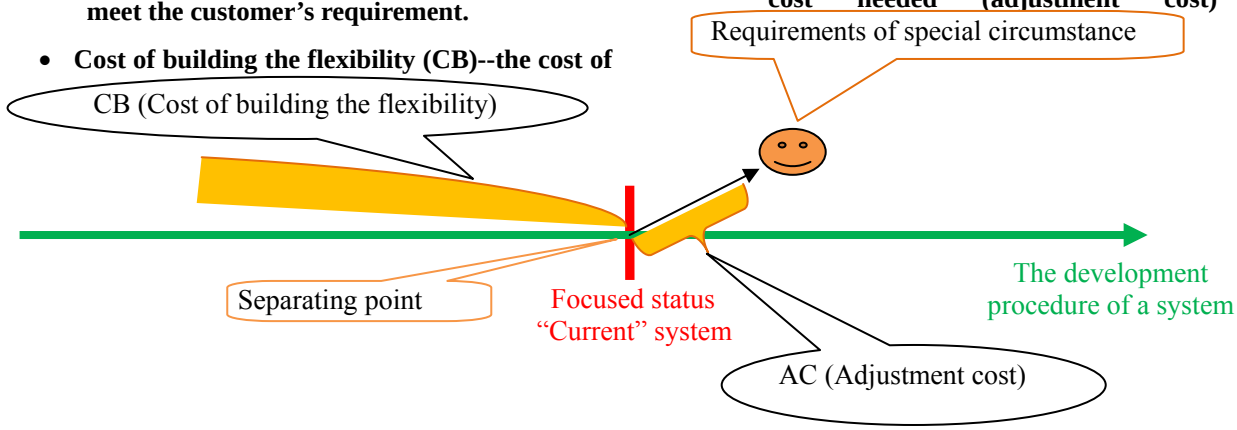

Figure 1. Difference Between CB and AC in a "Current System"

Variance of Performance

Upton (1994) adds uniformity as one of the elements of flexibility, which means "the uniformity of some performance measure (such as yield and quality) within the range." "A system which is flexible, is one in which such a performance measure is invariant with the position occupied within the range (Upton, 1994)." Uniformity means when a firm adapts to changes, their performance remains unchanged. "In general, managers see uniform performance across the range of the attribute space as more flexible than peaked performance (Upton, 1994)."

IV. Measurement of Flexibility Based on Systems Theory

Flexibility is a measure of potential capability (Slack N., 1983). The measurement of flexibility should base on the measurement of its four dimensions. We measure flexibility by measuring the four factors of a current system, i.e., range, response time, adjustment cost and variance of performance. Range of variety has positive relationship with flexibility while response time and adjustment cost has negative relationship with flexibility. Variance of performance is controlling factor and has negative relationship with flexibility. Flexibility is a function of these four factors.

Flexibility= f (range, response time, adjustment cost, variance of performance) (2)

We have known that the measurement of flexibility should be based on the measurement of the four dimensions with carefully defined scope and boundary of the system.

Since we consider performance as one of the measurement dimension in this method, we get:

$$Flexibilit\quad y = \frac{\sum_{i=1}^{n}\left[b\cdot g(respondtim\quad e_i) + c\cdot h(adjustment\quad \cos\ t_i)\right]\cdot\lambda_i}{n} + a\cdot f(number\quad, \deg\ reeofdiffe\quad rence\ ) - d\cdot(coefficient\quad of\quad Variation\quad of\ performance)^2 \tag{3}$$

$$Flexibilit\quad y = \frac{\sum_{i=1}^{n}\left[b\cdot g(respondtim\quad e_i) + c\cdot h(adjustment\quad \cos\ t_i)\right]\cdot\lambda_i}{n} + a\cdot f(number\quad, \deg\ reeofdiffe\quad rence\ ) - d\cdot\left(\frac{\sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}}}{\bar{x}}\right)^2 \tag{4}$$

The notations of formulas above are:

n is the amount of different requirements;
λ_i is the degree of different or novelty for the particular requirement *i*;
a, b, c and *d* are the weight of each dimension, they are given subjectively;
f, g, and *h* are functions, *g* and *h* should be the functions that reflect the negative relationship, in *f* function, the independent variable "degree of difference" should be the average degree of difference of all the requirements. *f, g,* and *h* are used to standardize the different dimension value so that they can cumulate to overall flexibility, also they reflect the relationship between flexibility with each dimension. The function of variance of performance has been decided to use quadratic function as we analyzed previously;

X_i is the performance level when meeting each requirement.

