International Refereed Journal of Engineering and Science (IRJES)
ISSN (Online) 2319-183X, (Print) 2319-1821
Volume 2, Issue 12 (December 2013), PP. 29-38

An Improved Methodology for Flexibility Design in Production System of Manufacturing Firms

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Abstract:- This research designs flexibility in production system in four categories: one-machine-one part, many-machines-one-part, one-machine-many-parts, and many-machines-many-parts. An important component in design and development of flexibility in a production system is the establishment of appropriate flexibility measures. A flexibility measure or a set of flexibility measures is used to determine the level of flexibility in a typical production system at a given situation. A firm with higher flexibility is expected to develop a variety of products at low cost, high quality, and with short throughput time. In order to achieve appropriate control over flexibility over time, the best option is to measure and evaluate it in quantitative terms. In this research, models pertaining to various flexibility dimensions are developed and applied in a typical engine manufacturing firm in India to quantify the level of flexibility.

Keywords:- Flexibility; Production System; Design; Implication; Process; Manufacturing Firm.

I. INTRODUCTION

In today's fiercely competitive global economy, the concept of "competing on flexibility" has become basic requirement to leading manufacturing firms (Wadhwa et al., 2009). After globalization, manufacturing firms are under tremendous pressure due to more sophisticated markets, mass customization and changing customer needs (Thakur and Jain, 2008). In essence, the ability to respond more rapidly than the competition-an ability enhanced by a flexibility competence places the firm in a position to better meet the customer's need and thus provides the firm with a competitive advantage (Spanos and Voudouris, 2009). While flexible production system (FPS) is a fairly common subject in the literature on quality and performance, it is observed that production systems with in-built flexibility are used to a grater extent in large firms than in small and medium-sized ones (Kahyaoglu et al., 2002; Sharma et al., 2008).

Production system becomes flexible, if the design and operation issues are considered (Ranky, 1983; Browne *et al*., 1984). Design considers selection of equipment, layout, material handling, and human workforce. Operation considers aggregate planning, part type selection, resource grouping, product ratio determination, resource allocation and loading. In the later half of the twentieth century, flexibility in production system has evolved (Buzacott and Yao, 1986; Gerwin, 1987). Flexible manufacturing has become one of the approaches for improvement of product quality and system performance (Jaikumar, 1986; Garetti, 1986). Flexibility increases variety of part types when design and operation of production systems are given importance (Yilmaz and Davis, 1987).

Over the years, favorable climatic condition has increased the purchasing capability of consumers (Dangyach and Deshmukh, 2004). Manufacturing firms worldwide have become an important aspect of industrial and economic progress of industrialized countries (Ramasesh and Jayakumar, 1993; Mohanty and Venkataraman, 1993). No manufacturer can produce all the components needed for a product. The firms have to outsource the above from vendors (Falkner, 1986). The above facts about production industry provided motivation for this research.

Review of literature in brief is provided in section 2. Section 3 details about the methodology applied in this research work. Section 4 discusses about the models for flexibility. Implications of flexibility models are provided in Section 5. Analysis and results are provided in section 6 and section 7 details about discussion and conclusions.

II. REVIEW OF LITERATURE

In the literature, production system flexibility has been discussed with its industrial applications. Lim (1987) studied the adoption of flexible manufacturing in UK. According to Mohanty and Venkataraman (1993), only 22% of the surveyed firms in India use flexible manufacturing. Rao and Deshmukh (1994) provided a strategic framework for implementing flexible manufacturing in India. Machine, routing, expansion, product flexibility are practiced when facing different environmental challenges (Braglia and Petroni, 2000). According to Dangayach and Deshmukh (2004) level of utility of flexible manufacturing is 30% in multi-product manufacturing firms. Utilization of flexible manufacturing in India is not satisfactory (Sharma *et al*., 2008). Nayak and Ray (2011) studied the adoption of flexible equipments in Indian manufacturing firms and knowledge of flexibility reveal that the level of practical applications in India is not satisfactory.

