AN APPROACH TO MEASURE MANUFACTURING SYSTEM FLEXIBILITY

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ABSTRACT:

Flexibility plays a vital role in manufacturing system. The impact of fluctuations is to be minimized in order to achieve an excellent flexibility in order to handle product over wide range of variety. Flexibility is dependent on the decision making of operator for desire operational measurements. Flexibility of the manufacturing system is also depends upon the various types, situations and various working conditions.

To take flexibility into adequate consideration in decision making, an operational measurement is needed. Yet, difficulties exist since flexibility has various dimensions, various types and is usually situation specific. This paper presents the approach to measure flexibility. The flexibility metric was developed from the transfer function namely the reciprocal of demand fulfillment time delay.

KEYWORDS: Flexibility, Flexibility characterization: types and dimensions, Flexibility classification: different types, Flexibility dimension: range and response, Flexibility measurement

INTRODUCTION:

Originally, flexibility means the ability to be bent, in a mechanics context. With more attention being paid to system dynamics, flexibility is used to indicate the system's ability to adapt to different circumstance. Particularly in manufacturing, since two decades ago, flexibility has becomes a key consideration ranging from long term decision making like production system design to short term operation planning.

As it is said by Viswanadh & Narahari (1992), flexibility is “an adapting organism capable of surviving in uncertain and changing markets”. It has been defined to be:
1. The adaptability to change (Nof et al. 1979, Buzacott 1982, Brown et al. 1984),
2. Ability to change, (Gupta 2004)

From those similar statements, distinction can be observed that there’re mainly two schools of viewpoints on flexibility. From the first viewpoint, flexibility is an intrinsic attribute of manufacturing system it’s a property of the system itself, independent of its operating context. The second one views flexibility as a relative concept. It can be related to demand, economic environment and performance criteria etc. Both viewpoints have their good reasons, while the latter one hinders an absolute measurement.

<table>
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<tr>
<th>Approach</th>
<th>Flexibility Meaning</th>
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<tr>
<td>Manufacturing</td>
<td>- The capability of producing different parts without major retooling</td>
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<td></td>
<td>- A measure of how fast company converts its processes from making an old line of products to produce a new product</td>
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<td>- The ability to change a production schedule, to modify a part, or to handle multiple parts</td>
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<tr>
<td>Operational</td>
<td>- The ability to efficiently produce highly customized and unique products</td>
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<td>Customer</td>
<td>- The ability to exploit various dimensions of speed of delivery</td>
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<td>Strategic</td>
<td>- The ability of a company to offer a wide variety of products to its customers</td>
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Fig: 1. Basics of flexible manufacturing system

Eighty papers have been classified according to the approach illustrated above. A summary showing the distribution of articles is given in figure 1.
LITERATURE SURVEY:

The philosophy of SD was invented in 1956 at the Massachusetts Institute of Technology by Forrester (1961). He introduced new ideas in Industrial Dynamics as well as launched his thoughts as a major breakthrough for decision makers' (Forrester 1958). The use of the method spread into the social sciences area (Forrester 1975), and as a consequence Forrester re-name the performance ‘system dynamics'. He considered SD to re act a universal applicability to any situation which can be modeled as a 'system', which combines people and/or machines (Towill 1993). Since this early conception, many contributions have been made to Wolstenholme.

The SD led, as discussed later in this paper. The basic values of SD are briefly summarized by Wolstenholme considers SD to exist in both a qualitative or quantitative form. Qualitative SD includes figure which symbolize the system under study by means of various ‘resources'. The resource may be either physical (e.g. the flow of money, material, people, etc.) or non-physical (e.g. knowledge or motivation). The state is denoted as any ascretion of assets which is related to the concern. Otherwise the states are clearly identifiable, e.g. record of manufacturing system, cash balance. They are the assessable quantities of much reserve in a system at any point in any time, and the measurement is the unit of resource. States all time to survive even if all the system activity ceases. The resources stream through the system give result of a driving activity which helps change the resource from one state to another. Such a driving activity shows in SD by rate variables, which are control variables as well as which increase or deplete resource levels directly i.e. they control flows into and out of store. As an example, in a developed system, the stock of a product is affected by the flow rates of sales and production. These flow charge changes constantly and must be represented in such a way as to capture this variation.

System dynamics can be considered to be a method of system enquiry, as such occupies a position among the sciences of operations research (OR) as well as 'systems thinking'). In considering how SD could be related to these ‘soft' and ‘hard' sciences, Keys (1988) concluded that the exact position of SD remained in doubt, but try to maintained that it is possible for scientists in both fields to relate to it. SD may also be considered in the sense of cybernetics and servomechanisms (organizational/human systems structuring for problem solving). Well (1993) believes that advocates of either viewpoint would benefit from an accepting of both the 'soft' and 'hard' perspectives.