V. Comprehensive Operational Definition of Flexibility

So far, we have a deeper and more comprehensive understanding of flexibility. Due to the complexity and obscurity of flexibility, it would be better if we give a more operational definition of flexibility so that researchers can get a clearer direction and strong base for their further research. We define flexibility as below:

Flexibility is an inherent but dynamic characteristic of a system; it is a measurement of a capability of a system to adapt to outside changing circumstances. It is a time-based, boundary-based capability of a system,

which comes from and can be improved by internal resources and competences. It can be reflected and measured by four weighted dimensions, i.e., range, response time, adjustment cost and variance of performance which are based on the current system status and measured via interaction with outside circumstances. The weight of each dimension is subjective and situation-based. Flexibility is an objective capability but cannot be measured totally objectively. (For different people, different times and situations, different system boundaries, flexibility values might be different; attempting to create an overall exact value of flexibility is an ideal but naïve intention). **Flexibility is a trade-off between three dimensions, and flexibility itself should also be a tradeoff with other objectives of the system.**

The definition presented above not only gives a deeper understanding of flexibility but also mentioned the issues that we should pay attention to when measuring flexibility.

VI. Discussion and Conclusion

Awareness of the ambiguity "is an important first step in ensuring that everyone has the same understanding of the subject under discussion (Upton 1994)" Although Slack (2005) noted that "rather than becoming (naively) frustrated by the ambiguous nature of flexibility, most of the later work in the area has focused more on how flexibility can enhance business performance. With some reservations this seems to have become generally accepted," this paper attempts to reduce the confusions and misunderstandings in this research area. I don't think our research is "naïve" (Slack, 2005) since we do have cleared some of the confusions and make the understanding of flexibility go a "small" step further. Although the definition of flexibility presented in this paper is not ultimate and standardization of the flexibility terminology, it will hopefully push the research of flexibility to a further step. Possibly it will give one hint or direction for the current research.

Systematic, intensive research on the connotations of flexibility will be beneficial in revealing the essence of flexibility, clarifying the blurred ideas that exist in research and practical areas. It will provide a theoretical foundation for further research. Based on the clearer understanding of flexibility, more practical and focused research in the future will benefit both the theoretical researcher and practitioner to a great extent.

Due to the complexity of this research area, it is difficult to solve all the confusions and problems existing in the research area in such a short paper. Some of the statements in this paper are just given brief analysis and need further proof or empirical data support. Secondly, to simplify the research, most of the referenced research used in this study is based on manufacturing flexibility. The basic theory and analysis can be expanded to wider areas. Since supply chain management has been increasingly important currently, it is better for the research to focus more widely and from supply chain perspective. Third, the purpose of the research of flexibility is not only to clarify what flexibility is, the eventual purpose would be to find out how to improve flexibility and get the most benefit from it for companies or supply chain, and hence figure out how to balance flexibility with other strategic objectives of the company. There are a lot of problems and issues that need to be solved about this topic.

The field of flexibility is interesting and useful for current and future decades. Further quest in this field will be necessary for both theoretical research and empirical practice.

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Background of Author

Baohua Qin is a Ph.D. student in Manufacturing Management at the University of Toledo. She is also an associate professor in the College of Economics and Management, Yanshan University, China. She has published papers in the areas of flexible software development, information systems and human resources management. Her current research interests are in supply chain risk management, flexible supply chain management.