STUDY OF ISSUES RELATED TO GREEN MANUFACTURING

THESIS

submitted in fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

J. C. BOSE UNIVERSITY OF SCIENCE &TECHNOLOGY, YMCA

by

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CANDIDATE'S DECLARATION

I hereby declare that this thesis entitled **"STUDY OF ISSUES RELATED TO GREEN MANUFACTURING"** by **SANDEEP HANDA** being submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy in DEPARTMENT OF MECHANICAL ENGINEERING under Faculty of Engineering and Technology of J.C. Bose University of Science and Technology, YMCA Faridabad, during the academic year 2019-2020, is a bonafide record of my original work carried out under guidance and supervision of **Dr. TILAK RAJ, PROFESSOR, DEPARTMENT OF MECHANICAL ENGINEERING, JCBUST, YMCA FARIDABAD** and **Dr. SANDEEP GROVER, PROFESSOR, DEPARTMENT OF MECHANICAL ENGINEERING, JCBUST, YMCA FARIDABAD.** It has not been presented elsewhere.

I further declare that the thesis does not contain any part of any work which has been submitted for the award of any degree either in this university or in any other university.

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CERTIFICATE OF THE SUPERVISORS

This is to certify that this Thesis entitled **“STUDY OF ISSUES RELATED TO GREEN MANUFACTURING”** by **SANDEEP HANDA,** submitted in fulfillment of the requirement for the Degree of Doctor of Philosophy in **DEPARTMENT OF MECHANICAL ENGINEERING** under Faculty of Engineering and Technology of J.C. Bose University of Science and Technology, YMCA Faridabad, during the academic year 2019-2020, is a bonafide record of work carried out under our guidance and supervision.

We further declare that to the best of our knowledge the thesis does not contain any part of any work which has been submitted for the award of any degree either in this university or in any other university.

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ABSTRACT

Manufactures today are at an inflection point due to animated concern for environmental protection. This is putting immense pressure on their operations and financial performance. Businesses are implementing green manufacturing technologies for mitigating environmental problems. Increasing resource productivity, escalating reliability of assets, improving flexibility of systems and optimizing energy consumption are inherent to the green manufacturing system. Implementing green manufacturing system must be in consonance with the organizational goals. The interest of the industry in green manufacturing is high as a direct result of increasing pollution, exhaustible nature of resources and problem of waste disposal etc. Green manufacturing utilizes the availability of new technologies in process and products. Green manufacturing employs a multi-functional approach which uses tools and techniques from a variety of well established disciplines such as industrial engineering, quality management and lean/agile manufacturing. Faced with increasing regulatory accountability and the need to reduce environmental impact of manufacturing activities, businesses are inclined to reorient and redesign their manufacturing operations.

Adoption of green manufacturing practices has numerous advantages for any business, but a number of formidable challenges act as barriers for successful implementation of proactive environmental technologies. Implementation of green manufacturing paradigms requires a structural change in manufacturing operations. There an urgent need to use a systematic approach to evaluate and rank the various factors for businesses to adopt green manufacturing. This will help businesses to identify and focus on key areas for improvements in making manufacturing activities environmentally resilient. The ranking of various parameters, facilitates assessment of the capabilities and strengths required for achieving breakthroughs and innovations for green manufacturing. The research provides a framework for manufacturers to strike a balance between the business performance and green initiatives.

The aim of this research is to identify the numerous issues in transition towards adopting green manufacturing .Various multi criteria decision making methodologies are employed to evaluate and understand the causal relationship among issues in the adoption of green manufacturing.

Keywords: *green manufacturing system; traditional manufacturing; critical success factors barriers; fuzzy TOPSIS, interpretive structural modeling; transitivity; graph theoretic matrix approach; analytic network process; DEMATEL*

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LIST OF ABBREVIATIONS

SL. NO.	NOMENCLATURE	ABBREVIATION
1	Analysis of Variance	ANOVA
2	Analytical Network Process	ANP
3	Critical Success Factors	CSF
4	Decision Making Trial and Evaluation Laboratory	DEMATEL
5	Decision Making Trial and Evaluation Laboratory and Analytical Network Process	DANP
6	Environmentally Conscious Manufacturing	ECM
7	Environmental Effectiveness Index	EEI
8	Flexible Manufacturing System	FMS
9	Graph Theoretic Matrix Approach	GTMA
10	Green Manufacturing	GM
11	Interpretive Structural Modeling	ISM
12	Life Cycle Analysis	LCA
13	Cross-Impact Matrix Multiplication Applied to Classification	MICMAC
14	Multi Criteria Decision Making	MCDM
15	Reachability Matrix	RM
16	Reverse Logistics	RL
17	Structural Self-Interaction Matrix	SSIM
18	The Technique for Order of Preference by Similarity to Ideal Solution	TOPSIS
19	Variable Permanent Function	VPF
20	Waste Reduction Techniques	WRT

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Traditional manufacturing system engages in relentless exploitation of natural resources for producing goods with the sole aim of earning profits. Such a system puts intense pressure on scant resources available and leads to environmental degradation. In recent decades, the exponential population growth and the rapid urbanization of population are responsible for problems such as global warming acidification, ozone layer depletion and anthropogenic pollutants, desertification, depletion of minerals and fossil fuels. The IPAT equation is used to compute the impact of human activities on the environment (Holdren and Ehrlich, 1974).The equation uses the multiplicative combination of population, affluence and technology to determine the environmental impact. The equation shows that with a rising population and rising consumption, environmental impact would inevitably increase unless the rate of technological improvement was sufficient to overcome it. Increased investments in green technology can offset the adverse environmental impact. The framework for IPAT equation is used to measure the effect of human activity on the environment is shown in Figure 1.1

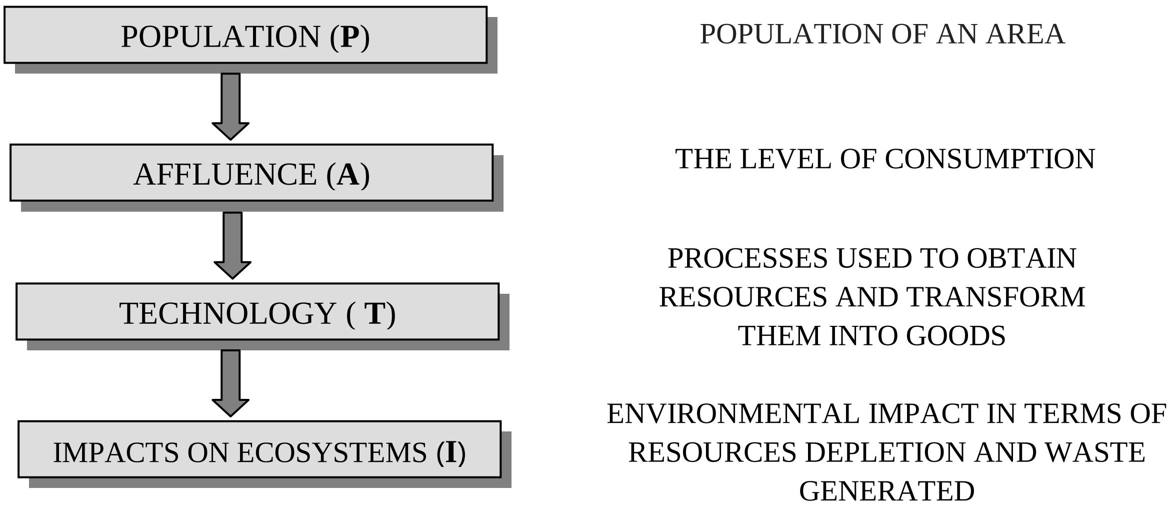

Figure 1.1: IPAT equation

IPAT equation (I=P x A x T) reflects the environmental impact of economic activities in terms of resources depletion and waste generated.

Manufactures today are at inflection point due to increased concern for environmental protection. Environmental responsibility has grown steadily as a corporate concern during the past decade due to newer environmental protection laws and waste disposal regulations. The business today, are reorienting their operational activities by using green manufacturing techniques to strive for harmony with the environment.

Green manufacturing aims to create goods through use of non-polluting and energy efficient processes for the benefit of all stakeholders (Glavič and Lukman, 2007).

Green manufacturing aims to establish a system which integrates product and process issues. The goal of such integration is to manage environmental waste so as to minimize environmental impact and maximize efficiency (Melnyk and Smith, 1996).

1.2 ROLE OF GREEN MANUFACTURING IN CORPORATE STRATEGY

Businesses make a comprehensive commitment to environmentally friendly practices across the entire manufacturing process (Polcari, 2007). However, businesses have distinct strategies' to adopt green practices. There are five distinct strategic green alternatives (Azzone and Noci, 1998). Table 1.1 shows the model for corporate strategic green alternatives. An unresponsive strategy implies that corporate ignore the need for investing environmental benign technology. These include companies with older legacy systems or businesses where regulatory supervision is minimal. A reactive strategy addresses environmental issues only when they pose an immediate threat. Responsive strategy considers environmental protection an isolated technical issue and provides limited finances for the same. Proactive strategy provides for sufficient funding for adopting systematic green initiatives throughout company. Evangelist strategy considers environment protection as paramount and provides open ended funding for the same.

Table 1.1 Model for strategic Green alternatives

STRATEGY	MINDSET OF CORPORATES	FINANCIAL RESOURCES
Evangelist	Ethical aims and strong approach to environmental issues	Open ended
Proactive	Anticipating completion and executing new initiatives	Sufficient funding
Responsive	Leveraging environmental issues to gain advantage	Consistent
Reactive	Complying with regulations	Budget for project based funding
Unresponsive	Delaying use of green manufacturing	No

1.3 KEY COMPONENTS OF GREEN MANUFACTURING

Green Manufacturing uses green products which are made from environmental friendly materials. These products can be disposed off in an eco-friendly way at the end of their life cycle (Baines et al., 2012). The development of green manufacturing requires newer approaches for design, production and operation for energy savings and reduced environmental impact. Manufactures are going in for eco-innovations for transformation of production process operations integrating the various facets of green as shown in Figure 1.2.

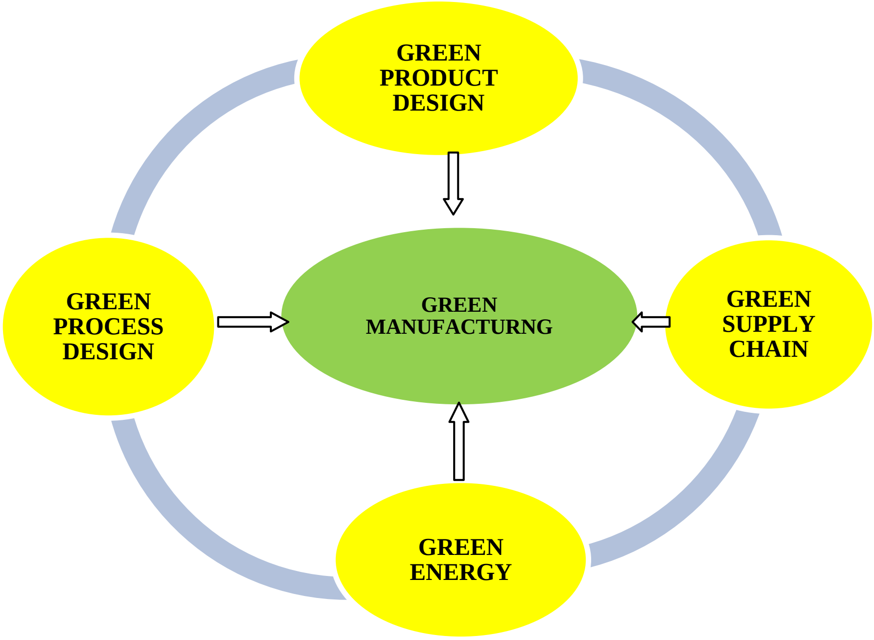

Figure 1.2: Various facets of Green manufacturing

1.3.1 Green process design

Use of Green process design implies that designers should evaluate the environmental impact, occupational health, safety issues and resource consumption of a product through all phases of its life. These include processes of extracting and processing raw materials, manufacturing, use and final disposal of a product. Green process design is an optimization problem of maximizing the value addition and minimizing the resource consumption and environmental impact at different stages of production and consumption of a product. Green process design focuses on altering/reducing operations and recycling of resources by using life cycle analysis (LCA) methodology. Life cycle analysis involves the study of the environment impact during different stages of the manufacturing, service life and final disposal of a product. The different techniques for an eco-balanced process design approach are suggested by various researchers are as follows:

i. *Cradle-to-grave* It is an LCA in which the environmental impact assessment of manufacturing a product is done from resource extraction, use product and final disposal of product. (Khasreen et al.,2009)

ii. *Cradle-to-gate LCA*: It involves an environmental assessment for a partial product life cycle. Cradle-to-gate life cycle analysis considers only extraction of resources required for product and its manufacturing phase only (Kirchain et al., 2017).

iii. *Cradle-to-Cradle LCA*: It is an LCA in which the end-of-life disposal step for the product is a recycling process. This LCA is used to minimize the environmental impact of products by employing sustainable production, operation and disposal practices. The aim of Cradle-to-Cradle LCA is to incorporate social responsibility concepts into product development process (Llorach et al., 2015).

iv. *Gate-to-Gate LCA*: It is a Life Cycle Analysis method, which considers only the value-added by different manufacturing processes in the factory (Jiménez et al., 2000).

v. *Well–to-Wheel LCA*: It is an approach in which the efficiency of fuels used for transportation is considered for evaluating environmental impact of manufacturing a product (Kirsten et al., 2016).

vi. *Life Cycle Energy Analysis*: It is an approach in which encompasses evaluation of all energy inputs required to manufacture a product. It considers all direct energy inputs needed for manufacturing components and allied services required in production process (Ajit and Pranesh, 2017).

1.3.2 Green product design

Green product design is a proactive approach which aims to address environmental impact issues at the design stage of the product development process. Green product design encompasses material selection, resource use, production requirements and planning for the final disposition of a product. Green Product Design methodology is integrated with other design approaches so that environmental parameters can be balanced with traditional product attributes such as quality, cost and functionality. In comparison with conventionally designed products, green products are designed so that they can be more easily upgraded, disassembled, recycled, and reused. Green Product Design uses principle of resources reduction and breaks down product into replaceable modular parts. Espousing green product design provides a number of tangible and intangible benefits to businesses. This strategy brings diverse functional groups together, there by driving product and process innovation. Various researchers have advocated use of different green design strategies which are listed below:

i. *Design for minimizing the discharge of hazardous byproduct:* It encompasses innovative design practices which minimize waste and reduces toxicity levels. The design approach is based on the principles of zero discharge of waste and encourages use of renewable energy consumption (Zaman, 2015).

ii. *Design for disassembly*: Design for Disassembly is a technique to design the product to be disassembled for easier repair and maintenance. The main emphasis is on recovery of components and their reuse. The objective of such a design process is to decrease environmental damage and increases end-of-life products value. Such a design methodology encourages for products to be recycled, by improving components for reuse and remanufacture. Design for disassembly extends the service life of the products and component (Krumenauer et al., 2008).

iii. *Design for recycling:* Design for recycling incorporates recycling-friendly qualities into the manufacturing during the design phase. The design the recycling classifies product design into three distinct stages. These are recycling during production, during use, and after use (Lee and Ishii, 1997; Yazdian et al., 2017).

iv. *Design for remanufacturing or part recovery*: Enhancing product and components reuse is an essential trait of design for remanufacture. Upgrading the functions of the products to meet customer requirements can prolong their service life. Design for remanufacturing strategy is based on closed loop product life cycle for optimization of product usage. Modular design methodology is adopted for achieving this concept (Ettlie and Kubarek, 2008; Tchertchian et al., 2012).

v. *Design for energy conservation*: It is a design strategy based on concept of reducing carbon emission by efficient use of energy resources. By focusing on energy efficiency at design stage reduce service life costs of operations and avoid ozone layer depletion (Seow et al., 2016).

1.3.3 Green energy

The conventional resources of energy are depleting at an enormous speed and the cost of energy is also increasing. The efficient use of energy for manufacturing operations has assumed a great importance due to the problem of green house gases associated with thermal power plants (Bhowmik et al., 2017). Businesses are implementing aggressive, corporate-wide energy efficiency strategies. Manufacturers are setting ambitious energy savings targets, engaging employees, reaching out to suppliers and customers, to advance an ethic of using energy from renewable resources. Use of green energy is at the core of green manufacturing operations. Green energy encompasses using energy from renewable sources. Green manufacturing employs sources like wind, biomass, geothermal, solar ocean, hydropower, landfill gases and municipal waste to meet business energy needs. Green manufacturing utilizes technologies and practices to improve energy efficiency.

1.3.4 Green supply chain management

Green supply chain management (GSCM) is designed to incorporate environmental considerations into decision making at each stage of an organization’s materials management and logistics functions until post-consumer disposal (Handfield, 2005). The integration between Green manufacturing and supply chain practices has significant implications for an organization’s environmental performance. A synergy between the two offers comprehensive means of defining and establishing environmentally benign practices among different networks of business organizations. Reverse logistics as a supply chain issue that includes recycling, remanufacturing, processing of used products, and packaging to meet overall environmental needs (Kulwiec, 2002). A reverse logistic network typical involves five main activities, i.e., collection, testing and grading, reprocessing, disposal and redistribution (Chanintrakul et al., 2009). Reverse logistics can also offer added revenue opportunities (Sangwan, 2011).

1.3.5 Economics of Green Manufacturing

Availability of green investment options and coordination among various stakeholders are essential for green manufacturing. It also requires affordable green finance and monetary incentives. (Park, 2018).

1.4 GAPS IDENTIFIED

A review in the area of green manufacturing highlighted the following gaps:

- Empirical studies on green manufacturing are mainly based on the case studies or deals with descriptive statistics alone

- There exists a gap in survey related to green manufacturing process parameters, critical success factors and environmental impact analysis of various elements of green manufacturing.

- There is a little documentation on green manufacturing and its distinguishing attributes.

- In the literature, the causal relationship among the various enablers / barriers of green manufacturing has not been explored.

1.5 MOTIVATION FOR RESEARCH

Conventional production methods aim at profit maximization through production of goods with scant concerns for the environment. This has resulted in problems like climate change and global warming. Increasing concerns for environmental protection is driving manufactures to alter their manufacturing practices. To avoid environmental degradation businesses are espousing environmentally benign manufacturing practices**.** Though green manufacturing practices has numerous advantages for any business, a number of formidable challenges act as barriers for its successful implementation. Execution of green manufacturing paradigms requires a structural change in manufacturing operations. Literature review reveals the various pitfalls which businesses encounter while transitioning towards green manufacturing.

While endeavoring for achieving environmental goals, businesses need to adopt an integrated approach which strikes a balance between factors such as economics, risk and reliability of the production process. Thus, it becomes imperative to establish and validate the relationship and linkages between these factors. Such an exercise would help in evaluating the environmental performance of a system and their impact on the implementation of green manufacturing. The current research is motivated by a need for a qualitative and quantitative evaluation of the framework for adopting green manufacturing .This research will help to reorient manufactures mindset and aid in the development of green processes leading to environment protection in the near and long term.

1.6 OBJECTIVES OF RESEARCH

The present research is aimed towards the studying the various issues in green manufacturing. The study identifies paramount factors for responsible for adoption of green manufacturing. The various factors which act as drivers and barrier for adoption of green manufacturing are identified. Multi criteria decision making techniques namely interpretive structural modelling, graph theory and analytical network process is used to evaluate the causal relationship among the various parameters that influence environmental performance of a manufacturing system. The research helps manufacturing managers better understand the implications from different perspectives for transition towards a green manufacturing. This research aims to improve manufactures position to develop the right strategy for environment protection in the near and long term.

The main objectives of this research are the followings:

a) Identification of critical success factors of green manufacturing system

b) Identification of various enablers and barriers towards adoption green manufacturing and to analyze the causal relationship among them using AHP/ANP analytical models

c) Qualitative analysis of drivers for green manufacturing with ISM to segregate the driving and driven elements of green manufacturing system

d) Quantitative analysis of various parameters of evaluating environmental performance of a manufacturing system with graph theoretic matrix approach

1.7 ORGANIZATION OF THE PROPOSED THESIS

The current research work has been planned in 10 chapters. The chapter wise organization of the research work is discussed below:

Chapter 1: This chapter covers the **introduction** on green manufacturing. Various facets of green manufacturing like green design, green process, green energy etc. have been discussed in this chapter. The various perspectives' and their sub-parameters, which affect the selection and consequent performance of a green manufacturing system, have been discussed. Numerous factors which act as enablers and barriers for adopting green manufacturing have been identified through literature review and experts' opinion. The gaps in current literatures towards the successful implementation are reported. The research objectives have also been discussed. A brief summary of the organization of the proposed thesis has been presented in this chapter.

Chapter 2: This chapter covers **literature review** related to green manufacturing practices. The literature review is focused on identifying the different perspectives' which need to be evaluated to determine environmental effectiveness of a green manufacturing system. A comprehensive literature review has been carried out to study various issue related to green manufacturing practices, traditional versus green manufacturing, Moreover, numerous issues in green manufacturing, enablers and barriers in green manufacturing, good manufacturing practices etc. has also been reviewed. Review of literature facilitated in the identification of various drivers and barrier for the success implementation towards green manufacturing. Furthermore, different research methodologies used in the present study have been reviewed.

Chapter 3: This chapter presents the **development and administration of questionnaire survey** conducted to obtain industry response to various issues in green manufacturing. The results of survey facilitated in ranking of various enablers and barriers towards implementing green manufacturing. Results of ANOVA analysis used for validating the results of survey data is also presented in this chapter.

Chapter 4: This chapter presents the **evaluation of environmental effectiveness of a manufacturing system using graph theoretic matrix approach**. GTMA is used to provide a green manufacturing effectiveness index for comparing competing manufacturing system. The integration of interdependencies among the evaluation perspectives and their sub parameters of evaluating environmental performance provide meaningful insights to businesses in reducing their carbon footprints.

Chapter 5: This chapter presents the **critical success factors for implementation of green manufacturing.** A total of 11 critical success factors have been identified from literature and expert opinion. MCDM technique of Fuzzy TOPSIS was employed to analysis the interdependencies among critical success factors. These critical success factors are ranked on the basis of their aggregate closeness coefficient

Chapter 6: This chapter presents **ISM modeling for drivers for green manufacturing.** The factors that act as drivers for espousing green manufacturing that are important for enhancing have been identified These drivers have been analyzed and modeling done using ISM technique.

Chapter 7: This chapter presents **integrated approach for evaluating the enablers for green manufacturing using DEMATEL and analytic network process**. Integration of the multiple criteria decision methods of DEMATEL and ANP for analyzing and prioritization relations between the various enablers of green manufacturing. The study priorities the various enablers of green manufacturing and filters them into cause and effect group.

Chapter 8: This chapter presents **integrated approach for evaluating the barriers for green manufacturing using DEMATEL and analytic network process.** The aim of this study is to identify the numerous factors that act as barriers towards adopting green manufacturing. This study uses MCDM of Decision Making Trial and

Evaluation Laboratory (DEMATEL) technique to analyze the causal relationships among the various barriers of adopting green manufacturing. The study further utilizes the Analytical Network Process (ANP) to obtain the weights of each barrier and rank the barrier on the basis of weight obtained.

Chapter 9: This chapter presents **synthesis of the research** work. The amalgamation of the various studies is done to evaluate and interpret the results. Synthesis of the research work establishes a relationship among different studies in this work and to draw meaningful conclusions.

Chapter 10: This chapter presents the **conclusion and scope for future research**. The present research has derived important managerial inputs on various aspects of green manufacturing system. The results obtained from this study would benefit manufactures in their endeavour to implement green manufacturing. New parameter may be deployed for measuring environmental effectiveness and their influence can be evaluated. Future research using newer multi criteria decision method may be employed.

1.8 SUMMARY AND CONCLUSION

In recent decades increase in environmental awareness has motivated the manufacturers towards minimizing the use of exhaustible resources. The paramount focus of this research is to provide an analysis of issues in implementing green manufacturing systems. The adoption of green manufacturing system is a challenging task especially for developing .Various issues, enablers and barriers related to the implementation of green manufacturing are identified through literature review. These issues have been analyzed using various techniques to determine their causal relationships. Graph theory matrix approach has been used to design a framework for establishing environmental effectiveness of a system. The study is to use a structured approach to examine and rank, from an environmental perspective, the various factors that act as pivot for supporting different businesses to espouse green manufacturing. The results will help business in taking better-informed decision for accelerating and managing the change for environmentally benign manufacturing.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Various studies have been conducted on the different facets of green manufacturing. Review of the literature was carried out to provide a balanced view of green manufacturing practices. The topics covered in the review of literature are green manufacturing, parameters for evaluating environmental effectiveness of a system, critical success factors for green manufacturing, drivers for green manufacturing, and barriers for green manufacturing. The literature review is focused on identifying the factors which act as catalyst successful adoption of green manufacturing.

The concept of Green Manufacturing originated in 1990's. Fiksel (1996) advocated that the business need to address environmental concerns by adopting reusability and recycling, minimizing waste, emissions and raw material consumption. Mohanty and Deshmukh (1998) highlighted that businesses wishing to have a competitive edge and to complete globally need to adopt green manufacturing practices. Naderi (1996) stressed that businesses need to focus waste management in production by eliminating the causal factors. According to Gungor and Gupta (1999) environmental protection regulations and customer demand coupled with technological advancements influenced businesses to adopt environmentally benign practices.

Green manufacturing minimizes the negative environmental impact in manufacturing (Chien and Shih, 2007). Such an innovative manufacturing system also considers resource consumption in the complete product life cycle. It harmonizes economic and social benefits without damaging the environmental (Liu et al., 2005). It aims to decrease environmental impact through optimal process design, product development and manufacturing operations (Deif, 2011). Green manufacturing combines various issues to counter negative environmental impacts (Tan et al., 2002). It focuses on development of new technologies to transform materials without emission of hazardous gases, eliminates the use exhaustible/ toxic materials and avoids generation of waste (Allwood, 2009). The target of green manufacturing is the application of principles of sustainability to the manufacturing industry. Such a paradigm is based on a framework for eliminating of environmental waste and reduces energy consumption by redesigning existing production process/system (Balan, 2008). Green manufacturing takes a sustainable approach to product design, development and engineering to minimize environmental impact.

2.2 EVALUATING ENVIRONMENTAL EFFECTIVENESS OF A MANUFACTURING SYSTEM

The aim of evaluation process is to provide information on activities with regards to achievement of goals and strategic objectives of an organization Evaluation of a green paradigm involves quantifying all the tangible and intangible parameters that affect the environmental performance of system. The need for evaluating environmental effectiveness is to provide a benchmark for comparing competing manufacturing alternatives. Such an evaluation can be used for monitoring processes and operations of an organization. The evaluation metrics of traditional manufacturing has been expanded to incorporate environmental concerns (Carter and Rogers, 2008). The following sub-sections present the review of literature on evaluation models and evaluation metrics.

2.2.1 Technical perspectives

Green manufacturing entails incorporating new technologies in processes, product design, installation, production and maintenance (Melnyk and Smith, 1996). Incorporation of new technologies are operationally and economically challenging task. Businesses from a technical perspective need to consider integration of these new technologies with the existing system (Hua et al., 2005). Business need to evaluate the adaptability and flexibility of these technologies before its transition towards new processes and products (Barbara et al., 2012). These parameters and their interdependences need to be considered for determining the performance of a system.

2.2.2 Environmental perspectives

Environmental parameters for a green manufacturing perspective imply the use of strategies that would reduce the degradation of environment during the entire life-cycle of a product. Carbon emissions, energy and water consumption are key performance indicators ascertaining environmental impact of manufacturing (Krajnc and Glavic, 2005). The use of renewable energy enhances the energy efficiency of manufacturing operations (Tseng et al., 2012). Azapagic (2000) provides a metrics for mitigating the use of hazardous substances and increasing material efficiency. The decrease in water contamination and reducing the cost of effluent treatment influences the effectiveness of green manufacturing system (Hervani et al., 2005). The method of scrap disposal and residual generation are essential determinants of environmental impact of a system (Zhou et al., 2008).

2.2.3 Operational perspectives

Evaluation of manufacturing system from operational parameters implies the use of measures that would lead to optimal use of resources during the entire product life cycle of a product. It is important to have material recyclability coupled with reusability for promoting environmentally benign production processes (Tsoulfas et al., 2008). Green manufacturing aims to optimize production schedules through synchronized use of assets (Amrina and Yusaf, 2011). The cost of setting up a green supply chain management system to reduce the overall environmental impact needs to be evaluated. The efficient use of resources to minimize waste generation through use of innovative technology increases operational efficacy of the system and reduces the waste generated in the system (Zhu et al., 2008). A decision framework for selection of green supplier and use of evaluation indexes will be helpful in choosing eco-efficient supplier (Tsui et al., 2014, He et al., 2008).

2.2.4 Commercial perspectives

Evaluation of environmental performance practices using commercial parameters considers the economic factors which influence the selection and performance of manufacturing system. The business should strike a balance between the economic cost of emitting undesirable pollutants and the punitive tax imposed on them (Bovenberg, 1994; Jhansson, 1997). A metrics of pollution abatement subsidies, which encourages business to adopt green manufacturing, plays an important role in selection of a manufacturing system (Golombek and Hoel, 2004). Many businesses are investing in green manufacturing to acquire tradable pollution credits (Malueg, 1989; Requate and Unold, 2003). The cost of investing in new technologies, with corresponding payback periods act as a key parameter for evaluating effectiveness of a manufacturing system (Hu and Bidanda, 2009; Park, 2018).

2.2.5 Social perspectives

Social parameters measure the effect of implementing new systems on various stakeholders. A greener manufacturing system should bestow huge benefits to the employees and community well-being (Sarkis et al., 2010). It reduces the probability for human error and industrial accidents that cause physical and psychological injury. For effective green manufacturing operations, technological innovations replace certain roles that require human involvement in hazardous activities. However, the role of the human worker in a green manufacturing environment requires greater levels of judgment and on-the-spot objective decision making which can lead to greater job satisfaction and a reduction in employee attrition rate (Kassinis and Vafeas., 2002).The business focuses on consumers and loyalty program for building brand image (Henriques and Sadorsky, 1996). Customers demand for green products act as an important evaluating factor for companies adopting green manufacturing (Ginsberg et al., 2004). The increasing pressure of Corporate Social Responsibility laws ensures that business activities do not harm the local environment (Dobers and Wolff, 2000). Businesses are evaluating and addressing the inclination of their investors to mitigate the risks and liability of environmental activism by adopting environmentally responsible operations. Investors have forced businesses to enact and adhere to stringent environmental management systems (Goldstein and Wiest, 2007).

2.3 IDENTIFICATION OF VARIOUS ENABLERS FOR GREEN MANUFACTURING

Numerous studies have been conducted on various facets of green manufacturing. Various topics covered in the review of literatures are: Enablers in Green manufacturing, environmentally conscious manufacturing, Environment and Sustainable development, Green productivity, Green process, Green design, Sustainable manufacturing etc. The literature review focused on identifying various factors that might enable smooth transition towards green manufacturing. A panel of experts comprising of Industry experts and Academicians were consulted to decide on important enablers towards green manufacturing. These are enumerated below:

2.3.1 Customer demand

Environmental activism is a manifestation of pro-green values of consumers. Consumers are motivated to use green products because of environmental sustainability and their personal consciousness towards the environment (Shamsi and Siddiqui, 2017). These values are driving organizations to reorient their manufacturing operations (Anderson and Cunningham, 1972). Use of green manufacturing enhances brand image of the products and increased sale volume (Qi et al., 2018). The presence of huge market for products that are in concurrence with environmental norms are encouraging manufactures to invest in technologies that can substitute hazardous substances and processes (Huang, 2016; Pawaskar et al., 2018). Customer demand for greener products is motivating the manufactures to prioritize environmental concerns over short-term economic gain (Chien and Shih, 2007).

2.3.2 Need of waste management

The impositions of polluter pays principles are causing a fundamental shift in how businesses design and manufacture products (Lisney et al., 2003). The need for effective waste management is driving businesses to reduce toxic waste by using Life Cycle Analysis approach (Lisney et al., 2003; Polcari, 2007). More and more industries are gradually shifting towards green manufacturing practices as waste prevention incurs lesser cost as compared to the cost associated with the waste disposal (Vos, 2003; Seth et al., 2018). Remanufacturing provides substantial economic and environmental advantages (Yazdian et al.,2017)

2.3.3 Conservation of exhaustible resources

Manufacturers are optimizing the production processes to meet the challenges posed by the escalating requirement of exhaustible resources (Bonilla et al., 2010; Tan et al., 2008). They are also under pressure to switchover to renewable resources to make their operations environmentally benign (Barbara et al., 2012). The manufacturers are adopting new approaches and promoting research and development aimed at reduction of usage of resources. Depleting resources are compelling manufacturers in implementing green manufacturing (Rusinko, 2007; Hoffman, 2001; Gandhi et al., 2018). Manufacturers the use a collaborated Lean and green techniques to improve the productivity and performance of the manufacturing industry (Ravi et al., 2016)

2.3.4 Economic benefits

Adoption of green manufacturing results in a host of economic benefits. These include decreased tax liability, financial subsidies, tradable carbon credits etc. (Montabon et al., 2007; Chen et al., 2015). These economic benefits encourage manufactures to innovate and set up new green technologies (Dauvergne et al., 2018). Green manufacturing has attained much interest in recent times, because its concept of product design noticeably affects the various cost related to the process of remanufacturing and recycling (Dem et al., 2015).

2.3.5 Collaborative supplier

In addition to traditional procurement costs a sustainable procurement process also takes into consideration non-traditional parameters such as end of the life disposal cost ,carbon emission cost etc (Singh and Kaur, 2019) . Supplier amenability to make additional investment enables faster adoption of green manufacturing (Routroy, 2009). Awareness of green manufacturing technologies and willingness to embrace new technologies are instrumental in establishing green supply chain mechanisms. Manufactures are reducing their carbon footprints by integration of green technologies across their entire supply chain systems (Raut et al., 2017; Handfield et al., 1997). Information Technology solutions based on green algorithms provides a robust infrastructure for developing vendor friendly green supply chain mechanisms. Adoption of such practices helps in building trust among suppliers and enables manufactures to offer greener products (Lee et al., 2001; Tayeb et al., 2010).

2.3.6 Shareholders’ Pressure

Shareholder activism is compelling businesses to re-align their manufacturing systems to greener systems for the benefit of the society (Vos, 2003). Shareholders use portfolio analysis approach based on environment issues to assist them to be socially responsible investors (Ouenniche et al., 2016). Shareholders pressurise manufacturers to reduce hazardous emissions and incorporate efficient waste management strategies. Environmental activism of shareholders enable manufactures to invest and run operations in environment friendly manner. Manufactures are being encouraged to disclose their environmental impact metrics alongside their financial performance statements (Greeno and Robinson, 1992; Darnall et al., 2009).

2.3.7 Market competition

To up-level their competitiveness manufactures are striving to adopt green manufacturing (Shubham and Murty, 2018). Environmental benchmarking is being implemented by manufacturers in their quest to gain market competiveness (Delmas and Toffel, 2004; Huang et al., 2009).

2.3.8 Conducive regulatory mechanism

A manufacturer-friendly regulatory framework is conducive for a business to espouse green paradigm. A transparent regulatory mechanism and strong government resolute for environmental protection is responsible for catapulting its prominence (Dobers and Wolff, 2000; Kassinis and Vafeas, 2002). The adherence to environmental compliance regulation act forces businesses to implement green technologies (Zeng, 2011; Zhu and Sarkis, 2007). Regulatory frameworks to reduce greenhouse gases (GHGs) emissions are currently being developed in many countries around the globe. As a consequence, companies need to consider the different available options and mechanisms to meet their legal obligation (Chaabane et al., 2011).

2.3.9 Eco-innovations

Development of new commercially viable cleaner production technologies are encouraging business houses to move toward green manufacturing. These innovations are in the areas of manufacturing processes, products, transportation technologies and waste disposal (Tseng et al., 2012; Tan et al., 2001). Also newer technologies like internet of thing, artificial intelligence and machine learning are playing a pro-active role for the adoption of green manufacturing. Manufacturers with an innovative management, empower their employees to undertake research and development on green manufacturing (Oke et al., 2007). Supply chain activities and many logistics activities are the leading sources of carbon dioxide emission and environmental pollutions. These issues have raised concerns to reduce carbon dioxide emissions amount through design and planning of supply chain networks. Operations research has been recognized by many studies as an effective tool to deal with carbon dioxide emission in design and planning of green supply chains (Li and Ho, 2008; Memari et al., 2016).

2.3.10 Adept human resources

Availability of abundant skilled technical persons in field of green manufacturing enables businesses to adopt green manufacturing (Buzzelli, 1991). Presence of large number of training institutes for training and mentorship augments the process of implementing green manufacturing (Fergusson and Langford, 2006; Daily and Huang, 2001). Sensitization of all stakeholders towards the benefits of green manufacturing plays an important role in promoting a 'green' atmosphere in any organization.

2.4 IDENTIFICATION OF VARIOUS BARRIERS FOR THE ADPOTION OF GREEN MANUFACTURING

Various studies have been conducted on the different aspects of green manufacturing. The topics covered in the reviewed literature for identifying barriers are: critical success factors for green manufacturing, green productivity, green process, green design, sustainable manufacturing and green scheduling. The literature review revealed the factors which act as inhibitors in the adoption of green manufacturing. These barriers are classified into different categories.

2.4.1 Financial barriers

Green manufacturing requires huge capital investments (Balaji et al., 2014; Govindan et al., 2014). The uncertainties with regard to the rate of return of capital make businesses reluctant to invest in green manufacturing (Govindan et al., 2014). Banks are reluctant to fund green initiatives making it difficult for manufactures to raise capital (Min and Galle, 2001). The absence of short-term financial gains and long gestation period of green initiatives is a disincentive for manufactures to invest in new technologies (Carter and Rogers, 2008). Manufacturers take investment decisions in new processes and products based on trade-offs between effect on ecology and its impact on their profits.

2.4.2 Technology barriers

Technological barriers arise due to the need for integration of newer innovations with the existing systems (Hadjimanolis and Dickson, 2000; Luken and Rompaey, 2008). Complexity of design and lack of flexibility in operation makes it difficult for a business to switch over to new processes and products (Gerstenfeld et al., 2000;

Beamon, 1999). Limited technological and managerial competencies, additional infrastructure requirements, and the need to assimilate newer technologies, materials and processes make the transition even more difficult (Mathiyazhagan et al., 2014; Govindan, et al., 2014).

2.4.3 Social barriers

Businesses face a challenge of paucity of professionals having technical expertise in green manufacturing. Green manufacturing is an emerging paradigm and demand for talented professionals outstrips their availability. This talent crunch is because of dearth of institutions to train, monitor and mentor professional in green manufacturing (Mathiyazhagan et al., 2013). Businesses need to implement strategies to bring about a change in employee attitude of resistance to adopting new technologies. Companies need to impart training on environmental issues to their employees to enhance their commitment towards this cause (Mittal et al., 2013; Govindan, et al., 2014). There is a direct impact of customer pressure on companies' decisions regarding environmental practices. The ultimate test of green initiatives is the acceptances of products by the customers. The customers are reluctant to pay higher price for greener products. Low customer acceptance and reduced demands for green products discourage manufactures. Businesses are unwilling to undertake huge advertisement and marketing expenses to stimulate consumer demand for green products (Yu et al., 2008; Yuksel, 2008). Companies are under constant scrutiny and pressure from their shareholders to deliver maximum returns (McAdam, 2004; Massoud et al., 2010).

2.4.4 Operational barriers

Establishing green supply chain management system is a challenge due to vendor resistance for investing in green technologically. This resistance may be due to lack of awareness of the benefits of green manufacturing adoption (Ravi et al., 2005; Mathiyazhagan et al., 2013). Disregard of green considerations at the strategic level may stem from reasons such as lack of confidence in the potential benefits, inadequate management commitment, and perception of 'out-of-responsibility' zone towards environmental protection (McAdam, 2004; Del Brío and Junquera, 2003; Wang et al., 2008). High cost of compliance certification is also a barrier for green manufacturing.

This requires paying high fee for third party environmental inspection (Massoud et al., 2010; Koho et al., 2011). The Complexity in maintaining and monitoring of environmental gains makes the adoption of green technologies even more difficult (Siaminwe et al., 2005; Massoud et al., 2010).

2.4.5 Environmental barriers

Effective environmental regulations are crucial for adoption of green manufacturing (Geng and Doberstein, 2008).Government inability to provide appropriate infrastructure, training, consultancy, tax incentives, benefits etc hinders the growth of green manufacturing. An ambiguous regulatory policy of financial subsidies and an arbitrary system of allotment of pollution abatement permits discourages businesses to invest in green manufacturing. Businesses are reluctant to incur any expenditure on research and development of innovative capabilities in design and testing technologies to support green manufacturing activates (Wang et al., 2008; Massoud et al., 2010). Such open ended policies delay the decisions concerning new technology, materials and processes to support green manufacturing. Unavailability of proven alternative solutions for green manufacturing, due to lack of focus on research and development has inhibited the efforts of many organizations to adopt green manufacturing. There is a lack of uniform implementation and benchmarking guidelines which act as a barrier (Koho et al., 2011; Seth, 2018; Yu et al., 2008). Environmental legislation inhibits innovation by mandating use of economically unviable techniques and setting unreasonable deadlines (Gadenne, 2009; Shubham and Murty, 2018).

2.5 METHODOLOGIES USED FOR ANALYSIS OF VARIOUS ISSUES IN GREEN MANUFACTURING

2.5.1 Graph theoretic matrix approach

Graph theory was invented by Leonhard Euler. Graph theoretic matrix approach consists of Digraph representation, Matrix representation and Permanent function representation. GTMA uses directed graphs called digraphs for representation of the relationships among the different parameters of a system. Digraph representation is a useful visual analysis tool. Matrix representation gives one-to-one representation of digraph and is used for mathematical modelling of the system. These matrixes representations are used for computational analysis to obtain the numerical value of permanent function representation at system and sub system level (Jurkat and Ryser, 1966). The digraph consists of a set of nodes and a set of directed edges. A node represents alternative criterion and edges represent the relative importance among the criteria. If a node ‘a’ is important over node ‘b’, then a directed edge or arrow is drawn from node ‘a to node ‘b’. If ‘b’ is more important than ‘a’ directed edge or arrow is drawn from node ‘b’ to node ‘a’. Digraph representation is converted into matrix representation using numeric value based on the mutual inheritance and inter-dependence among parameter and sub-parameters. Permanent function representation is evaluation of permanent value of VPF at the system/sub-system level (Bang and Gutin, 2008).The graph theoretic matrix approach is a systematic combinatorial mathematics method for conversion of qualitative factors to quantitative values. Use mathematical modeling is advantageous over conventional methods like flowcharts as it allow use of computers for various complex calculations to generate results. The various steps followed in graph theoretic matrix approach are:

i. Identification of main parameter and sub- parameters which influence the system

ii. Construct ‘system-digraph’ and ‘sub-system digraphs’ linking all parameters on the basis of their mutual relationships

iii. Develop matrix representation based on expert opinion of the using numerical values of inheritances and inter-dependencies for each sub-system and at system level

iv. Evaluation of variable permanent matrix values for each sub-parameter

v. Compute the of permanent value at the system level by incorporating the sub-system variable permanent matrix values diagonally in the matrix

vi. Computation of range for the system as well as for each sub-parameter

Graph Theoretic Matrix Approach (GTMA) has been applied in different areas. A few of these are enumerated below in Table 2.1

Table 2.1: Application and use of GTMA

S. No.	**Author(s)**	**Research scopes**
1	Dev et al., (2015)	Efficiency analysis of combined cycle power plant
2	Dou et al., (2009)	Reconfigurable Manufacturing Systems
3	Faisal et al., (2007)	Risk mitigation in Supply chains
4	Grover et al., (2004)	Role of human factors in TQM
13	Gupta and Singh, (2017)	Service Quality
5	Raj et al., (2010)	Intensity of barriers towards implementing FMS
6	Rao and Gandhi, (2002)	Failure cause analysis machine tools
7	Rao and Padmanabhan, (2006)	Selection of Industrial robots
8	Saha and Grover, (2011)	Factors effecting website performance
9	Sana et al.,(2015)	Selection of Locations of Collection Centers for RL
14	Singh et al.,(2019)	Supply chain Management
10	Wani and Gandhi, (1999)	Maintainability index of mechanical systems
11	Wu and Leahy, (1993)	Data clustering
12	Zerdi et al.,(2014)	Crowd behaviour analysis

2.5.2 Fuzzy-TOPSIS - MCDM technique of Fuzzy TOPSIS is employed to analysis the interdependencies among critical success factors. TOPSIS does not have any explicit limit over the number of alternatives/criteria that can be considered. TOPSIS technique does not require pair-wise comparison or a consistency check. This makes TOPSIS a better and simpler method for decision making. Different business areas like manufacturing systems, supplier selection, logistics, engineering design maintenance risk mitigation etc. Fuzzy TOPSIS methodology is explained below:

i. Determine the Linguistic variables and fuzzy scale for criteria and factors
ii. Construct the matrix for assessment of criteria. Replace the linguistic ratings by their fuzzy membership functions and calculate their Aggregate Fuzzy Weight.
iii. Construct the decision matrix. Replace the linguistic ratings by their fuzzy membership functions
iv. Normalize the decision matrix
v. Calculate the weighted normalized matrix.

vi. Determine the positive ideal solution and negative ideal solution by vertex method.

vii. Calculate the separation measure and calculate relative closeness to the ideal solution

viii. Rank the preference order.

Literatures reveal various applications of fuzzy TOPSIS methodologies. Table 2.2 gives a brief review of the same.

Table 2.2: Application and use of fuzzy TOPSIS

S.No	Author(s)	Research scopes
6	Baskaya and Avce, (2011)	Evaluation of Salesperson
7	Chu and Lin, (2003)	Robot selection
1	Darvishi and Mohamadi, (2019)	Evaluation of Construction Projects
4	Husin et al., (2019)	Project Risk
3	Jeong, Giho, (2017)	Evaluating IT proposals
9	Kim, (2017)	Energy Selection
8	Mittal and Sangwan, (2014)	Barriers in ECM implementation
2	Özbek, Aşır, (2015)	Supplier Selection
5	Tabor, (2019)	Assessment of Occupation Health Safety

2.5.3 ISM MODELING

ISM is a powerful tool to develop a comprehensive model involving a set of elements that may be directly or indirectly related. The model helps to structure a complex problem and gives graphical representation. MICMAC analysis is used to analyze the driving power and dependence of each element. Important steps in ISM are

i. Identification of various elements that influence the system.

ii. Development of SSIM (Structural Self Interaction Matrix)

iii. Development of Reachability Matrix

iv. Ranking of elements using Level Partitioning

v. MICMAC analysis for classification of variables based on their drive and dependence power

Literatures reveal various applications of ISM methodologies. Table 2.3 gives a brief review of the same.

Table 2.3: Applications and use of ISM

S. No.	Author(s)	Research scopes
1	Ansari et al., (2013)	Barriers To Implement Solar Power Installations
11	Attri et al.,(2013)	Total Preventive Maintenance
2	Diabat and Govindan, (2011)	Green Supply Chain Management
4	Govindan et al., (2014)	Supply Chain Performance:
5	Pfohl et al., (2011)	Supply Chain Risks
6	Raj et al., (2012)	Flexibility In FMS
7	Satapathy et al., (2012)	E-Electricity Utility Service.
8	Singh and Kant, (2008)	Knowledge Management Barriers
9	Talib and Rahman, (2011)	Barriers To Total Quality Management
3	Talib and Rahman, (2015)	Sustainable Healthcare quality
10	Thakkar et al., (2008)	IT-enablers for Indian manufacturing SMEs.

2.5.4 INTEGRATED DEMATEL and ANP

DEMATEL was developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva (Gabus and Fontela, 1972). The DEMATEL method is used for building and analyzing structural models involving dependency among factors. DEMATEL divides the multiple factors or criteria’s into cause groups and effect groups. Analytical network process (ANP) was presented by Saaty (2001). ANP method considers the interdependencies among factors and ranks them according to their relative importance. Important steps in integrated DEMATEL and ANP are

i. Identification of main criteria which influence the system
ii. Develop direct relationship matrix using expert opinion for the pair comparison between criteria’s using influence rating scale
iii. Normalise the direct relationship matrix and compute the total relationship matrix
iv. Calculate the sum of the elements of each column (D) and each row(R). The relation values of D+R and D-R is used to classify criteria’s into cause and effect groups

v. Normalise the total relation matrix (T) to obtain the Weighted

vi. Compute the Limiting Supermatrix by multiplying the Weighed Supermatrix values with itself until convergence.

vii. Rank on the basis of weights obtained in Limiting Supermatrix

The integrated DEMATEL and ANP technique has been employed in various fields by the researches. Some of these are enumerated in Table 2.4.

Table 2.4: Application and use of integrated DEMATEL and ANP

S.	Author(s)	Research scopes
2	Büyüközkan and Öztürkcan, (2010)	Six sigma project selection
13	Chang, (2011)	Maintenance rating program
4	Chen and Yu, (2008)	Location selection for high-tech firms
6	Chen et al., (2012)	Branding Taiwan's tourism
14	Dedasht et al., (2017)	Risk assessment in oil and gas construction
15	Hu et al., ((2015)	Assessment of supplier quality performance
12	Kfita and Drissi, (2018)	Evaluate fleet maintenance management
11	Kundakc et al., (2014)	Cargo shipping company selection problem
5	Lee et al., (2011)	Investment decision analysis
1	Liou et al., (2007)	Airline safety measurement
16	Sharma et al.,(2017)	Retail Location Decision
10	Tsai et al., (2010)	Risk management system of banking
9	Tsai et al., (2013)	Enterprise Resource Planning
7	Vujanovic et al., (2012)	Vehicle fleet maintenance management
8	Wang, (2012)	Interactive trade strategy evaluation
17	Wei et al., (2017)	Evaluating Stock Trade Strategies
3	Wu, (2008)	Selection of knowledge management strategies

2.6 GAPS IN LITERATURES

The review of literature highlighted the following gaps:

- There is a little documentation on green manufacturing and its distinguishing attributes Empirical studies on green manufacturing are mainly based on the case studies or deals with descriptive statistics alone.

- Literature highlights the need for a structured approach to examine and rank, from an environmental perspective, the various factors that act as pivot for supporting different businesses to espouse green manufacturing.
- Literature revive further elucidate gaps in process of ranking of various enablers/barriers that facilitates assessment of the abilities and attitudes businesses must have to achieve breakthroughs and innovations for green manufacturing.
- Literature review highlights the absence of focus on the objectives to provide the basic framework for manufactures to excel in business and environmental performance simultaneously.

2.7 CONCLUSION

Review of the literature was carried out to provide a holistic view on issues in green manufacturing .Also the literature on various methodologies to be applied in present research are reviewed. On the basis of literature the various, parameters for evaluating environmental effectiveness of a system, critical success factors for green manufacturing, drivers for green manufacturing, and barriers for green manufacturing were identified . The literature review focused on identifying the factors which act as catalyst successful adoption of green manufacturing.

CHAPTER 3

DEVELOPMENT AND ADMINISTRATION OF QUESTIONNAIRE

3.1 DEVELOPMENT OF QUESTIONNAIRE

A closed-ended questionnaire was developed based on various issues in adoption of green manufacturing. The questionnaire was developed based on literature available .The questionnaire is based on Likert scale of one to five. The response five indicates the most influencing criteria where as response of one is assigned to least affecting criteria. A panel consisting of industry experts and academicians were asked to vet the questionnaire before administration. The questionnaire was sent to professional working in the field of manufacturing industry through post and e-mail. Responses were elicited to obtain view on operational, environmental, economic, technical and social parameters in adoption of green manufacturing.

3.2 QUESTIONNAIRE ADMINISTRATION

This questionnaire survey was divided into two sections. Section 1 consisted of questions related to the profile of the organization. Section 2 consisted of questions on the issues related with various enablers and barrier to adoption of green manufacturing. The survey was conducted in manufacturing industries which are primarily based in the north India

3.3 SURVEY RESPONSE AND RESPONDENTS PROFILE

A total of 450 questionnaires were sent to professional working in the field of manufacturing industry through post and e-mail.151 responses were received back. Out of these, 9 responses were found to be incompletely filled and were rejected. Hence, 142 completely filed responses were considered important for the present analysis. The survey had a response rate of 31.55 %.

3.4 ANALYSIS AND DISCUSSION OF SURVEY RESPONSES

The following are the observations based on the responses obtained from the survey of industries.

Section 1: Organization Profile

The Distribution characteristic of the sample according to the total number of employees is shown in Table 3.1.

Table 3.1: Distribution characteristic of the sample according to the total number of employees

S. No.	Description	Number of employees	Frequency
1	Total number of employe	Less than 100	43
		Between 101to 500	56
		Between 501 to 1000	27
		More than1000	16

The survey result indicates that maximum responses are obtained from organization employing more than 100 and less than 500 persons. The least responses are from organization that employed more than 1000 persons. The frequency distribution of Number of employees in the organization is shown Figure 3.1:

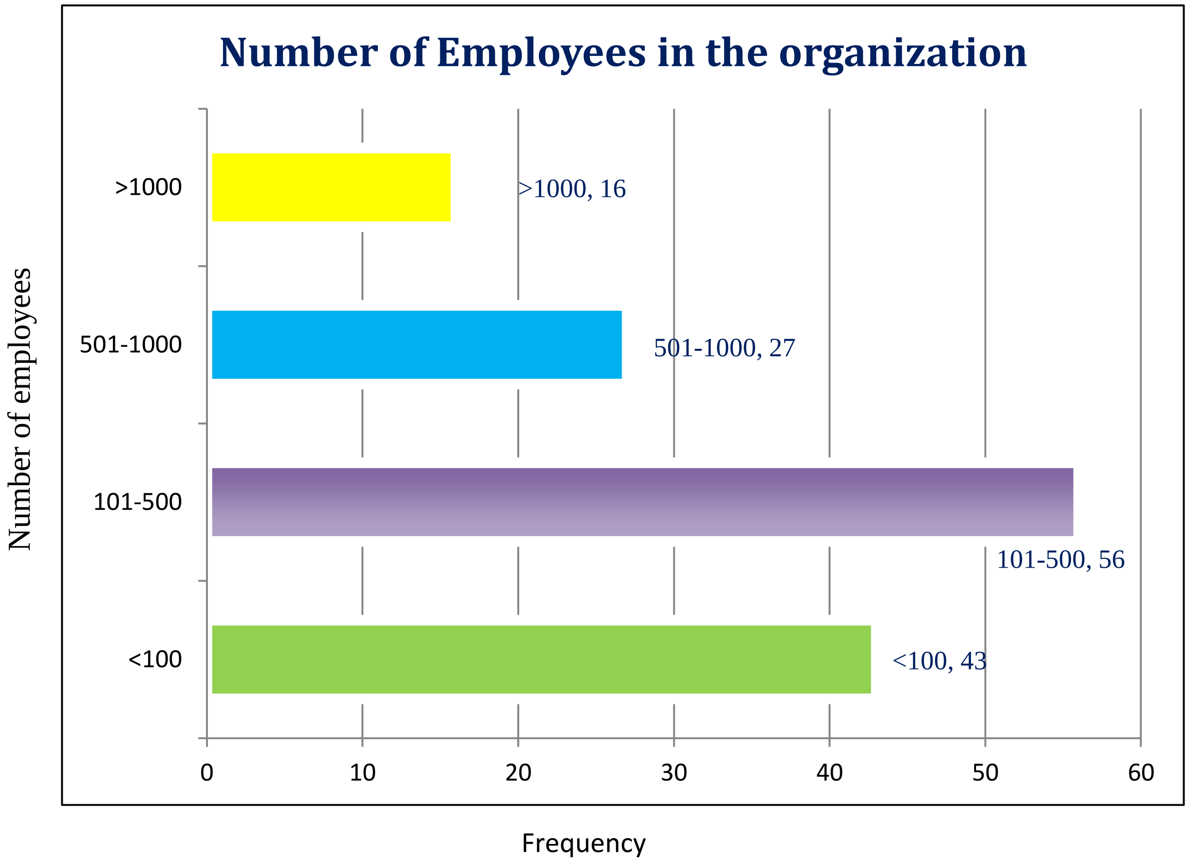

Figure 3.1: Number of employees in the organization

The Distribution characteristic of the sample according to the turnover of the organization is shown in Table 3.2.

Table 3.2: Distribution characteristic of the sample according to the turnover of the organization

S. No.	Description	Annual Turnover in crores	Frequency
2	Annual Turnover	less than10	44
		10-50	48
		50-100	29
		100-500	17
		> 500	4

Analysis of the responses reflects that 44 industries or 31% industries have less than 10 crores annual turnovers, 48 industries or 34% industries have turnover between 10-50 crores , 29 industries or 20% have between 50-100 crores turnover, 17 industries or 12% are in 100-500 crores range while 4 industries or 3 % lie in more than 500 crore ranges. Annual Turnover profile of the organizations is shown in Figure 3.2.

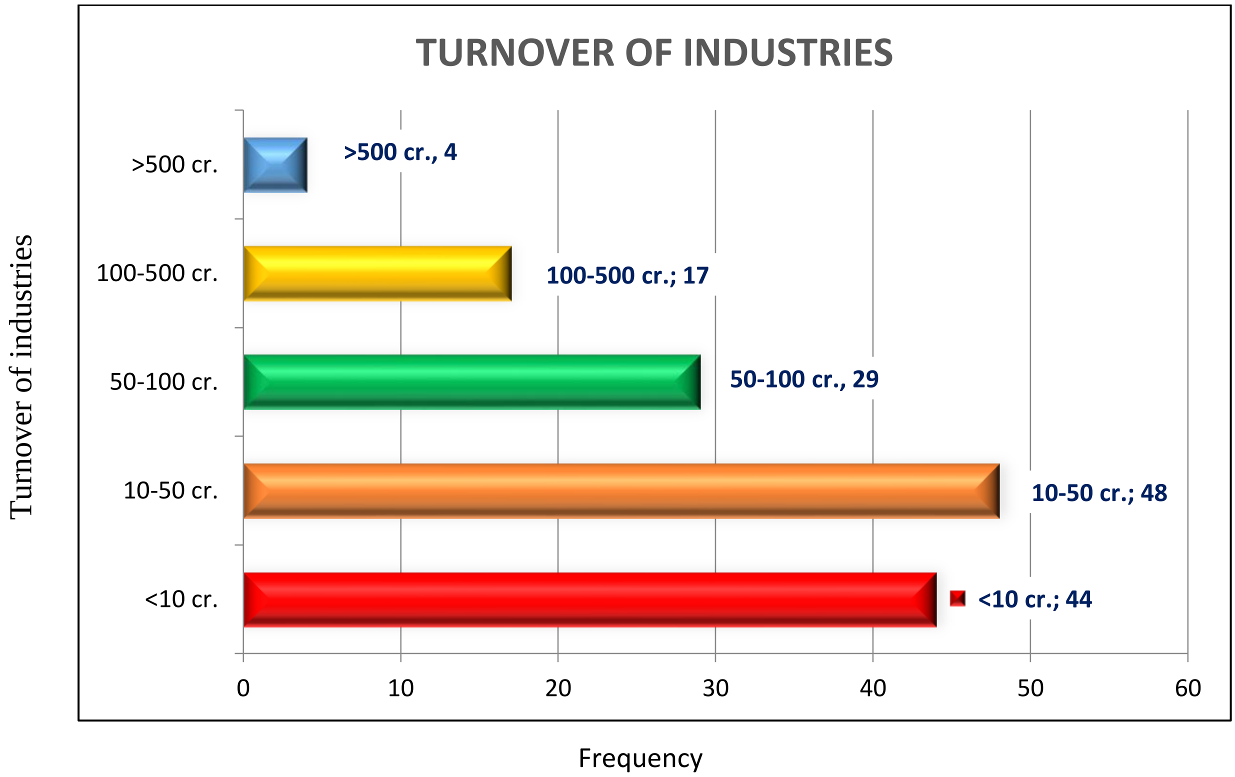

Figure 3.2: Turnover of Industries (Rs. in Cr.)

The Distribution characteristic of the sample according to the turnover of the organization is shown in Table 3.3.

Table 3.3: Distribution characteristic of the sample according to number of production shops in the organization

S. No.	Description	Production Shops	Frequency
3	No. of different production sho in the Organization	1	40
		Between 2 to4	56
		Between 5 to 8	36
		More than 8	10

The result of the survey indicates that maximum respondents were from organization between having between two to four shops. This is shown in Figure 3.3.

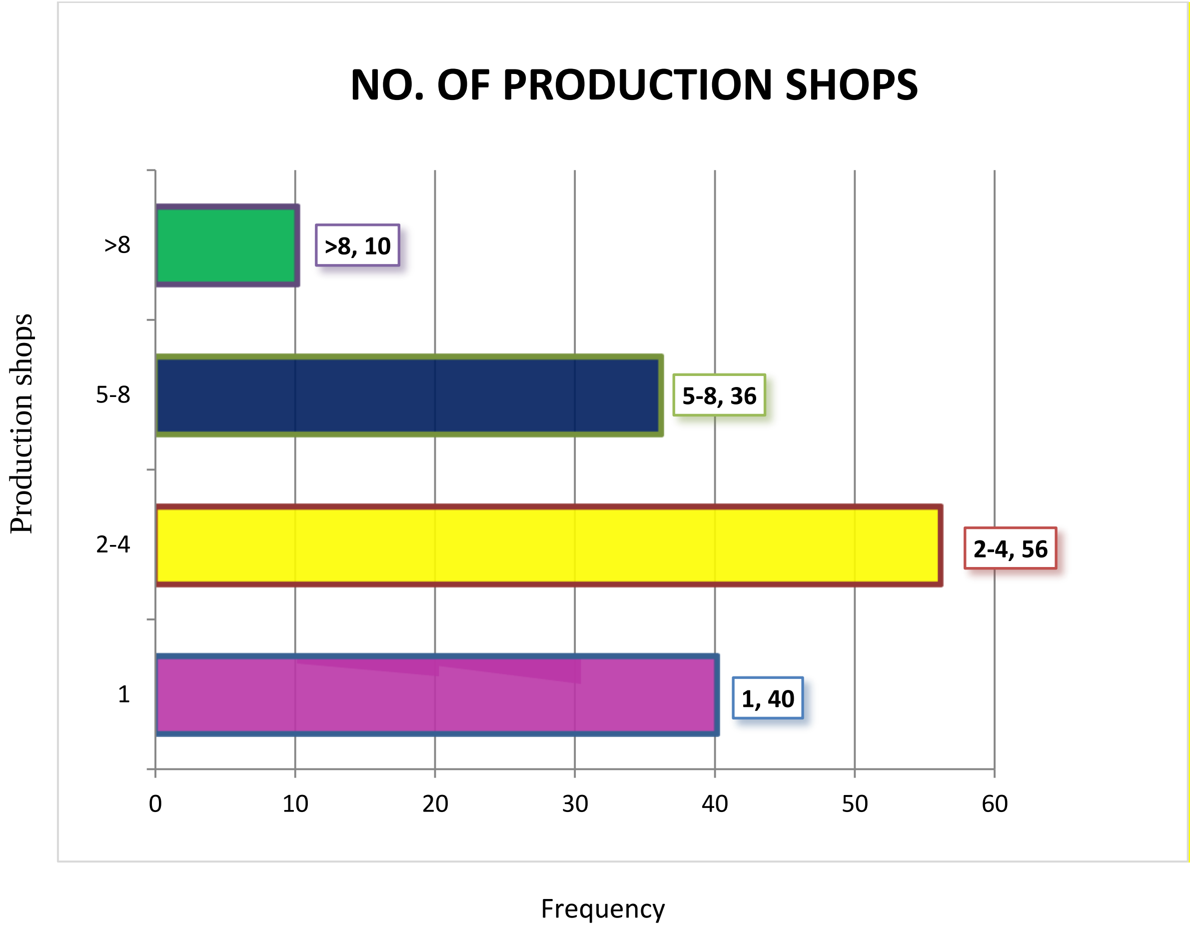

Figure 3.3: Number of Production shops in the organizations

The Distribution characteristic of the sample according to the number of components manufactured is shown Table 3.4.

Table 3.4: The Distribution characteristic of the sample according to the number of components manufactured

S. No.	Description	Number of components manufactured	Frequency
4	Number of components manufactured	Between 1-5	71
		Between 6-10	36
		Between 11-20	24
		More than 20	11

The result of the survey indicates that 50% respondents were from organization which manufactured less than five components, 26% respondents are from organization which between having between six to ten components. 17% respondents are from organization producing between 11-20 numbers of components where as 7% produce more than 20 components. Figure 3.4 depicts the profile of number of components manufactured in organizations whose employee responded to the survey.

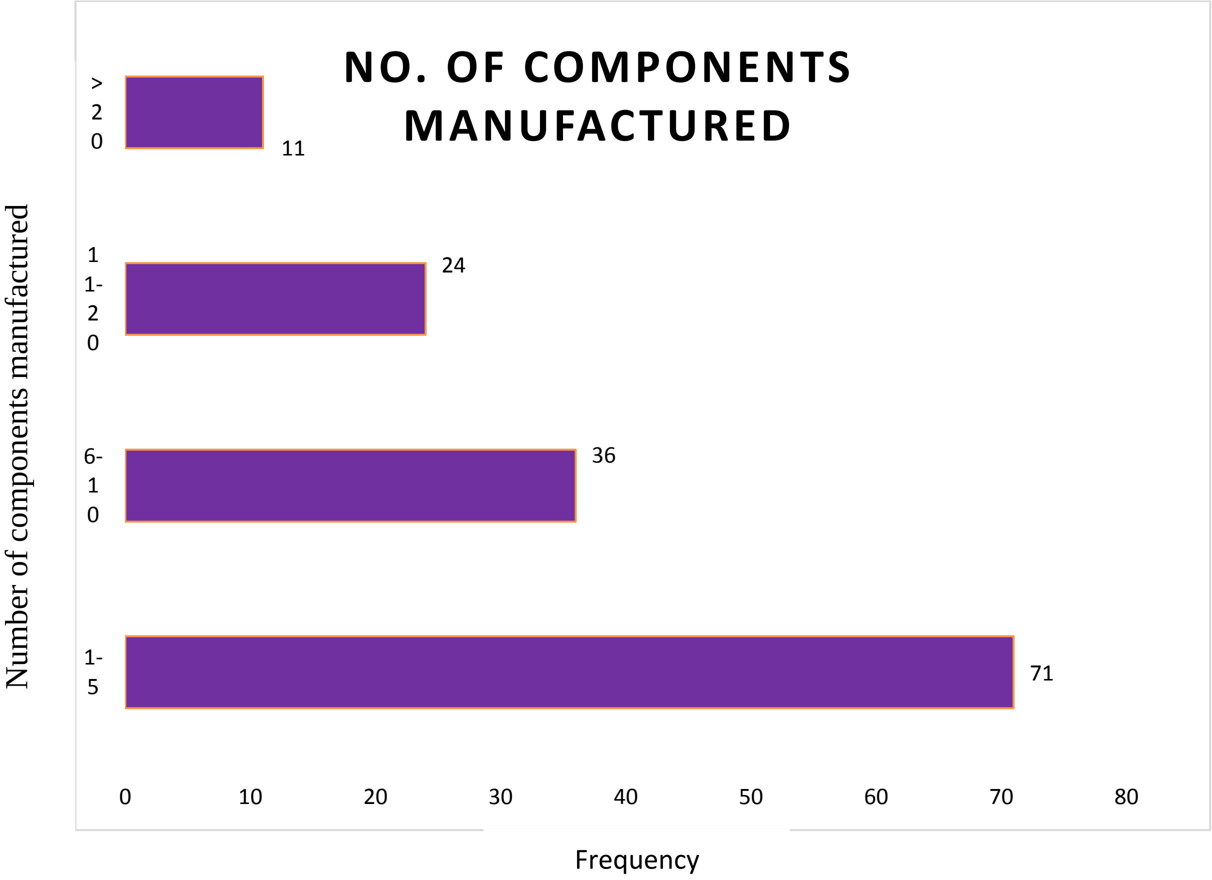

Figure 3.4: Number of components manufactured

SECTION 2:

Analysis of survey responses on identified enablers for green manufacturing

The responses of questionnaire survey give the ratings of each enabler on the Likert Scale for adoption of green manufacturing. Based on individual responses, the mean score of each enabler has been calculated and enablers have been ranked. Table 3.5 displays the scoring of each identified enablers.

Table 3.5: Enablers' ranking based on Questionnaire survey

S. No	ENABLER	Mean Score	Rank
1	Conducive regulatory mechanism	3.852113	
2	Need of waste management	3.936620	
3	Shareholders Pressure	3.950704	
4	Economic benefits	3.825175	
5	Eco innovations	4.007042	II
6	Collaborative supplier	3.978873	III
7	Market competition	3.957746	
8	Customer demand	4.028169	I
9	Conservation of exhaustible resource	3.957746	
10	Adept human resources	3.852113	

The results of survey indicate that that the most important enablers indicated by respondents are: customer demand (Mean score= 4.028), eco-innovations (Mean score= 4.007) and collaborative suppliers (Mean score= 3.978). Figure 3.5 displays the total scoring of each enabler from survey responses.

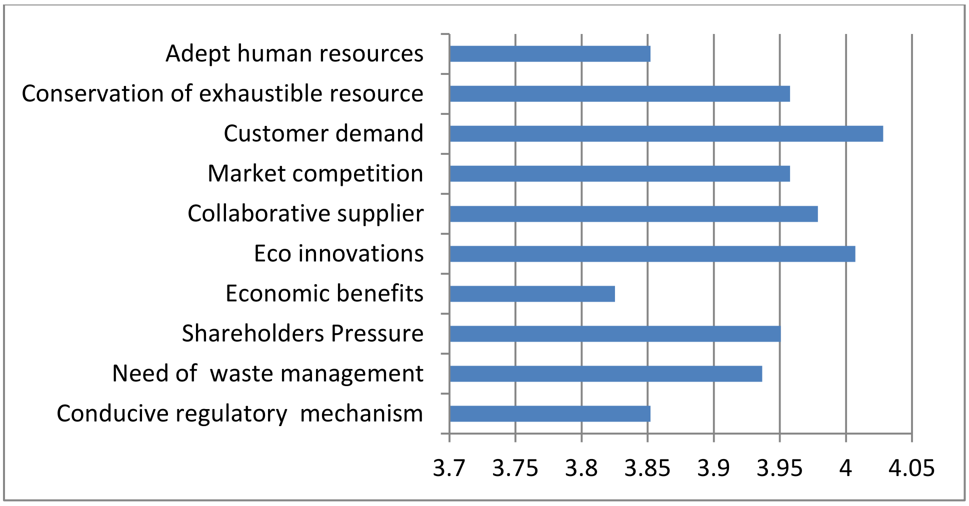

Figure 3.5: Bar chart displaying enabler scores obtained from survey responses

Analysis of survey responses on identified barriers for green manufacturing

The mean score of each barrier has been calculated and barriers have been ranked. Table 3.6 represents the same.

Table 3.6: Barriers' ranking based on Questionnaire survey

S.NO	Barrier	Priority	Rank
1	Uncertain Rate of Return	4.028	II
2	Inadequate Management Commitment	3.979	
3	Employee Altitude and Resistance	3.923	
4	Complexity of Design	3.951	
5	Adaptability	3.972	
6	Integration	3.937	
7	Lack of Effective Environmental Enforcement	3.972	
8	Suppliers Resistance	3.951	
9	Long Gestation Period	3.718	
10	Customers' Reluctance to Pay Higher Price	3.930	
11	High Cost of Compliance Certification	3.979	
12	Bank Reluctant to Fund Projects	4.014	
13	High Initial Capital Cost	4.049	I
14	Inadequate Infrastructure	4.007	
15	Lack of Uniform Benchmarking Indices	3.965	
16	Mandating use Unviable Techniques	3.972	
17	Maintainability	4.021	III
18	Lack of Flexibility	3.944	
19	Shareholder Pressure	3.930	
20	Lack of Experience Professional	4.028	II

The total mean score of each barrier from survey responses is displayed Figure 3.6. The chart reflects that the most important barriers indicated by respondents are: High initial capital cost (Mean score= 4.049), Uncertain rate of return (Mean score= 4.028), Lack of Experience Professional ((Mean score= 4.028) and Maintainability (Mean score= 4.021)

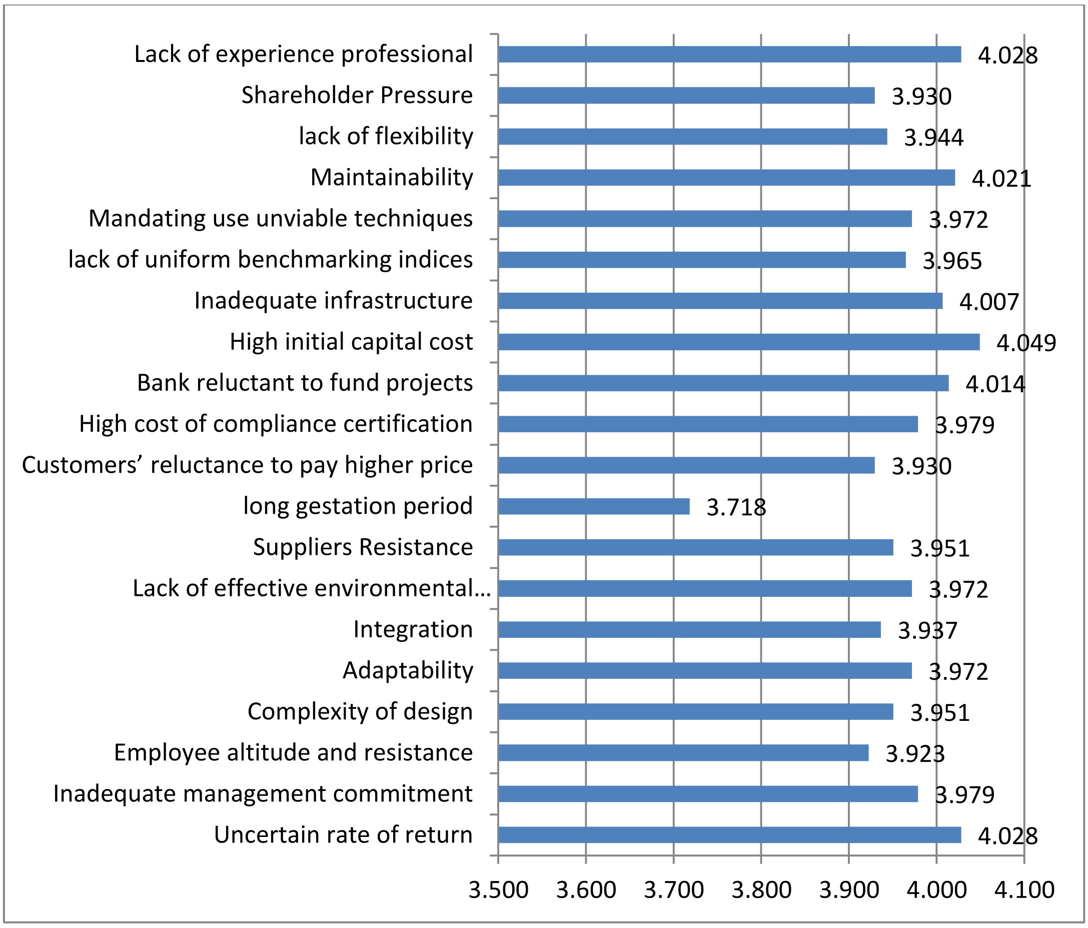

Figure 3.6: Bar chart displaying scores of barrier from survey responses

3.5 VALIDATION OF SURVEY QUESTIONNAIRE THROUGH ANOVA

ANOVA stands for Analysis of Variance. ANOVA was developed by statistician and evolutionary biologist Ronald Fisherin 1918. ANOVA analysis has applied to validate the data in the present study. ANOVA is a statistical technique, uses the principle of law of total variance. ANOVA tests the differences between two or more means of variables in a sample. ANOVA compares if two or more variables of sample population are equal, and generalize the t-test beyond two means. ANOVA compares the response variable means at different factor levels to computes the significance of one or more variable. ANOVA is based on fallowing assumptions:

I. Variances of all the errors are equal to each other
II. All errors are independent
III. Errors are normally distributed

Different types ANOVA analysis applied to evaluate data are: One-way ANOVA, Multivariate ANOVA, Repeated measures ANOVA and Mixed design ANOVA. The one-way analysis of variance is a type of independent two-samples t-test for comparing means in a situation where there are In this , the data is structured into several groups .This is done on bases on one single grouping , known as factor variable. One factor analysis of variance makes multiple simultaneous comparisons of the means of different variables under consideration rather than pair-wise comparison. ANOVA test compares two kinds of variation namely the variation between the sample means and the variation within each sample. Combination of these variations is called the ‘F statistic’ .This is compute by dividing the variation between samples by the variation within each sample. The following steps have been used evaluate the survey responses data for the present analysis.

1. Calculate the sample mean for each variable of sample.

Let the samples variables be: $A1, A2, A3, \ldots\ldots\ldots, A_N$

The mean of each sample is: $\overline{A1}, \overline{A3}, \ldots\ldots.., \overline{AN}$

2. Compute the mean for all of the sample means

Mean of ‘*all sample mean*’ is:

$\overline{\overline{A}} = (\overline{A1} + \ldots + \overline{A3} + \ldots\ldots.. + \overline{AN})/N$ ………… (i)

3. Compute the sum of squares of variance between the different samples by following equation

$SS_{between} = n_1(\overline{A1} - \overline{\overline{A}})^2 + n_2(\overline{A2} - \overline{\overline{A}})^2 + n_3(\overline{A3} - \overline{\overline{A}})^2 + \cdots + n_k(\overline{Ak} - \overline{\overline{A}})^2$ …….(ii)

4. Compute the variance between samples or mean square ($MS_{between}$) by dividing $SS_{between}$ obtained in equation (ii) by the degree of freedom between the different samples.

$MS_{between} = SS_{between} / (k-1)$ ……….. (iii), (k-1) represents the degree of freedom between the samples

5. Compute the sum of squares for variance within samples (SS_{within}) is by squaring the using following equation.

$SS_{within} = \sum(A1i - \overline{A1})^2 + \sum(A2i - \overline{A2})^2 + \sum(A3i - \overline{A3})^2 + \cdots + \sum(Aki - \overline{AK})^2$… (iv)

(i= 1, 2, 3 …k)

6. Compute Variance or mean square within samples (MS_{within}) is calculated as:

$MS_{within} = SS_{within} / (n-k)$………..v), (n-k) is the degree of freedom within samples, n is the total number of items in the entire samples and k is the number of samples

7. Compute sum of squares of deviations for total the variance in population

$$SS_{\text{total variance}} = \sum(Aij - \bar{\bar{A}})^2 \ldots\ldots\ldots\ldots\ldots\text{(vi)}$$

$$i = 1, 2, 3\ldots\ldots..n, \quad j = 1, 2, 3\ldots\ldots\ldots n$$

$$(SS_{\text{total variance}} = SS_{\text{between}} + SS_{\text{within}})$$

8. Compute lF-ratio

$$\text{F-ratio} = \frac{\text{MS between}}{\text{MS within}} \ldots\ldots\ldots\ldots \text{(vii)}$$

In cases, where F value is less than the F-critical value the difference is taken as insignificant. In such cases, the null hypothesis between variables of sample stands. But if F value is equal or greater than F- critical value, then the difference is taken to be significant. Such an F-value indicates that the samples of data could have come from different universe. Figure 3.7 shows the flow chart for Data Validation through ANOVA

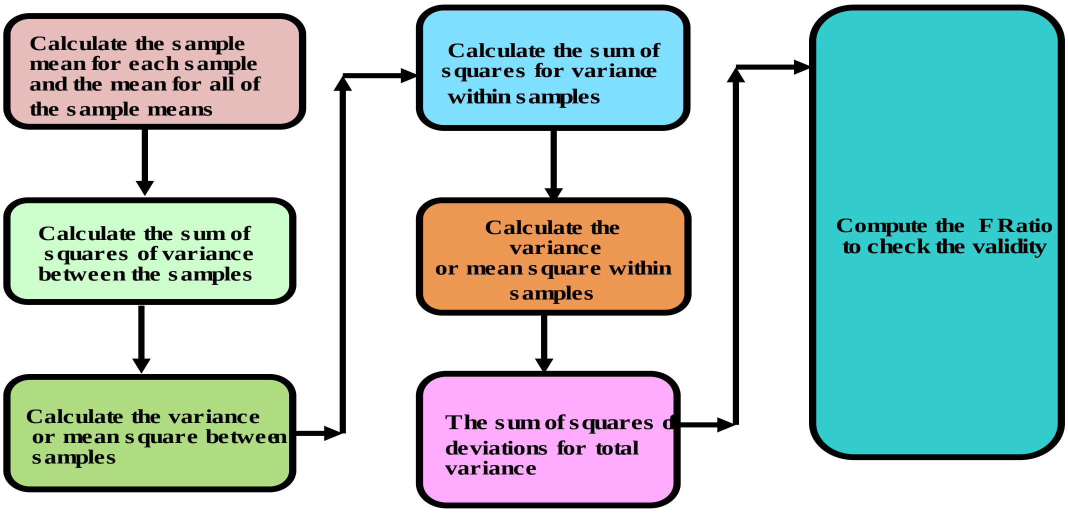

Figure 3.7: Flow chart for Data Validation through ANOVA

The results of Regression analysis based on for the responses of survey data is shown in Table 3.7.

Table 3.7: Regression analysis of Response vs. Predictor

Predictor	Coef	SE Coef	T	P
Constant	3.5768	0.3013	11.87	0
C2	0.0984	0.07746	1.27	0.214

S = 0.06639 R-Sq =5.5% R-Sq(adj) = 2.10%

The Table 3.8 displays the Fit and Residual of the respondent's data.

Table 3.8: Fit and Residual of the Respondents data

S. No	Predictor	Response	Fit	SE Fit	Residual	St Residual
1	3.9	3.8521	3.9605	0.0122	-0.1084	-1.66
2	3.8	3.9366	3.9507	0.0139	-0.014	-0.22
3	3.7	3.9507	3.9408	0.0189	0.0099	0.16
4	3.8	3.8252	3.9507	0.0139	-0.1255	-1.93
5	3.8	4.007	3.9507	0.0139	0.0564	0.87
6	3.9	3.9789	3.9605	0.0122	0.0184	0.28
7	3.8	3.9577	3.9507	0.0139	0.0071	0.11
8	3.9	4.0282	3.9605	0.0122	0.0677	1.04
9	3.8	3.9577	3.9507	0.0139	0.0071	0.11
10	4	4.0282	3.9703	0.015	0.0578	0.89
11	3.9	4.0141	3.9605	0.0122	0.0536	0.82
12	3.8	3.9789	3.9507	0.0139	0.0282	0.43
13	3.8	3.9225	3.9507	0.0139	-0.0281	-0.43
14	4.2	3.9507	3.99	0.0271	-0.0393	-0.65
15	4.3	3.9718	3.9999	0.0342	-0.028	-0.49 X
16	3.7	3.9366	3.9408	0.0189	-0.0042	-0.07
17	3.7	3.9718	3.9408	0.0189	0.031	0.49
18	4	3.9507	3.9703	0.015	-0.0196	-0.3
19	3.9	3.7183	3.9605	0.0122	-0.2422	-3.71R
20	3.8	3.9296	3.9507	0.0139	-0.0211	-0.32
21	3.9	3.9789	3.9605	0.0122	0.0184	0.28
22	3.9	4.0141	3.9605	0.0122	0.0536	0.82
23	4.1	4.0493	3.9802	0.0205	0.0691	1.09
24	3.7	4.007	3.9408	0.0189	0.0662	1.04
25	3.7	3.9648	3.9408	0.0189	0.024	0.38
26	3.9	3.9718	3.9605	0.0122	0.0113	0.17
27	4.2	4.0211	3.99	0.0271	0.0311	0.51
28	3.8	3.9437	3.9507	0.0139	-0.007	-0.11
29	3.8	3.9296	3.9507	0.0139	-0.0211	-0.32
30	4.1	4.0282	3.9802	0.0205	0.048	0.76

Analysis of Variance (ANOVA) consists of calculations that provide information about levels of variability within the regression models and form the basis for tests of significance. The Table 3.9 shows the Analysis of Variance for the surveyed questionnaires data.

Table 3.9: Analysis of Variance for the surveyed questionnaires data

Source	DF	SS	MS	F	P
Regression	1	0.007113	0.00711	1.61	0.214
Residual Error	28	0.123423	0.00441		
Total	29	0.130535			

F-value or F- statistic= $\frac{MSM}{MSE} = \frac{0.00711}{0.00441} =$1.61

The large value of F-statistic highlights that there is evidence against the null hypothesis. The p-value for the F-test statistic is 0.214, providing strong evidence against the null hypothesis.

The squared multiple correlation R2, indicates that the model fits the data.

3.6 SUMMARY AND CONCLUSION

The followings are important observations from the survey analysis.

- Maximum response were obtained from organization employing between 101 to 500 employees
- In term of turnover Maximum responses were obtained organizations having a turnover up to 50 Cr
- Maximum respondents have 2-4 number of production shops
- Maximum responses were obtained from by the industries which manufacture between 1- 5 components.
- The result of survey indicates that that the most important enablers indicated by respondents are: customer demand (Mean score= 4.028), eco-innovations (Mean score= 4.007) and collaborative suppliers (Mean score= 3.978).
- The chart reflects that the most important barriers indicated by respondents are: High initial capital cost (4.049) and Uncertain rate of return (Mean score= 4.028)
- ANOVA analysis was applied to validate data of survey respondents. ANOVA analysis reflects. The F-value of 1.61 is found to be lower than F-critical value. This highlights that the collected data from questionnaire survey is statically valid.

CHAPTER 4

EVALUATION OF ENVIRONMENTAL EFFECTIVENESS OF A MANUFACTURING SYSTEM USING GRAPH THEORETIC MATRIX APPROACH

4.1 INTRODUCTION

Manufactures today are at an inflection point due to animated concern for environmental protection. This is putting immense pressure on their operations and financial performance (Wang, 2007). Businesses are implementing green manufacturing technologies for mitigating environmental problems. Increasing resource productivity, escalating reliability of assets, improving flexibility of systems and optimizing energy consumption are inherent to the green manufacturing system (Dechant and Altman, 1994). Implementing green manufacturing system must be in consonance with the organizational goals. Selection of a green manufacturing system requires complex decision making exercise entailing analysis of multiple technical issues, expected gains, expenses incurred and risks associated while adopting green manufacturing (De Burgos et al., 2001). Several critical parameters and key performance indicators need to be evaluated for measuring environmental effectiveness of manufacturing systems.

Implementation of an apt green manufacturing leads to maximization of asset efficiency with minimal adverse environmental impact. A number of factors are now driving businesses to measure their environmental performance (James and Bennett, 1994). The paramount drivers for the adoption of environmentally effective manufacturing are innovations, need for resource conservation, financial incentives and employees' welfare (Govindan et al., 2014). For successful implementation of an environmentally effective manufacturing strategy it is essential for the businesses to coordinate with various regulatory institutions, investors, suppliers and consumers. Business need to have a balanced and integrated approach to be better able to balance cost, risk and reliability while meeting their environmental goals. An unbiased process for evaluating the same is therefore essential. The Table 4.1 shows the various parameters and sub parameters that determine the environmental effectiveness of a manufacturing system.

Table 4.1: Parameters for evaluation of green manufacturing paradigms

S.No	Main	Sub parameters		References
P1	Technical perspectives	P1.1	Integration	Hua et al.,(2005)
		P1.2	Adaptability	Liu and Seddon,(2009)
		P1.3	Performance.	Moors et al.,(2005)
		P1.4	Development	Barbara et al.,(2010)
		P1.5	Reliability	Halme, et al.,(2007)
P2	Environmental perspectives	P2.1	Mitigation of green house gas emissions	Krajnc,(2005)
		P2.2	Enhance Energy efficiency	Krajnc,(2005); Tseng et al.,(2012)
		P2.3	Mitigate use of hazards substances	Azapagic,(2000)
		P2.4	Reduced Water Contamination	Hervani et al.,(2005)
		P2.5	Waste segregation and scrap disposal	Zhou et at.,(2000); Presley et al.,(2007)
P3	Operational perspectives	P3.1	Remanufacture	Tsoulfas et al., (2008); Tseng et al., (2012)
		P3.2	Optimization of production schedule	Amrina and yusaf,(2011)
		P3.3	Choice of eco-efficient suppliers	Tsui, and Wen,(2014), He et al.,(2008)
		P3.4	Optimise resource productivity	Zhou et al.,(2008), Tsoulfas et al., (2008)
		P3.5	Reliability	Zhu et al., (2008)
P4	Commercial perspectives	P4.1	Reduction in Pigouvian tax	Bovenberg,(1994);Jhansson,(1997)
		P4.2	Allotment of Pollution abatement subsides	Golombek and Hoel,(2004)
		P4.3	Gain of tradable pollution permits	Malueg, (1989); Requate and Unold,(2003)
		P4.4	Rate of return on investment	Hu and Bidanda ,(2009)
		P4.5	Source of capital	Barney (1991); Buysse and Verbeke, (2003).
P5	Social perspectives	P5.1	Employees safety	Sarkis et al., (2010)
		P5.2	Customers satisfaction	Henriques and Sadorsky , (1996) Ginsberg and Bloom , (2004)
		P5.3	Investors gain	Goldstein and Wiest, (2007)
		P5.4	Regulatory compliance	Dobers and Wolff, (2000)
		P5.5	Communities benefits	Kassinis and Vafeas, (2002)

4.2 METHODOLOGY

The study uses GTMA approach to compute the environmental effectiveness index in a manufacturing system.

The environmental effectiveness index of a manufacturing paradigm is evaluated by taking into consideration the inheritance among all the parameters and interdependencies in their sub-parameter. The computational steps of GTMA framework are shown in Figure 4.1.

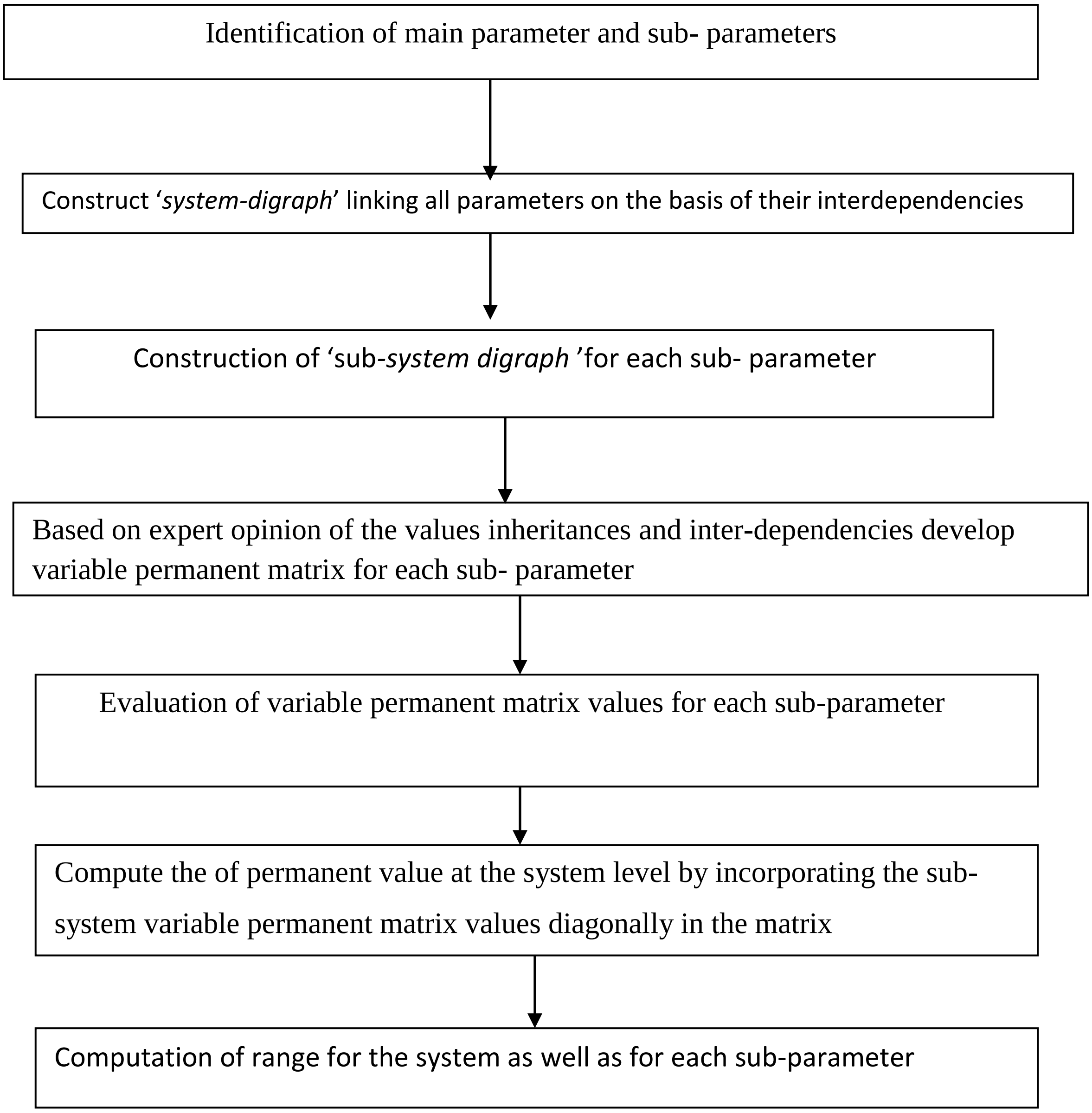

Figure 4.1: Computational steps of GTMA framework

4.2.1 Construction of digraph

The digraph consists of a set of nodes and a set of directed edges. A node represents parameters and edges represent the relative importance among the parameters.

4.2.2 Development of Permanent Matrix Representation

Mathematical modeling using matrix representation makes visual analysis easier than a complex digraph. Computational analysis of matrix information is easily done using computers. To establish a mathematical expression for computing environmental effectiveness index manufacturing, a matrix representation is established which will signify the digraph. Assuming 'n' number of parameter with interdependencies among all of them and no self-loops, the matrix for the evaluation effectiveness of manufacturing system digraph can be represented as:

$$\mathrm{PER(\,P)} \quad = \quad \begin{array}{c} \\ P1 \\ P2 \\ P3 \\ P4 \\ \cdots \\ \cdots \\ Pn \end{array} \begin{array}{c} \begin{array}{cccccccc} P1 & P2 & P3 & P4 & & & Pn \end{array} \\ \left(\begin{array}{cccccccc} P11 & P12 & P13 & P14 & \cdots & \cdots & P1n \\ P21 & P22 & P23 & P24 & \cdots & \cdots & P2n \\ P31 & P32 & P33 & P34 & \cdots & \cdots & P3n \\ P41 & P42 & P43 & P44 & \cdots & \cdots & P4n \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ Pn1 & Pn2 & Pn3 & Pn4 & & & Pnn \end{array} \right) \end{array} \tag{1}$$

In (1) Pij represent the inter-relationship between parameters Pi and Pj. Diagonal elements (P11, P22, P33, P44,……, Pnn) represent the inheritance of these parameters towards environmentally effective manufacturing. All the elements in the matrix have relative importance towards the evaluation of effectiveness of a manufacturing system. Quantitative estimation of environmental effectiveness index in manufacturing system of an organization can be obtained from variable permanent function (VPF) by substituting the numerical values assigned by the experts' opinion using Table 4.2 and Table 4.3.

Table 4.2: Inheritance value of sub parameters

S. No.	Intensity of inheritance	Assigned Value
1	Exceptionally low	1
2	Extremely low	2
3	Very low	3
4	Below normal	4
5	Normal	5
6	Above normal	6
7	High	7
8	Very high	8
9	Extremely high	9
10	Exceptionally high	10

Table 4.3: Interdependence value of main parameters

S. No.	Intensity of interdependence	Value to be assigned
1	Very weak	1
2	Weak	2
3	Medium	3
4	Strong	4
5	Very strong	5

4.2.3 Evaluation of Permanent Function

Quantitative estimation of effectiveness of manufacturing in an organization can be obtained from permanent function of the matrix (1). Permanent function is analogous to the determinant of a matrix where all the signs in the expression are taken as positive.

Quantitative estimation of effectiveness of manufacturing in an organization can be obtained from permanent function of the matrix (1). Permanent function is analogous to the determinant of a matrix where all the signs in the expression are taken as positive.

$$\text{Per}\begin{pmatrix} L & M & N \\ O & P & Q \\ R & S & T \end{pmatrix} = \text{L per}\begin{pmatrix} P & Q \\ R & T \end{pmatrix} + \text{M per}\begin{pmatrix} O & Q \\ R & T \end{pmatrix} + \text{N per}\begin{pmatrix} O & P \\ R & S \end{pmatrix}$$

$$= L*(P*T + Q*S) + M*(O*T + Q*R) + N*(O*S + P*R)$$

Similarly the computation of permanent function consisting of five parameters can be expressed by the following multinomial equation.

For simplicity, this can also be represented as below:

$$\text{VPF} = \text{PER (EEI)} = \prod_1^5 P_i + \sum_1^5 (p_{12}p_{21})P_3P_4P_5 + \sum_1^5 (p_{12}p_{23}p_{31} + p_{13}p_{32}p_{21})P_4P_5 + \{\sum_1^5 (p_{12}p_{21})(p_{34}p_{43})B_5 + \sum_1^5 ((p_{12}p_{23}p_{34}p_{41}) + (p_{14}p_{43}p_{32}p_{21}))B_5\} + \{\sum_1^5 (p_{12}p_{21})(p_{34}p_{45}p_{53} + p_{35}p_{54}p_{43}) + \sum_1^5 ((p_{12}p_{23}p_{34}p_{45}p_{51}) + (p_{15}p_{54}p_{43}p_{32}p_{21})\} \ldots\ldots\ldots\ldots \quad (1)$$

4.2.4 Determination of Environmental Effectiveness Index

Establishment of a green manufacturing system is challenging. A quantitative measure is required for measuring the performance of a system for transition towards green manufacturing. An assessment of environmental effectiveness index for the system will give an indication about the benefits that are obtained by implementation of new system. Environmental effective index of a manufacturing system is computed by the permanent function of the matrix representing relation among the parameters. Higher value of environmental effective index indicates that system is more environmentally benign. The environmental effectiveness index of different manufacturing systems can be evaluated using GTMA methodology for comparing competing systems. The following steps are employed to prepare framework to evaluate the environmental effectiveness index of manufacturing system. These are:

- Identification of various parameters which influence the environmental performance

- Structuring of Digraph linking parameters of environmental effectiveness
- Development of Matrix representation using inheritance value of each sub-parameters and computing VPF for each sub-parameters
- Computing the permanent value PER (E) environmental effectiveness index for the system by the integration of interdependencies among the evaluation parameters and their sub parameters.

4.3 CASE STUDY

To demonstrate the above methodology, a case of an industry is considered. Opinion from a panel of experts in field of green manufacturing is obtained to meet the research objectives and to obtain necessary inputs. A questionnaire-based survey was conducted to solicit responses to various parameters of environment effectiveness of a system and their sub parameters. On the basis of expert opinion, the quantitative measure of different parameters and the EEI value of a manufacturing system are determined by substituting the values of inheritance (Pi) and interdependencies (Pij) of parameters in equation (1).

Each perspective is considered as a unique sub-system and GTA is applied to each sub-system. Digraph of different perspectives encompassing different sub parameters is shown in Figure. 4.2 to Figure 4.5 along with their matrix representation. These are indicated below.

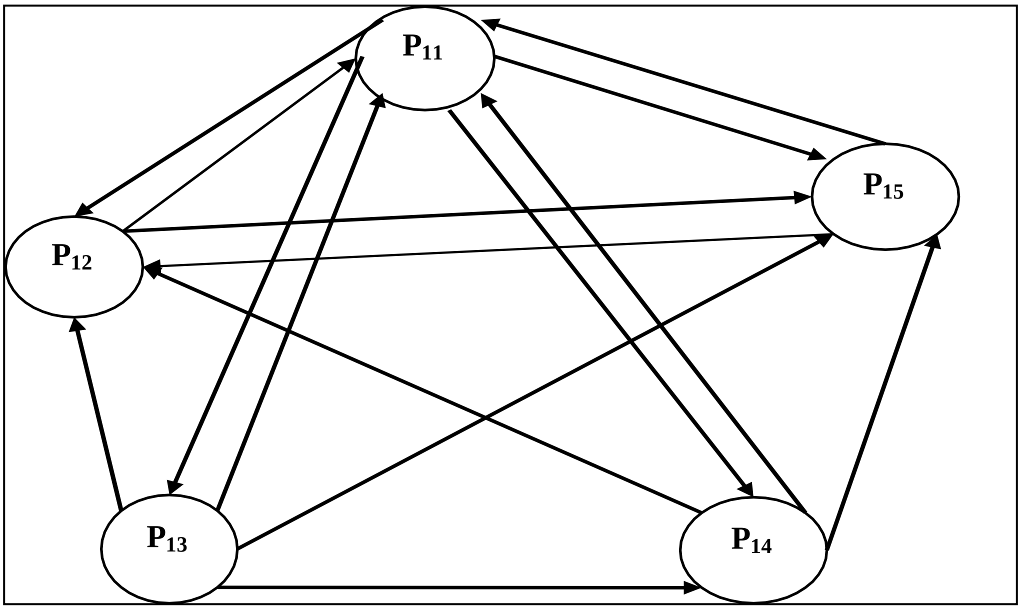

Figure 4.2: Digraph representing Technical Parameters

Matrix for technical parameters is shown below:

$$\text{VPF(T P)}=\begin{array}{c|ccccc|} & P11 & P12 & P13 & P14 & P15 \\ P11 & 6 & 4 & 3 & 2 & 1 \\ P12 & 4 & 6 & 0 & 0 & 3 \\ P13 & 5 & 4 & 6 & 2 & 3 \\ P14 & 5 & 4 & 0 & 6 & 5 \\ P15 & 4 & 4 & 0 & 0 & 9 \end{array}$$

VPF (T P) = 48600

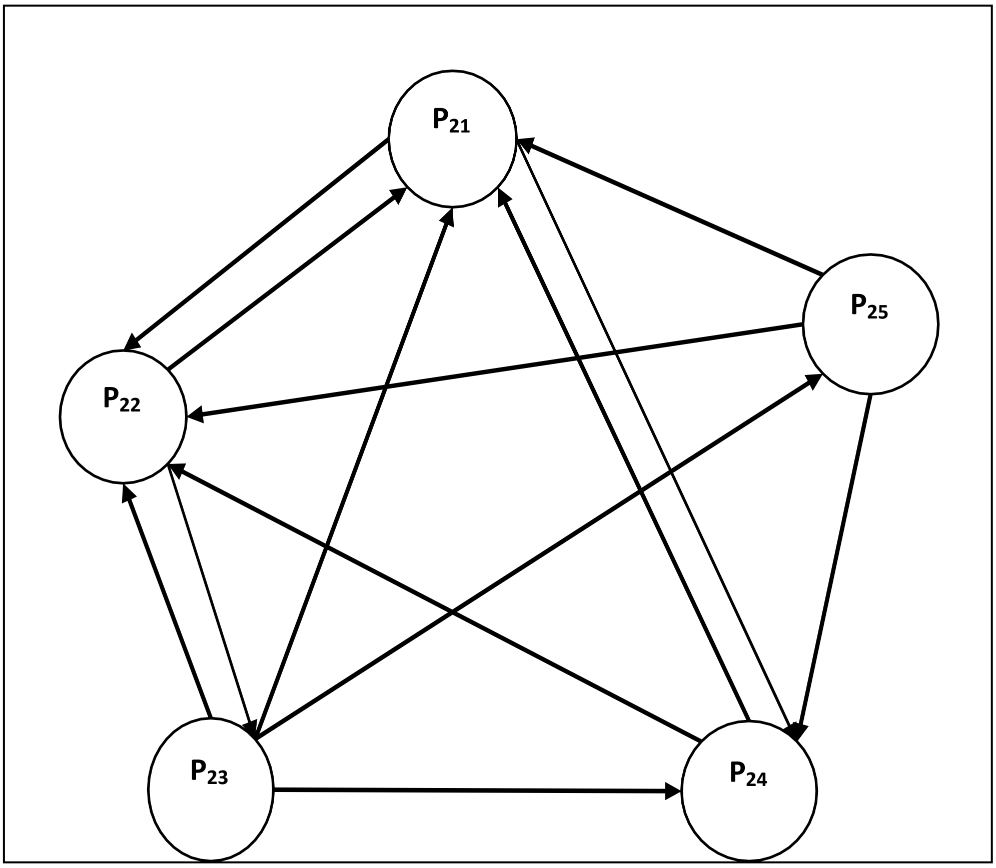

Figure 4.3: Digraph representing Environmental Parameters

Matrix for Environmental parameters is shown below:

$$
\text{VPF(EP)} = \begin{array}{c} \\ P21 \\ P22 \\ P23 \\ P24 \\ P25 \end{array}
\begin{array}{c}
\begin{array}{ccccc} P21 & P22 & P23 & P24 & P25 \end{array} \\
\begin{pmatrix}
7 & 4 & 0 & 5 & 0 \\
4 & 6 & 5 & 0 & 0 \\
5 & 6 & 6 & 4 & 4 \\
6 & 3 & 0 & 6 & 0 \\
5 & 4 & 0 & 4 & 6
\end{pmatrix}
\end{array}
$$

VPF (EP) =58638

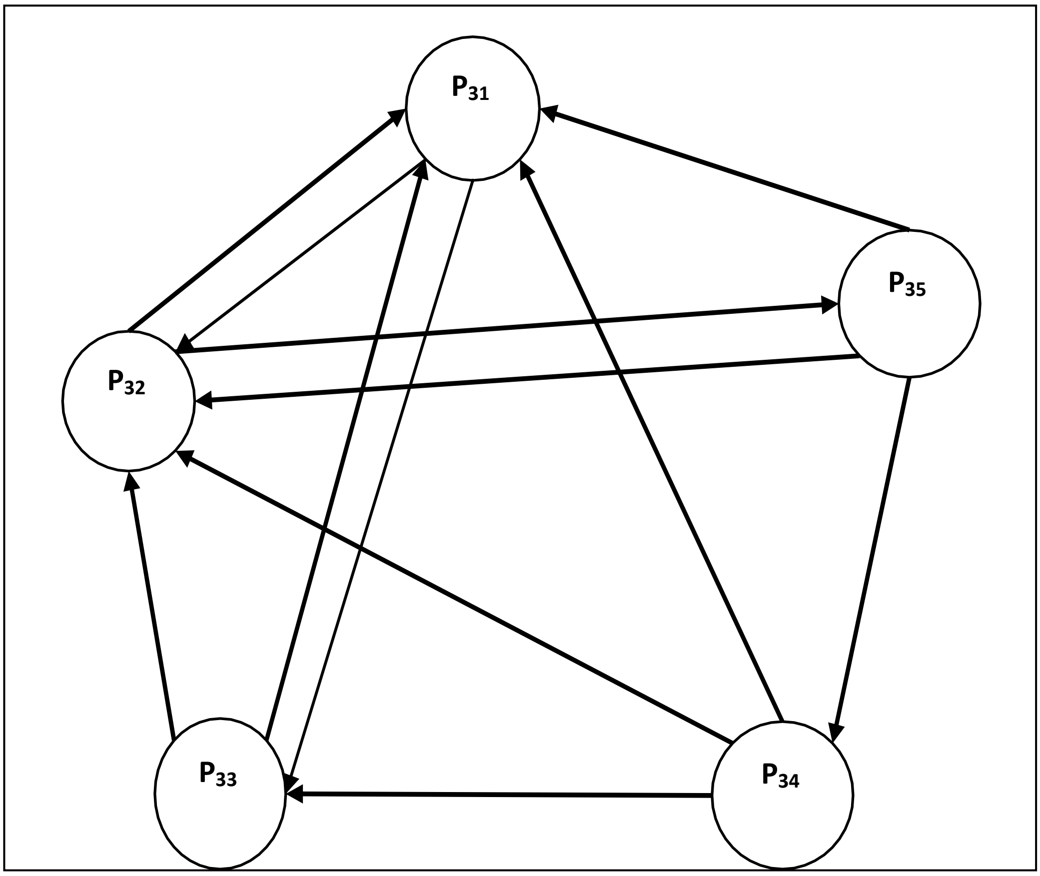

Figure 4.4: Digraph representing Operational Parameters

Matrix for Operational parameters is shown below

$$
VPF(OP) = \begin{array}{cccccc}
 & P31 & P32 & P33 & P34 & P35 \\
P31 & 7 & 6 & 4 & 0 & 0 \\
P32 & 4 & 6 & 0 & 0 & 4 \\
P33 & 4 & 5 & 7 & 0 & 0 \\
P34 & 4 & 3 & 3 & 2 & 0 \\
P35 & 4 & 3 & 0 & 4 & 6
\end{array}
$$

VPF (O P) =21120

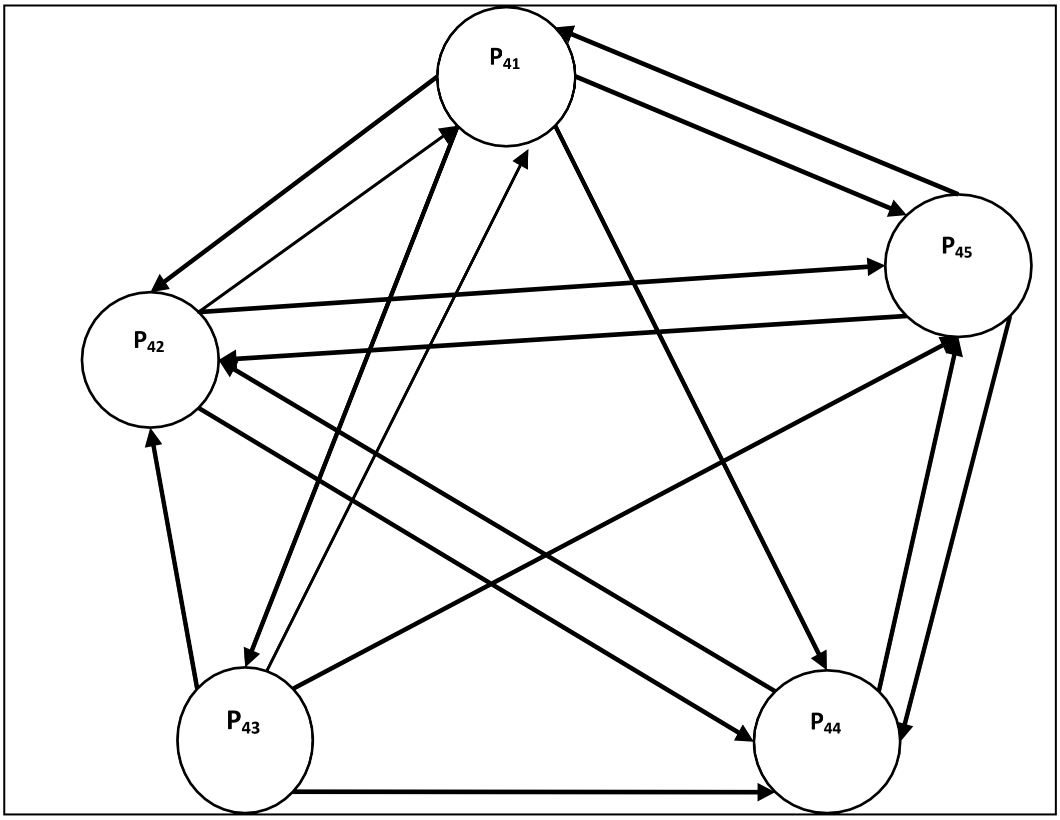

Figure 4.5: Digraph representing Commercial Parameters

Matrix for Commercial parameters is shown below:

$$VPF\ (C\ P) = \begin{array}{c|ccccc} & P41 & P42 & P43 & P44 & P45 \\ \hline P41 & 7 & 4 & 2 & 3 & 2 \\ P42 & 4 & 6 & 0 & 3 & 3 \\ P43 & 4 & 5 & 8 & 3 & 3 \\ P44 & 0 & 3 & 0 & 6 & 4 \\ P45 & 3 & 5 & 0 & 4 & 6 \end{array}$$

VPF (C P) =62040

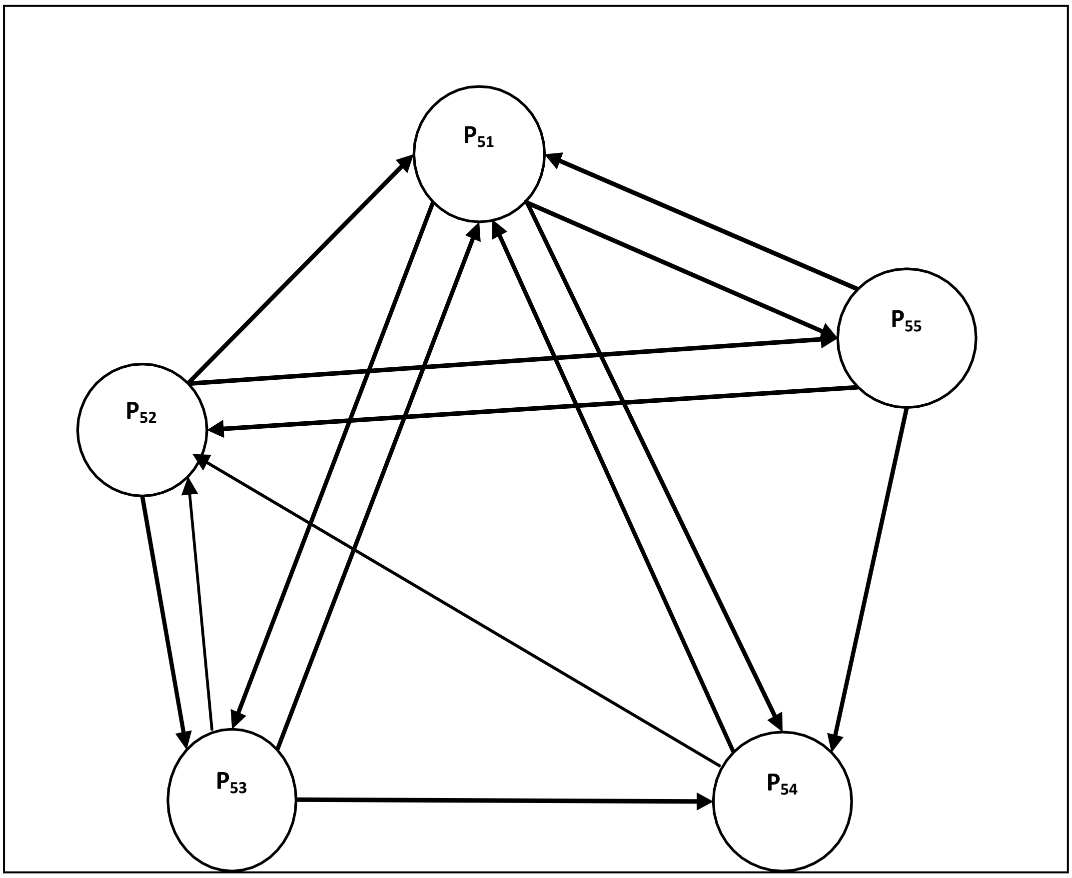

Figure 4.6: Digraph representing Social Parameters

Matrix for Social parameters is shown below:

$$\text{VPF (S)=}\begin{array}{c|ccccc} & P51 & P52 & P53 & P54 & P55 \\ \hline P51 & 7 & 0 & 2 & 3 & 4 \\ P52 & 2 & 5 & 2 & 0 & 3 \\ P53 & 2 & 3 & 7 & 3 & 0 \\ P54 & 3 & 3 & 2 & 3 & 0 \\ P55 & 3 & 3 & 0 & 4 & 5 \end{array}$$

VPF (S) =22961

This is obtained by computing the value of PER (EEI) using interdependence relationship among the various parameters indicated in Figure 4.7. The matrix at system level uses Table 3 for interdependence values among parameters. The values obtained at the subsystem level are used as the diagonal elements for computing permanent matrix

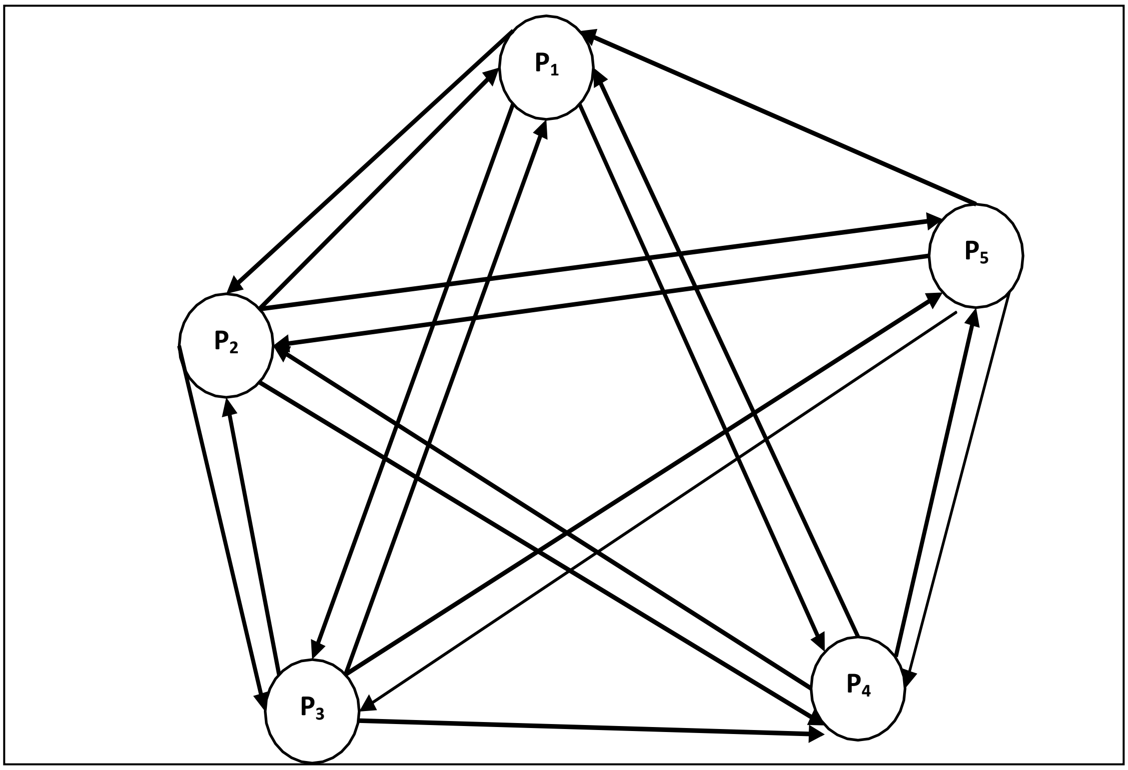

Figure 4.7: Digraph representing relationship between various parameters used for evaluating of environmental effectiveness of a system

Matrix representing relationships between various parameters used for evaluating of environmental effectiveness of a system is shown below.

$$
PER(EEI)=\begin{array}{c|ccccc}
 & P1 & P2 & P3 & P4 & P5 \\
\hline
P1 & 48600 & 3 & 1 & 2 & 0 \\
P2 & 2 & 58638 & 2 & 3 & 3 \\
P3 & 3 & 3 & 21120 & 2 & 3 \\
P4 & 2 & 3 & 0 & 62040 & 3 \\
P5 & 2 & 1 & 2 & 2 & 22961
\end{array}
$$

PER (EEI) =8.574 x 10^{22}

The value of permanent matrix Per (EEI) for the system is calculated as 8.574 x 10^{22}. This numerical value represents the cumulative effectiveness power of all parameters towards the environment evaluation of a system. To obtain a more meaningful implication from the analysis, the maximum and minimum values of manufacturing system must be determined. The PER (EEI) value for the system will be maximum if the inheritance of all sub parameters is 10 and will be minimum if inheritance value is 1. Table 4.4 shows the maximum and minimum values for each sub parameters and for the overall system.

Table 4.4: Range of EEI's

Sl. No.	Permanent function	Max value	Min value	Present value
1	VPF(T P)	193728	2496	48600
2	VPF(E P))	235770	8592	58638
3	VPF(O P)	188960	4613	21120
4	VPF(C P)	218510	4778	62040
5	VPF(S)	175722	3327	22961
6	Per P(EEI)	3.31 X 10^{26}	1.57 X10^{19}	8.574 X 10^{22}

It is observed that values in order of preference are VPF(C P) > VPF (E P)) > VPF (T P)>VPF(S) >VPF (OP). This signifies that in this case study commercial perspective is the predominant parameters towards evaluating environmental effectiveness of a system.

The range of PER (EEI) values can guide managers regarding the environmental effectiveness of the system. The PER (EEI) for various manufacturing can be evaluated using the GTA methodology as presented in this study. Based on the PER (EEI) values, competing systems can be compared for their environmental performance.

4.4 CONCLUSION

The main objective this work is to quantify the various parameters of evaluating the environmental effectives of system and provide a measureable single numerical index. For this purpose, a framework is proposed to evaluate environmental effectiveness of different parameters. The environmental evaluating index is a useful tool for to focus on parameters having low EEI. These types of parameters and sub parameters needs to be carefully addressed, while transition to green manufacturing system. Businesses must adopt necessary strategies for each parameter and sub parameter based on their EEI for successful adoption of green manufacturing. The framework developed also helps in evaluating alternative competing technologies.

Businesses actively pursuing a green manufacturing strategy are environmentally more benign than their competitors. Businesses need to adopt a balanced and integrated approach to balance cost, risk and reliability while meeting their environmental goals. It becomes imperative to understand the various parameters for evaluating the environmental performance of a system and their impact on the implementation of green manufacturing. Business focus on various considerations such as technical, environmental, operational, commercial and social parameters for an effective evaluation strategy

The computation of permanent function provides a single numerical value of environmental effectiveness index. By evaluating environmental effectiveness index of different industries, their manufacturing systems can be compared for their impact on environment.

By using an unbiased process of GTMA, helps businesses to focus on achieving goal of environmental protection. The will helps managers better understand the implications of different parameters for transition towards a green manufacturing. This will improve manufactures position to develop the right strategy for environment protection in the near and long term.

CHAPTER 5

EVALUATION OF CRITICAL SUCCESS FACTORS FOR IMPLEMENTATION GREEN MANUFACTURING

5.1 INTRODUCTION

Population explosion and the rapid industrialization are resulting in the depletion of non-renewable resources like fossil fuels, metals and minerals. This has aggravated the problems like climate change and global warming. Consequentially, serious environmental disasters, natural calamities etc are causing huge damages to life and property. The international community has become increasingly aware of these environmental concerns. The businesses' today are using green manufacturing techniques to prevent further damage to the ecosystem. They are espousing eco-efficient practices such as reduced hazardous gases emissions, optimal use of resources, proper waste management system etc. (Melnyk and Smith, 1996).

A quantitative analysis of factors which are critical for green manufacturing needs to be carried out. The green manufacturing initiatives are based on over-all assessments on the environmental impacts of manufactured products, energy consumption and waste generation using the Life Cycle Assessment (Dechant and Altman, 1994).The performance of green manufacturing can be evaluated based on operational, environmental, financial and social criteria as shown in Table 5.1.

Table 5.1: Criteria's for evaluating effectiveness of green manufacturing initiatives

Operational	Environmental	Financial	Social
• Optimum use of natural resources • Recycling of end-of-life products • Replacement of hazards products • Adoption of energy-saving processes and equipment	• Pre-use risk assessments for residual substances • Reducing the total waste generated • Proper waste segregation of substances produced • Using reverse logistics • Reducing greenhouse gases produced	• Revenue Growth • Reduced operating cost • Tax benefits and cheaper financing • Increased brand reputation	• Community well being • Safer working environment • Greater regulatory compliance

5.2 LITERATURE REVIEW

Many researchers have conducted studies on various elements of green manufacturing. Literature on issues such as green manufacturing, green design, sustainability, eco-innovation and lean manufacturing was studied. Based on this literature review, various critical success factors for green manufacturing were identified and the same are listed below:

5.2.1 Adopting Eco-innovations

These innovations are divided into, add-on innovations, integrated innovations and macro-organizational innovations (Liu and Seddon, 2009). Successful commercial implementation of newer methods requires a setting of cross functional team and financial resources (George and Jones, 2008). The critical factors considered for implementing new systems are integration and maintainability of newer technological processes and products with the existing system.

5.2.2 Setting up of Green supply chain

Establishing a comprehensive green supply chain system encompassing the various purchase activities, and suppliers, reduce the ecological impact of industrial activity **(**Routroy, 2009; Raut et al., 2017) .Conceptualization of environmentally benign procurement schemes with emphasis on communication, empowerment, vendor development, training and education of suppliers, financial support etc are key to adopting green manufacturing (Handfield et al., 1997; Lee and Kalseen et al., 2008). Unambiguous directions and frequent communications reduce the risk of conflicts among various stakeholders (Tayeb et al., 2010).

5.2.3 Integration with other waste reduction techniques (WRT)

Manufacturers need to assimilate waste reduction technique with in lean and green manufacturing implementation process (Halme, et al., 2007; Liu, et al., 2005) There direct correlation between lean and green manufacturing. Manufactures should adopt technologies for recycling of end products, remanufacturing, reuse of products/components, waste reduction and waste segregation

5.2.4 Use of Green Products and Process

Environmental regulatory compliances are driving organizations to adopt green processes and products. Substitution of hazardous substances by green products is critical for green manufacturing (Azzone and Noci, 1988). Manufactures are reorienting their operations by use of green products and processes. To survive the competitive pressures, manufactures need to incorporate green practices to project a green brand image (Digalwar and Sangwan, 2007).

5.2.5 Support of Management

For successful implementation of green manufacturing, sincere and sustained support of top management is imperative (Huang et al., 2009).A progressive management provides entrepreneurship skills, leadership, commitment, clear vision, and sufficient resources for investment in green manufacturing. Implementation of green manufacturing requires full-time competent, cross-functional, and process-centric teams possessing a comprehensive business and technical acumen (Kassinis and Vafeas, 2002; Del Brio et al., 2008).

5.2.6 Using Alternative Energy Sources

Manufactures are adopting alternative energy sources due to reduction in their cost and increased reliability (Bonilla et al., 2010). Alternative energy sources are those that can generate electricity with negligible harmful emissions. These inexhaustible sources offer environmental and economic benefits compared to fossil fuel energy sources (Barbara et al., 2012). Use of alternative energy source is paramount for establishing green manufacturing system.

5.2.7 Adopting Green disposal

Establishing an effective waste management system is critical for espousing green manufacturing. The regulatory and legal frameworks are being enacted based on the "polluter pay principal" (Lisney et al., 2003). Manufactures are implementing waste prevention strategies to reduce the cost of waste disposal. Adopting effective green manufacturing systems also involves less or no use of hazardous substances resulting in reduction of waste disposal cost (Polcari, 2007).

5.2.8 Government and regulatory support

Setting up of enabling infrastructure, financial incentives and regulatory norms are critical factors for transitioning to greener manufacturing (Huang et al., 2009).Effective financial incentives such as subsidies, tax exemptions and green permits are incentivize green manufacturing. Government and regulatory support stimulate confidence in manufactures to invest in technologies for green manufacturing (Dobers and Wolff, 2000).

5.2.9 Use of reverse logistics

Businesses are espousing processes which adopt reverse logistics techniques (Zhao, 2008). This reduces the use of resources for making new products. Manufacturers utilize previously shipped products for consumption through recycling and re-manufacturing. Reverse logistics uses products obtained from 'returns' due to defective production ; commercial returns because of low sales ; product recalls, warranty returns, service returns, end-of-use returns etc.(Shan and Yao, 2009; Wang and Gong, 2007).

5.2.10 Enhancing consumer base

Increased consumer acceptance of environmentally benign products is critical for green manufacturing. A green brand image helps in attracting a newer client base. This encourages manufactures to invest in green technologies. Flexibility in business model and effective financial management are critical elements for maintaining a strict environmental marketing budget (Chien and Shih, 2007).

5.2.11 Environmental benchmarking

Using an effective benchmarking system for Environmental Management that sets challenging goals and empowers employees to achieve them act as powerful tool in augmenting green manufacturing (Presley and Meade, 2010). Manufacturers are utilizing environmental benchmarking to improve their market competitiveness (Ginsberg and Bloom, 2004).

The critical success factors along with references are shown in Table 5.2.

Table 5.2: Critical success factors for implementation of green manufacturing

Sl. No.	Critical success factor	References
1	Adopting Eco innovations	Liu and Seddon, (2009); Geroge and Jones, (2008)
2	Setting up of Green supply chain	Routroy, (2009); Raut et al., (2017); Handfield et al., (1997);Lee et al., (2001);Tayeb, (2010)
3	Integration with other WRT	Halme et al., (2007); Liu et al., (2005)
4	Use of green products and process	Azzone and Noci, (1988); Digalwar and Sangwan, (2007)
5	Support of management	Huang et al.,(2009) ;Kassinis and Vafeas, (2002)
6	Using alternative energy sources	Bonilla et al., (2010); Barbara et al.,(2012)
7	Adopting Green disposal	Lisney et al.,(2003); Polcari, (2007)
8	Government and regulatory support	Dobers and Wolff, (2000)
9	Use of reverse logistics	Zhao, (2008); Shan and Yao (2009);Wang and Gong, (2007)
10	Enhancing consumer base	Chien and Shih, (2007)
11	Environmental Benchmarking	Presley and Meade, (2010); Ginsberg and Bloom, (2004)

5.3. METHODOLOGY

Factors responsible for successful transitioning to green manufacturing are identified based on literature reviews and opinion of professionals from industry and academia. Multi-criteria decision making techniques (MCDM), is one of the effective methodologies in decision making for complicated problems that exhibit uncertainty, conflicts, alternatives, variable interests and multiple criteria. MCDM methodologies are used for prioritizing, weighting and selecting the most appropriate factors. MCDM techniques commonly used for such type of research are: AHP, ANP, TOPSIS, and VIKOR etc. In the present research, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) has been preferred over other MCDM techniques. This is due to the fact that TOPSIS does not have any explicit limit over the number of alternatives/criteria that can be considered. Moreover, TOPSIS technique does not require pair-wise comparison or a consistency check. This makes TOPSIS a better and simpler method for decision making. Researchers have successfully used TOPSIS in different business areas like manufacturing systems, supplier selection and logistics, engineering design and marketing strategies.

TOPSIS method was introduced for the first time by Hwang and Yoon (1981) and later modified by Hwang et al., (1993).The fuzzy version of the TOPSIS was suggested by Triantaphyllou and Lin, (1996). TOPSIS is a goal based approach for finding the factors that is closest to the ideal solution. Various factors are ranked based on their similarity with ideal solution. An option is ranked higher if it is more similar to an ideal solution. Fuzzy TOPSIS is a useful method dealing with multi-attribute or MCDM problems. Use of Fuzzy TOPSIS removes vagueness associated with subjective judgments.

The fuzzy mathematical programming was developed for treating uncertainties *i.e.* ambiguity and vagueness in real life. In fuzzy methodology conversion scales based on a triangular fuzzy number set that are applied to transform the linguistic terms into fuzzy numbers. Figure 5.1 shows the various steps involved in fuzzy TOPSIS.

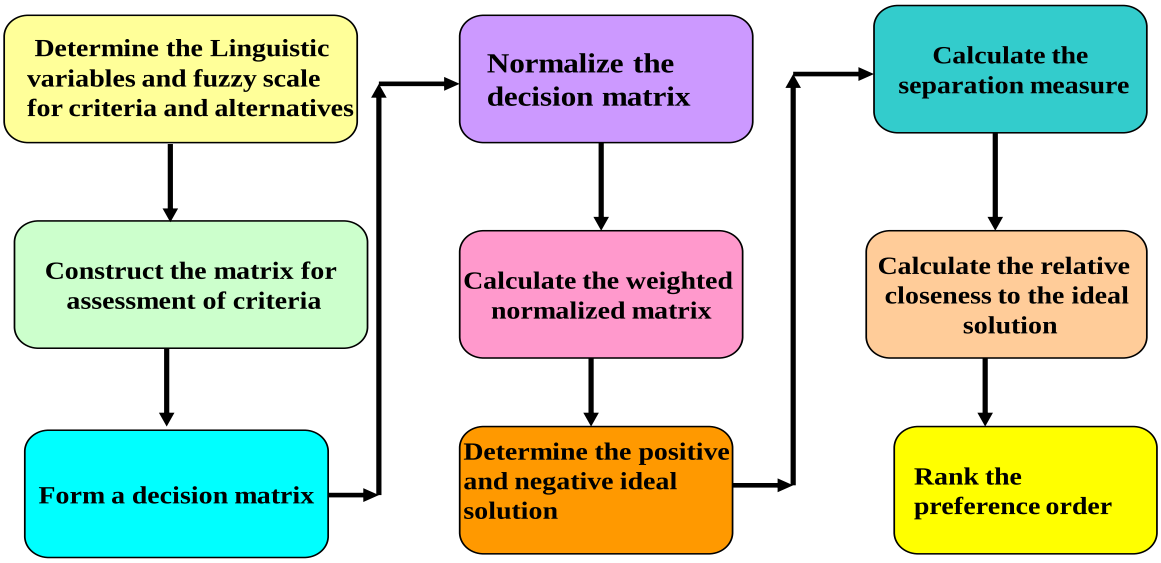

Figure 5.1: Various steps involved in Fuzzy TOPSIS

The Linguistic variables and fuzzy scale for criteria and critical success factors for implementing green manufacturing are shown in Table 5.3.

Table 5.3: Linguistic variables and fuzzy scale for criteria and critical success factors

Linguistic terms for Criteria	**Linguistic terms for factors**	**Membership Function on Fuzzy Scale**
Poor	Not Important	(1,1,3)
Fair	Less Important	(1,3,5)
Good	Fairly Important	(3,5,7)
Very good	Important	(5,7,9)
Excellent	Very Important	(7,9,9)

For this study Operational, Environmental, Financial and Social factors are identified as criteria for evaluating successful transition from traditional to green manufacturing. A panel comprising of experts from government, industry and academies working in the field of green manufacturing was formed. Their assessment ratings so obtained are shown in Table 5. 4.

Table 5.4: Assessment of criteria

Criteria	**Group I**	**Group II**	**Group III**
Operational	Very Good	Very Good	Good
Environmental	Good	Very Good	Very Good
Financial	Good	Very Good	Excellent
Social	Good	Excellent	Very good

The linguistic ratings are replaced by their fuzzy membership functions using Table 3 and their Aggregate Fuzzy Weight calculated using the relationship below.

$$\mathbf{X = \min_u (x_u), \quad Y = \frac{1}{U}\sum_{U=1}^{U} y_u, \quad Z = \max_u (z_u)}$$

Aggregate Fuzzy weights of the criteria are shown Table 5.5.

Table 5.5: Aggregate fuzzy weights of the criteria

Criteria	Group I	Group II	Group III	FUZZY WEIGHTS	
Operational	(5,7,9)	(5,7,9)	(3,5,7)	W1	(3,6.33,9)
Environmental	(3,5,7)	(5,7,9)	(5,7,9)	W2	(3,6.33,9)
Financial	(3,5,7)	(5,7,9)	(7,9,9)	W3	(3,7,9)
Social	(3,5,7)	(7,9,9)	(5,7,9)	W4	(3,7,9)

The decision matrix for the various critical success factors obtained in linguistics terms from experts is shown below in Table 5.6.

Table 5.6: Assessment of critical success factors

Criteria → **CSF** ↓	**Operational**	**Environmental**	**Financial**	**Social**
C1	Fairly Important	Important	Very Important	Important
C2	Important	Very Important	Important	Important
C3	Important	Less Important	Important	Fairly Important
C4	Fairly Important	Important	Very Important	Very Important
C5	Important	Important	Very Important	Important
C6	Fairly Important	Important	Important	Fairly Important
C7	Important	Important	Important	Important
C8	Important	Fairly Important	Important	Very Important
C9	Important	Important	Very Important	Important
C10	Less Important	Important	Very Important	Fairly Important
C11	Important	Important	Important	Very Important

The linguistic ratings are replaced by their fuzzy membership functions of different alternatives using table 5.3 is indicated below in Table 5.7.

Table 5.7: Assessment of critical success factor in fuzzy terms

Criteria → CSF ↓	Operational	Environmental	Financial	Social
C1	(3,5,7)	(5,7,9)	(7,9,9)	(5,7,9)
C2	(5,7,9)	(7,7,9)	(5,7,9)	(5,7,9)
C3	(5,7,9)	(1,3,5)	(5,7,9)	(3,5,7)
C4	(3,5,7)	(5,7,9)	(7,9,9)	(7,9,9)
C5	(5,7,9)	(5,7,9)	(7,9,9)	(5,7,9)
C6	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)
C7	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)
C8	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
C9	(5,7,9)	(5,7,9)	(7,9,9)	(5,7,9)
C10	(1,3,5)	(5,7,9)	(7,9,9)	(3,5,7)
C11	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,9)

The various alternatives are then normalized using a linear scale transformation as given below.

$$\tilde{r} = \left(\frac{a}{c_{ij}^{*}}, \quad \frac{b}{c_{ij}^{*}}, \quad \frac{c}{cij^{*}} \right)$$

$$c^{*} \quad = max\{c\} \text{ (Benefit or Importance Criteria) } c_{ij}^{*}$$

This is to align the various alternative scales on a comparable scale as shown in Table 5.8.

Table 5.8: Normalized valve of critical success factors

Criteria → CSF ↓	Operational	Environmental	Financial	Social
C1	(0.33,0.56,0.78)	(0.56,0.78,1)	(0.78,1,1)	(0.56,0.78,1)
C2	(0.56,0.78,1)	(0.78,0.78,1)	(0.56,0.78,1)	(0.56,0.78,1)
C3	(0.56,0.78,1)	(0.11 ,0.33,0.56)	(0.56,0.78,1)	(0.33,0.56,0.78)
C4	(0.33,0.56,0.78)	(0.56,0.78,1)	(0.78,1,1)	(0.78,1,1)
C5	(0.56,0.78,1)	(0.56,0.78,1)	(0.78,1,1)	(0.56,0.78,1)
C6	(0.33,0.56,0.78)	(0.56,0.78,1)	(0.56,0.78,1)	(0.33,0.56,0.78)
C7	(0.56,0.78,1)	(0.56,0.78,1)	(0.56,0.78,1)	(0.56,0.78,1)
C8	(0.56,0.78,1)	(0.33,0.56,0.78)	(0.56,0.78,1)	(0.78,1,1)
C9	(0.56,0.78,1)	(0.56,0.78,1)	(0.78,1,1)	(0.56,0.78,1)
C10	(0.11 ,0.33,0.56)	(0.56,0.78,1)	(0.78,1,1)	(0.33,0.56,0.78)
C11	(0.56,0.78,1)	(0.56,0.78,1)	(0.56,0.78,1)	(0.78,1,1)

The weighted normalized matrix is calculated using the weights of criteria (P_{ij}).This is shown in in Table 5.5 and normalize alternatives value x (α_{ij}) is shown in Table 5.8.

$V_{ij} = (P_{ij}) \times (\alpha_{ij})$

The weighted normalized matrix is given below in table 5.9

Table 5.9: Weighted normalized value of critical success factors

Criteria → CSF ↓	Operational	Environmental	Financial	Social
C1	(0.99,3.54,7.02)	(1.68,4.94,9)	(2.34,7,9)	(1.68,5.46,9)
C2	(1.68,4.94,9)	(2.34,4.94,9)	(1.68,5.46,9)	(1.68,5.46,9)
C3	(1.68,4.94,9)	(0.33,2.08,5)	(1.68,5.46,9)	(0.99,3.92,7.02)
C4	(0.99,3.54,7.02)	(1.68,4.94,9)	(2.34,7,9)	(2.34,7,9)
C5	(1.68,4.94,9)	(1.68,4.94,9)	(2.34,7,9)	(1.68,5.46,9)
C6	(0.99,3.54,7.02)	(1.68,4.94,9)	(1.68,5.46,9)	(0.99,3.92,7.02)
C7	(1.68,4.94,9)	(1.68,4.94,9)	(1.68,5.46,9)	(1.68,5.46,9)
C8	(1.68,4.94,9)	(0.99,3.54,7.02)	(1.68,5.46,9)	(2.34,7,9)
C9	(1.68,4.94,9)	(1.68,4.94,9)	(2.34,7,9)	(1.68,5.46,9)
C10	(0.33,2.08,5)	(1.68,4.94,9)	(2.34,7,9)	(.99,3.92,7.02)
C11	(1.68,4.94,9)	(1.68,4.94,9)	(1.68,5.46,9)	(2.34,7,9)
Vj+	(9,9,9)	(9,9,9)	(9,9,9)	(9,9,9)
Vj-	(0.33, 0.33, 0.33)	(0.33, 0.33, 0.33)	(0.33, 0.33, 0.33)	(0.33, 0.33, 0.33)

TOPSIS involves calculating the Fuzzy positive ideal solution and Fuzzy negative ideal solution. Table 5.10 indicates that Fuzzy Positive ideal solution maximizes the benefit criteria, and minimizes the cost criteria. This situation is depicted by:

$V_j+ = \{v_i + \dots v_n+\} = ((\max v_{ij} \mid i \in I), (\min v_{ij} \mid i \in I))$

Table 5.10: Fuzzy Positive ideal solution

Criteria →	**Operational**	**Environmental**	**Financial**	**Social**
CSF ↓				
C1	5.679	4.809	3.995	4.671
C2	4.809	4.481	4.671	4.671
C3	4.809	6.774	4.671	5.561
C4	5.679	4.809	3.995	3.995
C5	4.809	4.809	3.995	4.671
C6	5.679	4.809	4.671	5.561
C7	4.809	4.809	4.671	4.671
C8	4.809	5.684	4.671	3.995
C9	4.809	4.809	3.995	4.671
C10	6.372	4.809	3.995	5.561
C11	5.319	4.809	4.671	3.995

Table 5.11 indicates Fuzzy Negative ideal solution showing the maximum cost criteria and minimizes the benefit criteria. This is given by

$$V_j^- = \quad \{v_i^- \ldots v_n^-\} = \quad ((\min v_{ij} \mid i \in I), (\max vij \mid i \in I).$$

Table 5.11: Fuzzy Negative ideal solution

Criteria →	**Operational**	**Environmental**	**Financial**	**Social**
CSF ↓				
C1	4.280	5.694	6.389	5.839
C2	5.694	5.758	5.839	5.839
C3	5.694	2.865	5.839	4.378
C4	4.280	5.694	6.389	6.389
C5	5.694	5.694	6.389	5.839
C6	4.280	5.694	5.839	4.378
C7	5.694	5.694	5.839	5.839
C8	5.694	4.279	5.839	6.389
C9	5.694	5.694	6.389	5.839
C10	5.081	5.694	6.389	4.378
C11	3.865	5.694	5.839	6.389

Calculate the separation measure & calculate the relative closeness to the ideal solution using vertex method. It is expressed as aggregated closeness coefficient. The mathematical relationship is as below

$$S_1{}^{+} = \{\frac{1}{3} \text{x} \sum\nolimits_{j=1}^{n} (\,\mathbf{vij} - \mathbf{vj}^{+})^2\,\}^{0.5}$$

$$S_2{}^{-} = \{\frac{1}{3} \text{x} \sum\nolimits_{j=1}^{n} (\,\mathbf{vij} - \mathbf{vj}^{-})^2\,\}^{0.5}$$

The Aggregated closeness coefficient for critical success factors calculated as:

$$\text{S} = \frac{\text{S}_2^-}{\text{S}_1^+ + \text{S}_2^-}$$

The aggregated closeness coefficient for the critical success factors are shown in Table 5.12.

Table 5.12: Closeness coefficient for critical success factors

Critical success factor	**S_1+**	**S_2^-**	S= $\frac{\mathbf{S_2^-}}{\mathbf{S_1^+ + S_2^-}}$
C1	19.153	22.202	0.53686
C2	18.631	23.129	0.56364
C3	21.815	18.776	0.55386
C4	18.477	22.752	0.55185
C5	18.283	23.616	0.54886
C6	20.720	20.191	0.5484
C7	18.959	23.065	0.53688
C8	19.158	22.201	0.53679
C9	18.283	22.202	0.50952
C10	20.737	21.542	0.49354
C11	18.794	21.786	0.46257

The critical success factors are ranked in decreasing order of their closeness coefficient The Critical Success Factor closest to the FPIS and farthest from the FNIS is considered as the paramount factor. Table 5.13 depicts the ranking of critical success factors based on their aggregated closeness coefficient.

Table 5.13: Ranking of critical success factors for implementation of green manufacturing

Priority Rank	Critical Success Factor	Aggregated closeness coefficient
1	Adopting Eco innovations	0.563643
2	Use of reverse logistics	0.553857
3	Government and regulatory support	0.551846
4	Adopting Green disposal	0.548859
5	Using alternative energy sources	0.548403
6	Support of management	0.536876
7	Use of green products and process	0.536859
8	Integration with other WRT	0.536793
9	Setting up of Green supply chain	0.509523
10	Environmental Benchmarking	0.493536
11	Enhancing consumer base	0.462566

The closeness coefficient for individual criteria is evaluated to determine the effect of individual factor with respect to different criteria's. Table 5.14 shows closeness coefficient for individual criteria.

Table 5.14: Closeness coefficient for critical success factors

Factor → Criteria ↓	Adopting Eco innovations	Setting up of Green supply chain	Integration with other WRT	Use of green products and process	Support of management	Using alternative energy sources	Adopting Green disposal	Govt and regulatory support	Use of reverse logistics	Enhancing consumer base	Environmental Benchmarking
Operational	0.430	0.542	0.542	0.430	0.542	0.430	0.542	0.542	0.471	0.444	0.421
Environment	0.542	0.562	0.297	0.542	0.542	0.542	0.542	0.430	0.542	0.542	0.542
Financial	0.615	0.556	0.556	0.615	0.615	0.556	0.556	0.556	0.615	0.615	0.556
Social	0.556	0.556	0.440	0.615	0.556	0.440	0.556	0.615	0.556	0.440	0.615

5.4. RESULT AND DISCUSSION

As compared to traditional manufacturing, green manufacturing has the distinguishing features such as reduction in hazardous emissions, optimal use of resources and efficient waste management. This study ranks the various factors, which act as pivots for promoting a transition towards green manufacturing. These factors are ranked using Fuzzy Logic for Order Preference by mapping these to an Ideal Solution. The analysis highlights that the factor “adoption of eco-innovations” has an aggregated closeness coefficient of 0.563643 which is ranked I and is therefore of paramount importance. Use of eco-innovations provides enhanced flexibility and automation through use of newer technologies like artificial intelligence, internet of things, smart sensors etc. Use of eco-innovations is followed by “Use of reverse logistics” having an aggregated closeness coefficient of 0.553857 and is ranked II. This factor emphasizes on re-manufacture and reuse of materials for resource conservation. “Government and regulatory support” has an aggregated closeness coefficient of 0.551846 and is ranked III. This factor highlights the fact that government should extend tax incentives and subsidies for transitioning towards Green manufacturing. A business friendly regulatory structure is critical for stimulating green manufacturing. “Adopting Green disposal” has an aggregated closeness coefficient of 0.548859 and is ranked IV. Design of greener products should be based on Life Cycle Assessment of products and its end of life disposal policy. On a similar note, other factors have been ranked as given in Table 5.13. “Support of management” has an important role towards environment protection thus paving the way for greener manufacturing. There is an urgent need for switching to “Alternate energy sources” so as to minimize hazardous gas emission. “Setting up of Green supply chain” with green credentials can enable organizations to substitute hazardous products with environment friendly products. A green brand image can be leveraged to enhance customer base and increase revenues

For operations criteria, setting up of green supply chain, integration with other waste reduction techniques, and support of management, green disposal, and government and regulatory support with 0.542 closeness coefficient are paramount. For environmental criteria, adopting eco innovations, green supply chain, use of green products and adopting green disposal with 0.562 closeness coefficient are critical. For financial criteria, adopting eco innovations, use of green products and processes, management support, use of reverse logistics with coefficient of 0.615 are important.

For social criteria, government and regulatory support, use of green products and processes with closeness coefficient of 0.615 are important.

5.5 CONCLUSION

Manufactures today are using green techniques to make their operations environmentally benign and prevent damage to the ecosystem. They are implementing systems to make manufacturing eco-efficient by reducing hazardous gases emissions, optimal utilization of resources , proper waste disposal system etc. This study identifies the critical success factors for transitioning from traditional to green manufacturing. The study uses Fuzzy TOPSIS to filter the uncertainties and ambiguity in linguistic terms to evaluates and rank critical success factors for implementing green manufacturing. The effects of these factors on green manufacturing are evaluated using operational, environmental, financial and social criteria. This study provides managerial insights to the decision makers in prioritizing factors which affect the green manufacturing paradigm. Specifically for the current study, factors of adoption of eco-innovations and reverse logistics are placed at priority Level I & II. Each critical factor is designated by a particular value of closeness coefficient which reveals the ‘nearness’ to Fuzzy positive ideal solution and distance from Fuzzy negative ideal solution.

CHAPTER 6

ISM MODELING FOR DRIVERS OF GREEN MANUFACTURING

6.1 INTRODUCTION

The rapid growth in manufacturing activities over the past few decades through indiscriminate use of natural resources has played havoc on our environment. Businesses now find it imperative to address the challenges of environmental degradation. Organizations are developing strategies to re-orient their manufacturing operations for green manufacturing. Green manufacturing paradigm uses technologies based on green energy, green design and green process to achieve the goals of environmentally benign manufacturing. Green manufacturing increases resource efficiency and reduces waste. Consequently, businesses are leveraging innovative technologies like green computing for reducing energy usage and artificial intelligence to optimize production schedules.

Numerous drivers act as pivots for adopting green manufacturing. These factors act as motivators to propel the innate desire of business to improve their environmental performance.

ISM is used to construct a conceptual co-relational model for green manufacturing. The study provides an insight into clusters of drive/driven factors using MICMAC analysis. These factors complement each other, further strengthening the argument for environmentally benign manufacturing. Table 6.1 shows list of drivers along-with the references.

Table 6.1: List of driver for adoption of green manufacturing

Driver No	Drivers for green manufacturing	References
1	Regulatory compliance Pressure	Kassinis and Vafeas,(2002); Zeng,(2011); Zhu et al., (2007); Raut et al., (2017)
2	Impetus of investors	Vos et al.,(2003);Greeno and Robinson,(1992); Darnall et al., (2009)
3	Eco- innovations	Tseng et al., (2012); Oke, (2007); Weng et al., (2015)
4	Competitor Pressure	Shubham and Murty,(2018);Delmas and Toffel (2004); Huang et al., (2009)
5	Need for resource conservation	Rusinko,(2007);Hoffman,(2001);Gandhi et al .,(2018)
6	Waste disposal	Dornfeld, (2009); Vos, (2004); Seth, et al., (2018)
7	Suppliers awareness	Handfield et al., (1997); Lee et al., (2001); Tayeb, (2010); Moktadir et al., (2018); Routroy, (2009), Raut. et al., (2017)
8	Financial Incentives	Montabon et al., (2007); Chen et al., (2015); Dauvergne et al.,(2018)
9	Consumers pull for greener products	Anderson and Cunningham, (1972), Henriques et al., (1996), Qi et al., (2018), Huang, (2015);Pawaskar et al., (2018).
10	Employees welfare	Buzzelli ,(1991); Fergusson and Langford, (2006); Daily et al., (2001) ; Ghazilla, et al., (2015)

6.2 ISM METHODOLOGY

ISM is a powerful tool to develop a comprehensive model involving a set of elements that may be directly or indirectly related. The model helps to structure a complex problem and gives graphical representation. Important steps in ISM are:

i. Identification and listing of variables/ elements of green manufacturing
ii. Development of SSIM (Structural Self Interaction Matrix)
iii. Development of Reachability Matrix
iv. Ranking of variables using Level Partitioning
v. MICMAC analysis for classification of variables based on their drive and dependence power

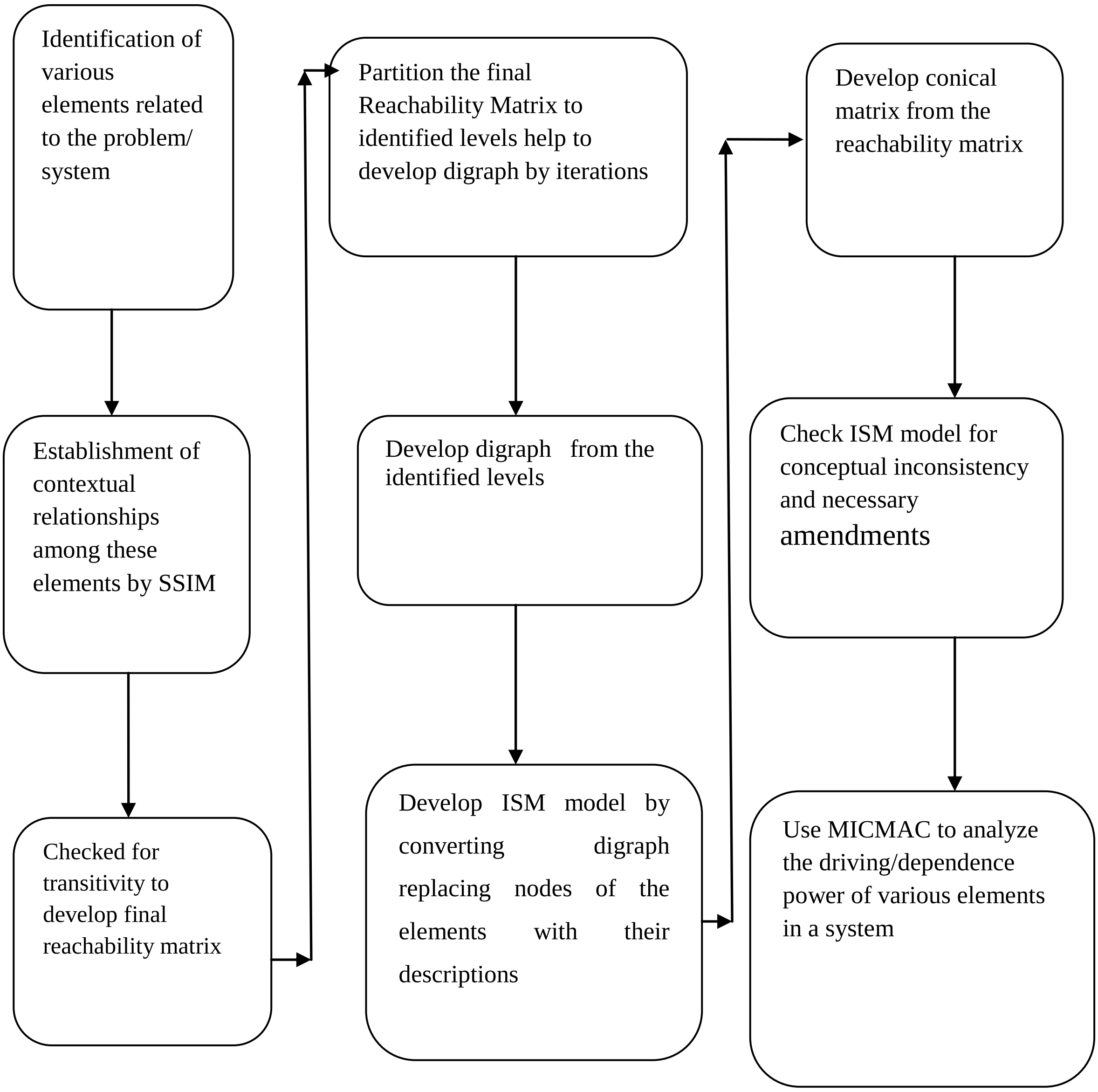

Figure 6.1: Computational steps of ISM framework

6.3 DEVELOPMENT OF ISM MODEL

With the help of Academicians and Industry Experts' the contextual relationships among the identified drivers of green manufacturing were developed. Symbols V, A, X and O are used to denote the mutual relationships among the driver metrics (a, b):

V: If a help to achieve b

A: If b help to achieve a

X: If both a and b help to achieve each other

O: If a and b has no relation

Table 6.2 represents the contextual relationships among the drivers for green manufacturing.

Table 6.2: Contextual relationships among the drivers for green manufacturing

Sl. No.	→	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**
↓	Drivers for green manufacturing	Employees welfare	Consumer pull	Financial Incentive	Supplier awareness	Waste disposal	Resource conservation	Pressures from competitors	Eco innovation	Imputes of investors
1	Regulatory compliance Pressure	V	V	V	V	V	V	V	**V**	**V**
2	Impetus of investors	V	V	V	V	O	V	A	**X**	
3	Eco innovations	X	V	V	V	V	O	A		
4	Pressures from competitors	V	V	V	V	V	V			
5	Resource conservation	O	V	A	A	X				
6	Waste disposal	A	V	A	A					
7	Suppliers awareness	A	V	V						
8	Financial incentives	A	V							
9	Consumers pull	**A**								

The following rules in Table 6.3 are used to prepare the Initial Reachability Matrix.

Table 6.3: Rule adopted for Initial Reachability Matrix

Matrix	Matrix	Substitution rule followed
$A_{(a,b)}$	V	Put 1 in place of $A_{(a,b)),}$0 of $A_{(b,a)}$
	A	Put 0 in place of $A_{(a,b)}$ and 1 in place of $A_{(b,a)}$
	X	Put 1 in place of $A_{(a,b)}$ and $A_{(b,a)}$
	O	Put 0 in place of $A_{(a,b)}$ and $A_{(b,a)}$

Initial Reachability matrix is shown in Table 6. 4

Table 6.4: Initial Reachability Matrix

Driver no.	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	1	1	1	1	1
2	0	1	1	0	1	0	1	1	1	1
3	0	1	1	0	0	1	1	1	1	1
4	0	1	1	1	1	1	1	1	1	1
5	0	0	0	0	1	1	0	0	1	0
6	0	0	0	0	1	1	0	0	1	0
7	0	0	0	0	1	1	1	1	1	0
8	0	0	0	0	1	1	0	1	1	0
9	0	0	0	0	0	0	0	0	1	0
10	0	0	1	0	0	1	1	1	1	1

Final reachability matrix (Table 6.5) is obtained by applying the Transitivity rule. Transitivity rule states that if a variable p affects q and q affects r, then p will affect r.

Table 6.5: Final Reachability Matrix

Driver no.	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	1	1	1	1	1
2	0	1	1	0	1	1^*	1	1	1	1
3	0	1	1	0	1^*	1	1	1	1	1
4	0	1	1	1	1	1	1	1	1	1
5	0	0	0	0	1	1	0	0	1	0
6	0	0	0	0	1	1	0	0	1	0
7	0	0	0	0	1	1	1	1	1	0
8	0	0	0	0	1	1	0	1	1	0
9	0	0	0	0	1^*	1^*	0	0	1	0
10	0	1^*	1	0	1	1^*	1	1	1	1

*Transitivity

6.3.1 Level partitioning

Final reachability matrix (RM) contains the reachability set and antecedent set. Reachability set consists of the driver itself and other drivers influenced by it. Antecedent set consists of the driver itself and all other drivers that may influence it. The intersection consists of common sets between the reachability set and antecedent set. Table 6.6 to Table 6.11 shows the different iterations of level identification process.

Table 6.6: Partition of RM (first iteration)

Driver no.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7,8,9,10	1	1	
2	2,3,5,6,7,8,9,10	1,2,3,4,10	2,3,10	
3	2,3,5,6,7,8,9,10	1,2.3,4,10	2,3,10	
4	2,3,4,5,6,7,8,9,10	1,4	4	
5	5,6,9	1,2,3,4,5,6,7,8,9,10	5,6,9	I
6	5,6,9	1,2,3,4,5,6,7,8,9,10	5,6,9	I
7	5,6,7,8,9	1,2,3,4.7,10	7	
8	5.6,8,9	1,2,3,4,7,8,10	8	
9	5,6,9	1,2,3,4,5,6,7,8,9,10	5,6,9	I
10	2,3,5,6,7,8,9,10	1,2,3,4,10	2,3,10	

Table 6.7: Partition of RM (second iteration)

Driver no.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,7,8,10	1	1	
2	2,3,7,8,10	1,2,3,4,10	2,3,10	
3	2,3,7,8,10	1,2.3,410	2,3,10	
4	2,3,4, 7,8,10	1,4	4	
7	7,8,	1,2,3,4.7,10	7	
8	8	1,2,3,4,7,8,10	8	II
10	2,3,7,8,10	1,2,3,4,10	2,3,10	

Table 6.8: Partition of RM (third iteration)

Driver no.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,7,10	1	1	
2	2,3,7,10	1,2,3,4,10	2,3,10	
3	2,3,7,10	1,2.3,4,10	2,3,10	
4	2,3,4, 7,10	1,4	4	
7	7	1,2,3,4.7,10	7	III
10	2,3,7,10	1,2,3,4,10	2,3,10	

Table 6.9: Partition of RM (fourth iteration)

Driver no.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,10	1	1	
2	2,3,10	1,2,3,4,10	2,3,10	IV
3	2,3,10	1,2.3,4,10	2,3,10	IV
4	2,3,4,10	1,4	4	
10	2,3,10	1,2,3,4,10	2,3,10	IV

Table 6.10: Partition of RM (fifth iteration)

Driver	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,4	1	1	
4	4	1,4	4	V

Table 6.11: Partition of RM (sixth iteration)

Driver no.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1	1	1	VI

6.3.2 Conical matrix formation

The conical matrix is developed to identify the driving power and dependence power of each driver. This is presented in table 6.12.

Table 6.12: Driving and Dependence Power in Reachability Matrix

DRIVER NO.	5	6	9	8	7	2	3	10	4	1	Driving power
5	1	1	1	0	0	0	0	0	0	0	3
6	1	1	1	0	0	0	0	0	0	0	3
9	1	1	1	0	0	0	0	0	0	0	3
8	1	1	1	1	0	0	0	0	0	0	4
7	1	1	1	1	1	0	0	0	0	0	5
2	1	1	1	1	1	1	1	1	0	0	8
3	1	1	1	1	1	1	1	1	0	0	8
10	1	1	1	1	1	1	1	1	0	0	8
4	1	1	1	1	1	1	1	1	1	0	9
1	1	1	1	1	1	1	1	1	1	1	10
DEPENDENCE POWER	10	10	10	7	6	5	5	5	2	1	

The ISM model is constructed based on various level of drivers and is shown below in Figure 6.2.

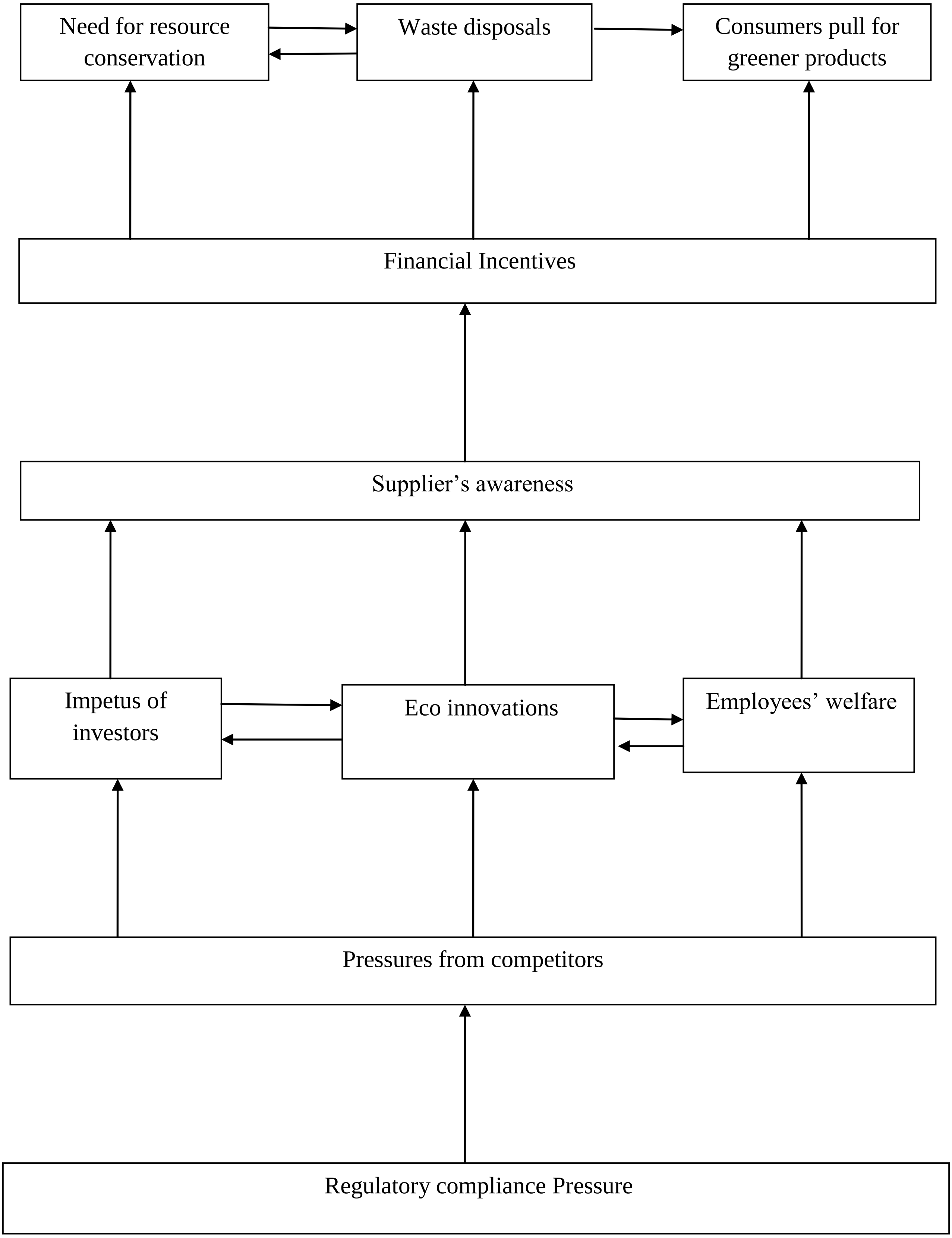

Figure 6.2: Green manufacturing model based on ISM

6.4 MICMAC ANALYSIS

MICMAC (Matrice d’ Impacts croises multiplication applique’ an classment) analysis has been used to analyze the driving power and dependence power of the drivers of green manufacturing. Depending on their driving power and dependence power these are classified into four categories. This is depicted in Figure 6.3.

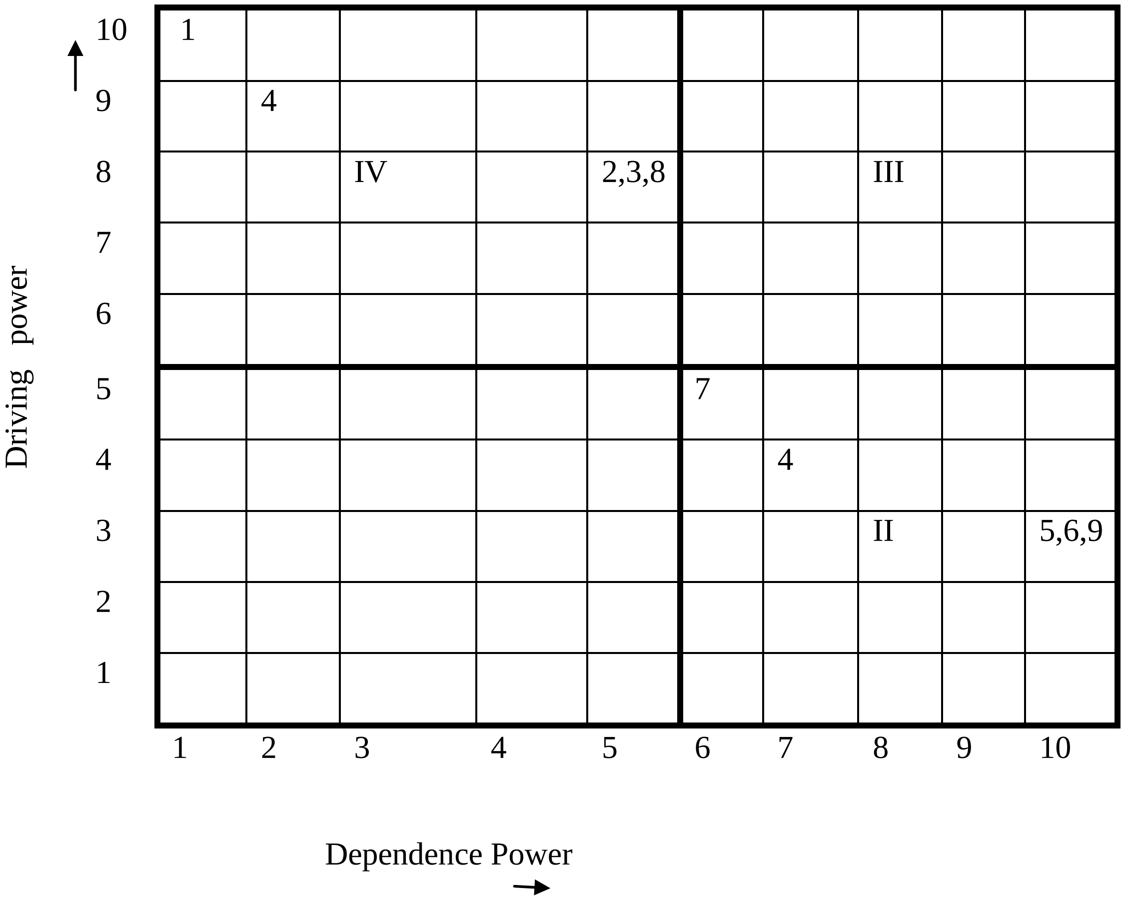

Figure 6.3: MICMAC ANALYSIS

6.5 CONCLUSION

Green manufacturing practices aim for environmental protection by emphasizing on reduction of resource use, pollution abatements and waste management. The adoption of green technologies results in reduction of harmful emissions, minimization of energy and material usage. This paper reveals the linkages amongst the crucial drivers pertaining to green manufacturing. This study offers important insights for policy makers and managers in formulating strategies for promoting green technologies in the manufacturing industry. The study identifies some of the important drivers which influence green manufacturing by attributing ‘driving’ and ‘dependency’ power to each driver. These drivers of green manufacturing are ranked using Interpretive Structural Modeling techniques. Drivers of green manufacturing are analyzed to construct a six level hierarchy framework model. Review of the results of MICMAC analysis establishes that Regulatory compliance Pressure, Pressures from competitors, Impetus of investors, Eco innovations, financial incentives are Independent drivers. These drivers have low driving power and high dependence power. Resource conservation Waste disposal Suppliers awareness Consumers pull Pressures from competitors are linkage drivers. These have high driving and high dependence power. The results further show that no driver belongs to the autonomous driver group indicating that there are no drivers of green manufacturing which have weak driving power and as well as weak dependence. Also no driver of green manufacturing is in linkage drivers group. This highlights the facts that no drivers of green manufacturing have strong driving power and strong dependence.

CHAPTER 7

INTEGRATED APPROACH FOR EVALUATING THE ENABLERS FOR GREEN MANUFACTURING USING DEMATEL AND ANALYTIC NETWORK PROCESS

7.1 INTRODUCTION

In the current era of globalization, environmental responsibility has grown steadily as a corporate concern in recent decades. Manufacturing companies are striving for more environment-friendly operations and products, creating an increased need for a balance between environment friendliness and efficiency gains.To tackle this issue, businesses are focusing on manufacturing technologies and initiatives that optimize energy usage and resource conservation. Green manufacturing has become a new paradigm for ensuring economic and social well being. Green branding has stimulated interest from various business disciplines like information technology, logistic management and financial management. The increasing concern for environment issues is due to their by economic and ecological impact (Toke and Kalpande , 2019). Green manufacturing aims at integrating the environmental protection issues and parameters of the production processes, products and energy usage to gravitate towards the optimization of resources (Melnyk and Smith, 1996).The positive relationship between Green Manufacturing and Operating Cost is strengthened with reduced pollution level in the local city (Mao and Wang, 2018). Environmental protection measures have to guarantee improvements in productivity and quality for their successful adoption. Green operational practices are related directly to the firms' green and operational performance and manufactures who are looking for green competitive advantages should try to reduce internal barriers. (Jabbour, et al., 2016).Green manufacturing processes use resources which have relatively lower environmental impacts as compared to the existing ones (Dechant and Altman, 1994**).** Green manufacturing eliminates or minimizes waste in the form of energy, emission, hazardous chemical and solid waste. Green manufacturing is based on green product design for source reduction, recycling and reverse manufacturing (Azzone and Noci, 1998). Green Manufacturing is an intersection of product development and manufacturing practices with utmost concern towards environmental issues. Many of the manufacturing industries are implementing innovations in the field of energy, process and products in their operations for transition towards green manufacturing. One of the important dimensions of environmental protection is the reuse and/or recycling of the items that are returned by the customers for various reasons. Such recycling and reuse prevents the flow of these unusable items into the environment and as such prevents environmental degradation (Prasher and Singh, 2017). Green manufacturing can provide significant financial gains as well as reduced environmental impact (Barbara et al., 2012*)*.Table 7.1 lists the various identified enablers for adoption of green manufacturing.

Table 7.1: Enablers for adoption of green manufacturing

S. No.	**ENABLERS**	**BRIEF DESCRIPTION**	**REFERENCES**
E1	Customer demand	Alteration of manufacturing operations due to increased customer demand for green products.	Anderson and Cunningham, (1972); Qi. et al., (2018); Huang (2016); Pawaskar, et al., (2018); Chien and Shih, (2007); Shamsi ,(2017).
E2	Need of waste management	“Polluter pays principles” to reduce toxic waste by using Life Cycle Analysis approach.	Lisney et al., (2003); Polcari, (2007); Von, (2004); Seth et al., (2018).
E3	Conservation of exhaustible resources	Optimising production processes to meet the challenge of increasing productive use of exhaustible resource	Bonilla et al.,(2010); Barbara, et al., (2012), Rusinko, (2007); Hoffman, (2001), Gandhi et al. (2018); Ravi Kumar et al.,(2016).
E4	Economic benefits	Financial benefits through reduced taxes, allotment of tradable pollution abatement permit and subside.	Montabon et al., (2007); Chen et al., (2006); Dauvergne, et al., (2018), Dem et al., (2015).
E5	Collaborative supplier	Supplier’s awareness and a willing approach in setting-up green supply chain. Additional	Routroy, (2009); Raut, et al., (2017); Handfield et al., (1997); Lee and Klassen,

		investment to enable faster adoption of green manufacturing	(2008); Tayeb (2010); Singh and Kaur, (2019).
E6	Shareholders Pressure	Shareholders activism to reorient manufacturing systems in a greener mode for the benefit of the communities.	Vos et al., (2003); Greeno and Robinson, (1992); Darnall, et al., (2009); Ouenniche et al., (2016).
E7	Market competition	To mitigate onslaught of competition strives businesses towards green manufacturing	Shubham and Murty, (2018); Delmas and Toffel, (2004); Huang, et al., (2009)
E8	Conducive regulatory mechanism	A business friendly legal framework encourages green paradigm.	Dobers and Wolff, (2000); Kassinis and Vafeas, (2002); Zeng et al. (2011) Zhu et al. (2008); Raut, et al. (2017); Chaabane et al.,(2011).
E9	Eco innovations	Development of new commercially viable cleaner technologies for green manufacturing	Tseng et al. (2012); Oke, (2007); Weng et al., (2015);Liu and Seddon, (2009).
E10	Adept human resources	Availability of abundant skilled technical persons in field of green manufacturing	Buzzelli, (1991); Fergusson and Langford (2006); Daily et al., (2001); Ghazilla., et al., (2015).

7.2 MCDM TECHNIQUES: DEMATEL and ANP

Combination of the two methods helps to overcome the weaknesses associated with applying only one method, by counterbalancing with the strength of the other method. DEMATEL quantitatively analyzes and filters the criteria's into cause-effect relationships. But, DEMATEL methodology does not determine the weights of individual criteria. This problem is overcome by additionally using ANP. ANP can determine priorities weights of different criteria and help in ranking the same. Integrating both MCDM can provide support in dealing with complex problems and to achieve the desired results DEMATEL methodology was developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva (Gabus and

Fontela, 1972). The DEMATEL method is used for building and analyzing structural models involving dependency among factors. DEMATEL divides the multiple factors or criteria's into cause groups and effect groups. Analytical network process (ANP) was presented by Saaty (1996). ANP method considers the interdependencies among factors and ranks them according to their relative importance. The integrated DEMATEL and ANP technique has been employed in various fields by the researches.

7.3 METHODOLOGY

The following methodology has been adopted for the present study:

- Identification of enablers on the basis of literature reviews and expert opinions
- Employ DEMATEL method to explore the causal relationships among the enablers and evaluate their mutual influence
- Employ ANP method for evaluating the priorities among the various enablers.
- Ranking of enablers from the results obtained from DEMATEL and ANP method

The computational steps of DEMATEL-ANP framework are shown in Figure 7.1

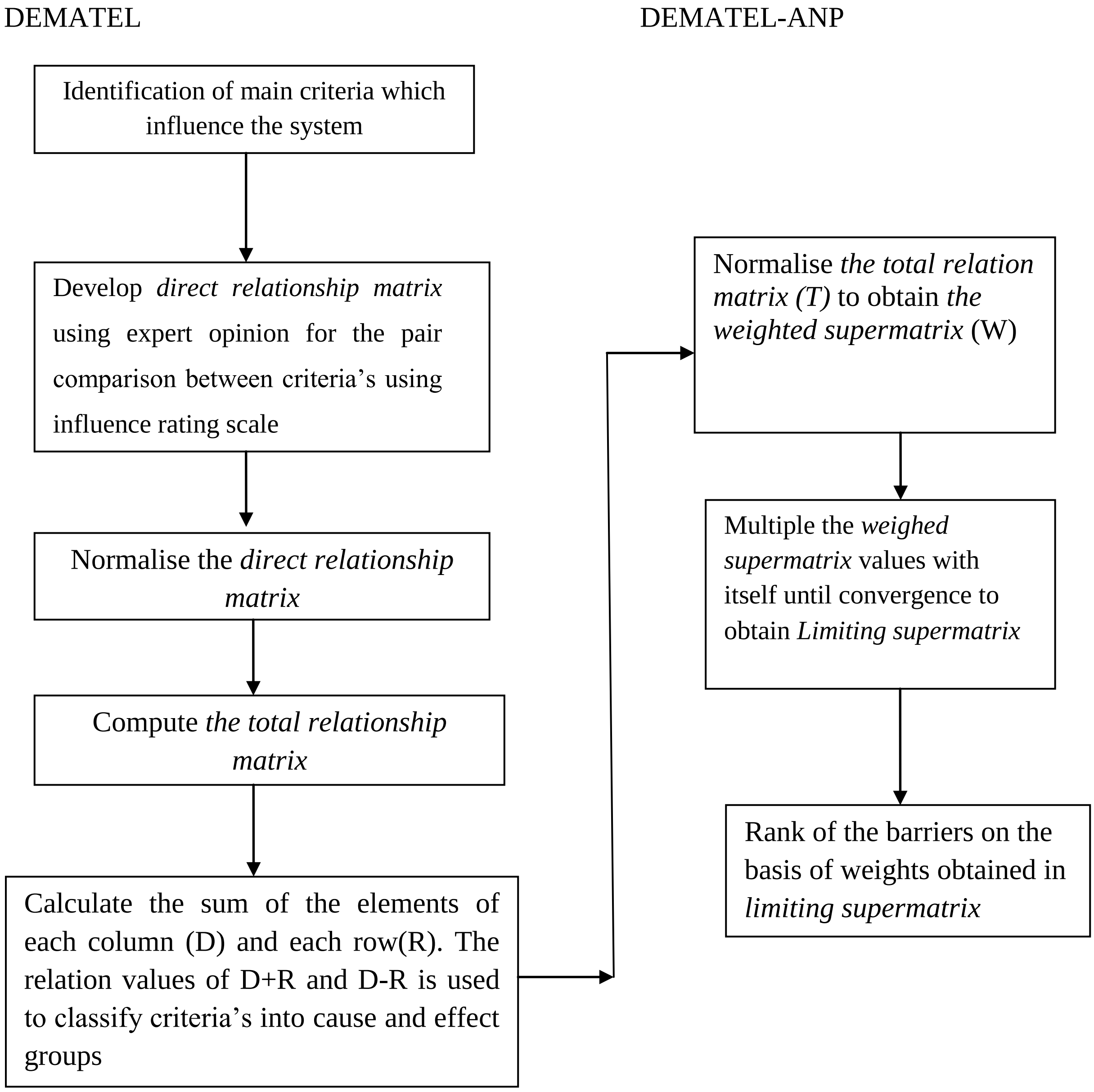

Figure 7.1: Computational steps of Integrated DEMATEL-ANP framework**.**

7.3.1 DEMATEL method

The DEMATEL method divides the dominant enablers into cause and effect group. The various steps used in the study are listed below.

7.3.1.1 Identification of different criteria

On the basis of literature reviews and expert opinions of professionals, the various criteria that influence the paradigm are enumerated and define

7.3.1.2 Establish a direct-relation matrix

A panel of experts are invited for pair-wise comparison of the criteria under study by using the influence rating scale as given in table 7.2.

Table 7.2: Influence rating scale

Rating score	levels of significance
0	No influence
1	Very low influence
2	Low influence
3	High influence
4	Very high influence

The judgements of various experts are aggregated using the arithmetic mean method. The direct-relation matrix M (ij) so obtained shows the mutual dependence between two criteria. The diagonal elements of the direct-relation matrix are 0.

7.3.1.3 Normalization of the direct relation matrix.

Normalization of the direct relation matrix is done by using fallowing equations (1) and (2).

$$M= \lambda A \qquad (1)$$

$$\lambda = \frac{1}{Max\left(\sum_{j=1}^{n} x_{ij}\right)} \qquad (2)$$

$$1 \leq I \leq n$$

Calculate Total relation matrix (T) using equation (3) as below:

$$T= M\,(I-M)^{-1} \qquad (I=\text{Identity matrix}) \qquad (3)$$

Calculate the sum of the elements of each column (D) and each row (R).

$$D= \left(\sum_{j=1}^{n} T_{ij}\right)_{n\times 1}, (i=1,2\ldots n) \qquad (4)$$

$$R= \left(\sum_{i=1}^{n} T_{ij}\right)_{n\times 1}, (j=1,2\ldots n) \qquad (5)$$

The values of D+R and D-R are used to classify criteria’s into cause and effect groups. A criterion is considered a cause if it has high D+R and high D-R and as effect if criteria has high D+R and low D-R.

7.3.2 ANALYTIC NETWORK PROCESS

ANP methodology consists of three steps namely calculation of unweighted supermatrix, the weighted supermatrix and the limiting supermatrix.

7.3.2.1 Unweighted Supermatrix

The integrated approach uses the transposed matrix T obtained from the DEMATEL method as ANP unweighted supermatrix.

7.3.2.2 Compute the Weighted Supermatrix. The total relation matrix (T) normalized to obtain the weighted supermatrix (**W**)

$$w_{ij=} \sum_{i=1}^{n} \mathrm{Tij} \qquad (6)$$

$$W_{ij} = \frac{\mathrm{Tij}}{\sum_{i=1}^{n} \mathrm{Tij}} \qquad (7)$$

7.3.2.3 Generate the Limiting Supermatrix.

Limiting Supermatrix is obtained by multiplying the weighed super matrix values with itself until convergence.

7.3.2.4 Prioritize and ranking

Rank different criteria on the basis of weights obtained in the limiting supermatrix of ANP.

The ranking of the criteria generated by DEMATEL and that based weights obtained by ANP are combined to obtain its overall rank of criteria.

7.4. RESULTS

Ten experts from the field of manufacturing and academics were asked to rank the identified enablers of green manufacturing using Table 7.2. The aggregate judgement of expert obtained using arithmetic mean method is shown matrix M.

$$M=\begin{pmatrix}
0 & 3 & 3 & 3 & 4 & 3 & 3 & 4 & 4 & 4 \\
3.8 & 0 & 3 & 3.9 & 2.8 & 2.2 & 2.1 & 3 & 2.9 & 2 \\
3 & 3.8 & 0 & 3.1 & 2.9 & 3 & 2 & 2.1 & 2.2 & 2.8 \\
2.7 & 2 & 3 & 0 & 2 & 3.7 & 2.9 & 2.9 & 3 & 2.1 \\
3.4 & 3.9 & 2.8 & 3.8 & 0 & 3 & 2.9 & 3 & 3 & 2.8 \\
3.3 & 2.1 & 2.8 & 3.9 & 2 & 0 & 2.8 & 2 & 2.1 & 2.3 \\
2.9 & 1.1 & 2.1 & 3 & 2.9 & 1.4 & 0 & 3 & 3.1 & 4 \\
2.9 & 2.8 & 3.8 & 2 & 2.8 & 2 & 2 & 0 & 4 & 3.9 \\
3.8 & 2 & 2 & 2.9 & 3 & 3 & 3 & 3 & 0 & 4 \\
4 & 3 & 2 & 1 & 2 & 2.9 & 4 & 3.1 & 4 & 0
\end{pmatrix}$$

The normalized matrix was obtained using equation (1) and (2).The value of λ = 1/31=.03255

$$M_n=\begin{pmatrix}
0.0000 & 0.0968 & 0.0968 & 0.0968 & 0.1290 & 0.0968 & 0.0968 & 0.1290 & 0.1290 & 0.1290 \\
0.1226 & 0.0000 & 0.0968 & 0.1258 & 0.0903 & 0.0710 & 0.0677 & 0.0968 & 0.0935 & 0.0645 \\
0.0968 & 0.1226 & 0.0000 & 0.1000 & 0.0935 & 0.0968 & 0.0645 & 0.0677 & 0.0710 & 0.0903 \\
0.0871 & 0.0645 & 0.0968 & 0.0000 & 0.0645 & 0.1194 & 0.0935 & 0.0935 & 0.0968 & 0.0677 \\
0.1097 & 0.1258 & 0.0903 & 0.1226 & 0.0000 & 0.0968 & 0.0935 & 0.0968 & 0.0968 & 0.0903 \\
0.1065 & 0.0677 & 0.0903 & 0.1258 & 0.0645 & 0.0000 & 0.0903 & 0.0645 & 0.0677 & 0.0742 \\
0.0935 & 0.0355 & 0.0677 & 0.0968 & 0.0935 & 0.0452 & 0.0000 & 0.0968 & 0.1000 & 0.1290 \\
0.0935 & 0.0903 & 0.1226 & 0.0645 & 0.0903 & 0.0645 & 0.0645 & 0.0000 & 0.1290 & 0.1258 \\
0.1226 & 0.0645 & 0.0645 & 0.0935 & 0.0968 & 0.0968 & 0.0968 & 0.0968 & 0.0000 & 0.1290 \\
0.1290 & 0.0968 & 0.0645 & 0.0323 & 0.0645 & 0.0935 & 0.1290 & 0.1000 & 0.1290 & 0.0000
\end{pmatrix}$$

Determine the total relation matrix (T) using the equation (3)

$$T=\begin{pmatrix}
0.606 & 0.579 & 0.592 & 0.626 & 0.621 & 0.590 & 0.601 & 0.655 & 0.697 & 0.690 \\
0.620 & 0.414 & 0.515 & 0.569 & 0.511 & 0.492 & 0.496 & 0.544 & 0.577 & 0.546 \\
0.582 & 0.511 & 0.412 & 0.533 & 0.498 & 0.499 & 0.479 & 0.504 & 0.540 & 0.549 \\
0.559 & 0.447 & 0.488 & 0.428 & 0.462 & 0.505 & 0.491 & 0.512 & 0.548 & 0.519 \\
0.659 & 0.565 & 0.550 & 0.610 & 0.468 & 0.553 & 0.560 & 0.588 & 0.626 & 0.613 \\
0.558 & 0.437 & 0.469 & 0.525 & 0.448 & 0.385 & 0.475 & 0.474 & 0.508 & 0.508 \\
0.557 & 0.418 & 0.455 & 0.503 & 0.479 & 0.436 & 0.401 & 0.510 & 0.547 & 0.565 \\
0.607 & 0.506 & 0.542 & 0.522 & 0.518 & 0.493 & 0.502 & 0.464 & 0.616 & 0.607 \\
0.639 & 0.488 & 0.501 & 0.554 & 0.530 & 0.527 & 0.538 & 0.561 & 0.510 & 0.619 \\
0.632 & 0.504 & 0.490 & 0.493 & 0.495 & 0.511 & 0.553 & 0.553 & 0.613 & 0.494 \\
6.017 & 4.869 & 5.012 & 5.363 & 5.029 & 4.990 & 5.098 & 5.363 & 5.783 & 5.710
\end{pmatrix}$$

Calculate the sum of the elements of each column (D) and each row (R) using equation (4) and (5). Also calculate the value vector dispatcher (D+R) and vector receiver (D-R). These are shown in table 7.3.

Table 7.3: Vector dispatcher and vector receiver

E No.	Enabler	D	R	D+R	D-R
E1	Customer demand	6.255	6.017354	12.273	0.238
E2	Need of waste management	5.283	4.86899	10.152	0.414
E3	Conservation of exhaustible resources	5.106	5.012092	10.118	0.094
E4	Economic benefits	4.958	5.362996	10.321	-0.405
E5	Collaborative Supplier	5.793	5.02946	10.822	0.763
E6	Shareholders Pressure	4.787	4.990388	9.778	-0.203
E7	Market competition	4.870	5.09764	9.968	-0.227
E8	Conducive regulatory mechanism	5.377	5.363401	10.740	0.013
E9	Eco innovations	5.467	5.782861	11.249	-0.316
E10	Adept human resources	5.339	5.70978	11.049	-0.370

The DEMATEL distribution of vector dispatcher and vector receiver for different enablers is shown in Figure7.2. It depicts causal relationships and strength of mutual influence among the various enablers of green manufacturing. DEMATEL filters enablers into cause groups and effect groups.

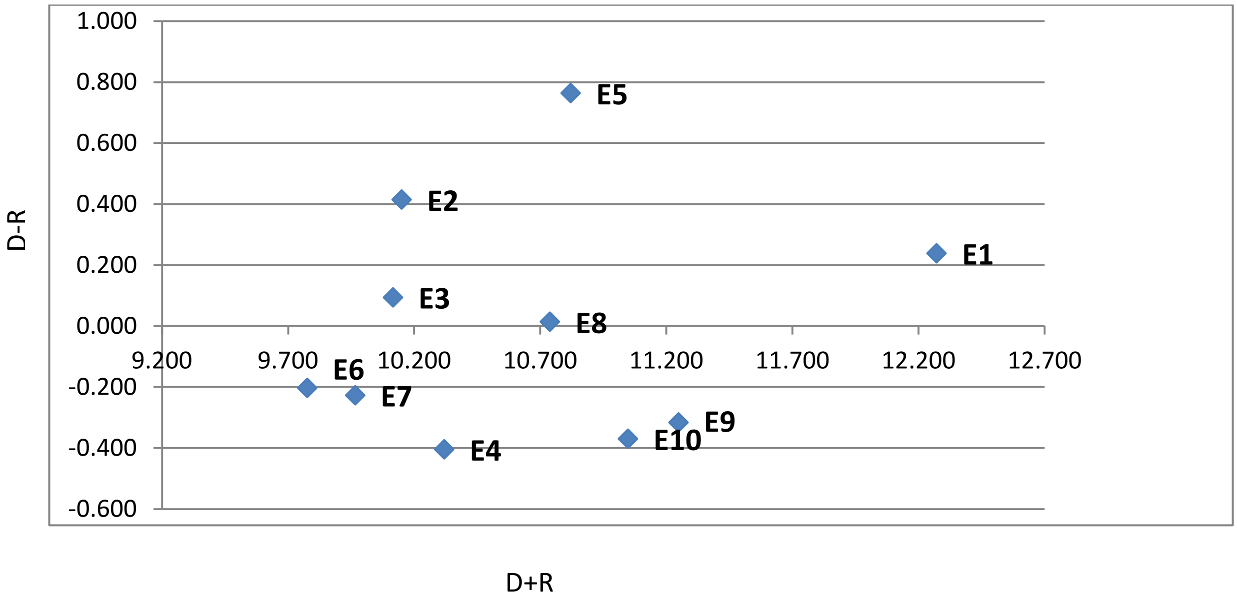

Figure 7.2: vector dispatcher and vector receiver for different enablers

Normalize the total influence matrix to obtain the Weighted Supermatrix W for integrated DEMATEL-ANP using equation (6) and (7)

$$W=\begin{pmatrix}
0.101 & 0.119 & 0.118 & 0.117 & 0.123 & 0.118 & 0.118 & 0.122 & 0.121 & 0.121\\
0.103 & 0.085 & 0.103 & 0.106 & 0.102 & 0.099 & 0.097 & 0.102 & 0.100 & 0.096\\
0.097 & 0.105 & 0.082 & 0.099 & 0.099 & 0.100 & 0.094 & 0.094 & 0.093 & 0.096\\
0.093 & 0.092 & 0.097 & 0.080 & 0.092 & 0.101 & 0.096 & 0.095 & 0.095 & 0.091\\
0.109 & 0.116 & 0.110 & 0.114 & 0.093 & 0.111 & 0.110 & 0.110 & 0.108 & 0.107\\
0.093 & 0.090 & 0.093 & 0.098 & 0.089 & 0.077 & 0.093 & 0.088 & 0.088 & 0.089\\
0.093 & 0.086 & 0.091 & 0.094 & 0.095 & 0.087 & 0.079 & 0.095 & 0.095 & 0.099\\
0.101 & 0.104 & 0.108 & 0.097 & 0.103 & 0.099 & 0.099 & 0.086 & 0.106 & 0.106\\
0.106 & 0.100 & 0.100 & 0.103 & 0.105 & 0.106 & 0.106 & 0.105 & 0.088 & 0.108\\
0.105 & 0.103 & 0.098 & 0.092 & 0.098 & 0.102 & 0.109 & 0.103 & 0.106 & 0.087
\end{pmatrix}$$

Generate the Limiting Supermatrix of ANP for prioritizing by multiplying the Weighed Supermatrix values with itself until convergence.

$$W^{*}=\begin{array}{cc}
 & \text{PRIORITY}\\
\begin{pmatrix}
0.117 & 0.117 & 0.117 & 0.117 & 0.117 & 0.117 & 0.117 & 0.117 & 0.117 & 0.117\\
0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.099\\
0.096 & 0.096 & 0.096 & 0.096 & 0.096 & 0.096 & 0.096 & 0.096 & 0.096 & 0.096\\
0.093 & 0.093 & 0.093 & 0.093 & 0.093 & 0.093 & 0.093 & 0.093 & 0.093 & 0.093\\
0.109 & 0.109 & 0.109 & 0.109 & 0.109 & 0.109 & 0.109 & 0.109 & 0.109 & 0.109\\
0.090 & 0.090 & 0.090 & 0.090 & 0.090 & 0.090 & 0.090 & 0.090 & 0.090 & 0.090\\
0.091 & 0.091 & 0.091 & 0.091 & 0.091 & 0.091 & 0.091 & 0.091 & 0.091 & 0.091\\
0.101 & 0.101 & 0.101 & 0.101 & 0.101 & 0.101 & 0.101 & 0.101 & 0.101 & 0.101\\
0.103 & 0.103 & 0.103 & 0.103 & 0.103 & 0.103 & 0.103 & 0.103 & 0.103 & 0.103\\
0.100 & 0.100 & 0.100 & 0.100 & 0.100 & 0.100 & 0.100 & 0.100 & 0.100 & 0.100
\end{pmatrix}
&
\begin{matrix}1\\6\\7\\8\\2\\10\\9\\4\\3\\5\end{matrix}
\end{array}$$

The Priority rankings of enablers as per D-ANP are shown in Figure 7.3. The results highlights “Customer demand” has the highest priority weight of 0.117 .This is followed by “Eco innovations” having priority weight of 0.109. Collaborative suppliers” enabler (E5) is ranked third having priority weight of 0.109.

The overall priority of an enabler is determined by integrating DEMATEL and D-ANP ranking. This is shown in Table 7.4.

Table 7.4: Overall ranking

ENABLER NO	ENABLER	RANK DEMATE	RANK D-ANP	TOTAL	PRIORITY
E1	Customer demand	1	1	2	1
E2	Need of waste management	7	6	13	6
E3	Conservation of exhaustible resources	8	7	15	7
E4	Economic benefits	9	8	17	9
E5	Collaborative supplier	3	3	6	3
E6	Shareholders Pressure	6	9	15	8
E7	Market competition	5	5	10	5
E8	Conducive regulatory mechanism	4	4	8	4
E9	Eco innovations	2	2	4	2
E10	Adept human resources	10	10	20	10

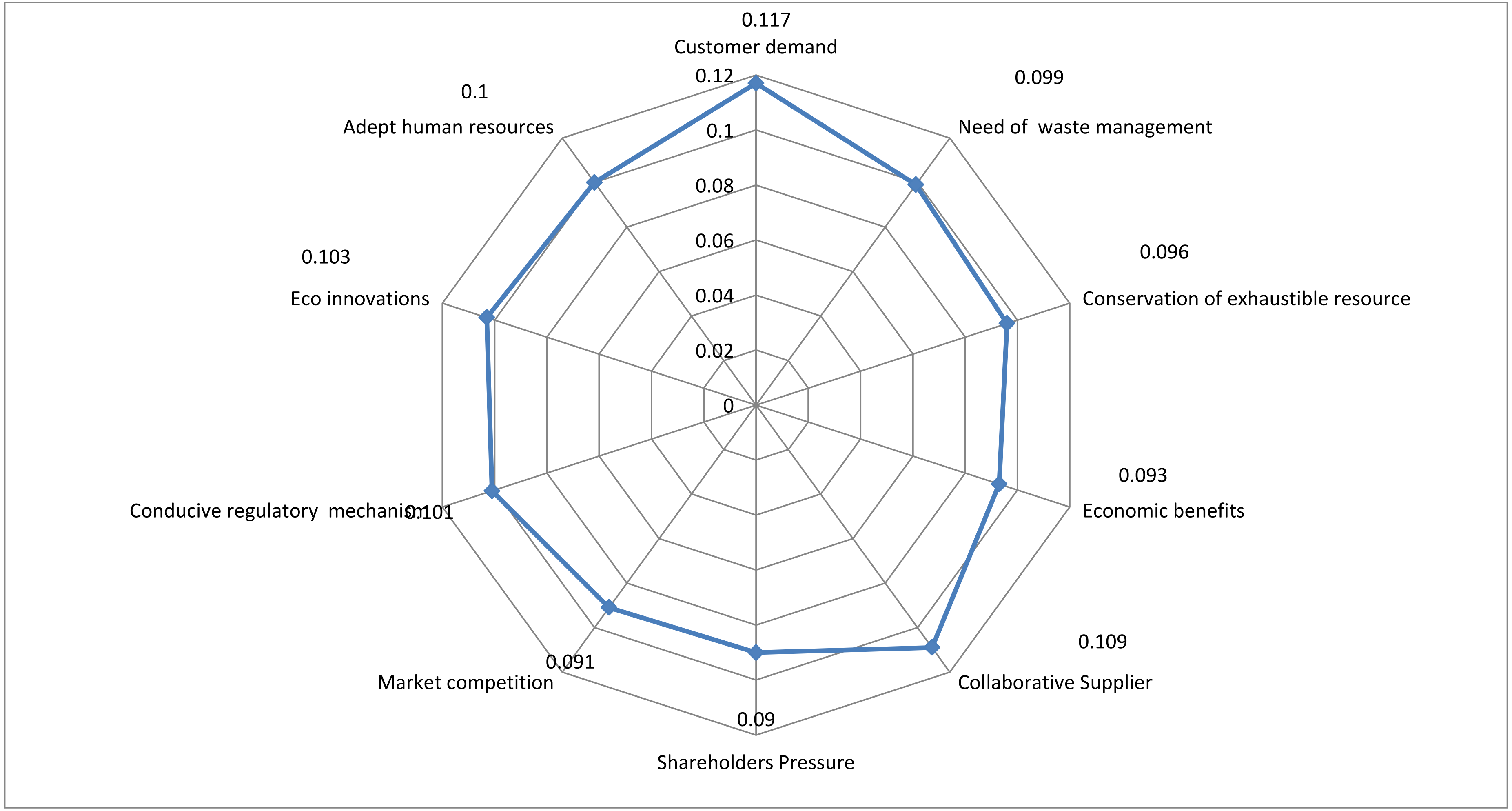

Figure 7.3: Priority raking of various enablers as per DEMATEL-ANP

7.5. DISCUSSION

Green manufacturing paradigm focuses efforts towards the optimal use of exhaustible resources, reduction in harmful emissions, and efficient waste disposal. The integrated DEMATEL and ANP results in Table 7.4 show the priority wise preference order of identified enablers given as E1 >E9 > E5 > E8>E7>E2>E3>E6>E4>E10 . The integrated approach of DEMATEL and ANP determine the relative importance of enablers of green manufacturing offers several findings, and managerial insights. The important managerial insights are that enabler (E1) "Customer demand" has the highest priority. It highlights that the customer demand for greener products provides businesses with confidence to make additional investment for transforming their manufacturing practices. While, the "eco innovation" (E9) is ranked at second position and priority with respect to other enablers. Successful commercialization of "eco innovations" in processes and products enhance the overall environmental performance of a system. The study's findings indicate that the "Collaborative suppliers" enabler (E5) is ranked third as it allows businesses to establish a green supply chain mechanism. This is only possible due to supplier's awareness about green issues and a mutually corporative approach. Next, the enabler (E8) Conducive regulatory mechanism occupies the fourth position, among the enablers. It highlights the important role played by of government agencies and regulatory bodies for enabling an effective and efficient green manufacturing system. Market competition (E7) and need of waste management (E2) are at the fifth and sixth positions respectively. These depicts the role of the competitive pressure and financial penalties on businesses so that they protect resources and reduce environmental impact

The DEMATEL results for Vector dispatcher and vector receiver in Table 7.3 shows enablers (E1) "Customer demand" (12.273,0.238), (E2) "Need of waste Management "(10.152,0.414), (E3)" Conservation of exhaustible resources" (10.118, 0.094),(E5) Collaborative Supplier (10.822,0.763), (E8) Conducive regulatory mechanism (10.740, 0.013) have a high D+R and high D-R.. This indicates that these enablers have has considerably high level of influencing and are being influenced by other enablers. These are considered as cause enablers, having high influence and high prominence. The enablers "Economic benefits, Eco innovations, Market competition, Adept human resources, Shareholders Pressure” have high D+R and low D-R .This indicates that these enablers have high influence over other enablers but their total influence is low. These enablers are independent and can affect a low number of other enablers. These are considered as effect enablers, having high influence and low prominence. The results highlight “Customer demand” has the highest influence with D+ R value of 12.273. This is followed by “Eco innovations” having D+R value of 11.249. The enabler “Market competition” scored the least with D+R value of 9.778 preceded by “Shareholders Pressure” having a D+R of 9.968.

Analytic Network Process calculated as matrix W * highlights the priority of each enables on the basis of their global weights. Figure 7.4 shows the priority of various enablers as per Analytic Network Process. The results obtained that DEMATEL and ANP for the priority of various enablers are in consonance with each other. The results highlights “Customer demand” has the highest priority weight of 0.117 .This is followed by “Eco innovations” having priority weight of 0.109. Collaborative suppliers” enabler (E5) is ranked third having priority weight of 0.109. Figure 7.4 shows the priority weights of various enablers as per Analytic Network Process analysis.

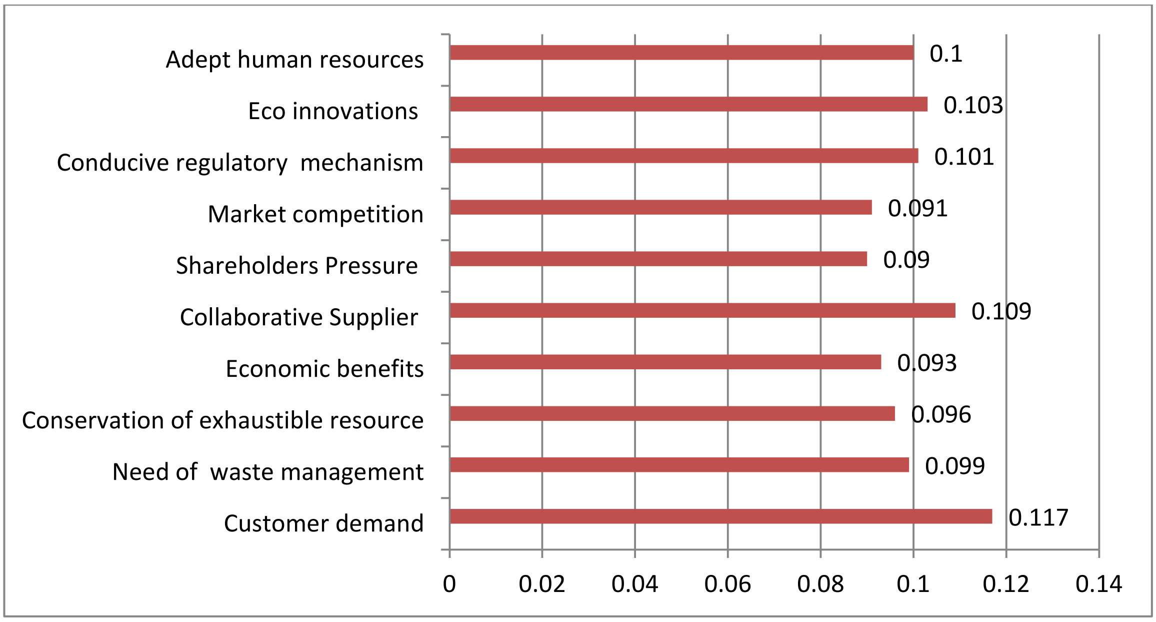

Figure 7.4: Weights as per Analytic Network Process

7.6. CONCLUSION

The study presents a structural framework for ranking the various enablers of green manufacturing. The present study proposes using an integrated approach of DEMATEL and ANP operational model to priorities enablers for green manufacturing. The proposed integrated methodology provides means to integrate the qualitative and quantitative group decision-making for analyzing the causal relationships and strength of mutual influence among various enablers. The proposed study contributes in two-ways: initially, the MCDM DEMATEL help in building and analyzing structural models involving dependency among the various enablers of green manufacturing. DEMATEL filters enablers into cause groups and effect groups. Secondly, the results obtained through DEMATEL are collaborated with ANP analysis.ANP analysis determines the relative priorities of enablers of green manufacturing. The results of the study obtained indicate that customer demand, implementing eco innovation and availability of collaborative suppliers as the top three enablers for transition towards green manufacturing. The societal impact of this study is that it proves that these enablers help as to manage waste better and conserve non-renewable resources though eco innovation and environmental consciousness.

CHAPTER 8

INTEGRATED APPROACH FOR EVALUATING THE BARRIERS FOR GREEN MANUFACTURING USING DEMATEL AND ANALYTIC NETWORK PROCESS

8.1 INTRODUCTION

Traditional manufacturing system which was in practice since ages does not consider the damages caused to our environment. Manufacturers are engaged in relentless exploitation of natural resources for producing goods with the sole aim of earning profits. Such a system puts up intense pressure on limited resources available and leads to environmental degradation. Green manufacturing is a management approach aimed at achieving quantum improvements in environment protection parameters by the adoption of newer technologies for eco-friendly process and products .The interest of the industry in green manufacturing is high as a direct result of increasing pollution, exhaustible nature of resources and problem of waste disposal etc. Green manufacturing utilizes the availability of new technologies in process and products (Zhu and Sarkis, 2007). Green manufacturing employs a multi-functional approach which uses tools and techniques from a variety of well established disciplines such as industrial engineering, quality management and lean/agile manufacturing (Zhu et al., 2019). Faced with increasing regulatory accountability and the need to reduce environmental impact of manufacturing activities, businesses are inclined to reorient and redesign their manufacturing operations.

Adoption of green manufacturing practices has numerous advantages for any business, but a number of formidable challenges act as barriers for successful implementation of proactive environmental technologies. Implementation of green manufacturing paradigms requires a structural change in manufacturing operations. The objective of the study is to use a systematic approach to evaluate and rank the various factors that act as barriers for businesses to adopt green manufacturing. The study of such barriers can help businesses to identify and focus on key areas for improvements in making manufacturing activities environmentally resilient. The ranking of various barriers facilitates assessment of the capabilities and strengths required for achieving breakthroughs and innovations for green manufacturing. The study provides a framework for manufacturers to strike a balance between the business performance and green initiatives.

DEMATEL methodology is applied to analyze the causal relationships among the various barriers faced in the implementation of green manufacturing. ANP utilises the relationship matrix obtained from DEMATEL to obtain the priority weights of each sub-barrier and rank these barriers on the basis of weight obtained.

Table 8.1 shows the various barriers and sub barriers to transition towards green manufacturing.

Table 8.1: Barriers to adoption of green manufacturing

S.No	BARRIER	SUB BARRIER		REFERENCES
B1	FINANCIAL BARRIERS	B11	Uncertain rate of return	Govindan et al., (2014)
		B12	High initial capital cost	Govindan.,et al.,(2013); Balaji et al.,(2014)
		B13	Long gestation period	Carter et at.,(2008)
		B14	Bank reluctant to fund projects	Min and Galle, (2001)
B2	TECHNOLOGY BARRIERS	B21	Complexity of design	Gerstenfeld et al., (2000); Beamon, (1999)
		B22	lack of flexibility	Govindan et al.,(2014)
		B23	Integration	Singh et al., (2012); Mathiyazhagan et al.,(2013)
		B24	Adaptability	Hadjimanolis and Dickson (2000); Luken and Rompaey (2008)
B3	SOCIAL BARRIERS	B31	Employee altitude and resistance	Mittal et al., (2013); Govindan et al.,(2013)

		B32	Customers' reluctance to pay	Yu et al., (2008); Yuksel (2008)
		B33	Shareholders pressure	McAdam (2004); Massoud et al., (2010)
		B34	Lack of experience professional	Angel et al.,(2008), Mathiyazhagan et al(2013)
B4	OPERATIONAL BARRIER	B41	Suppliers Resistance	Mathiyazhagan et al., (2013)
		B42	Inadequate management commitment	McAdam, (2004); Brío,. and Junquera, (2003); Wang et al., (2008)
		B43	High cost of compliance certification	Massoud et al., (2010); Koho et al., (2011)
		B44	Maintainability	Siaminwe et al., (2005); Massoud et al., (2010)
B5	ENVIRONMENTAL BARRIERS	B51	Lack of effective environmental enforcement	Geng and Doberstein,(2008)
		B52	lack of uniform benchmarking indices	Koho et al. (2011); Seth,(2018);Yu et al., (2008)
		B53	Mandating use unviable techniques	Gadenne(2009);Shubham (2018)
		B54	Inadequate infrastructure	Wang et al.,(2008); Gazelle,(2015); Massoud et al., (2010)

8.2 RESULT

Nine experts from the field of manufacturing and academics were asked to express their judgment on the pair-wise comparison of the barriers using the influence rating scale given in Table7.2. The aim was to measuring the level of influence determining the levels of causal relationships between two barriers. The aggregate judgement of experts obtained using arithmetic mean method is shown in matrix M.

The initial influence matrix – M

	B_{11}	B_{12}	B_{13}	B_{14}	B_{21}	B_{22}	B_{23}	B_{24}	B_{31}	B_{32}	B_{33}	B_{34}	B_{41}	B_{42}	B_{43}	B_{44}	B_{51}	B_{52}	B_{53}	B_{54}
B_{11}	0.0	3.0	3.0	3.0	4.0	3.0	3.0	4.0	4.0	4.0	3.0	4.0	4.0	4.0	3.0	4.0	3.7	3.7	3.0	3.7
B_{12}	3.3	0.0	3.0	4.0	2.3	2.7	2.0	3.0	2.7	2.0	2.7	2.3	3.0	2.0	3.0	3.0	3.3	2.3	3.0	3.3
B_{13}	3.0	3.3	0.0	3.3	2.7	3.0	2.0	2.3	2.3	2.3	3.7	3.0	2.0	3.0	4.0	3.0	2.7	3.3	3.7	3.0
B_{14}	2.3	2.0	3.0	0.0	2.0	3.0	2.7	2.7	3.0	2.0	3.0	4.0	3.0	2.3	3.0	4.0	3.0	2.0	3.0	3.7
B_{21}	3.3	3.7	3.0	3.7	0.0	3.0	2.7	3.0	3.0	2.3	3.7	2.7	3.0	3.0	4.0	2.3	3.3	3.3	3.7	2.7
B_{22}	3.7	2.0	2.3	3.7	2.0	0.0	2.7	2.0	2.0	2.0	3.0	3.0	2.0	2.7	3.0	3.0	2.3	2.0	3.0	3.3
B_{23}	3.0	1.0	2.0	3.0	2.7	1.0	0.0	3.0	3.3	4.0	4.0	4.0	3.0	4.0	4.0	4.0	3.0	3.0	3.3	3.7
B_{24}	3.0	2.3	3.3	2.0	2.3	2.0	2.0	0.0	4.0	4.0	3.0	3.3	4.0	3.3	3.0	3.3	4.0	3.7	3.3	3.3
B_{31}	3.3	2.0	2.0	2.7	3.0	3.0	3.0	3.0	0.0	4.0	4.0	3.0	4.0	3.3	3.3	3.0	3.7	3.0	3.0	3.0
B_{32}	4.0	3.0	2.0	1.0	2.0	2.7	4.0	3.3	4.0	0.0	2.0	3.0	4.0	2.7	2.0	2.0	3.3	3.0	2.7	2.3
B_{33}	3.0	2.0	3.0	2.0	2.3	2.0	2.0	3.0	3.0	3.0	0.0	2.3	3.3	2.3	2.0	2.3	3.0	2.3	3.0	2.7
B_{34}	3.0	2.0	2.0	3.0	3.0	1.0	1.0	2.0	3.7	2.0	3.0	0.0	3.3	2.7	2.7	1.0	3.3	1.7	2.0	2.7
B_{41}	4.0	2.3	2.7	3.0	2.7	3.0	3.0	2.7	2.3	3.7	4.0	3.0	0.0	3.0	3.0	3.0	4.0	3.0	3.0	4.0
B_{42}	3.7	3.3	2.7	1.7	2.7	3.3	3.7	3.0	3.7	2.0	2.3	2.3	4.0	0.0	3.0	4.0	3.0	2.0	2.0	3.0
B_{43}	3.0	2.3	2.7	2.3	3.0	2.3	2.7	3.3	3.0	3.0	3.0	2.7	3.0	4.0	0.0	3.0	3.0	3.0	2.0	2.0
B_{44}	3.3	2.0	2.3	3.3	3.0	2.0	1.7	2.0	3.3	2.0	2.7	2.7	2.7	2.0	3.0	0.0	2.0	4.0	3.0	3.0
B_{51}	3.0	3.3	2.0	2.7	3.0	3.0	2.7	2.7	3.0	3.3	3.3	3.0	3.0	4.0	3.0	4.0	0.0	3.0	3.0	3.0
B_{52}	3.0	3.3	2.7	2.7	2.0	2.7	2.0	2.7	2.7	3.7	2.3	2.7	3.0	2.3	3.0	4.0	2.0	0.0	2.7	2.0
B_{53}	3.3	3.0	2.0	2.7	2.7	3.0	2.3	2.7	2.7	3.0	3.0	3.0	2.7	1.3	2.3	3.0	3.0	1.3	0.0	3.0
B_{54}	3.7	3.3	3.0	2.7	2.7	2.7	2.0	2.3	2.7	3.7	2.0	2.3	3.0	3.0	4.0	2.0	3.0	2.0	2.0	0.0

Calculate normalized matrix using equation (1) and (2).The value of λ = 1/67 =0.014925

	B_{11}	**B_{12}**	**B_{13}**	**B_{14}**	**B_{21}**	**B_{22}**	**B_{23}**	**B_{24}**	**B_{31}**	**B_{32}**	**B_{33}**	**B_{34}**	**B_{41}**	**B_{42}**	**B_{43}**	**B_{44}**	**B_{51}**	**B_{52}**	**B_{53}**	**B_{54}**
B	0.000	0.045	0.045	0.045	0.060	0.045	0.045	0.060	0.060	0.060	0.045	0.060	0.060	0.060	0.045	0.060	0.055	0.055	0.045	0.055
B	0.050	0.000	0.045	0.060	0.035	0.040	0.030	0.045	0.040	0.030	0.040	0.035	0.045	0.030	0.045	0.045	0.050	0.035	0.045	0.050
B	0.045	0.050	0.000	0.050	0.040	0.045	0.030	0.035	0.035	0.035	0.055	0.045	0.030	0.045	0.060	0.045	0.040	0.050	0.055	0.045
B	0.035	0.030	0.045	0.000	0.030	0.045	0.040	0.040	0.045	0.030	0.045	0.060	0.045	0.035	0.045	0.060	0.045	0.030	0.045	0.055
B	0.050	0.055	0.045	0.055	0.000	0.045	0.040	0.045	0.045	0.035	0.055	0.040	0.045	0.045	0.060	0.035	0.050	0.050	0.055	0.040
B	0.055	0.030	0.035	0.055	0.030	0.000	0.040	0.030	0.030	0.030	0.045	0.045	0.030	0.040	0.045	0.045	0.035	0.030	0.045	0.050
B	0.045	0.015	0.030	0.045	0.040	0.015	0.000	0.045	0.050	0.060	0.060	0.060	0.045	0.060	0.060	0.060	0.045	0.045	0.050	0.055
B	0.045	0.035	0.050	0.030	0.035	0.030	0.030	0.000	0.060	0.060	0.045	0.050	0.060	0.050	0.045	0.050	0.060	0.055	0.050	0.050
B	0.050	0.030	0.030	0.040	0.045	0.045	0.045	0.045	0.000	0.060	0.060	0.045	0.060	0.050	0.050	0.045	0.055	0.045	0.045	0.045
B	0.060	0.045	0.030	0.015	0.030	0.040	0.060	0.050	0.060	0.000	0.030	0.045	0.060	0.040	0.030	0.030	0.050	0.045	0.040	0.035
B	0.045	0.030	0.045	0.030	0.035	0.030	0.030	0.045	0.045	0.045	0.000	0.035	0.050	0.035	0.030	0.035	0.045	0.035	0.045	0.040
B	0.045	0.030	0.030	0.045	0.045	0.015	0.015	0.030	0.055	0.030	0.045	0.000	0.050	0.040	0.040	0.015	0.050	0.025	0.030	0.040
B	0.060	0.035	0.040	0.045	0.040	0.045	0.045	0.040	0.035	0.055	0.060	0.045	0.000	0.045	0.045	0.045	0.060	0.045	0.045	0.060
B	0.055	0.050	0.040	0.025	0.040	0.050	0.055	0.045	0.055	0.030	0.035	0.035	0.060	0.000	0.045	0.060	0.045	0.030	0.030	0.045
B	0.045	0.035	0.040	0.035	0.045	0.035	0.040	0.050	0.045	0.045	0.045	0.040	0.045	0.060	0.000	0.045	0.045	0.045	0.030	0.030
B	0.050	0.030	0.035	0.050	0.045	0.030	0.025	0.030	0.050	0.030	0.040	0.040	0.040	0.030	0.045	0.000	0.030	0.060	0.045	0.045
B	0.045	0.050	0.030	0.040	0.045	0.045	0.040	0.040	0.045	0.050	0.050	0.045	0.045	0.060	0.045	0.060	0.000	0.045	0.045	0.045
B	0.045	0.050	0.040	0.040	0.030	0.040	0.030	0.040	0.040	0.055	0.035	0.040	0.045	0.035	0.045	0.060	0.030	0.000	0.040	0.030
B	0.050	0.045	0.030	0.040	0.040	0.045	0.035	0.040	0.040	0.045	0.045	0.045	0.040	0.020	0.035	0.045	0.045	0.020	0.000	0.045
B	0.055	0.050	0.045	0.040	0.040	0.040	0.030	0.035	0.040	0.055	0.030	0.035	0.045	0.045	0.060	0.030	0.045	0.030	0.030	0.000

Calculate total relation matrix (T) using equation (3) and (4)

	B_{11}	**B_{12}**	**B_{13}**	**B_{14}**	**B_{21}**	**B_{22}**	**B_{23}**	**B_{24}**	**B_{31}**	**B_{32}**	**B_{33}**	**B_{34}**	**B_{41}**	**B_{42}**	**B_{43}**	**B_{44}**	**B_{51}**	**B_{52}**	**B_{53}**	**B_{54}**
B	0.251	0.244	0.241	0.254	0.262	0.240	0.235	0.271	0.294	0.285	0.276	0.284	0.301	0.281	0.278	0.290	0.290	0.263	0.262	0.284
B	0.247	0.161	0.202	0.226	0.198	0.197	0.183	0.214	0.227	0.212	0.225	0.216	0.237	0.208	0.231	0.230	0.238	0.202	0.218	0.233
B	0.251	0.215	0.165	0.223	0.208	0.207	0.188	0.212	0.230	0.223	0.245	0.232	0.231	0.228	0.251	0.237	0.236	0.222	0.234	0.235
B	0.235	0.190	0.202	0.170	0.194	0.201	0.192	0.210	0.233	0.212	0.230	0.239	0.238	0.213	0.231	0.244	0.234	0.198	0.219	0.238
B	0.270	0.231	0.219	0.240	0.182	0.219	0.209	0.234	0.253	0.237	0.259	0.241	0.260	0.242	0.265	0.243	0.259	0.234	0.247	0.245
B	0.239	0.179	0.182	0.210	0.183	0.148	0.182	0.190	0.206	0.200	0.217	0.214	0.211	0.206	0.219	0.218	0.212	0.186	0.207	0.221
B	0.264	0.193	0.204	0.228	0.219	0.189	0.170	0.232	0.257	0.258	0.262	0.258	0.259	0.254	0.263	0.263	0.253	0.229	0.240	0.256
B	0.266	0.213	0.223	0.216	0.216	0.205	0.201	0.191	0.268	0.260	0.250	0.250	0.274	0.247	0.252	0.256	0.269	0.240	0.242	0.253
B	0.271	0.208	0.205	0.226	0.225	0.219	0.215	0.234	0.211	0.260	0.264	0.246	0.274	0.247	0.256	0.251	0.264	0.231	0.238	0.249
B	0.259	0.205	0.189	0.186	0.195	0.197	0.212	0.221	0.248	0.186	0.218	0.227	0.254	0.220	0.219	0.219	0.240	0.213	0.215	0.221
B	0.228	0.178	0.189	0.185	0.185	0.175	0.171	0.202	0.218	0.212	0.172	0.202	0.228	0.199	0.203	0.207	0.219	0.190	0.205	0.210
B	0.215	0.168	0.166	0.188	0.184	0.152	0.148	0.177	0.215	0.187	0.204	0.157	0.216	0.193	0.200	0.176	0.212	0.169	0.180	0.198
B	0.279	0.213	0.215	0.230	0.221	0.219	0.214	0.229	0.245	0.255	0.263	0.246	0.217	0.242	0.252	0.251	0.268	0.230	0.238	0.263
B	0.262	0.216	0.204	0.202	0.211	0.213	0.213	0.223	0.250	0.221	0.230	0.225	0.261	0.188	0.240	0.253	0.243	0.207	0.213	0.238
B	0.245	0.196	0.198	0.204	0.208	0.193	0.194	0.221	0.234	0.227	0.231	0.222	0.240	0.238	0.189	0.232	0.235	0.213	0.206	0.216
B	0.236	0.181	0.183	0.207	0.198	0.179	0.169	0.191	0.226	0.202	0.214	0.210	0.222	0.198	0.220	0.177	0.209	0.216	0.208	0.218
B	0.261	0.222	0.201	0.222	0.221	0.214	0.206	0.225	0.249	0.245	0.249	0.240	0.255	0.251	0.246	0.260	0.207	0.226	0.233	0.244
B	0.237	0.203	0.191	0.202	0.187	0.191	0.178	0.204	0.221	0.228	0.213	0.214	0.231	0.206	0.224	0.237	0.213	0.163	0.208	0.208
B	0.237	0.194	0.179	0.198	0.193	0.192	0.179	0.200	0.217	0.215	0.219	0.215	0.222	0.189	0.211	0.219	0.223	0.179	0.166	0.218
B	0.250	0.207	0.199	0.205	0.200	0.195	0.182	0.204	0.225	0.232	0.213	0.213	0.235	0.220	0.242	0.214	0.231	0.195	0.202	0.183

Calculate the sum of the elements of each column (C_i) and each row (R_i) . The value of ($R_i + C_{i,}$) indicates the level of importance of each criteria. .($R_i - C_i$) is used to divide criteria into cause and effect group. If ($R_i - C_i$) is positive than the criteria is considered as cause else it signifies that the criteria is an effect .The sum of the elements of each column (C_I) and each row (R_I) and is shown in Table 8.2.

Table 8.2: Vector dispatcher and vector receiver

NO.	**BARRIER**	**SUB BARRIER**		**C_i**	**R_i**	**R_i+C_i**	**R_i-C_i**
B1	Financial	B11	Uncertain rate of return	5.003	5.388	10.391	0.384
		B12	High initial capital cost	4.019	4.305	8.324	0.287
		B13	Long gestation period	3.958	4.475	8.433	0.517
		B14	Bank reluctant to fund projects	4.221	4.321	8.543	0.100
B2	Technology	B21	Complexity of design	4.090	4.790	8.880	0.700
		B22	Lack of flexibility	3.944	4.028	7.973	0.084
		B23	Integration	3.841	4.751	8.593	0.910
		B24	Adaptability	4.285	4.793	9.078	0.508
B3	Social	B31	Employee altitude and resistance	4.729	4.796	9.525	0.066
		B32	Customers’ reluctance to pay higher price	4.556	4.345	8.901	-0.211
		B33	Shareholder pressure	4.654	3.979	8.633	-0.675
		B34	Lack of experience professional	4.553	3.705	8.258	-0.847
B4	Operational	B41	Suppliers Resistance	4.869	4.791	9.660	-0.078
		B42	Inadequate management commitment	4.469	4.514	8.983	0.045
		B43	High cost of compliance certification	4.691	4.343	9.034	-0.349
		B44	Maintainability	4.677	4.064	8.741	-0.613
B5	Environmental	B51	Lack of effective environmental enforcement	4.755	4.676	9.430	-0.079
		B52	Lack of uniform benchmarking indices	4.206	4.159	8.365	-0.046
		B53	Mandating use unviable techniques	4.382	4.065	8.448	-0.317
		B54	Inadequate infrastructure	4.632	4.246	8.878	-0.386

Network Relation Map (NRM). The causal diagram is obtained by using the value of the (R_I – $C_{I,}$), R_I+ C_I) and is shown in Figure 8.1The (R_I – C_I) is plotted on vertical axis and the horizontal axis represents (R_I + C_I). The causal diagram shows the structural relationship between the barriers to green manufacturing and assists to visualize complex correlation

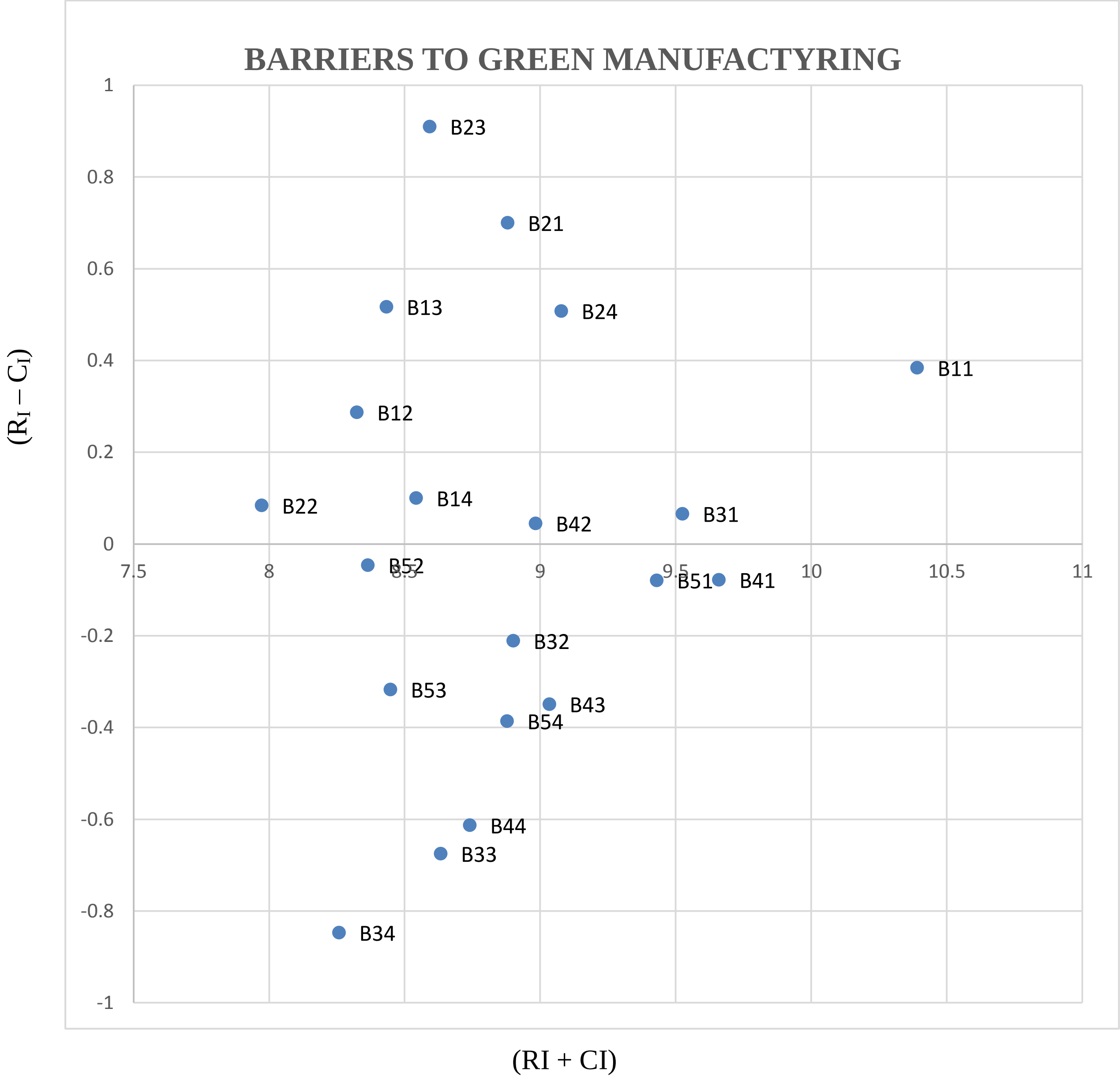

Figure 8.1: Network Relation Map (NRM) of various barriers to adoption of green manufacturing.

Normalize the total influence matrix to obtain the Weighted Supermatrix W for hybrid DEMATEL-ANP using equation (6) and (7)

Computed Weighted Supermatrix for DEMATEL-ANP using equation (6) and (7).

	B_{11}	**B_{12}**	**B_{13}**	**B_{14}**	**B_{21}**	**B_{22}**	**B_{23}**	**B_{24}**	**B_{31}**	**B_{32}**	**B_{33}**	**B_{34}**	**B_{41}**	**B_{42}**	**B_{43}**	**B_{44}**	**B_{51}**	**B_{52}**	**B_{53}**	**B_{54}**
B	0.050	0.061	0.061	0.060	0.064	0.061	0.061	0.063	0.062	0.063	0.059	0.062	0.062	0.063	0.059	0.062	0.061	0.063	0.060	0.061
B	0.049	0.040	0.051	0.054	0.048	0.050	0.048	0.050	0.048	0.046	0.048	0.048	0.049	0.047	0.049	0.049	0.050	0.048	0.050	0.050
B	0.050	0.053	0.042	0.053	0.051	0.053	0.049	0.049	0.049	0.049	0.053	0.051	0.048	0.051	0.054	0.051	0.050	0.053	0.053	0.051
B	0.047	0.047	0.051	0.040	0.047	0.051	0.050	0.049	0.049	0.047	0.049	0.053	0.049	0.048	0.049	0.052	0.049	0.047	0.050	0.051
B	0.054	0.058	0.055	0.057	0.045	0.055	0.054	0.055	0.054	0.052	0.056	0.053	0.053	0.054	0.057	0.052	0.055	0.056	0.056	0.053
B	0.048	0.045	0.046	0.050	0.045	0.037	0.047	0.044	0.044	0.044	0.047	0.047	0.043	0.046	0.047	0.047	0.045	0.044	0.047	0.048
B	0.053	0.048	0.051	0.054	0.054	0.048	0.044	0.054	0.054	0.057	0.056	0.057	0.053	0.057	0.056	0.056	0.053	0.054	0.055	0.055
B	0.053	0.053	0.056	0.051	0.053	0.052	0.052	0.045	0.057	0.057	0.054	0.055	0.056	0.055	0.054	0.055	0.057	0.057	0.055	0.055
B	0.054	0.052	0.052	0.053	0.055	0.055	0.056	0.055	0.045	0.057	0.057	0.054	0.056	0.055	0.055	0.054	0.056	0.055	0.054	0.054
B	0.052	0.051	0.048	0.044	0.048	0.050	0.055	0.052	0.052	0.041	0.047	0.050	0.052	0.049	0.047	0.047	0.051	0.051	0.049	0.048
B	0.046	0.044	0.048	0.044	0.045	0.044	0.045	0.047	0.046	0.047	0.037	0.044	0.047	0.045	0.043	0.044	0.046	0.045	0.047	0.045
B	0.043	0.042	0.042	0.045	0.045	0.039	0.039	0.041	0.045	0.041	0.044	0.034	0.044	0.043	0.043	0.038	0.045	0.040	0.041	0.043
B	0.056	0.053	0.054	0.055	0.054	0.055	0.056	0.054	0.052	0.056	0.057	0.054	0.045	0.054	0.054	0.054	0.056	0.055	0.054	0.057
B	0.052	0.054	0.052	0.048	0.051	0.054	0.056	0.052	0.053	0.048	0.049	0.049	0.054	0.042	0.051	0.054	0.051	0.049	0.049	0.051
B	0.049	0.049	0.050	0.048	0.051	0.049	0.050	0.052	0.050	0.050	0.050	0.049	0.049	0.053	0.040	0.050	0.049	0.051	0.047	0.047
B	0.047	0.045	0.046	0.049	0.048	0.045	0.044	0.045	0.048	0.044	0.046	0.046	0.046	0.044	0.047	0.038	0.044	0.051	0.048	0.047
B	0.052	0.055	0.051	0.052	0.054	0.054	0.054	0.052	0.053	0.054	0.054	0.053	0.052	0.056	0.053	0.056	0.043	0.054	0.053	0.053
B	0.047	0.050	0.048	0.048	0.046	0.048	0.046	0.048	0.047	0.050	0.046	0.047	0.047	0.046	0.048	0.051	0.045	0.039	0.047	0.045
B	0.047	0.048	0.045	0.047	0.047	0.049	0.047	0.047	0.046	0.047	0.047	0.047	0.046	0.042	0.045	0.047	0.047	0.043	0.038	0.047
B	0.050	0.051	0.050	0.049	0.049	0.049	0.047	0.047	0.048	0.051	0.046	0.047	0.048	0.049	0.052	0.046	0.049	0.046	0.046	0.039

Generated Limiting Supermatrix by Multiplying the weighed Supermatrix with itself until convergence

	B_{11}	**B_{12}**	**B_{13}**	**B_{14}**	**B_{21}**	**B_{22}**	**B_{23}**	**B_{24}**	**B_{31}**	**B_{32}**	**B_{33}**	**B_{34}**	**B_{41}**	**B_{42}**	**B_{43}**	**B_{44}**	**B_{51}**	**B_{52}**	**B_{53}**	**B_{54}**
B	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
B	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
B	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051
B	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
B	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
B	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
B	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
B	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
B	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
B	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
B	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
B	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
B	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
B	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051
B	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
B	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
B	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
B	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
B	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
B	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048

The Table 8.3 indicates the Priority weights of various barriers to adoption of green manufacturing obtained by using integrated DEMATEL and ANP.

