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Developing a Framework for Green Flexible Manufacturing System

Dimple Bhandari[1], Rajesh Kumar Singh[2] and S. K. Garg[3]

Abstract

The economic growth of a country significantly depends on performance of manufacturing sector. The designs of products are changes very frequently. Product life cycle is reducing very fast. Hence it is challenge for the manufacturers to fulfil the market requirements without affecting environment. This paper develops the framework for green flexible manufacturing system (GFMS) consisting of application of advanced manufacturing technologies (AMTs), green process design and green product design for controlling and maintaining reverse impact on environment. Study has used Analytic hierarchy process (AHP) approach. On the basis of study, green product design has highest ranking for green flexible manufacturing system followed by green process design and application of AMT. This paper helps to encompass various aspects of technology which help us to reduce the human impact on environment and create ways for sustainable development.

***Keywords**:* Green flexible manufacturing systems, Environmental pollution, Ecofriendly technology, Analytic hierarchy process.

Introduction

The fast changing and dynamic global business environment requires firms to be more flexible to quickly adapt and respond to market changes. Among the forces that drive changes, requirements for corporate responsibility and sustainability are getting more urgent. During such difficult time as this economic downturn, companies are faced with hard choices to survive. Research has acknowledged that addressing sustainability issues is critical to the long-term existence and thriving of companies (Porter and Kramer, 2006). According to Singh et al. (2005), in such a dynamic environment, organizations that are able to continually build new strategic assets faster, cheaper and more flexible than those of their competitors will create long term competitive advantage. In this process core competencies have a pivotal role to play.

Manufacturing flexibility has been heralded as a major competitive weapon for manufacturing organisations operating in increasingly uncertain environments and turbulent markets. It has been argued that green manufacturing flexibility has the capability to provide organisations with the ability to change levels of production rapidly, to develop new products more quickly and more frequently, and to respond more rapidly to competitive threats. Green Manufacturing flexibility literature reveals that many of the new competitive frontiers advocated by authors appear to depend on manufacturing flexibility. For instance, it is argued (Bolwijn and Kumpe, 1990) that

1. Research Scholar, DTU, Department of Mechanical Engineering
2. MDI, Gurugram, Department of Operations Management
3. DTU, Delhi, Department of Mechanical Engineering

while, it is quite possible to be flexible without being innovative, the reverse is not true: "you cannot be innovative without being flexible". According to Roth (1996) strategic agility is achievable only with competitive strength in a combined set of generic capabilities, of which flexibility is important element.

Business competitiveness at a global scale is customary for manufacturing firms (Roh et al., 2014; Tang and Tomlin, 2008). Furthermore, environmental challenges such as climate change, air and water pollution, and resource depletion have also caused concern for organizations and countries (Bai et al., 2015b). To compete globally, manufacturing firms need to improve their manufacturing economic and business performance in terms of cost, quality, and flexibility while providing improved environmental performance (Deif, 2011; Liu, 2008).

A manufacturing paradigm embraces a group of integrated strategies, principles and techniques that work together to achieve one of more objectives. The term green manufacturing was coined to reflect the new manufacturing paradigm that employs various green strategies (objectives and principles) and techniques (technology and innovations) to become more eco-efficient. This includes creating products/systems that consumes less material and energy, substituting input materials (e.g. non-toxic for toxic, renewable for non-renewable), reducing unwanted outputs and converting outputs to inputs (recycling). Thus as much as the word "green" is used to reflect environmental friendly awareness. It is used to describe manufacturing approach that is aware of its production/product impact on the environment and resources. It also includes overall efficiency along with planning and control. Green practice is a very broad term and covers a number of activities of green supply chain, such as green purchasing, green packaging of the product, green product, recycling of wastes and end products, remanufacturing, collection of discarded product, reuse and disposal, green design, less emission, and low use of energy (Kumar et al., 2016).

Green flexibility systems that can provide flexibility with respect to environmental operations have not been studied in the green manufacturing literature (Bai et al., 2016). Increased green flexibility enables a manufacturing firm to adjust more easily to change in the green consumer and stakeholder market place and in environmental regulations requirements, while maintaining high quality standards for its products and maintaining high performance of manufacturing systems (Liu, 2008; Priore et al., 2006).