System dynamics met with some criticism in its early days, most notably from Slevin and Ansoff (1968), who queried the validity of the theory base applied by Forrester. To his credit, Forrester reiterated the theory which is published in Industrial Dynamics (1961) and pointed out that his models were not absolutely complete. Slevin's and Ansoff article is particularly relevant as it represents one of the earliest examples of an independent evaluate of SD. The review focus the rapid growth of SD at that time, for Forrester pointed out in his response to Slevin and Ansoff (Forrester 1975) that much work had been carried out which was yet to be published, and this research had not been available to Slevin and Ansoff when writing their critique of Forrester's work.

Pidd (1992) search two main problems associated with SD in the early years: the mathematical equations were too complex to be understood by managers. On the other hand, Forrester foresaw in his early work that the development of the computer would help the use of his technique. Now the equations may be solved rapidly whilst being hidden behind a user-friendly graphical interface.

In terms of manufacturing applications of SD, a conceptualized model of a manufacturing system is outlined by Parnaby in (1979). Similarly, by Roberts and Byrne (1994) who use SD to evaluate manufacturing performance using kanban-based system. To an advocate of the value of Forrester’s work and much of Towill's research activity has been involved with developing the Forrester supply chain models (Towill and del Vecchio 1994). Edghill and To will (1989a,b) have, e.g. developed a generic library of control
theory-based models of manufacturing systems. They argue that these models fulfill the criteria of being meaningful and comprehensible, as these three components give the holistic view that a manufacturing manager requires. Similarly, Baines (1994) considers the respective merits of DES and SD for evaluating the effect of proposed changes to a manufacturing system. He argues that although DES seems to give more credible models due to the level of detail that can be included in such models, SD model building times are considerably less. Baines argues that when considering strategic issues within a manufacturing company, then SD has some distinct advantages over DES.

2.2 FLEXIBILITY CHARACTERIZATION: TYPES AND DIMENSIONS:

Flexibility can be defined generally as the adaptability to changes [Nof et al. 1979, Buzacott 1982, Brown et al. 1984]. However, it means different things to different people [Upton 1995]. To a firm which desires a number of broad product lines and/or numerous variations within a line, flexibility is the ability to handle wide range of products with fast setups [Gerwin 1993]. To a manager whose focus is on cost control under demand fluctuations, flexibility means the ability to profitably produce at different output levels. In a mass customization context, while company’s competitive edge comes from its ability to offer broad spectrum of products, make easily switch between products, deal with various demand levels.

Various flexibilities deal with various uncertainties; various flexibilities serve various strategic objectives. In addition, one type of flexibility has two layers of meaning, each of which has different implications. In the following sections of this chapter we will discuss about flexibility classifications and dimension characterization in details:

Flexibility has different types, another way to put it. It is mirrored into different images from different perspectives. Individual resource flexibility, such as machines and labor, process alternatives, and material handling mechanism comprise the base. The base constitute and support system level flexibility through the organizational structure, enable system to handle multiple products, mix flexibility, to profitably produce at different output levels, volume flexibility, to produce new parts/handle design changes economically and quickly, new product/modification flexibility, and to produce a part by alternate routes, routing flexibility.

In this work, system level flexibility is our focus. New product and modification flexibility is more long term product life cycle related. Routing flexibility is to coping with machine breakdowns. We would like to discuss in detail the rest two, mix and volume flexibility, which mitigates the negative impact of demand uncertainty on regular production operation.

Although researchers had used different terms to describe flexibilities and there’re some confusion caused by that, we’re not going to list and clarify those terms here, but rather quote well accepted terms and their definition. For who are interested in term comparison, please refer to Sethi and Sethi 1990 and Gupta 2004.

Mix flexibility derives from the machines flexibility, operation flexibility of products, and material handling system, it enables the system to produce a set of product without major setup (Sethi & Sethi 1990) with fast setups (Gerwin 1993), with presumed low changeover cost (Berry and Cooper 1999), or to change the mix within a given time period (Slack 1988).