Dixon (1992) and Suarez et al. (1995) carried out an empirical study for measuring flexibility in manufacturing. Upton (1997) made an empirical study of flexibility considering the process range in manufacturing. Chan and Zhang (2001) provided a petri-net modeling for reconfigurabilty, reusability, scalability and flexibility in agile manufacturing system. Chang et al. (2003) investigated the empirical relationship between business strategy and manufacturing flexibility to investigate its effect on improvement of business performance. Chan (2004) studied the effects of different levels of operation flexibility and dispatching rules on the performance of flexible manufacturing systems. Wadhwa et al. (2005) developed simulation models of flexible manufacturing system, studied the effect of sequencing flexibility on the lead-time performance under different conditions of part-load and machine-load balancing and it is observed that sequencing flexibility has a significant effect on the lead time performance of the manufacturing system. Chan et al. (2006) provided an approach to identify productive and counterproductive performance zones of an FMS at different flexibility levels while considering physical and operating characteristics and the results show that flexibility increase up to certain level is productive and further increase is counter-productive. Wahab (2005) measured machine and product mix flexibility of a manufacturing system. Wadhwa et al. (2006) studied the impact of flexibility types on the lead-time performance of a manufacturing system and indicated that product flexibility has the greatest influence followed by transformation flexibility and sequencing flexibility. Nayak and Ray (2010) carried out an empirical investigation to find out the relationships between flexibility and performance in a bearing manufacturing firm in India. According to Chan et al. (2007), the expected benefits from increasing the level of flexibility may not be achieved if the physical and the operating parameters of alternate machines have variations. If the variations are higher, than increase in flexibility level may be counter-productive. Nayak and Ray (2012) empirically investigated the relationship between flexibility and quality in an engine manufacturing firm in India.

Son and park (1987) provided an economic measurement of productivity, quality and flexibility in advanced manufacturing systems. Bernado and Mohammed (1992), Abdel-Malek and Wolf (1991) studied the measurement and use of operational flexibility in the loading of flexible manufacturing systems (FMS). All the studies had a broad scope, investigating different frameworks in productivity, quality, and performance of production systems and not focusing in detail on flexibility (Ward et al., 1995). The objective of this research is more focused, investigating the knowledge of FPS, the utility and methods for flexibility measurement.

III. RESEARCH METHODOLOGY

A comprehensive methodology for measuring the flexibility of production systems taking into consideration its requirements, procedure, and constraints are discussed in this paper. The research work considers four flexibility dimensions and each dimension has been described with different factors. While existing methodologies for measuring flexibility are found to be of limited use, this research takes into account all possible combinations in a production system: one-machine-one-part to many-machines-many-parts. Thus, predictive models for quantifying flexibility are developed and the methodology becomes highly useful for measuring flexibility in a production system.

• *Assumptions of the Measure*: The proposed flexibility measurement model for a manufacturing firm is based on the following assumptions:

i) The productivity of the production system does not vary with time,
ii) The characteristics of the raw material does not vary,
iii) The age of production system has no effect,
iv) Rework related measures are not incorporated,
v) All the flexibility dimensions are different from one another
vi) Time period is considered as sufficiently large (more than a month or so), and
vii) The firm produces multiple products with a large variety.

This research aims to highlight the processes and products that help a firm to achieve greater market share in engine manufacturing. Sample in this study includes various sections/departments within the firm, namely, machining, heat treatment, inspection, assembly etc. The sections are chosen carefully to represent the entire firm. **Table 1** provides an overview of the firm.