The author proposes an establishment of a relationship between sustainability as a concept and green flexible manufacturing. The aim of this relationship refers to reduce energy, less emissions, recycling of waste and to increase the productivity. In light of these gaps, the purpose of this paper is to build an evaluation and performance framework of green flexible manufacturing systems to help manufacturing firms improve green flexibility to mitigate risks and build competitiveness. In this study AHP method is applied for finding the priority weight for green flexibility factors.

The next section reviews the literature for the framework for green flexible manufacturing systems. It is followed by the discussion of AHP methodology and finally the results and conclusions.

Literature Review

Literature review is the ladder of study along with research work. This section contains developing of a framework for green flexible manufacturing system.

With new customer demands and higher awareness (Willson, 2011 and Ackerman, 1997) together with tougher global competitiveness pressure, manufacturing enterprises need to review their manufacturing strategies. Green manufacturing should be viewed as an opportunity to expand the local and global market share in this dynamic environment. A deeper understanding of green manufacturing strategies and techniques will enable manufacturers to realize that unlike other competing manufacturing strategies(like cost and time), being green positively impact all other manufacturing competitive edges (as shown in Fig. 1). For example reducing material wastes and energy consumption will reduce production cost and improve production time. Adopting green flexible manufacturing will also improve the quality of the production process which will in turn impact product quality and also will be more appealing to the growing number of customers looking for green manufacturers and products.

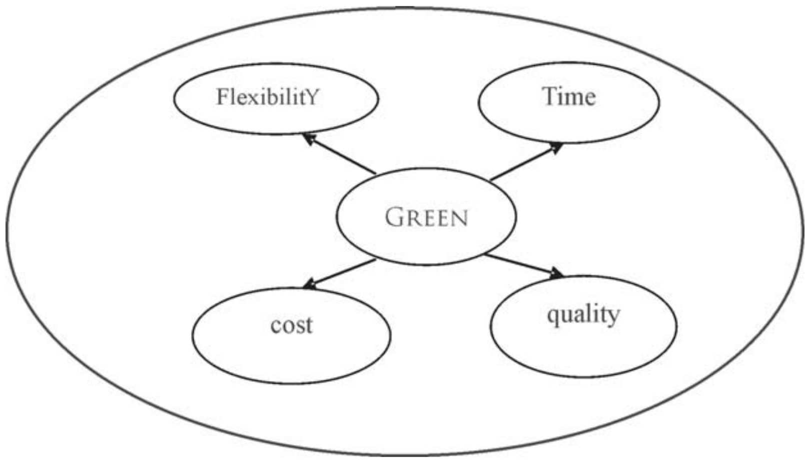

Figure 1: Green flexible manufacturing and competitive manufacturing strategies

The sustainability refers meeting the needs of the present generation without compromising the ability of future generations to meet their own needs (World Commission on the Environment and Development, 1987). With this definition all eco-friendly approaches, methodologies and research to preserve environmental conditions and resources through wastes reduction, prevention or recycling can be categorized under sustainability. Sustainability is a concept and a paradigm that has its different implementation and interpretation at different fields. For example, it is defined in the business field as "adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today while protecting, sustaining and enhancing the human and natural resources that will be needed in the future" (Deloitte and Touche, 1992). Green manufacturing deals with maintaining sustainability's environmental, economical and social objectives in the manufacturing domain. Reducing hazardous emissions, eliminating wasteful resources consumption and recycling are examples of sustainable green manufacturing activities.

Green flexible manufacturing systems can be defined as the creation or improvement in flexibility of products or processes involved in energy saving, pollution-prevention, waste recycling, green product designs, or corporate environmental management that aims to prevent or reduce environmental impacts and contribute to environmental sustainability (Chen et al. 2006). To investigate the effective patterns of green flexible manufacturing systems adoption, we conceptualized framework as shown in figure 2 which consists of applications of AMT, green product design and green process design which are consistent with prior studies (Zhang et al. 2006). Application of AMT refers to technologies that focus primarily on product definition, design, and related information processing functions, which includes computer-aided process planning (CAPP), computer-aided design (CAD), computer-aided engineering (CAE), product data management (PDM), and rapid prototyping. In these terms, the essential characteristic of AMT is its application of computers to manage data associated with manufacturing processes (Sohal et al.2006). For flexible green manufacturing, AMT is one of the important factor. It refers to a multi-dimensional concept that focuses on technologies comprising the "factory automation" component of computer-integrated manufacturing (Swink and Nair, 2007; Das and Jayara, 2003). AMT presents the important strategic resource (e.g., technological knowledge, expertise, and information) and an integral part of organizational capabilities that associated with green flexibility activities. Since flexibility performance is largely dependent on the assets or resources that firms own internally (Wagner et al. 2011) the implementation of AMT provides critical resources and capabilities that enable a firm to respond to increasing environmental pressure by designing and producing green products and processes. As a result, AMT is vital for establishing and sustaining a defensible competitive advantage in green innovation flexibility.