Volume flexibility is the ability to profitably produce at different aggregated output level (Browne 1984, Sethi & Sethi 1990), is the extent of change in aggregated output level without incurring high transitional penalties, is the ability to overcome the changes in aggregated volume (Gupta 2004) Oke(2003) did research on drivers of volume flexibility requirement and found volume flexibility is increasingly required as demand variability and uncertainty increase, and customer’s influence in lead-time determination increase. Holweg and Pfl (2004) once quote a folk saying on volume flexibility, “I’ve got my head in the freezer and my feet in the oven, but on average the temperature is quite pleasant here.” Feeling pleasant implies high ability of capacity expansion, contraction, switching, in short, high volume flexibility.

2.2.2 FLEXIBILITY DIMENSION: RANGE AND RESPONSE:

Adaptability to changes, flexibility’s definition implies two layers of meaning: can or cannot adapt to,
and the ease of adaptation. The first layer is about "the quality or state of being able" that is range. The second layer is about "the competence in doing", that is response. (Merriam-Webster Dictionary). Since Slack (1983) did a survey on ten manufacturing firms, based on which he suggest range, and response as dimensions of flexibility, more than two decades of flexibility literatures, more of them follow this idea [Gerwin (1987 1993), Crowe (1992), Bateman (1999), Gupta A. (2004)]. Some others trying to enrich this decomposition by adding heterogeneity (Koste 2004), mobility, uniformity (Upton 1994 ) etc. There is another stream of researchers who follow Mandelbaum (1978) with action and state flexibility. Action flexibility is the ability created by managerial action in response of new circumstances and state flexibility is the ability inherent in the system.

We'll adopt more widely accepted characterization, range and response, with range referring to the number of different options or the size of the option universe, and response referring to the ease of movement between these options.

Generally speaking range is more strategic related, such like a wider range of parts offering for larger market size, excessive capacity banking for peak season's customer service level and market expansion. Response factor, on the other hand, is more operational. According to two previous examples, shorter switching time from one part type to another, less effort to shifting capacity would make above option possibility attractive.

2.3 FLEXIBILITY MEASUREMENT:

2.3.1 MEASURING PERSPECTIVE AND METHODOLOGIES:

1. ABSOLUTE INTRINSIC MEASURE VS. RELATIVE MEASURE:

When it comes to the problem of designing the right metrics for flexibility, we noticed there're two types of measures due to researcher's distinctive views about flexibility. Gupta and Buzacott (1996) argued the measure should relate to a specific situation or changes. Kumar (1987) considered flexibility as an intrinsic attribute of the system, thus measures the potential of the system to handle changes. Both viewpoints have merit (Chryssolouris 2006), and he argued any flexibility calculation which omits external demand run the risks of omitting relevance and thus, estimation beats omission. Meanwhile Kahyaoglu and Kayaligil (2002) said many flexibility measurement in literature requires specifying the relevant probability distribution associate with uncertainty explicitly. However, the need of a flexibility measure is greatest when probability cannot be assigned, and when it doesn't vary with situations. Here, we are standing on "Intrinsic" side, holding the preference for the second view so that our flexibility can be reliable to assist decision making. And we believe system demonstrated its flexibility during its regular performance.

2. MEASURING METHODOLOGIES:

As to measurement approaches, “Intrinsic” side are loyal supporters of measuring-by-type approach, using physical characteristics of the system to measure each flexibilities. Financial analysis methods are common tools for “Relative” side. Other approaches are used by both side in different context, such as survey, performance benchmarking, decision theory approach (Mandelbaum 1978; Mandelbaum and Buzacott 1990), Petri nets (Kochilas and Narendran 1992), fuzzy logic (Tsourveloudis and Piliis 1998; Deskes et al. 2004), information theory approach, i.e. entropy measure (Yao 1985, Kumar 1987, Rao and an 1994 Shuabi et al. 2005).

2.3.2 FLEXIBILITY QUANTIFICATION: MEASURE BY TYPE VS. HOLISTIC MEASURE:

2.3.2.1 FLEXIBILITY MEASUREMENT: MEASURE BY TYPE:

1. VOLUME FLEXIBILITY:

Descriptive measure of volume flexibility can be the lower and upper bound of capacity for range dimension and time/cost of capacity adjustment for response perspective. But economic metrics are most commonly used in literature, since many researchers define volume flexibility as the ability to profitably produce at different levels. Stigler (1939) considered a plant to be flexible if it has a relatively flat average cost curve. Falkner (1986) suggest the stability of manufacturing costs over widely varying levels of total production volume to be the measure of volume flexibility. Sethi and Sethi (1990) developed volume flexibility metric to be the curvature of the average cost curve.

There’re also metrics that consider the interaction with demand market. Marschak and Nelson (1962) argued the value of volume flexibility increases as the variation in market price increases and as the ability to predict market price before making an output decision increases. Gerwin (1987) measures it by the ratio of average volume fluctuations over a given period of time to the production capacity limit.