Table 1: An overview of firm under study

Attributes	Response
Year of establishment	1905

Nature of product	Automobile Engines of Heavy Vehicles
Sales turnover ($ million)	300
Number of employees	1200
Domestic market share	14%
Export as % of total sales	25

Flexibility parameter values are collected from the concerned firm using the nominal group technique using the following mathematical modeling. Multi-method may help maintain both the validity and reliability of the field data, where one aspect is discussed with more than one respondent for collection of data. This study further confirmed in a follow-up interview with the managers of concerned departments. Numerous foreman and workers are also randomly chosen to discuss the issues during data collection. Departmental managers provided more reliable information and the supplementary information from foreman help enrich the data sources. The interviews coupled with process mapping, department/section visits, and document verification form the basis of data validation for reducing the data bias to the minimum (Das, 2001). Details about the informants are provided in **Table 2**.

Table 2: Details of Informants

Position	Percentage
Department heads	10%
Department managers	35%
Foreman and others	55%

• *Tools for data collection*: The questionnaire was developed on the basis of the existing literature and was pre-tested with academicians as well as industry experts for checking its reliability and content validity. The suggestions collected during pre-testing of the questionnaires were incorporated in the questionnaire. Cronbach's alpha test was applied and the value of coefficient was above 0.75 (O' Kelly and Vokurka, 1998). Thus, pre-tested and modified questionnaire was administered to all the respondents. The questionnaire contains questions regarding the parameters of flexibility in production systems. For accurate fill up of questionnaire, exploratory notes, wherever necessary have been provided at either beginning or end of each questionnaire. All participants have been assured with confidentiality in data and results.

IV. FLEXIBILITY MEASURES

Firms usually follow four different combinations for parts (components) to be produced. The measures for various flexibility dimension focuses mainly on the number of machines in use, number of batch, configuration of part type, process plan, operations in each process plan and material handling equipments in use. Objective of this research work is to explore and form an overall assessment of the flexibility in production system and its implications in process industry. Process, expansion, operation and material handling flexibility related to process industry are selected for this research. Each dimension of flexibility is defined and measures as developed are discussed below:

4.1 Process Flexibility Measure

Process flexibility (*PRF)* of a production system over time, *t*, is defined as the ratio of the volume of the set of part types that the system (machine) can produce without major setups to the total number of part types produced in a production system. Volume may be expressed by the number of different part types in the set. Process flexibility of a system derives from the machine flexibility of machines, operation flexibility of parts, and the flexibility of the material handling system composing the system. It is useful in reducing batch sizes and, in turn, inventory costs. The flexibility measures for different machine-part combinations are as follows:

(i) One machine producing one part type

$$PRF1_{it} = \frac{L_{it}}{\sum_{k=1}^{s_i} L_{ikt}} \qquad \ldots (1)$$

(ii) Many machines producing one part type

$$PRF2_t = \frac{\sum_{i=1}^{n} L_{it}}{\sum_{i=1}^{n} \sum_{k=1}^{s_i} L_{ikt}} \quad \ldots (2)$$

(iii) One machine producing many part types

$$PRF3_{it} = \frac{\sum_{j=1}^{m_i} L_{ijt}}{\sum_{j=1}^{m_i} \sum_{k=1}^{s_i} L_{ijkt}} \quad \ldots (3)$$

(iv) Many machine producing many part types

$$PRF4_t = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m_i} L_{ijt}}{\sum_{i=1}^{n} \sum_{j=1}^{m_i} \sum_{k=1}^{s_i} L_{ijkt}} \quad \ldots (4)$$

where, i is the number of machines, $i = 1, \ldots n$; j is number of part features, $j = 1, \ldots m$; k is number of setups, $k = 1, \ldots s$; and t is the time period.

PRF_t : Process flexibility measure during time, t (measured at the end of the t^{th} period)

L_{it}: Number of part types produced in the i^{th} machine, without setup change, in time, t

L_{ikt}: Number of part types produced in the i^{th} machine, during the k^{th} setups in time, t

L_{ijt}: Number of part types produced in the i^{th} machine, with the j^{th} feature of a part, without setup change in time, t

L_{ijkt}: Number of part types produced in the i^{th} machine, with the j^{th} feature of a part, during k^{th} setups, in time period, t

s_i: Number of setup changes in the i^{th} machine during the period, t

m_i: Number of part features produced in the i^{th} machine during time period, t.

