Feedback Based Framework for Flexibility Management & Control

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Abstract

The recent years have observed an increase of interest in flexibility, which provides capability to react rapidly to market opportunities and shifting technologies. Flexibility as a tool facilitates enterprises to deal with the environmental uncertainty and subsequently enhancing the performance. The topic of manufacturing flexibility has been addressed by many researchers highlighting its importance both at industrial and academic level. In the past many pioneering efforts have been made to achieve manufacturing excellence through various frameworks, but none of the existing frameworks provide effective management and control of flexibility. An attempt is made to develop a conceptual framework for the management and control of flexibility in manufacturing organizations. A feedback based approach for managing and controlling manufacturing flexibility is suggested.

Keywords: Manufacturing Flexibility, Conceptual Framework, Feedback Control.

1. Introduction

Global competition, rapidly changing technology, and shorter product life cycles have contributed to making the current manufacturing environments extremely complex. Traditional manufacturing approaches, such as mass production of a few standardized products, are no longer able to provide sufficient competitive edge to the organizations. Customers are demanding a greater variety of high quality, low-cost goods and services [31]. The ability to change with uncertainty is often referred to as the degree of flexibility the system. The need for flexibility is growing due to the changing nature of competition, which is based more than ever on constantly improving the technical characteristics of products and being responsive to differing customer requirements. Manufacturing flexibility is a complex, multidimensional concept that has evolved over the years. [33]. It is the ability of the organization to manage production resources and uncertainty to meet various customer requests [16, 23, 25, and 26]. Sethi and Sethi [33] contend that manufacturing flexibility is a hard-to-capture concept, and Upton [40] believes that confusion and ambiguity about this concept inhibit its effective management.

Flexibility represents one of the more important perspectives to be taken into account for improving manufacturing performance. The management of flexibility has been a key issue in various previous studies. The intention of this research is to develop a strategic framework for the implementation and management of manufacturing flexibility in manufacturing organizations. The proposed framework suggests that manufacturing flexibility should be managed using a feedback based approach, which can give a better control in real times.

The remainder of the paper has been organized in the following manner - section 2 extensively reviews the literature on manufacturing flexibility which is needed in the development of proposed strategic framework by blending the strengths of other conceptual frameworks, whereas section 3 delineates the detailed design and description of the proposed framework. Section 4 presents the major findings of the research and concludes the paper with a note about its future scope.

Manufacturing flexibility is a difficult, complex concept that has grown over the years [33]. In the earlier developments, Brown [5] suggested a series of small, functionally oriented machines that can be combined to make different products. Hayes [22] observed manufacturing flexibility as a tradeoff between efficiency in production and dependability in the marketplace. Implementation of flexibility in mass production can be made efficient with the development of manufacturing cells and flexible manufacturing systems. Efficiency and flexibility are attained by reducing set-up time and cost, shifting to product-oriented layouts, increasing equipment reliability, and enhancing quality. Manufacturing flexibility is the capability of the manufacturing organization to manage resources and uncertainty to meet various customer requests. Hayes [22] considers manufacturing flexibility to be a strategic element of business, along with cost, quality, and reliability. Priorities assigned to each of these factors determine how an organization positions itself relative to its competitors. Flexibility can be defined as a set of internal elements that are integrally designed and carefully linked to assist the adaptation of processes and resources to a variety of production tasks [33]. Upton [40] identifies attributes of flexibility including potential flexibility versus demonstrated flexibility and robustness (maintaining a status quo despite a change) versus agility (instigating change rather than reacting to it). Upton [40] also describes internal flexibility as what the firm can do and external flexibility as what the customer sees (capabilities). However, manufacturing flexibility remains a key strategic objective of many manufacturing companies.

The core content of a manufacturing strategy includes cost, quality; flexibility and technology Adam [1] and Collin [11] observe various priorities in manufacturing such as product quality, product cost, delivery dependability, and flexibility. It is also becoming true that the ability to produce to the least cost is no longer the dominant factor in remaining competitive. In the past, demand was steadier, there was less variety and life cycles and lead times were longer [7]. Now, the capacity to absorb fluctuations in demand economically, to develop and introduce new products quicker using existing facilities are seen as important competitive issues. Such considerations have been a catalyst for the interest now being shown in manufacturing flexibility. Many researchers have illustrated the role of flexibility in the manufacturing strategy of organizations. Early work presented by Skinner [36] identifies manufacturing flexibility as one of four objectives of a manufacturing organization; other objectives are costs, delivery, and quality [14]. In the literature, a lot of justification for acquiring flexibility has been suggested. Wadhwa [41] claims flexibility is necessary in order to maintain competitiveness in a changing business environment, and quotes current issues such as a rapidly decreasing product life, the invasion of competitors, an increasing demand for product changes and the introduction of new products, materials and processes. Slack [38] proposes the motivations to seek flexibility are founded in the instability and unpredictability of the manufacturers' operational environment, developments in production technology such as FMS and robotics, and the widening aims of production to progress beyond cost and productivity issues to manufacturing system flexibility. Owing to the flexibility, decision-making problems require the judicious combination of flexibility and information based integration and automation [42]. Despite increasing interest, flexibility remains poorly understood in theory and poorly utilized in practice. One reason for this is the lack of general agreement on how to define flexibility. Over 70 terms (types and measures) can be found in the literature [34].

Flexibility has been defined in different manners by different authors in current literatures. Koste & Malhotra [26] had defined the flexibility as the ability of the firm to anticipate, adapt or react to the changes in its environment. Gupta and Goyal [20] had defined the flexibility of a manufacturing system as its capability to respond to the changing circumstances and/or to the instability caused by the environment.

Summarizing the efforts made by above researchers in defining manufacturing flexibility, two general points can be drawn i.e. Flexibility as the ability to respond to change, and the use of flexibility to accommodate uncertainty. The use of flexibility for the purpose of accommodating uncertainty is a concept which has received wide recognition, but the types of uncertainty a system can be anticipated to address appears to be dependent on the operational level from which it is viewed, e.g. the machine cell, the function or the manufacturing system. It is justified in the literature that each type of uncertainty in its turn requires a different and particular type of flexibility to accommodate it. Perhaps the earliest recognition of this fact was that of Gerwin [17] whose attempt at associating types of uncertainty with types of flexibility is summarized in Table 1.

Table 1. Flexibility with Associated Uncertanities [17]

Flexibility type	Uncertainty
Mix	Uncertainty as to which product will be accepted by customer, created a need for mix flexibility
Change over	Uncertainty as to the length of product life cycles lead to change over flexibility
Modification	Uncertainty as to which a particular attribute customer wants lead to modification flexibility
Routing	Uncertainty with respect to machine downtime makes for routing flexibility
Volume	Uncertainty with regard to the amount of customer demand for the product order lead to volume flexibility
Material	Uncertainty as to whether the material input to process meet standards give rise to the need for material flexibility
Sequence	Sequence flexibility arise from the need to deal with delivery times of raw materials

2.1 Flexibility Types

Various researchers described different types of flexibility types like Sethi and Sethi [33] gave the concept of eleven flexibility types, which include the machine, material handling, operation, process, product, routing, volume expansion, production and marketing flexibilities. As per the original classification illustrated by Browne et al. [12] only eight flexibility types were recognized, these were; machine flexibility, process flexibility, routing flexibility, operation flexibility, product flexibility, volume flexibility, part mix flexibility and production flexibility.

2.1.1 Machine flexibility
It is the capability of a machine to perform different operations economically and effectively. A machine with machine flexibility can perform various types of operations without requiring an excessive effort in switching from one operation to another. It is an important variable in shop floor scheduling and the dual resource constrained job shop [33, 19, 24, 32, and 44].

2.1.2Labor flexibility
It is the ability of the workers to perform a wide range of manufacturing tasks economically and effectively. It is a key element in the dual resource constrained literature, but the conceptual and empirical literature has a tendency to stress on equipment flexibility and to overlook the probable impact of labor [24, 32, 40, and 44].

2.1.3 Material handling flexibility
It is defined as the ability to transport different work material between various

machining centers over several paths economically and effectively. Flexibility of a material handling system is its capability to move different part types effectively for proper positioning and processing through the manufacturing resources it serves [5, 10, 27, 30, 33, and 44].

2.1.4 Routing flexibility

Routing flexibility of a manufacturing system is its ability to produce a part by alternate routes through the system. It is the ability to process a given set of part types using multiple routes economically and effectively. Routing flexibility is widely studied in the flexible manufacturing system literature because it allows firms to find alternate processing centers in case of machine breakdowns or system overloads [33, 35, 40, 42, 43, and 44].

2.1.5 Volume flexibility

Volume flexibility is the ability of a system to be operated profitably at different overall output demand levels. It is the capability of the organization to operate at different batch sizes and/or at different production output demand levels effectively. It exhibits the competitive potential of the firm to increase production volume to meet increasing demand and to keep inventory low as demand decreases [6, 16, 33, and 44]

2.1.6 Mix flexibility

Mix flexibility is defined as the capability of the organization to produce various combinations of products economically given certain capacity level. It relates to the set of part types that the system can manufacture without major setups. It enables a firm to improve customer satisfaction by providing the kinds of products that customers request in a timely manner. [4, 15, 21, 33, 35, 44]

2.1.7 Operation flexibility

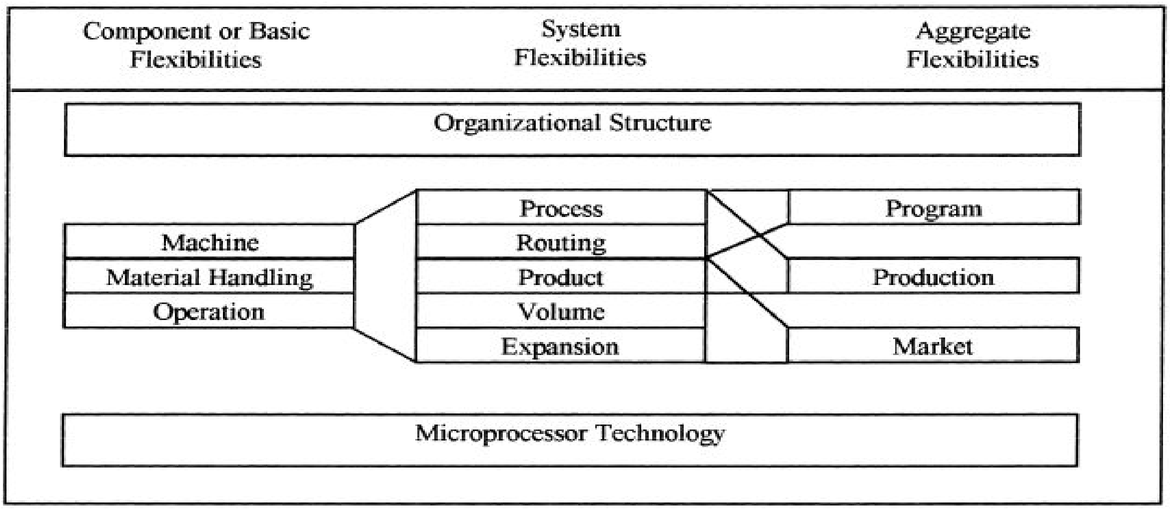
It is the ability of a part to be manufactured in alternative ways. Operation flexibility is a property of the part, and represents that the part can be produced with alternate process plans, where a process plan means a sequence of operations required to produce the part [5, 10, and 33].

Sethi & Sethi [33] added three more flexibility types' viz. material handling, program and market flexibility to the original taxonomy of Browne et al. (Table 2). He also suggested the linking between various flexibility types by introducing a basis system framework with basic level flexibility, system flexibility and aggregate flexibility. The interrelationships of these eleven flexibilities are shown diagrammatically in Figure 1

Table 2 Flexibility types [5]

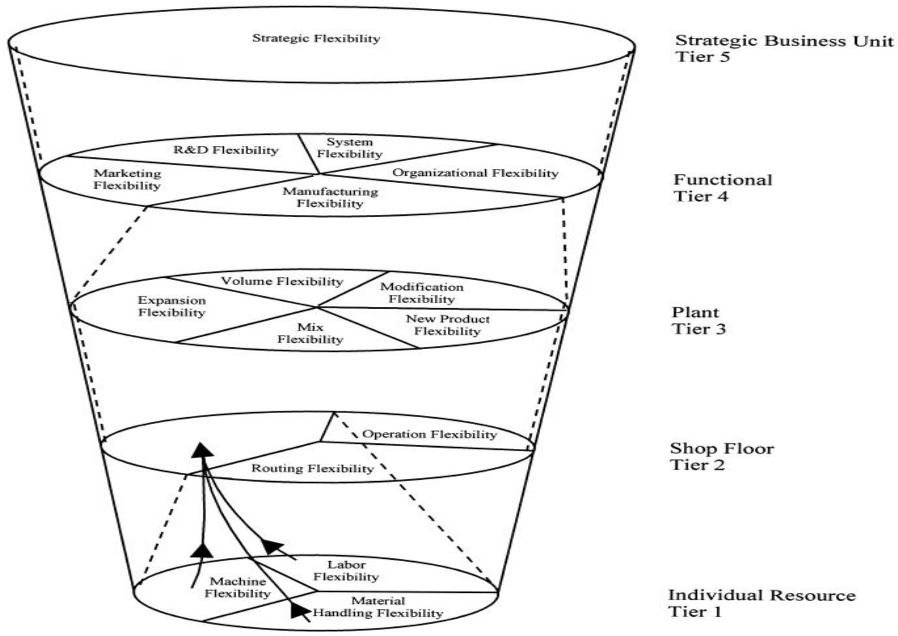
Flexibility type	Definition
Machine	The ease of making the changes required to produce a given set of part type
Process	The ability to produce a given set of part type , each possibly using different material , in several ways
Routing	The ability to changeover to produce a new (set of) product(s) very economically and quickly
Volume	The ability to operate an FMS profitably at different production volume
Expansion	The capability building system and expanding it as needed, easily and modularly
Operation	The ability to interchange the ordering of several operations for each part type
Production	The Universe of parts types that the FMS can produce

Figure 1 Linking various flexibility types [5]



Koste & Malhotra [26] proposed a new flexibility hierarchy (Figure 2), by suggesting a five tier framework for flexibility. The lower tiers contain flexibility types that serve as building blocks for the flexibility types in the upper tiers. The flexibility types in lower tier also tend to be more planned, while those in the upper tiers of the hierarchy tend to be more strategic. Finally, even though each tier of the hierarchy contains numerous flexibility types, the nature of lateral relationships between dimensions at any given tier is not being discussed. The framework proposed by Koste & Malhotra [26] has also been supported by the work of Hyun and Ahn [24], with some key differences. Hyun and Ahn [24] described only three tiers of flexibility, while Koste & Malhotra [26] suggested five tiers in the organization. Besides that Hyun and Ahn [24] illustrated an inverted cone as opposed to an upright one. The shape of cone represents flexibility as a capability. As an organization grows in the development of flexibility, i.e., moves up the cone, its abilities with respect to flexibility increase.

Figure 2 Hierarchy of Flexibility Dimensions [26]



In previous studies, many researchers have tried to quantify the flexibility in monitory terms, and to integrate it with decision making tools [42, 43]. Efforts have been made to quantify the flexibility in manufacturing systems. Gupta and Somers [21] also related manufacturing flexibility to the capability of an organisation as an entity to adapt and respond to changes. Gupta and Goyal [20] and Sethi and Sethi [33] surveyed the development in literature, defined several terms and suggested means of achieving different kinds of flexibility, mostly from a qualitative perspective. Wadhwa and Rao [42] provided a framework to quantify flexibility value in Automated Manufacturing Systems. Ramashesh & Jaikumar [32] laid a theoretical basis for measuring flexibility in manufacturing systems. Chan et al. [8] examined the flexibility measurements and performance of FMSs.

3. Feedback based Framework for Flexibility Management and Control

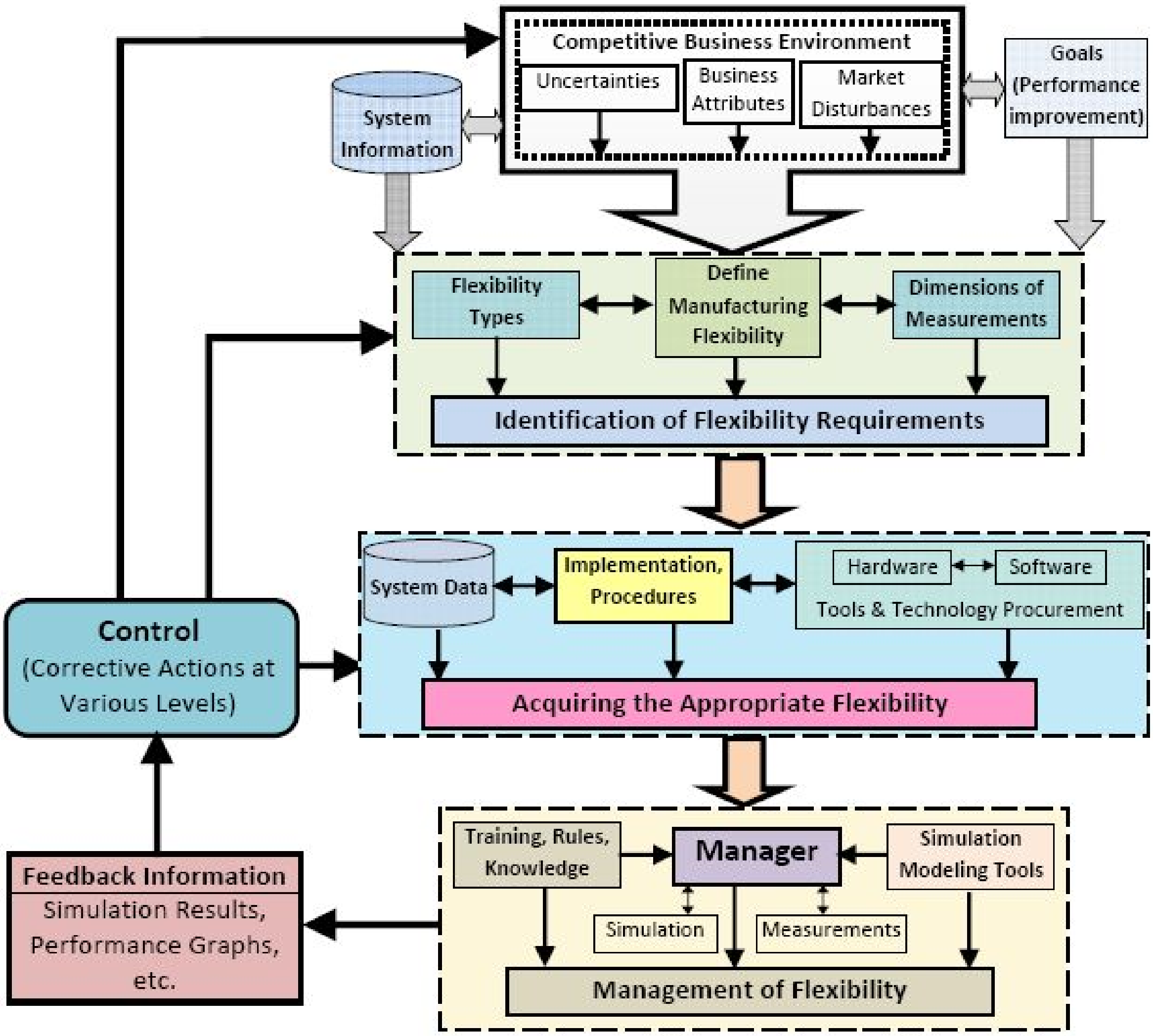
Conceptualization of flexibility framework is considered to be a complex task due to its multidimensional nature. There are various types (routing, mix, product, volume, machine etc.) and levels of manufacturing flexibility (strategic and operational level) which also add to its complexity. Consequently there are no standard policies for successful implementation of manufacturing flexibility in enterprises. Instead, a framework must be designed in order for its potential benefits to be fully realized. Gerwin [16] proposes a sequence of four steps or phases for implementing manufacturing flexibility, specifically identifying flexibility dimensions requiring investigation, measuring gaps, selecting methods for closing gaps, and continuous assessment. In the first phase, identifying flexibility dimensions requiring investigation, senior managers must identify the specific aspects of flexibility they believe are necessary to compete. Narain *et al.* [29] suggest the first step in implementing manufacturing flexibility is the identification of the uncertainties that exist as a result of the organization's competitive situation. These uncertainties are then evaluated against the capability of the organization to address such uncertainties. This evaluation is performed using a SWOT (i.e., strengths, weaknesses, opportunities, and threats) analysis.

Based on reviews of the existing manufacturing flexibility implementation frameworks and research literature, this research proposes that manufacturing flexibility should be implemented using a feedback based approach, as illustrated in Figure 3. The first two stages of the framework focus on managers identifying (i.e., Stage I) and obtaining (i.e., Stage II) the required flexibility types and levels needed to achieve the competitive, manufacturing and marketing strategies. The third stage focuses on managers monitoring and changing the required flexibility types and levels, in light of changing uncertainty and competitive, manufacturing and marketing strategies. Various feedback information elements such as simulation results, charts etc. are interacting with other levels to regulate better control on different uncertain scenarios. The framework proposes a feedback based approach to achieve manufacturing flexibility in an enterprise system, consisting of identification of flexibility requirements, acquiring the appropriate flexibility, and management and control of flexibility using feedback information. The flexibility requirements can be identified by primarily understanding the uncertain behavior of the competitive market. The second level is about acquiring the correct flexibility type in the enterprise, consequently the third level utilizes the various state of the art simulation modeling techniques to effectively manage and control the flexibility in a manufacturing organization.

3.1 Identification of Flexibility Requirements

The flexibility type and level is decided on the basis of dynamic business environment and uncertainties spread over the domain. Before identifying the flexibility type it is recommended to define all the business goals of the firm. Flexibility and their types must be studies and reviewed extensively keeping various factors in mind like system information, goals, market conditions, disturbances, uncertainties etc. To achieve the type of flexibility that customers want (i.e. quick delivery of a variety of high-quality, low-cost products), organization must focus on filling customer orders rather than on just improving the efficiency and effectiveness of equipment and processes.

Figure 3 Feedback – Control framework of flexibility



An appropriate flexibility selection supports enterprises to produce excellent-quality, demand-oriented products at a low cost and provides a quicker response to dynamically changing market conditions. The proposed framework is initiated by the dynamic environment of market and uncertainties associated with the decisions; these are the enablers of flexibility decisions. In order to implement the manufacturing flexibility, managers are required to analyze the uncertainty encountered and the impact of this uncertainty in achieving the goals of the organization. The uncertainty is observed in the external environment (e.g., financial and political climate, demand characteristics, market and buyer behavior), raw materials (e.g., standards, availability of raw materials), production technology (e.g., availability of the machine, availability of the material handling system) and finished products (e.g., end product specifications, delivery schedules) that contain the manufacturing system.

3.2 Acquiring the Appropriate Flexibility

The identification of flexibility type is a crucial step in the framework of flexibility in enterprises; the proposed framework transmits the information achieved in the first level to the next level for acquiring the appropriate flexibility type. This is accomplished by implementing the standard procedures along with the required hardware and software tools. Sometimes, the flexibility types and levels acquired (i.e., actual flexibility) may not be similar to the flexibility types and levels desired (i.e., required flexibility). As a result, the actual and desired flexibility must be evaluated to make sure that there is a satisfactory fit.[39] If a suitable fit (i.e., negligible gap) exists between the actual and desired flexibility, then it is anticipated that there will be a fulfillment in business goals and also there will an improvement in the performance.

3.3 Feedback Based Management and Control of Flexibility

Manufacturing flexibility is considered as a means of performance improvements, especially for enterprises in very competitive markets. Level three focuses on three activities: i) monitoring the actual flexibility to ensure that the desired flexibility is being realized, ii) controlling the flexibility implementation, iii) the desired flexibility continues to help attain the competitive, manufacturing and marketing strategies and enhancing the business performance. It is evident that simply acquiring and implementing manufacturing flexibility will not necessarily fulfill the goals; rather it will depend on the measures taken to manage and control the manufacturing flexibility. Manufacturing flexibility is considered hard to manage and control as it requires measurement models, knowledge, simulation techniques etc. It is necessary to develop and establish management rules that are both reliable and valid. Thus, an effectively flexible enterprise is one that is efficiently managed and controlled by the use of knowledge, rules, simulation models, and data models. Manufacturing flexibility, after being identified and acquired, can be cautiously monitored, managed and controlled by a manager. The feedback information such as simulation results, charts etc. must be compiled at management level to effectively manage and control the flexible system. These feedback reports are actually the strategic tools available in the hands of the manager who can control the activities, performance, output and productivity of the firm using the methodology depicted in the proposed framework. The proposed plan could effectively be utilized in flexibility adaptation, management and control in manufacturing organizations facing competitive markets and uncertain environments consequently fulfilling the desired business goals.

4. Conclusion

Manufacturing flexibility is a difficult, complex concept that has grown over the years. A number of flexibility frameworks have been suggested from time to time, but none of them suggest the feedback based approach.

This framework has been illustrated by synthesizing the strengths of other conceptual frameworks in the literature. As a result, the major components of the framework are supported by the current research on the adaptation and management of manufacturing flexibility, as well as the current literature on manufacturing system management.

It is also crucial to empirically investigate what constitutes flexibility in the flexible system domain in various industries. Another issue of managerial interest concerns the way different manufacturing flexibility types relate to one another, and whether organizations should acquire certain flexibility types as a pre-requisite for performance improvements.

Based on this framework, a number of potential management practices can be identified and their impact on the performance can be analyzed. The paper also suggest areas where future studies may be focused to develop a more complete and rigorous list of management practices needed for the adaptation and control of manufacturing flexibility in a manufacturing organization.

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