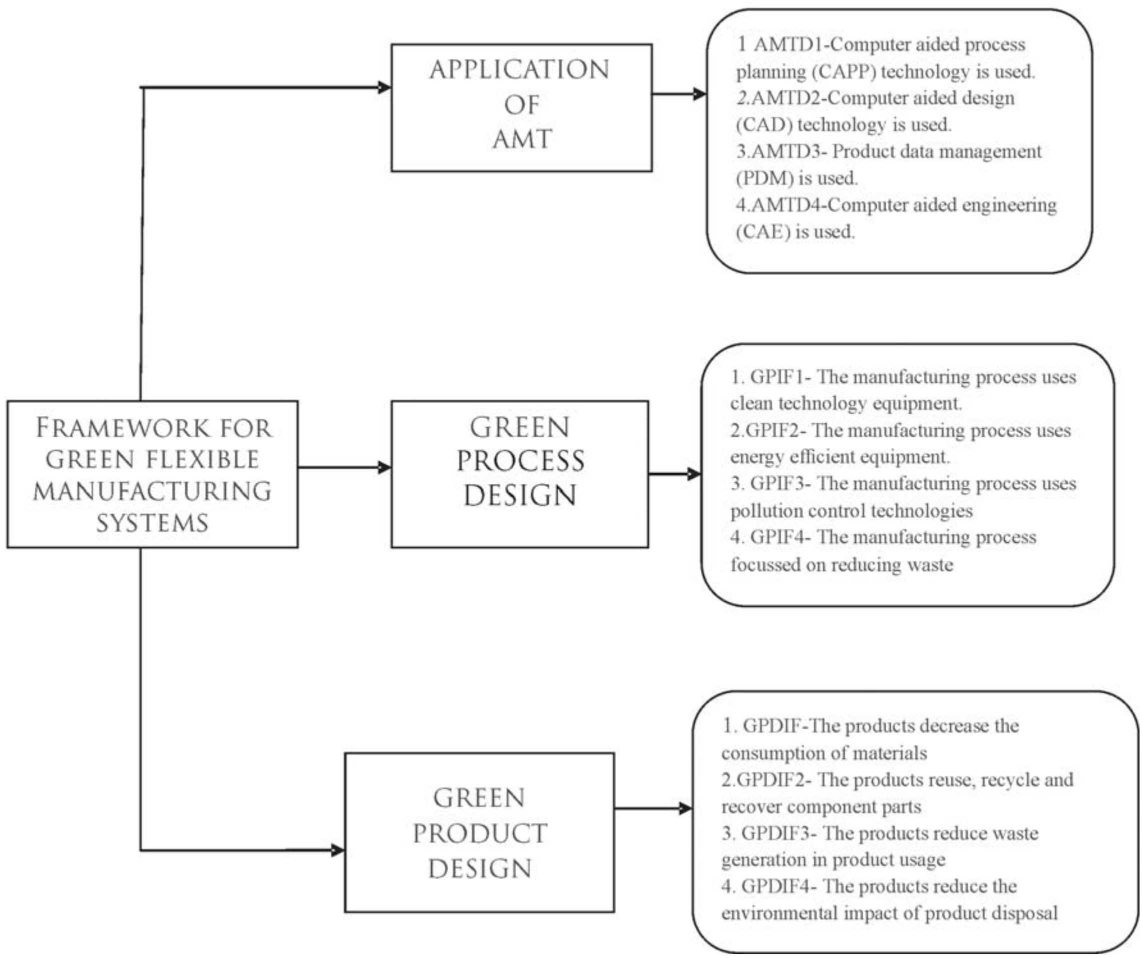

Figure 2: Framework for green flexible manufacturing systems

Second important factor is green product design. It refers to environmental product design that helps to reduce resource, control pollution, manage waste costs, and decrease the negative impact on the environment. Companies that pioneer green product design can improve their product design, quality, and reliability with respect to environmental concerns, which can yield a better chance to gain the "first mover advantage" and thus improve their corporate image, develop new markets, and further obtain competitive advantages (Chen, 2008).

Third important factor is green process design. It refers to an improvement in the existing process and/or a generation of new processes that involve green manufacturing technologies or equipment to avoid or reduce environmental damage and lead to environmental improvements. Green process design not only prevents costly pollution, but also reduces resource expenses and overall costs (Orsato, 2006). Companies can undertake green process design to enhance resource productivity and manufacturing efficiency, thus obtaining cost advantages. Both green product and process design can enhance the performance of environmental management and help businesses develop new market opportunities to increase competitive advantage (Chen, 2008)

Research Methodology

As this study is trying to propose a framework for green flexible manufacturing system, for prioritising different sub factors of the framework, AHP approach is used.

AHP is the multiple criteria decision making tool. This is an eigen value approach which is very simple to calculate. The AHP has found widespread application in decision making problems involving multiple criteria in systems of many levels. This method has the ability to structure complex, multiperson, multiattribute and multi period problem hierarchically. According to Chhabra and singh (2016), the advantage of AHP lies in its flexibility by which it can be integrated with various techniques like quality function deployment (QFD), fuzzy-based logic, linear programming, etc. This facilitates the researchers to realise their research objectives more effectively by drawing benefits from all the methods collectively. The AHP can be very useful in involving several decision makers with different conflicting objectives to arrive at a consensus decision (Singh, 2012; Bhandari et al., 2017).

It also provides a methodology to calibrate the numeric scale for the measurement of quantitative as well as qualitative performance. The scale ranges from 1 to 9. Some key and basics steps involved in this methodology are:

1. State the problem and broaden the objectives of the problem.
2. Identify the criteria that influence the behaviour.
3. Structure the problem in a hierarchy of different levels constituting goal, criteria, sub - criteria and alternatives.
4. Compare each element in the corresponding level and calibrate them on the numerical scale. This requires n (n-1)/2 comparisons, where n is the number of elements with the considerations that diagonal elements are equal to 1 and the other elements will simply be the reciprocals of the earlier comparisons.
5. Perform calculations to find the maximum Eigen value, consistency index CI, consistency ratio CR, and normalized values for each criteria / alternative.
6. If the maximum Eigen value, CI, and CR are satisfactory then decision is taken based on the normalized values; else the procedure is repeated till these values lie in a desired range.

7. AHP helps to incorporate a group consensus. Generally this consists of a questionnaire for comparisons of each elements and geometric mean to arrive a final solution.

The nine-point scale (Table 1) was used to allocate relative scores to pair wise comparisons among the important factors. The experts were asked to assign a score to each comparison using the nine point scale. This method continued till all levels of the hierarchy and finally a series of judgement matrices for the important factors were obtained.

Table 1: Scale for pair wise comparisons (Saaty, 1994)

Intensity of numbers	Explanation	Definition
1	Two activities contribute equally to the objective	Equal preferred
3	Experience and judgement slightly favour one activity over another	Moderately preferred
5	Experience and judgement strongly favour one activity over another	Strongly preferred
7	An activity is favoured very strongly over another; its dominance demonstrated in practice	Very strongly
9	The evidence favouring one activity over another is of the highest possible order of affirmation	Extremely preferred
2,4,6,8	When compromise is needed	Intermediate values between the two adjacent judgement

Results and discussions

There are a number of factors for achieving green flexible manufacturing systems which can be implemented. Out of them following are important:

1. Application of AMT
2. Green process design
3. Green product design

Pair wise comparison and weight calculation for the factors of green flexible manufacturing systems are as follows and shown in table 2:

Table 2: Pair wise comparison and priority value calculation for the factors of green flexible manufacturing system

	Application of AMT	Green process Design	Green product Design	Priority Value
Application of AMT	1	1/2	1/3	0.164
Green process design	2	1	1/2	0.297
Green product design	3	2	1	0.539

χ_{max}(Maximum eigen value) = 6×0.164 +3.5×0.297+1.833×0.539 =3.01

CI (Consistency Index) = χ_{max}-n / n-1

= 3.01-3 / 3-1

= 0.05

CR (Consistency Ratio) = CI / RCI (Value from table 3)

= 0.05 / 0.58

= 0.0862

= 8%

Where RCI= Random Consistency Index

Table 3: Average random index values, (Saaty, 1980)

N	1	2	3	4	5	6	7	8
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41

If the value of CR is less than or equal to 10%, judgements are considered consistent or feasible.

There are 4 main important subfactors of application of AMTs for achieving green flexible manufacturing systems.Pair wise comparison and priority value calculation for the sub factors of application of AMTs for green flexible manufacturing system is shown in table 4.

Table 4: Pair wise comparison and priority value calculation for the sub factors of application of AMT for green flexible manufacturing systems

	AMTD1	**AMTD2**	**AMTD3**	**AMTD4**	**PV**
AMTD1	1	1/2	2	1/3	0.171
AMTD2	2	1	2	1/2	0.260
AMTD3	1/2	1/2	1	1/3	0.120
AMTD4	3	2	3	1	0.450

λ_{max}= 4.08 CI= 0.027 CR=3%

There are 4 main important subfactors of green process design for green flexible manufacturing systems. Pair wise comparison and priority value calculation for the sub factors of green process design for green flexible manufacturing is shown in table 5.

Table 5: Pair wise comparison and priority value calculation for the sub factors of green process design for green flexible manufacturing systems

	GPIF1	GPIF2	GPIF3	GPIF4	PV
GPIF1	1	2	1/4	1/3	0.142
GPIF2	1/2	1	1/3	1/2	0.115
GPIF3	4	3	1	3	0.497
GPIF4	3	2	1/3	1	0.246

λ_{max}= 4.26   CI= 0.086 CR=9%

There are 4 main important sub factors of green product design for green flexible manufacturing system. Pair wise comparison and priority value calculation for the sub factors of green process design for green flexible manufacturing systems is shown in table 6.

Table 6: Pair wise comparison and priority value calculation for the sub factors of green product design for green flexible manufacturing systems

	GPIDF1	GPIDF2	GPIDF3	GPIDF4	PV
GPIDF1	1	1/3	1/2	1/3	0.107
GPIDF2	3	1	1/2	1/2	0.209
GPIDF3	2	2	1	1/3	0.235
GPIDF4	3	2	3	1	0.444

λ_{max}= 4.25   CI= 0.083 CR= 9%

A summary of local and global weight of factors and sub factors for green flexible manufacturing system is shown in table 7.

Table 7: Local and global weight

	Local Weight	Global weight
Design AMT	0.164	
AMTD1	0.171	0.028
AMTD2	0.260	0.043
AMTD3	0.120	0.020
AMTD4	0.450	0.074
Green process design	0.297	
GPIF1	0.142	0.042
GPIF2	0.115	0.034
GPIF3	0.497	0.148
GPIF4	0.246	0.073
Green product design	0.539	
GPIFD1	0.107	0.058
GPIFD2	0.209	0.113
GPIFD3	0.235	0.127
GPIFD4	0.444	0.239

On the basis of this study, it is found that Green product design has most important factor (0.539) for achieving green flexible manufacturing systems followed by green process design (0.297) and application of AMT (0.164) at local level.

At global level, the products reduce the environmental impact of product disposal (0.239) sub factor of green product design is most important for achieving green flexible manufacturing systems followed by the manufacturing process uses pollution control technologies (0.148) sub factor of green process design, the products reduce waste generation in product usage(0.127) sub factor of green product design, the products reuse, recycle and recover component parts (0.113) sub factor of green product design, Computer aided engineering (CAE) application of AMT(0.074) and so on.

Conclusion

This paper develops a framework for green flexible manufacturing systems. In present scenario, design of product is changes from day to day basis. Hence the flexibility of the process for manufacturing of the products plays an important role. Findings of this paper will help to sustain or reduce environment impact by means of applications of AMTs, green product design and green process design.AHP approach is used to analyse the data. On the basis of this study, green product design (0.539) has highest ranking for green flexible manufacturing system followed by green process design (0.297) and application of AMTs(0.164). This study is carried out with well prepared plan. However, inevitably there were some limitations affecting the study. Pair wise comparison of factors is based on perception of experts. Mainly crisp data is used. As a future scope of study, fuzzy AHP may be applied. Framework for green FMS may be also validated with empirical analysis.

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