4.2 Expansion Flexibility Measure

Expansion flexibility (*EXF)* measure over time, t, is defined as the ratio of the capacity and capability increase when needed to the maximum feasible output level of the system. The capacity is in terms of output rate per unit time, whereas capability refers to such characteristics as quality, the technological state, and other type of flexibilities. Expansion flexibility makes easier to replace or add machinery in the original design. Ease in this connection refers to the overall effort needed for the expansion. This flexibility may help shorten implementation time and reduce cost for new products, variations of existing products, or added capacity. It is the measure of how large the system can be. The measures for different machine-part combinations are as follows:

(i) One machine producing one part type

$$EXF1_{it} = \frac{C_{it}}{\sum_{k=1}^{s_i} C_{ikt}} \quad \ldots (5)$$

(ii) Many machines producing one part type

$$EXF2_t = \frac{\sum_{i=1}^{n} C_{it}}{\sum_{i=1}^{n} \sum_{k=1}^{s_i} C_{ikt}} \quad \ldots (6)$$

(iii) One machine producing many part types

$$EXF3_{it} = \frac{\sum_{j=1}^{m_i} C_{ijt}}{\sum_{j=1}^{m_i} \sum_{k=1}^{s_i} C_{ijkt}} \qquad \dots (7)$$

(iv) Many machine producing many part types

$$EXF4_{t} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m_i} C_{ijt}}{\sum_{i=1}^{n} \sum_{j=1}^{m_i} \sum_{k=1}^{s_i} C_{ijkt}} \qquad \dots (8)$$

where, i is the number of machines, $i = 1, \dots n$; j is number of part features, $j = 1, \dots m$; k is number of setups, $k = 1, \dots s$; and t is the time period.
EXF_t : Expansion flexibility measure during time, t
C_{it}: Capacity increase in part in the i^{th} machine, without setup change, in time period, t
C_{ikt}: Maximum capacity of the i^{th} machine during the k^{th} setups, in time, t
C_{ijt}: Capacity increase in part in the i^{th} machine, with the j^{th} feature of a part, without setup change, in time, t
C_{ijkt}: Maximum capacity of the i^{th} machine, with the j^{th} feature of a part, during the k^{th} setup, in time period, t
s_i: Number of setup changes in the i^{th} machine during the period, t
m_i: Number of part features produced by the i^{th} machine, during time, t.

4.3 Operation Flexibility Measure

Operation flexibility (*OPF)* measure of a part over time, t, is defined as the ratio of the number of alternate process plans (ways) to produce a part to the total number of ways a part is produced. Operation flexibility is a property of the part, where a process plan means a sequence of operations required to produce the part. An alternative process plan may be obtained by either an interchange or a substitution of certain operations by others. A process will be considered to have operation flexibility if parts that are being produced in the system possess operation flexibility and if the material handling system is able to deliver parts to machine in different possible orders. Operation flexibility of parts contributes to various system flexibilities, especially the routing flexibility. The measures for different machine-part combinations are as follows:

(i) One machine producing one part type

$$OPF1_{it} = \frac{W_{it}}{\sum_{k=1}^{s_i} W_{ikt}} \qquad \dots (9)$$

(ii) Many machines producing one part type

$$OPF2_{t} = \frac{\sum_{i=1}^{n} W_{it}}{\sum_{i=1}^{n} \sum_{k=1}^{s_i} W_{ikt}} \qquad \dots (10)$$

(iii) One machine producing many part types

$$OPF3_{it} = \frac{\sum_{j=1}^{m_i} W_{ijt}}{\sum_{j=1}^{m_i} \sum_{k=1}^{s_i} W_{ijkt}} \qquad \dots (11)$$