2. MIX FLEXIBILITY:

There exists a lot of measures on mix flexibility range, the number of product types a system can produce. (Ettlie 1988, Jaikumar 1986), the size of the universe of products the system is capable of producing (e.g. Chatterjee et al. 1984), or the range of products characteristics handled (e.g. Gerwin 1987) These metrics are measuring the potential of the system, while the others, The number of products handled by the system,
or the ratio of the number of products handled by the system to the total number of products which the manufacturer is interested in, are relative measures. Buzacott (1982) about mix flexibility response, people either care about setup duration or setup cost, or both. Relative measures estimate the percentage of product demand and possibility of sequence and using expected setup duration, which probability from demand estimation) (Bateman 1999) as the flexibility response measure.

2.3.2.2 FLEXIBILITY MEASUREMENT: MEASURE BY PERFORMANCE:

Holistic measure is a unification or integration of flexibility measures of various types. These measures typically cover two or three flexibility types. A variety of ways are applied to holistically evaluate flexibility, such like qualitative measurement, measurement based on economic consequences, multi-variant analysis approach, performance benchmarking, and information theory. A special metrics developed by Chryssolouris (1998) is based on system transfer function.

Gerwin (1987) used domain definition to investigate the impact on manufacturing flexibility of computerized processes for body framing. This qualitative measure usually runs the risk of perceptual bias.

Typical multi-variant analysis approaches, principle component analysis and factor analysis, are applied in the flexibility measurement to investigate whether flexibility is a unitary or multi-dimensional variable under specific situations.

As to performance criteria, Buzacott (1982) evaluated system flexibility by determining the expected value for a particular performance criterion over all feasible job characteristics. Brill and Mandelbaum (1990) formulated it by weighted average performance relative to a reference task set. Pfugheooff (1999) measured flexibility by the relative performance improvement due to flexibility difference.

Monetary terms can be easily integrated. That might be the reason why literature applies economic consequence to evaluate flexibility by manufacturing cost saving and machine utilization increase etc. (Son and Park 1987) (Gupta 1993). Some of the researchers calculate the value of flexibility using option price formula (Andreou 1988, Bengtsson 2002). Besides being applied in routing and loading flexibility measured, entropy is also used to study operational flexibility, mix and volume by Shuiabi et al (2005).

An interesting and special measurement comes from a “spring damper analogy” by Chryssolouris (1998). He drew an analogy between a mechanical system, a mass spring oscillator, and a manufacturing system. Based on the analogy, he argued that damping factor, which measure the ability of this mechanical system to keep stable under time varying input force, can be a good metric for manufacturing system flexibility, defined as sensitivity to change. Flexible system will have uniform performance when demand fluctuates. Inflexible system cannot. Order expected processing time is the input like an external force. Actual time order spends in the system is the output, like the displacement/response. Manufacturing system “damping” is defined as system’s flexibility and calculated from system transfer function. This metric is easy to apply and mathematically elegant. However, there’re limitations. First of all, a flexible is widely accepted as the adaptability to change, which doesn’t directly lead to stability. Secondly assumptions such as Poisson arrival and normal demand quantity are made. Reality may not conform well to the assumption. Thirdly, the analogy from a spring damper to manufacturing system is hard for readers to build up, since there’s no fewer similarity, e.g. how the manufacturing product can be force when it’s the input and changed into displacement when it output. Finally, this analogy is built on a strong assumption of LSI while the author doesn’t reason clearly.

CONCLUSION:

The proposed method covers broad range of flexibility reference appeared in literature. We categorized and critically reviewed existing literatures on flexibility definition, characterization, and most importantly different flexibility measurement in terms of methodology, and perspectives. From literature, flexibility measure that treats flexibility as internal property, yet encompass all interested system flexibility types is still lacking. Theoretically systematical and meanwhile practically useful flexibility metrics is still to be developed. Through a broad range literature review, flexibility definition, characterization, and most importantly different flexibility measurement in terms of methodology, and perspectives are categorized and summarized. From literature, flexibility measure that treats flexibility as internal property, yet industry-independent is still lacking. Theoretically systematical and meanwhile practically useful flexibility metrics is still to be developed.

We approach manufacturing system flexibility measurement problem from system dynamics point of view and consider flexibility as one of the “identity code” which can be revealed from its system transfer function. Flexibility index is derived from system transfer...
function, which can be estimated from production systems regular input demand and production output data.

REFERENCES:


