

Flexibility: A Multi Node Manufacturing Context

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Abstract

Owing to global competitive market, rapidly changing demand and high product varieties, industries are looking for the adaptability in their systems which can cope up with all the uncertainties of the environment. The flexibility provides the option to make the system so adaptable which can change the system according to the changed internal and external factors. The aim of this paper is to give the literature review in flexibility to understand the notion of flexibility and its applications in multi node manufacturing. The Industrial and academic view has been provided to make this paper more advantageous for both practitioners and researchers. The paper discusses the generic notion of the flexibility and its definitions. Various flexibility frameworks help us to understand the different dimensions of flexibility in manufacturing. The authors provide a manufacturing flexibility assessment framework which will enrich the research domain of flexibility. The detailed discussion has been provided the future roadmap for the further research in manufacturing flexibility. The futuristic view has been classified according to the practitioners and researchers. Therefore, this paper provides the great understanding for the concept of flexibility in multi node manufacturing domain with futuristic view.

Keywords: Flexibility, Flexibility Frameworks, Manufacturing Flexibility

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1. Introduction

Nowadays, the customer demand and product varieties are varying rapidly due to the continuously changing globalized markets and economy and it is resulted as the very high competitive pressure on the manufacturers and suppliers both. They are seeking the systems which should be adaptive to cope up with the changes of markets. The flexible system is one of the rays of hope which can provide the solution for all the aforementioned challenges from the markets. The flexible systems are having the different types of flexibility which can help it to adapt the rapidly changing market responses within no time or very less time. Therefore, flexibility is the ability of the system which can change the system state according to the internal and external factors.

Flexibility as a generic notion is well known in several domains. For example, an Internet search on flexibility yields numerous links in various disciplines spanning from human physiology to new ways of working. The dictionary meaning of flexibility is the ability of being bent easily, the ability of being changed to be suitable for new needs, changed conditions etc. The IEEE standard dictionary (IEEE, 1990) defines flexibility as the ease with which a system or component can be modified for use in applications or environments other than those for which it was specifically designed. Most of the researchers view the flexibility as the great facilitator to the system for adapting the changes in internal and external factors^{23,44,60,61}. The usage of

flexibility provides a lot of advantages to the practitioners with some limitations.

Due to the various benefits of flexibility to the practitioners or market players, the researchers have focused their research in the multi node manufacturing domain. In multi node manufacturing environment, flexibility makes the system more productive and reliable by improving the quality of products, shorter lead times and efficiency of the system. Due to the adaptability according to the changing market demand, it reduces the inventory of raw material, semi-finished goods and finished product.

A flow chart of literature review analysis for present work is presented in Figure 1. In this paper, the generic view of flexibility has been discussed in detail with the various definitions of flexibility in different context. The prominent literature review shows the various dimensions of flexibility in different domains. This paper provides an insight about flexibility from industrial and academic point of view which explains that there is still a need of further exploration about flexibility. Therefore, the aforementioned research area still attracts a lot of researchers and practitioners. The literature review of flexibility is the evidence that most of the researchers have worked in multi node manufacturing environment. They have provided various domain specific definitions of flexibility. The presented paper gives an overview of manufacturing flexibility. The detailed discussion about the flexibility frameworks for manufacturing has also been presented in this paper. Those frameworks give the deep thought

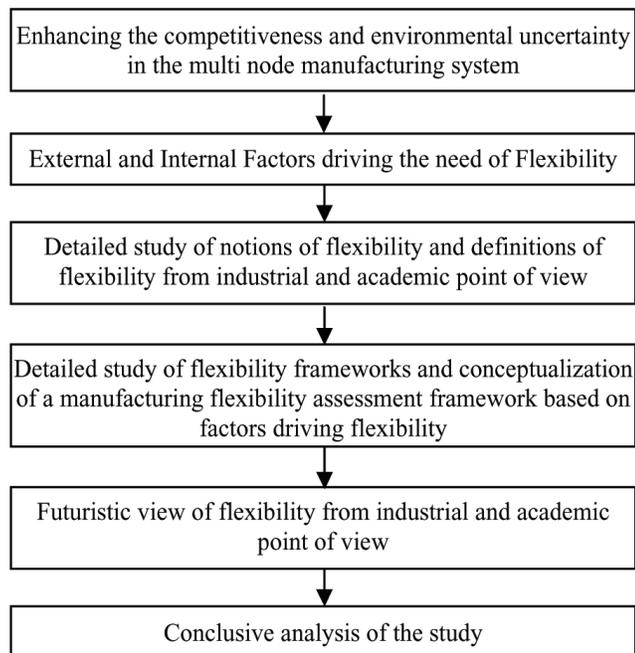


Figure 1. Flowchart of literature review analysis.

of flexibility and its implications. Later on, the authors provide a manufacturing flexibility assessment framework which is the novelty of this paper. This framework helps to conceptualize different dimensions of flexibility of manufacturing domain based on factors that acts as motivation towards these enterprise flexibilities. The authors also discuss about the future roadmap for the research in flexibility. The discussion shows the different ways for further research from industrial and academic viewpoint. The conclusion also provides the new insights for the managers, practitioners and researchers. Therefore, this paper is a state of art in the research area of flexibility.

The remainder of this paper is organized as follows: Section 2 describes the concept of flexibility and its industrial and academic view. Basic concepts and classification of manufacturing flexibility with flexibility assessment framework are described in Section 3. In section 4 futuristic view of flexibility in industrial and academic view has been discussed which shows the future roadmap for the researchers. Finally, in section 5, the paper has been concluded with some managerial insights.

2. Notion of Flexibility

Literature indicates the existence of several definitions and perceptions on flexibility in the domain of manufacturing systems. While use of the term flexibility' is ubiquitous, its meaning is not always clear²⁸. One reason why flexibility is so difficult to define is that definitions are often colored by particular managerial situations or problems⁶⁹. Definitions available propose

that flexibility is an ability^{7,55} or capability²⁵ which an organization possesses to change^{4,42} or react⁷⁰. Evans²⁸ supports this concluding that flexibility is polymorphous, having different meanings in various contexts. In order to progress research on flexibility, Upton⁶⁹ argues that what is required is the identification of the multiple types of flexibility so that they can be split into component parts which can be prioritized, measured and improved. Reaching such a commonality of purpose is, he argues, a critical step in any improvement path, be it for quality, productivity, or flexibility. Some definitions given by the previous prominent researchers have been given in Table 1.

Benjaafar and Ramakrishnan⁶ cite several definitions from literature that portrays flexibility as; (a) the capacity of a system to assume different positions or to assume a certain number of different states, (b) the ability of a manufacturing plant of being usable for different production tasks, (c) the ability to reconfigure manufacturing resources so as to produce efficiently different products of acceptable quality, (d) the ability to respond effectively to changing circumstances and (e) a measure of its capacity to adopt to changing environmental conditions.,

From the Table 1, it is clearly shown that there is no exact definition of flexibility and there is more ambiguity. Some of the authors like Gerwin (1993), Upton⁶⁹, Koste et al⁴⁹, Goyal and Netessine³⁷, Francas et al²⁹ etc. have seen the flexibility from the manufacturing viewpoint while some authors like Sushil⁶⁴ have seen it at the organizational or system level. Some of the researchers like Chan et al (2009), Acar et al (2010) etc. have viewed flexibility from different viewpoint rather than manufacturing. They have shown the various aspects of flexibility with its limitations.

Wadhwa and Rao⁷⁴ examined the concept of flexibility in relation to the other important concept of agility and highlighted certain commonalities and differences and also suggested a possible vision for future evolution of these two important concepts. According to Chang et al¹⁵, flexibility is not achieved by installing computer aided system but it needs to be planned, managed and integrated with firm's entrepreneurial activities. Swafford et al⁶⁵ defines flexibility as a measure of reaction capabilities of firm. According to Chahal¹¹, Flexibility in manufacturing provides the more options to the customers for selecting goods and it increases the level of customer satisfaction. Sarulienė and Rybakovas⁶¹ described flexibility as an ability to adapt to changes of inner and external environment.

The definitions of the flexibility have been reviewed but still there is vagueness and ambiguity to characterize the flexibility. Some of the authors have shown the applicability of flexibility in the industrial application whereas some of them have viewed the flexibility from the research viewpoint. The industrial view and academic view of flexibility has been described in the following sections.

Table 1. Definitions of Flexibility

S. No.	Researchers	Definitions
1	Gupta and Goyal ⁴¹	The ability of a system to cope with changing circumstances or instability caused by the environment
2	Cox ²²	The quickness and ease with which plants can respond to changes in market conditions
3	Ramasesh and Jayakumar ⁶⁰	Flexibility is desired in order to handle uncertainties and variations in both internal and external environment
4	Nagarur ⁵⁶	The ability of the system to quickly adjust to any change in relevant factors
5	Gerwin ³³	Flexibility as an adaptive response to environmental uncertainty
6	De Groote ²⁴	Flexibility as a hedge against the diversity of the environment
7	Nilsson and Nordahl ¹⁵⁷	Flexibility as the ability to respond effectively to changing circumstances
8	Upton ⁷⁰	Flexibility as the ability to change with little penalty in time, effort, cost or performance
9	Jordan and Graves ⁴³	Flexibility is a form of string of the manufacturing system for multi product type
10	Benjaafar and Ramakrishnan ⁶	Flexibility as the ability of a manufacturing system to respond cost-effectively and rapidly to changing production needs and requirements
11	Tincknell and Radcliffe ⁶⁷	Flexibility as the ability to cope with uncertainty of change
12	Das ²³	Flexibility as the ability of a system or a facility to adjust to changes in its internal or external environment
13	Gupta and Buzacott ⁴⁰	Flexibility is generally seen as situation specific in nature
15	Koste and Malhotra ^{47,48}	Flexibility as a responsive mechanism to the competitive environment.
16	Wadhwa and Rao ⁷²	Flexibility as the ability to deal with change by judiciously providing and exploiting controllable options dynamically
17	Golden and Powell ³⁴	Flexibility as the capacity to adapt across four dimensions; temporal, range, intention and focus
18	Sushil ⁶⁴	Flexibility as the exercise of free will or freedom of choice on the continuum .
19	Tomlin ⁶⁸	Flexibility as a form of “chaining” of the manufacturing enterprises, in a multi-factory system
20	Mello ⁵³	Flexibility as the ability to restructure the system quickly and inexpensively
21	McAdam and Brown ⁵²	Flexibility as the ability to meet one-off needs
22	Gunasekaran et al ³⁹	Flexible refer to making available the products/services to meet the individual demands of customers
23	Viswanath and Gilbert ⁷¹	Flexibility as a way of providing options to the customers
24	Englehardt and Simmons ²⁶	Flexibility centres on modification and adaptation.
25	Gosain et al. ³⁶	Flexibility refers to the ability of supporting the changes in product or service offerings in response to changes in the business environment
26	Chan and Chan ¹²	Flexibility can reduce the impacts of the uncertainties in delivery
27	Chang et al. ¹⁵	Flexibility is not achieved by installing computer aided system but it needs to be planned, managed and integrated with firm's entrepreneurial activities
28	Alexopoulos et al. ³	Flexibility is like a dampening factor in mechanical system
29	Swafford et al. ⁶⁵	Flexibility is a measure of reaction capabilities of firm
30	Tang and Tomlin ⁶⁶	Flexibility enhances supply chain resiliency but in limited manner
31	Boulaksil et al. ⁸	Flexibility a long-term relationship with a number of outsourcers with different levels of demand uncertainty in contract manufacturing
32	Francas et al. ²⁹	Flexibility as the plant's way to breathe because it is often the only alternative to adjust capacity in the short run.
34	Chahal ¹¹	Flexibility in manufacturing provides the more options to the customers for selecting goods and it increases the level of customer satisfaction
35	Saruliene and Rybakovas ⁶¹	Flexibility is described as ability to adapt to changes of inner and external environment.

2.1 Industry view of Flexibility

Literature review indicates substantial industry motivation to study flexibility. For example, Ettl and Penner-Hahn²⁷ mention that there has been considerable interest in flexibility in both theoretical and applied literature in the last decade. Upton⁷⁰ observes that flexibility has become increasingly important as a method of achieving competitive advantage in manufacturing. Stecke and Raman⁶³ note that, while global competition has clearly underlined the need for enhanced productivity, shorter product life cycles and greater product proliferation and market fragmentation indicate that manufacturing flexibility is essential for the long-term viability of any firms. Chen and Chung¹⁷ observe that evolving from cost, quality, and delivery (time), flexibility is becoming a key dimension of firm's competitive priorities. Bucki and Pesqueux¹⁰ mention that, firms, for economic reasons are currently turning to efficient techniques of organization and management of the zero stock, just-in-time flows, which can make them fragile and vulnerable to unexpected events and potential hazards resulting from accelerated modification of products, operational breakdowns, strikes etc. Chandra et al.¹⁴ have shown the importance of flexibility in an enterprise and they have shown the benefits of flexibility at enterprises level. Matthews et al.⁵¹ views the flexibility in a food processing equipment industry and they give a constraint based approach for it. Ling-yee and Ogunmokun⁵⁰ have done an empirical study of manufacturing flexibility in the context of Chinese firms to determine the conditions that foster manufacturing flexibility and the way in which firms support it. Francas et al.³⁰ have given a model for handling the flexibility in an automotive industry. Boulaksil et al.⁸ defines Flexibility as a long-term relationship with a number of outsourcers with different levels of demand uncertainty in contract manufacturing.

From the prominent review of literature, it is clear that the various researchers have shown the applicability of flexibility in industrial application. Now the flexibility will be described at the conceptual level or in other words it shows the academic standpoint about the research of flexibility.

2.2 Academic View of Flexibility

Several researchers perceive that there are number of gaps in understanding of flexibility, thereby highlighting the research motivation to study flexibility. For example, Ettl and Penner-Hahn²⁷ observe that, the concept has not enjoyed broader conceptualisation and it has often been confused with diversity and closely linked with complexity and velocity in operations. Upton⁷⁰ mentions that one of the most serious impediments to flexibility improvement has been the vagueness of the term. Das²³ observes that there is lack of clear understanding by managers and designers, of flexibility options and implications. Koste and

Malhotra⁴⁸ state that while the potential benefits of flexibility are familiar, the concept of flexibility itself is not well understood. Several researchers highlighted the problem of generic definition, for example, Katok⁴⁵, Golden and Powell³⁴, Beach et al.⁵ tabulated the different flexibility types found in the literature and highlighted the terminology overlap. Wadhwa and Rao⁷⁴ provide a detailed literature review on the interrelationships between these two important concepts. Wadhwa et al.⁷⁵ present a conceptual framework and show the comparative influence of the transformation flexibility, sequencing flexibility and product flexibility on the lead time performance of the system. Some researchers like Aksin and Karaesmen², Chou et al.^{19,20} have worked on the process flexibility in FMS environment. Fitzgerald et al.³¹ have also presented one of the flexibility frameworks as a cloud representation. Patel⁵⁸ has also made the effort for measuring the manufacturing flexibility. Rahardian and Suyono⁵⁹ defined Flexibility as the ability of the company to meet the expectations of an increasingly diverse customer at no extra charge, time, organizational disruption or excessive loss of performance.

As per the flexibility definitions, it has been seen that most of the researchers have described the flexibility notion in the area of manufacturing. Therefore, the next section will describe the flexibility in manufacturing context.

3. Manufacturing Flexibility Frameworks

Literature indicates that, the domain of multi node manufacturing is enriched with different notions or definitions of flexibility and its essence given by researchers and practitioners with some excellent reviews on manufacturing flexibility⁵. Previous section briefly reviewed the notion of flexibility and its various definitions. In this section, the focus continues on relevant to our research, the following are some of the frameworks found in the literature.

Browne et al.⁹ has identified and defined eight types of manufacturing flexibility in his most acknowledged framework, which views flexibility from a multi node manufacturing system perspective. These flexibilities are machine flexibility, routing flexibility, product flexibility, process flexibility, operation flexibility, volume flexibility, expansion flexibility and production flexibility.

Sethi and Sethi⁶² proposed hierarchical structure of flexibility components in his framework. They introduced three new flexibility types (material handling, program and market flexibility) while defining manufacturing flexibility and their interrelationship.

Gerwin³³ proposed a conceptual framework for flexibility with four generic strategies named; adaption, redefinition, banking and

reduction, which shows strategic viewpoint of flexibility in multi node manufacturing environment. Environmental uncertainty, strategy, required manufacturing flexibility; methods for delivering flexibility and performance measurement are the five main variables in his framework for attaining flexibility in the system.

Correa and Slack²¹ also stressed on the environmental uncertainties. They observed that environmental uncertainty and variability in outputs are the two main reasons for which manufacturing flexibility is sought. These two factors, in whatever form they may materialise, can be further categorised according to whether the need for change is planned or unplanned. According to their framework size, novelty, frequency, certainty and rate are five main dimensions of the unplanned changes for which forms of control is applied and as result flexibility is required to handle those elements that remain.

Considering flexibility as a hedge against diversity De Groote²⁴ proposed a generic framework for modelling and analysis of flexibility. In his framework he considers flexibility as a property of technology and diversity as property of the environment in which the technology is operated.

Upton⁷⁰ proposed a framework of flexibility considering dimensions, time horizon, range-element, uniformity element and mobility element.

Tincknell and Radcliffe (1996) define flexibility as the ability to cope with uncertainty of change and proposed a generic model of manufacturing flexibility based on system control hierarchies

Benjaafar and Ramakrishnan⁶ classified manufacturing flexibility as product or process specific based on physical and logical characteristics of a manufacturing system.

In comparison to Upton's⁷⁰ flexibility framework, Koste and Malhotra⁴⁶ included an additional dimension of flexibility: the range number and the range heterogeneity in his flexibility framework. They identified a five tier hierarchical structure of flexibilities and their interrelationship in the multi node manufacturing environment.

A consolidated framework based on all the previous frameworks is proposed by Beach et al⁵. Wadhwa and Rao⁷³ viewed flexibility as a desired/achievable combination of concurrency and constraints. Zhang et al.⁷⁷ proposed another framework for flexibility. They have included some other flexibility which is related to human being also. They have proposed seven types of flexibilities in a flexible system: manufacturing flexibility, machine flexibility, labour flexibility, material handling flexibility, volume flexibility, routing flexibility, and mix flexibility.

Gong and Hu³⁵ have considered labor flexibility, machine flexibility, routing flexibility and information technology in his flexibility model. He has developed the economic evaluation model for the same.

Fitzgerald et al.³¹ have analysed the flexibility characteristics in the cloud framework which are divided into two phases. In the

first phase the object under investigation is analysed in terms of its designed flexibility characteristics. The second phase of the framework looks at the object under change and examines its behaviour in terms of its ability to adapt to new circumstances.

Boulaksil et al⁸ have introduced contract flexibility as the new dimension of flexibility in contract manufacturing whereas Chahal¹¹ shows the level of customer satisfaction and its relation with flexibility as important key point for applying manufacturing flexibility in multi node manufacturing environment.

From the literature review^{16,44}, it can be observed that internal and external factors are present in the multi node manufacturing system environment that influence manufacturing decisions. A manufacturing flexibility assessment framework based on mapping based approach is given in Figure 2, which relates industrial initiatives with factors driving flexibility in manufacturing environment. The framework can be justified on the basis of tools, methods and techniques^{38,54,76} applied by manufacturing industries with a view to improve the performance index in terms of internal or external factors. For example, Sethi and Sethi⁶² and Chen and Everett¹⁸ have identified that general purpose fixtures, ergonomics, automated guided vehicles (AGV), robots, suitable layout and transport devices are some of the recourses/tools/ methodologies that helps in achieving better material handling flexibility that provides ways to manage the issue of short life cycles of products and technologies, increased product diversity, demand uncertainty etc. Similarly, Gerwin^{32,33}, Sethi and Sethi⁶² and Chen and Everett¹⁸ have suggested the use of CNC machines, Flexible fixtures, Rapid exchange of tool & die, CAD/CAM, CAPP, group technology (GT) as tools and methodologies that help to provide product flexibility which are needed to address the issue of mass customization, product proliferation, shorter product life cycles etc.

4. Futuristic View of Flexibility

As per the literature review, it can be shown that various researchers have given multiple views of flexibility. Some of the researchers have projected similar scope in the way flexibility has been defined, while others have indicated distinct perspective of flexibility for e.g. managerial, academic and resource capabilities. These researchers have provided the definitions of flexibility to highlight their own viewpoints of flexibility. Most of the researchers have provided the definition of flexibility in the context of multi node manufacturing system. Some researchers have provided the flexibility frameworks to classify the flexibilities in the manufacturing domain.

However, there is still a need to enrich the current understanding of flexibility in multi node manufacturing system and provide an integrative approach to flexibility. From the literature review, it is clearly established that there is a need of generic

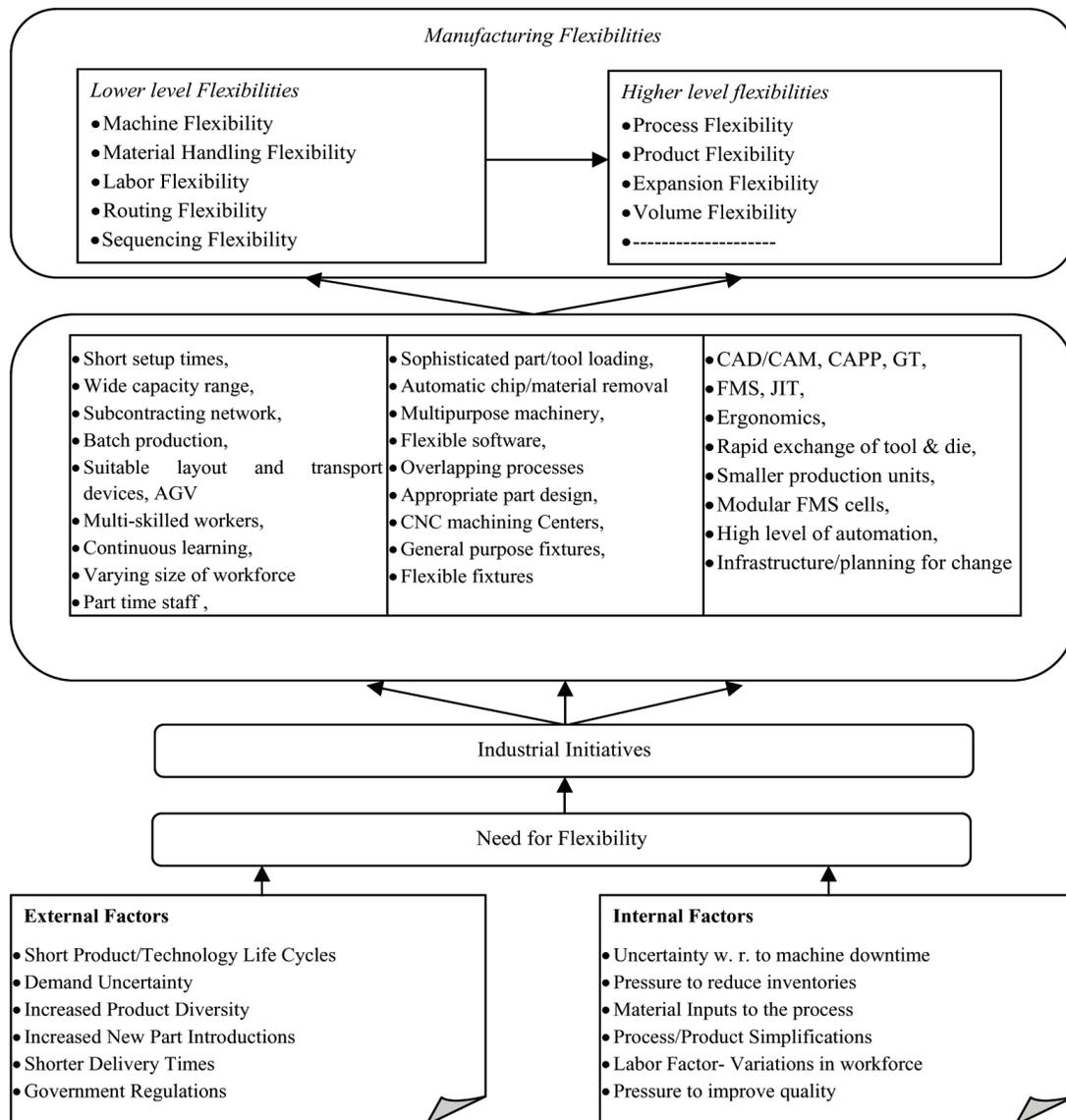


Figure 2. Manufacturing Flexibility Assessment Framework.

understanding about the flexibility which should be applicable in all the context and scenario. Therefore, to make the clear perception of flexibility, the generic definition of flexibility has been introduced which will be helpful for researchers and practitioners. In our view, flexibility is a notion of sensitivity to the uncertainties in the system due to internal and external factors and systems ability to dampen the impact of uncertainties on the performance through adapting the changes accordingly.

The futuristic roadmap for exploring the flexibility can be enriched by the above mentioned definition but on the other hand there is a need of to show the future roadmap of flexibility research from academic and industry view point. The industrial and academic futuristic view for exploring flexibility is given below.

4.1 Industrial View

As a whole, the literature review indicates substantial industrial motivation to study manufacturing flexibility as an enabler of enterprise performance enhancement in the emerging business environment. However, while there is a broad agreement among the researchers and practitioners on the importance of flexibility in manufacturing context, the perceptions on the flexibility varies. Many authors view flexibility from a product perspective, some view flexibility from a process perspective and system perspective. In case of multi node manufacturing, very few authors view manufacturing flexibility from a multi node structural relationship perspective. There is a need for unified thinking and a common approach to identify and define the flexibility in this context.

In the context of real life multi node manufacturing, this is viewed that a lot of researchers have addressed the various real life issues. However, some of them explored the flexibility to the real life problems which are very complicated. The flexibility has a great capability of handling the real life issues inside and makes the decision dynamically. The application of flexibility for real life system problems still needs more exploration.

4.2 Academic View

From the viewpoint of multi node manufacturing flexibility, the literature review is providing the clear insight that the flexibility has been defined at the conceptual level by various researchers. As the multi node manufacturing is a very complex system, therefore applying and measuring the flexibility is also very complex issue. The literature review also established the fact that above mentioned areas were less attentive by the researchers and practitioners. Therefore, it can be stated that to measure the multi node manufacturing flexibility and its impact is still an evolving research area. From the literature review, it can be clearly shown that various researchers have addressed the conceptual frameworks of flexible system but very less research has dealt with the performance improvement of flexible system and the impact of level of flexibility on the system performance. Thus this area should be explored more widely and this is also identified as a new insight for future research. Literature also points out that most of the researchers have used only the data for improvement of system by applying flexibility but they have not used the knowledge (explicit and implicit) for improving the performance of the system after applying flexibility. This is identified as a futuristic insight from the academic point of view.

On the basis of the prominent literature review, need for fresh research is observed for developing the most efficient flexible framework to resolve the various issues in the multi node manufacturing system. The following points indicate the future research insight more clearly.

- To explore the research motivation to study the flexibility in manufacturing system
- To develop the unified thinking about the flexibility in multi node manufacturing among the researchers and practitioners
- To study the judicious level of flexibility to apply in the system as the complexity also increases with increasing the flexibility level
- To use the power of knowledge, to provide the better understanding of flexibility and its framework in different context

The futuristic view of flexibility research has been described and it will give the new insights to the researchers as well as practitioners to explore this evolving research area. It will also help the practitioners to understand the underlying complexities

of the flexible system which will make it more applicable in the industry. The paper is concluded in the subsequent section.

5. Conclusion

This paper gives the vast review of literature in the area of flexibility. The paper has discussed the concept of flexibility which gives the clear understanding to the researchers and practitioners about the flexibility. The notion of flexibility has shown the various explanations of flexibility specifically in the domain of manufacturing. The industrial view motivates the practitioners for further research in flexibility while academic view shows the various research gaps which encourage the researchers to explore the area of flexibility with more understanding. To relate factors with flexibility, a flexibility assessment framework is given by the authors that relate industrial initiatives with factors motivating flexibility in manufacturing. The new definition given by the authors also enrich the realm of research but it is equally helpful to the practitioners.

The futuristic view provides the clear roadmap to the more exploration of this area. The futuristic view has also been classified according to practitioners and researchers. The future roadmap has discussed about the new dimension of flexibility and new paths to explore this evolving area of research. Therefore, this paper is very helpful to the new researchers as well as practitioners as it provided the past understanding of flexibility with the new insights. The researchers can explore other different paradigm of flexibility in the different domain.

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