(iv) Many machine producing many part types

$$OPF4_t = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m_i} W_{ijt}}{\sum_{i=1}^{n} \sum_{j=1}^{m_i} \sum_{k=1}^{s_i} W_{ijkt}} \quad \ldots (12)$$

where, i is the number of machines, $i = 1, \ldots n$; j is number of part features, $j = 1, \ldots m$; k is number of setups, $k = 1, \ldots s$; and t is the time period.
OPF_t : Operation flexibility measure during time, t
W_{it}: Number of alternate process plans (ways) available at the i^{th} machine, for producing a given part, in time period, t
W_{ikt}: Total number of ways available at the i^{th} machine during the k^{th} setups, in time, t
W_{ijt}: Number of alternative ways available at the i^{th} machine, with the j^{th} feature of a part, in time, t
W_{ijkt}: Total number of ways available at the i^{th} machine, with the j^{th} feature of a part, during k^{th} setup, in time period, t
s_i: Number of setup changes in the i^{th} machine during the period, t
m_i: Number of part features produced by the i^{th} machine, during time, t.

4.4 Material Handling Flexibility Measure

Material handling flexibility (*MHF)* measure of a given system over time, *t*, is defined as the ratio of the number of paths that the system can support to the number of paths supported by the universal material handling system (to move one part). A universal material handling system can link every machine to every other machine. To move different part types efficiently it is the ratio of the alternative manufacturing facilities (paths) to the total number of possible material handling paths that can be supported by the production system. The ability of the material handling system is to accommodate different parts of different shapes and sizes for proper positioning and processing, and the readjustment of paths in case of machine breakdown and/or expansion. Material handling system flexibility increases availability of machines and thus their utilization and reduces throughput times. Different measures for material handling flexibility are as follows:

(i) One machine producing one part type

$$MHF1_{it} = \frac{P_{it}}{\sum_{i=1}^{n} P_{uit}} \quad \ldots (13)$$

(ii) Many machines producing one part type

$$MHF2_t = \frac{\sum_{i=1}^{n} P_{it}}{\sum_{i=1}^{n} P_{uit}} \quad \ldots (14)$$

(iii) One machine producing many part types

$$MHF3_{it} = \frac{\sum_{j=1}^{m_i} P_{ijt}}{\sum_{j=1}^{m_i} \sum_{i=1}^{n} P_{fijt}} \quad \ldots (15)$$

(iv) Many machine producing many part types

$$MHF4_t = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m_i} P_{ijt}}{\sum_{i=1}^{n} \sum_{j=1}^{m_i} P_{fijt}} \quad \ldots (16)$$

where, i is the number of paths supported by the material handling system, $i = 1, \ldots n$; j is number of part features, $j = 1, \ldots m$; and t is the time period.

MHF_t : Material handling flexibility measure during time, t
P_{it}: Number of alternative manufacturing facility (path) available at the i^{th} material handling system, in time, t
P_{uit}: Number of paths supported by universal material handling system, in time, t
P_{ijt}: Number of alternative manufacturing facility (path) available at the i^{th} material handling system, for the j^{th} feature of a part, in time, t
P_{fijt}: Total number of manufacturing facility (path) available at the i^{th} material handling system, with the j^{th} feature of a part, in time period, t
m_i: Number of part features supported by the i^{th} material handling system during time, t

V. IMPLICATIONS OF FLEXIBILITY MEASURES

Flexibility models developed in this paper have been used in a engine manufacturing firm in India to evaluate the flexibility value of a given production system in numeric (value ranges from 0 to 1). To obtain data on different variables, nominal group technique is used. A group of fifteen individuals at the managerial level or above, who has expertise in flexibility are selected from product design, process design, manufacturing, and sales and distribution functions of the firm. A questionnaire is provided to them to obtain the data relating the values of the input variables for a flexibility type, starting from their respective minimum possible values to maximum possible values. Responses are collected after a few interactions and, the average value of the fifteen responses is calculated. The data represent the average figures for corresponding variables during a particular month. This exercise is carried out for all the variables and for all the selected dimensions of flexibility (process - PR, expansion - EX, operation - OP, material handling - MH) for sixty consecutive months (Month-wise data from 2007 to 2012).

VI. ANALYSIS AND RESULTS

The details of the data collected in 1-M-1-P production system are plotted in Fig 1 (flexibility vs. time). In this situation process and operation flexibility are at the upper level, material handling flexibility at middle level and expansion flexibility at low level.

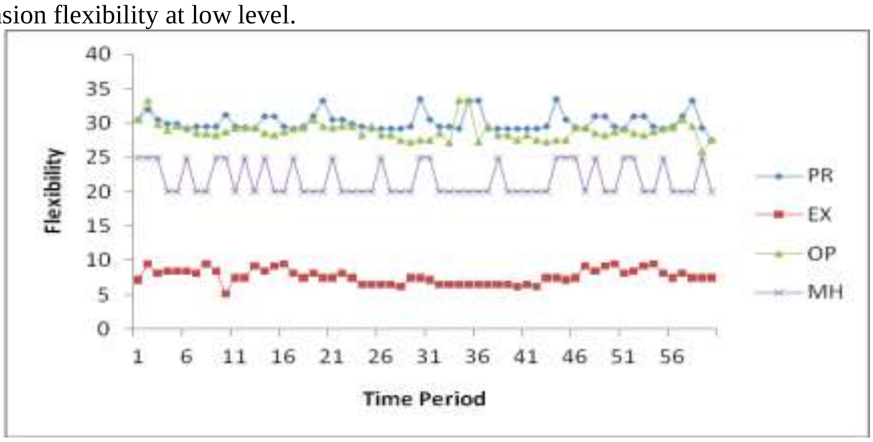

Figure 1: Flexibility in 1-M-1-P production system with time

Flexibility in M-M-1-P production system is calculated, plotted with time and shown in Figure 2. In this situation process and operation flexibility are at the upper level, material handling flexibility is at middle level, and expansion flexibility are at the lowest level.

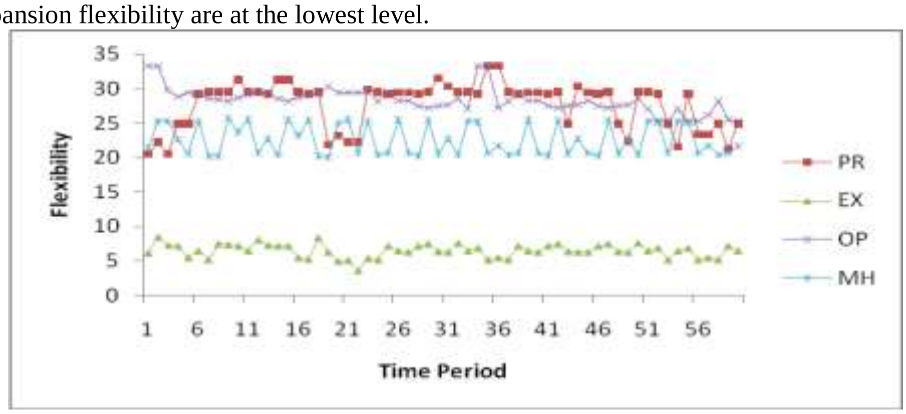

Figure 2: Flexibility in M-M-1-P production system with time

The details of the data collected in 1-M-M-P production system are provided in Table A.3 in which variation of flexibility with time has been plotted as in Fig. 3. It is evident that process flexibility is at upper level, material handling flexibility is at the middle level, and expansion and operation flexibility are at the lowest level.

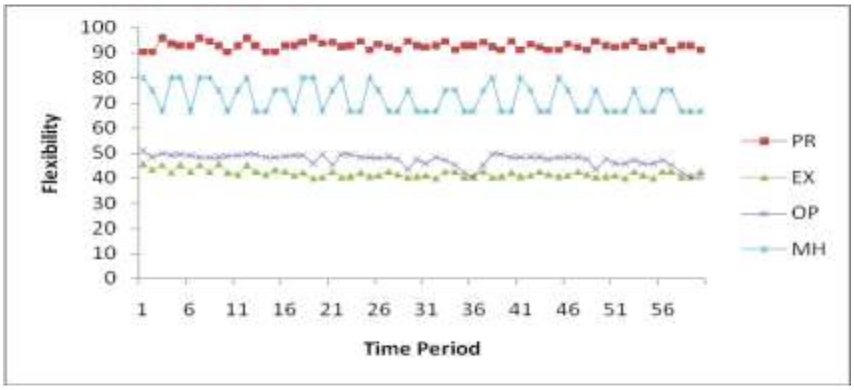

Figure 3: Flexibility in 1-M-M-P production system with time

Flexibility in case of M-M-M-P has been calculated, the relevant data is provided in Table A.4 and the variation of flexibility with time is plotted in Fig. 4. It is found that material handling flexibility is at upper level followed by process flexibility, expansion flexibility at the lowest level, and operation flexibility is just above expansion flexibility.

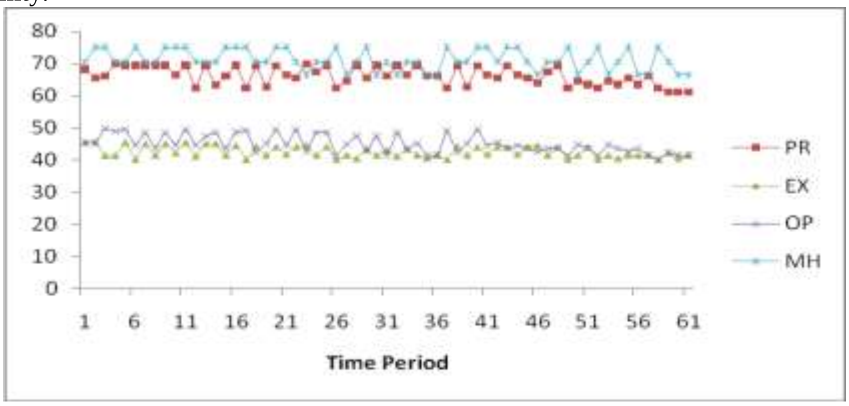

Figure 4: Flexibility in M-M-M-P production system with time

VII. DISCUSSION AND CONCLUSIONS

7.1 Contribution

The proposed methodology is comprehensive in the sense that, it considers (i) several dimensions simultaneously with (ii) any number of possible factors describing each dimension and (iii) may be applicable for measuring various dimension on flexibility in manufacturing firms producing multiple part(s) and/or product(s). A firm implementing the proposed methodology needs to consider a number of points: (i) depending on the type of part or product, the relevant input variables are to be identified, (ii) the values of the variables as computed need to be updated at a regular interval and (iii) as the methodology proposed is generic in nature, the numbers and types of factors to be considered depend on the type of flexibility.

7.2 Managerial Applications

This research has identified three types of manufacturing firms, namely independent company, operating/subsidiary unit of large firm and public sector undertakings. Independent companies are adopting cost-driven strategies. Their dominant competitive priority is low cost. These companies focus on short-term gains. For large firm, conformance to quality is the top preferred competitive priority. Firms have moderate investment in quality tools. These firms place high emphasis on innovation and flexibility issues. Public sector undertaking firms invest more in activities such as CAD, CNC, etc.

7.3 Limitations and future research

Development of the above models is a first step towards developing a metric to quantify the flexibility of production systems. Such models are missing in the literature. There are certain important directions of future flexibility research. Though the measures developed in this research concentrates only to determine the level of flexibility in a production system, yet it can be extended to obtain other flexibility dimensions, such as, worker flexibility, delivery flexibility, design flexibility etc.

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