Table 8.3: Priority weights of various barriers to green manufacturing

S.NO	BARRIER	SUB BARRIER	DESCRIPTION	PRIORITY WEIGHTS
B1	Financial Barrier	B11	Uncertain rate of return	0.060786
		B12	High initial capital cost	0.048589
		B13	long gestation period	0.050537
		B14	Bank reluctant to fund projects	0.048666
B2	Technology Barrier	B21	Complexity of design	0.054124
		B22	lack of flexibility	0.045539
		B23	Integration	0.053362
		B24	Adaptability	0.054037
B3	Social Barrier	B31	Employee altitude and resistance	0.054149
		B32	Customers’ reluctance to pay higher price	0.049284
		B33	Shareholders pressure	0.04502
		B34	Lack of experience professional	0.041961
B4	Operational Barrier	B41	Inadequate management commitment	0.054187
		B42	Suppliers Resistance	0.050991
		B43	High cost of compliance certification	0.049168
		B44	Maintainability	0.045901
B5	Environmental Barrier	B51	Lack of effective environmental enforcement	0.052815
		B52	lack of uniform benchmarking indices	0.046927
		B53	Mandating use unviable techniques	0.045958
		B54	Inadequate infrastructure	0.047998

The Table 8.4 indicates the ranking of various barriers to adoption of green manufacturing obtained by using hybrid DEMATEL and ANP methodologies.

Table 8.4: Ranking of various Sub-barriers to adoption of green manufacturing

RANK	SUB BARRIER	DESCRIPTION	PRORITY
1	B11	Uncertain rate of return	0.060786
2	B41	Inadequate management commitment	0.054187
3	B31	Employee altitude and resistance	0.054149
4	B21	Complexity of design	0.054124
5	B24	Adaptability	0.054037
6	B23	Integration	0.053362
7	B51	Lack of effective environmental enforcement	0.052815
8	B42	Suppliers Resistance	0.050991
9	B13	long gestation period	0.050537
10	B32	Customers' reluctance to pay higher price	0.049284
11	B43	High cost of compliance certification	0.049168
12	B14	Bank reluctant to fund projects	0.048666
13	B12	High initial capital cost	0.048589
14	B54	Inadequate infrastructure	0.047998
15	B52	lack of uniform benchmarking indices	0.046927
16	B53	Mandating use unviable techniques	0.045958
17	B44	Maintainability	0.045901
18	B22	lack of flexibility	0.045539
19	B33	Shareholder Pressure	0.04502
20	B34	Lack of experience professional	0.041961

The Priority rankings of enablers as per DANP are shown in Figure 8.3. The result highlights the sub barrier Uncertainty of rate of return has the highest priority weight of 0.060786 .This is followed by inadequate management commitment having priority weight of 0.054187. Employee altitude and resistance barrier is ranked third having priority weight of 0.054149.

8.3 DISCUSSION

The hybrid DEMATEL and ANP results in Table 8.3 show the priority wise order of identified barriers as Financial barriers>Technology barriers>Operational barriers > Environmental barriers >Social barriers. Figure 8.2 shows the cumulative priority weight of each main barrier on the basis results of D-ANP study.

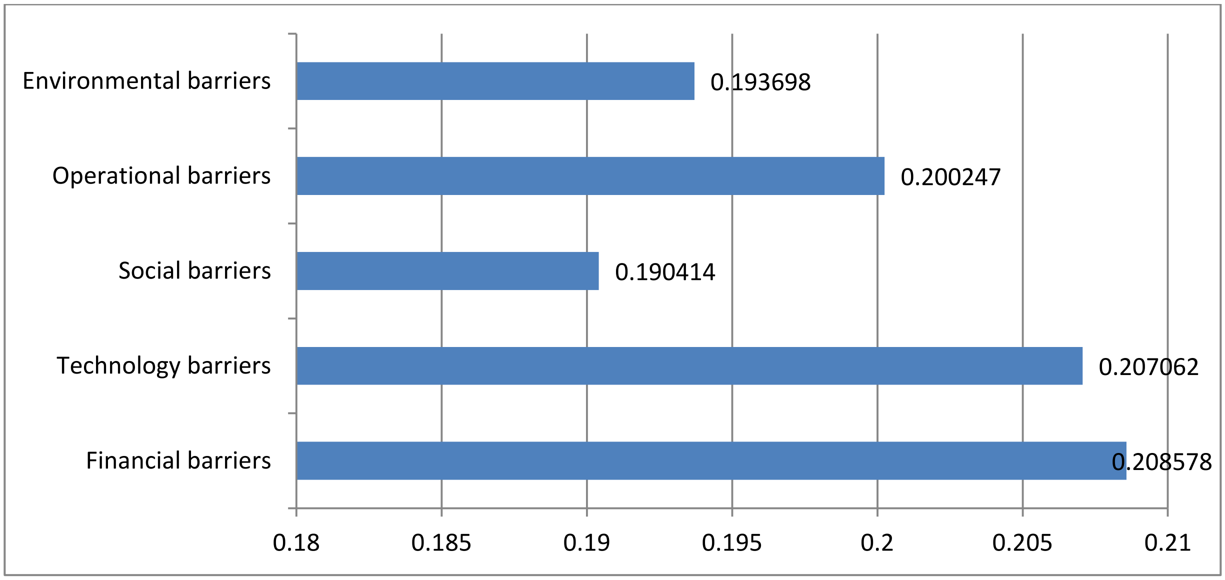

Figure 8.2: Priority weights main barriers to green manufacturing as per DANP.

Green manufacturing paradigm focuses efforts towards the optimal use of resources. The hybrid DEMATEL and ANP mythology results in Table 8.4 show the priority weight wise preference order of identified barriers. The results indicate financial barrier as paramount barrier. The hybrid approach of DEMATEL and ANP determine the relative importance of barriers of green manufacturing offers useful managerial insights. The sub barrier “Uncertain rate of return” has the highest priority weight of 0.060786 and is ranked as the most important sub criterion. It highlights that business are reluctant to investment in green manufacturing due to fear of financial loss and probability of business not being able to recover their investments. Other important barriers to adoption of green manufacturing are: - Inadequate management commitment, employee altitude and resistance, complexity of design, adaptability. These have a priority weight of 0.054187, 0.054149, 0.054124 and 0.054037 respectively. Figure 8.3 shows the priority of each sub barriers of DEMATEL-ANP study.

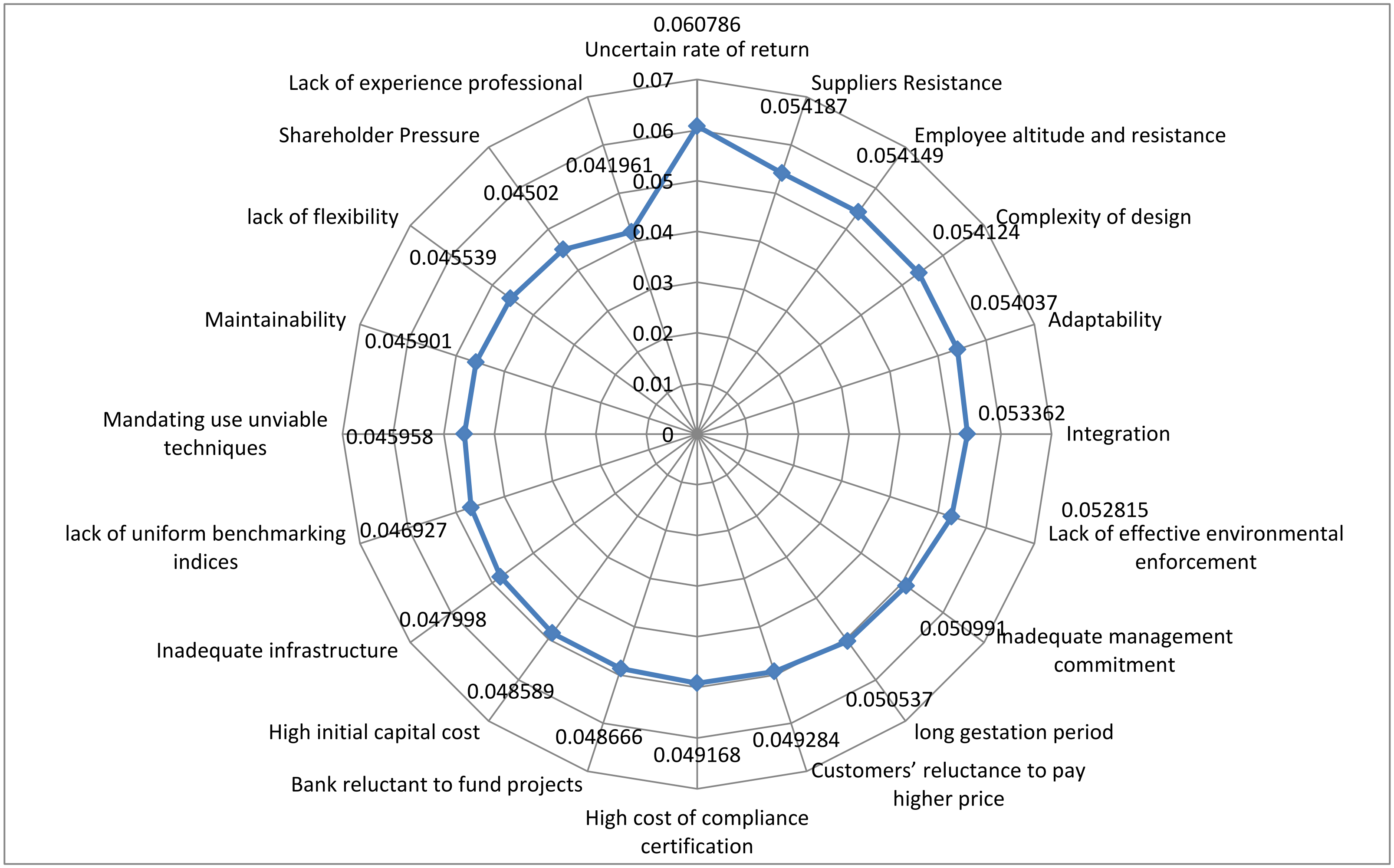

Figure 8.3: Priority weights of each sub barriers to green manufacturing using DEMATEL and ANP.

The DEMATEL results for vector dispatcher and vector receiver in Table 8.2 .It shows that the barriers having a high R+C value are “Uncertain rate of return”, “Inadequate management commitment”, “Employee altitude and resistance” ,”Complexity of design” and “Adaptability”. These barriers are considered as high prominence barriers. Figure 8.4 indicates the prominence value of various barriers to adoption of green manufacturing obtained using DEMATEL methodology.

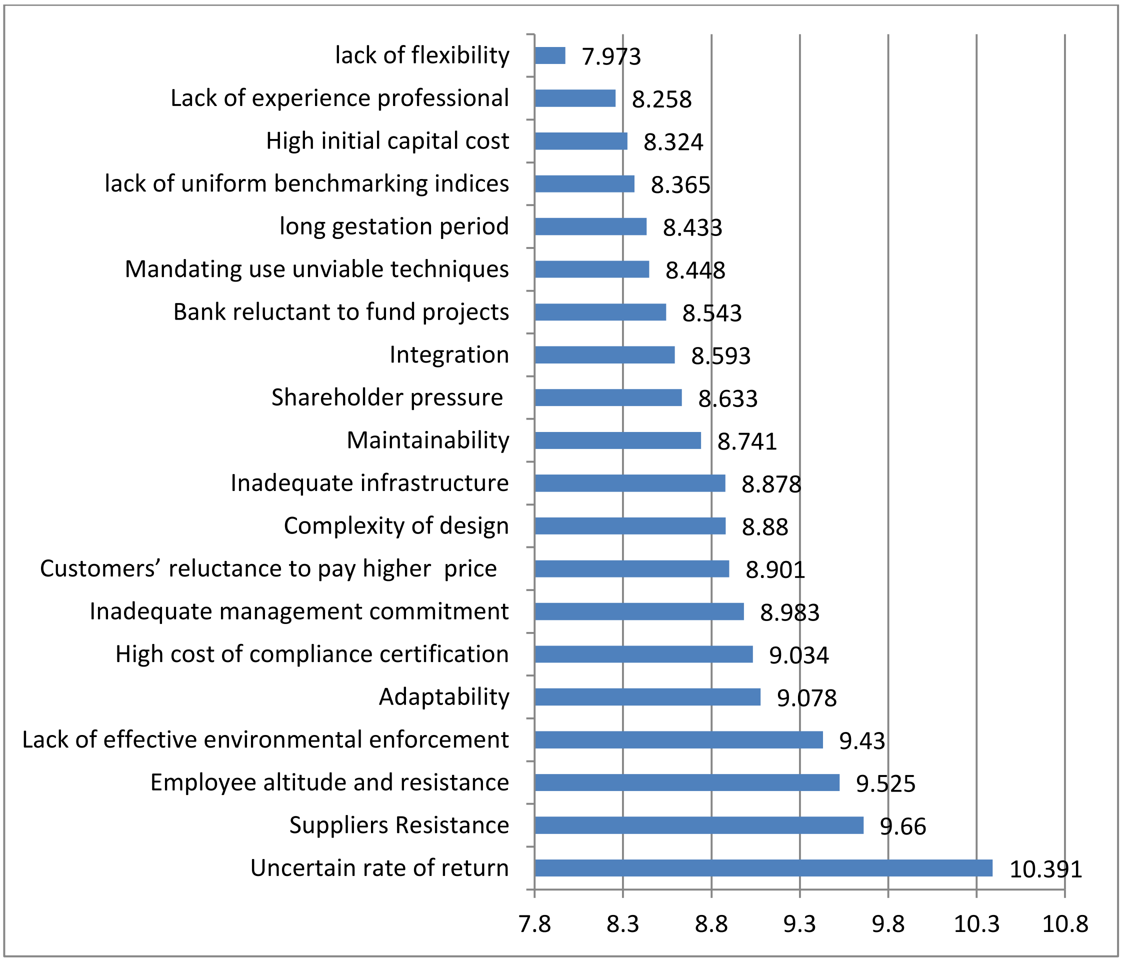

Figure 8.4: The prominence value of various sub barriers to adoption of green manufacturing obtained using DEMATEL methodology.

Influential Factor (R_I-C_I) helps to classify the barriers into cause and effect barriers. Barriers having a positive (R_I-C_I) value are regarded as cause barriers. As per Table 8.2 the barriers integration (0.91), complexity of design (0.7) and long gestation period (.0571) are main cause barriers. The barriers with a negative R-C vale are regarded as effect barriers. As per Table 8.3 the barriers Lack of experience professional (-0.847), Customers’ reluctance to pay higher price (-0.675), Maintainability (-0.613) are the paramount effect barriers.

8.4 CONCLUSIONS

Systematic evaluation of barriers towards the transition towards green manufacturing using a hybrid DEMATEL and ANP methodology for analyze the causal relationships and strength of mutual influence among various barriers. The MCDM DEMATEL helps in building and analyzing structural relationships involving dependency among the various barriers of green manufacturing. DEMATEL classifies the various barriers into cause groups and effect groups.ANP analysis determines the relative priorities of sub-barriers to espousing green manufacturing. The results of the study obtained indicate that uncertainty of rate of return, inadequate management commitment and employee altitude and resistance, as the top three barriers for transition towards green manufacturing. Mitigation of these barriers will enable smoother implementation of green manufacturing. There is need to have a mutually beneficial and a corporative approach among the various stakeholder of green manufacturing paradigm. There is a need to provide technical and financial support for establishing newer facilities by manufacturers. Conducting awareness programs highlighting potential benefits of green manufacturing helps in negating these barriers.

CHAPTER 9

SYNTHESIS OF THE RESEARCH WORK

9.1 INTRODUCTION

In recent decades increase in environmental awareness has motivated the manufacturers towards minimizing the use of exhaustible resources. Green manufacturing focuses on manufacturing technologies and initiatives that optimize energy usage and resource conservation. Green manufacturing aims to minimize environmental impact of manufacturing activities. The adoption of green manufacturing makes a business more responsive to environmental issues. It is pertinent for businesses to carefully implement green manufacturing system as it entails significant impact on the economic viability of their operations. The central objective of a green paradigm is the combination of economic and ecological efficiency. This chapter summarizes the research work presented in previous chapters. The objective of the study is to use a structured approach to examine and rank, from an environmental perspective, the various factors that act as pivot for supporting different businesses to espouse green manufacturing

9.2 SYNTHESIS OF THE RESEARCH WORK

This study evaluates the causal relationship among the various parameters that influence environmental performance of a manufacturing system. The present work aims to address the various issues in adoption of green manufacturing. The research achieved the objectives listed in chapter1.These are enumerated below.

- A compressive literature review indentified the various parameters which affect the environmental performance of a manufacturing system.
- Pivotal issues which act as enablers and barriers in adopting green manufacturing were identified on the basis of literature reviews and industrial experts in the field of green manufacturing
- A questionnaire based survey approach was employed to obtain industry perspective and results are statically analyzed.
- GTMA has been used to provide a framework for measuring the environmental effectiveness index for comparing competing manufacturing systems.

- DEMATEL and Analytic Network Process is used analyze the importance of various enablers of adopting green manufacturing and the casual relations among these enablers.
- Interpretive Structural Modeling is used to develop a hierarchical model incorporating the drivers for green manufacturing.
- MICMAC analysis provides meaningful insights portraying the driving and driven powers of identified elements.
- Fuzzy TOPSIS methodology is used to filter the uncertainties and ambiguity in linguistic terms and prioritizes the critical success factors for adoption of green manufacturing.
- DEMATEL and Analytic Network Process employed to establish the importance of various to adoption of green manufacturing and the casual relations among these barriers

The methodologies adopted for analysis of select issues in green manufacturing are enlisted in Table 9.1.The process of amalgamation of these methodologies is reflected in Figure 9.1.

Table 9.1: Methodologies used in this research

S. No.	Objectives	Methodology used	Study No.
1	To identify issues in adoption of green manufacturing system	Literature review and expert opinion from industry and academia	I
2	Statically quantify the industry opinion towards adoption of green manufacturing practices.	Survey Questionnaire	II
3	Quantitative evaluation of parameters for environmentally benign manufacturing	Graph Theoretic Matrix Approach	III
4	Ranking of identified Critical Success factors for the successful adoption of green manufacturing	Fuzzy TOPSIS	IV
5	Development of an ISM model to analyze the selected enablers of SMS	Interpretive Structural Modelling	V
6	Ranking identified enablers for the successful adoption of green manufacturing	DEMATEL AND ANP methodology	VI
7	Ranking identified barriers towards the successful adoption of green manufacturing	DEMATEL AND ANP methodology	VII

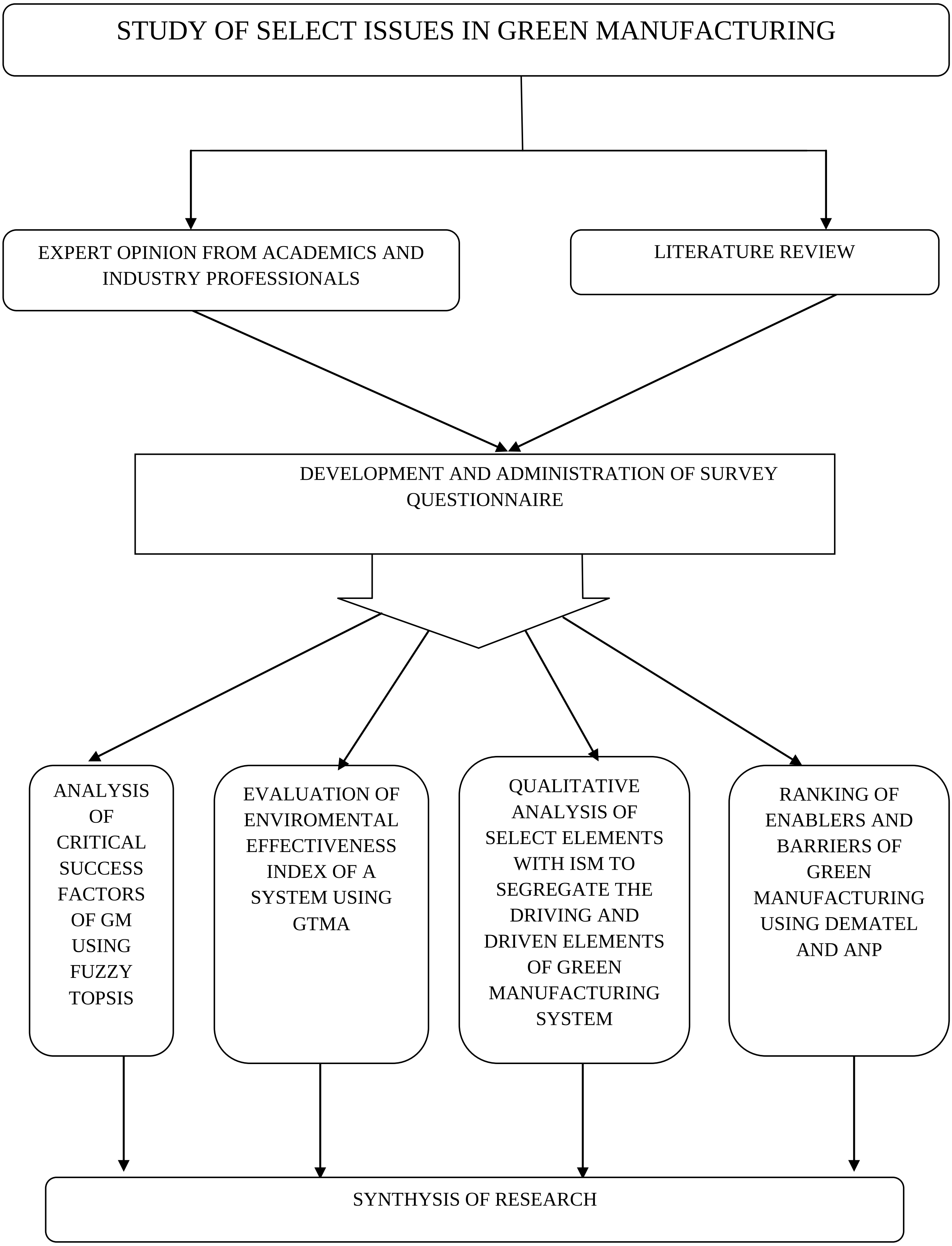

Figure 9.1: Synthesis of Research

Followings are significant outcomes of the present research.

9.2.1 Literature Review

A literature review was done to identify various issues in the implementing green manufacturing. The topics covered in the review of literature are green manufacturing, parameters for evaluating environmental effectiveness of a system, critical success factors for green manufacturing, drivers for green manufacturing, and barriers for green manufacturing. Literature Review also included the different MCDM methodologies employed in study were also listed in research work.

9.2.2 Development and administration of questionnaire

On the basis of Literature review a questionnaire on issues related to green manufacturing was developed. To ascertain the views of manufacturing professionals a survey was conducted in different industries. Data obtained from respondents was subjected to statistical analysis and validation

9.2.3 Evaluation of environmental effectiveness of a manufacturing system using Graph Theoretic Matrix Approach

Chapter 4 presents the framework for evaluation of environmental effectiveness of a manufacturing system using graph theoretical matrix approach. The GTMA analysis reflects that the Technological competence is the main pillar towards the implementation of green manufacturing. This study highlights the need to evaluate from different perspectives of environmental effectiveness and their interdependency. By using an unbiased process of GTMA, helps businesses to focus on setting goals that best achieve environmental protection. The study helps manufacturing managers better understand the implications from different perspectives for transition towards a green manufacturing.

9.2.4 Critical success factors for implementation green manufacturing using Fuzzy TOPSIS

Chapter 5 presents the analysis of critical success factors for implementation green manufacturing. The analysis highlights that the factor “adoption of eco-innovations” ranked I and is therefore of paramount importance. Successful adoption of eco-innovations provides enhanced flexibility and automation through use of newer technologies are important for transition towards green manufacturing. The factor

“Use of reverse logistics” is ranked II. This factor emphasizes on re-manufacture and reuse of materials for resource conservation. “Government and regulatory support” is ranked III. This factor highlights the fact that government should extend tax incentives and subsidies for transitioning towards Green manufacturing. A business friendly regulatory structure is critical for stimulating green manufacturing.

9.2.5 ISM modeling for drivers for green manufacturing.

Chapter 6 presents an ISM based model for drivers for green manufacturing. ISM MODELLING of drivers of green manufacturing constructs a six level hierarchy framework model. MICMAC analysis establish that consumer pull for greener products, Competitor Pressure and Regulatory compliance Pressure are independent drivers which have strong ‘driving’ power and ‘weak’ dependence power.

9.2.6 Evaluating the enablers for green manufacturing using DEMATEL and ANALYTIC NETWORK PROCESS

Chapter 7 presents the evaluation of the enablers for green manufacturing using DANP. This study uses integration of the multiple criteria decision methods of DEMATEL and ANP for analyzes and prioritization relations between the various enablers of green manufacturing. The results obtained indicate that customer demand, implementing eco innovation and availability of collaborative suppliers as the top three enablers for transition towards green manufacturing. The study priorities the various enablers of green manufacturing and filters them into cause and effect group. DANP is used to rank the various enablers.

9.2.7 Evaluating the barriers for green manufacturing using DEMATEL and ANALYTIC NETWORK PROCESS

Chapter 8 presents an analysis of the various barriers for green manufacturing using DANP. The results obtained from analyses reveal indicate that financial risk aversion is the paramount barrier for businesses’ to adopt green practices. The multi-fold transformations of manufacturing operations which have far reaching economic consequences make businesses reluctant for espousing green practices. The uncertainty with regard to successful technology absorption also inhibits heralding of green practices. Green manufacturing needs to weave a collaborative approach among various stake holders for boosting cleaner production. The businesses' face numerous difficulties due to ambiguous and vacillating government and regulatory support.

9.3 CONCLUSION

This chapter presents the synthesis of present study. Figure 9.1 represents a flow diagram of different methodologies that are utilized used in this research work. A literature review was undertaken to identify various issues in espousing green manufacturing. Various MCDM techniques have been employed to develop a structured framework for analysis of these issues. Fuzzy TOPSIS, Graph Theoretic Approach Interpretive, Structural Modeling (ISM), DEMATEL and ANP for analyzes of various issues for successful adoption of green manufacturing system. The prioritization of critical success factors of successful implementation green manufacturing has been done using fuzzy methodology. The relationships among selected drivers have been established using ISM methodology. The evaluation of environmental effectives of a manufacturing system has been obtained using graph theoretic approach. Quantities analysis of various issues has been carried out using DEMATEL and ANP. The prominent features in this research are:

i. Important issues that play paramount role in transition towards green manufacturing has been analyzed by using various MCDM techniques
ii. GTA analysis is used to develop an index for environmental effectiveness of a system
iii. ISM analysis highlights that consumer pull for greener products , pressure from competitors and need for regulatory compliance are the paramount drivers for transition towards green manufacturing.
iv. DEMATEL and ANP analysis highlights customer demand, eco innovation and collaborative suppliers are paramount enabler which helps in espousing green manufacturing.
v. DEMATEL and ANP analysis highlights that uncertainty of rate of return; employee altitude and resistance, complexity of design are paramount issues which hinder adoption of green manufacturing.

CHAPTER 10

CONCLUSION AND SCOPE FOR FUTURE RESEARCH

10.1 INTRODUCTION

Increased awareness of the consequences of environment degradation due to manufacturing activities coupled with government regulatory guidelines are galvanizing organizations to adopt practices which are environmentally benign. Green manufacturing paradigm enables companies to improve their sustainability index elevates their resource efficiencies and bestows competitive advantages. Such practices have umpteen advantages for any business but a number of formidable challenges act as barriers to the cause of espousing proactive environmental policies. This has motivated the researchers to explore and analyze the various issues for successful adoption of green manufacturing paradigm. This chapter presents the, contribution, limitations, future scope of future research.

10.2 MAJOR CONTRIBUTION OF THE RESEARCH

The paramount focus of this research is to provide an analysis of issues in implementing green manufacturing systems. The adoption of green manufacturing system is a challenging task especially for developing economies. Major contributions of research are listed below.

- The present research provides an exhaustive review of literature on green manufacturing.
- A GTMA is used to evaluate environmental effectiveness of a system. The computation of permanent function is used provides a single numerical value of environmental effectiveness index for comparing competing system.
- Fuzzy TOPSIS has been used to rank a total of 11 critical success factors identified for successful transition toward green manufacturing.
- A total of 10 key enablers of adoption of green manufacturing were identified There causal relationship were analyzed by using DEMATEL and ANP methodology

- An ISM model AND MICMAC analysis is performed on drivers on green manufacturing.
- Five key barriers and twenty sub barriers towards the adoption of green manufacturing were identified There causal relationship were analyzed by using DEMATEL and ANP methodology

10.3 KEY FINDINGS OF THE RESEARCH

Followings are significant finding of the present research.

- Need for environmental protection is altering how businesses look at their manufacturing operations, markets, delivery of products to consumers and new investments. Businesses appetite and indent for greener manufacturing is evident through literature review and responses by the professionals to the survey questioners.

- Graph theory matrix approach based on digraph approach provided an important qualitative cum quantitative framework for evaluating competing technologies. The computation of permanent function provides a single numerical value of environmental effectiveness index. By evaluating environmental effectiveness index of different industries, their manufacturing systems can be are compared for their impact on environment.

- Use of Fuzzy TOPSIS for ranking Critical success factors highlights that the factor adoption of eco-innovations has an aggregated closeness coefficient of 0.563643 is ranked I. Use of eco-innovations provides enhanced flexibility and automation through use of newer technologies like artificial intelligence , internet of things, smart sensors etc.

- ISM MODELLING of drivers of green manufacturing constructs a six level hierarchy framework model. MICMAC analysis establish that consumer pull for greener products, Competitor Pressure and Regulatory compliance Pressure are independent drivers which have strong ‘driving’ power and ‘weak’ dependence power.

- DANP analysis determines that high customer demand and adoption use eco innovations have the highest priority among the enablers of green manufacturing.

- DANP analysis determines financial barriers are the paramount barriers in transition towards green manufacturing. The sub barrier “Uncertain rate of return” has the highest priority weight of 0.060786 and is ranked as the most important sub criterion**.**

10.4 CONCLUSION

A number of innovative green technologies are being embraced by companies in quest for environmental protection. The green transformations of manufacturing operations approach aligns with businesses focus on customers, environmental protection and future readiness. The unique combination of innovative manufacturing operations powered by green practices and products are helping manufactures achieve ambitious business targets. Companies adopting green practices in manufacturing are able to establish newer benchmarks in environmental protection. These benefits are not restricted to reduced environmental impact but also in cost efficiencies and greater adherence to regulatory compliance. Adoption of green manufacturing brings in increased revenue due to higher customer preference for environmentally begin products. While manufactures have embraced green practices in one form or the other, they are predominantly lagging in releasing the true potential of using green process and products due to numerous reasons acting as barriers to the cause of espousing proactive environmental policies.

GTMA approach provides an important qualitative cum quantitative framework for evaluating competing technologies for espousing green manufacturing. The computation of permanent function provides a single numerical value of environmental effectiveness index. By evaluating environmental effectiveness index of different industries, their manufacturing systems can be compared for their impact on environment. By using an unbiased process of GTMA, helps businesses to focus on achieving goal of environmental protection.

Fuzzy TOPSIS filter the uncertainties and ambiguity in linguistic terms to evaluates and rank critical success factors for implementing green manufacturing. The effects of these factors on green manufacturing are evaluated using operational, environmental, financial and social criteria. Factors of adoption of eco-innovations and reverse logistics are placed at priority Level I & II. ISM MODELLING provides linkages amongst the crucial drivers pertaining to green manufacturing. MICMAC analysis establishes that Resource conversation, waste disposal and employee welfare are dependent drivers. These drivers have low driving power and high dependence power. Impetus of investors, supplier awareness, eco-innovation and financial incentives” are linkage drivers. These have high driving and high dependence power. The results further show that no driver belongs to the autonomous driver group. Pressure from competitors, pressure of consumers and regulatory compliance pressure are independent drivers. These drivers have high drive power and low dependence power.

The results of DANP analysis of the enablers obtained indicate that customer demand, implementing eco innovation and availability of collaborative suppliers as the top three enablers for transition towards green manufacturing. The societal impact of this study is that it proves that these enablers help as to manage waste better and conserve non-renewable resources though eco innovation and environmental consciousness. DANP analysis indicates that the barriers integration with the existing system, complexity of design and long gestation period are main cause barriers. The barriers lack of experience professional, customers’ reluctance to pay higher price and maintainability are the paramount effect barriers.

The multi-fold transformations of manufacturing operations which have far reaching economic consequences make businesses reluctant for espousing green practices. The uncertainty with regards successful technology absorption also inhibits heralding of green practices. Green manufacturing needs to weave a collaborative approach among various stake holders in supply chain for driving the change for cleaner production. The businesses face numerous difficulties due to ambiguous government and regulatory supports. The businesses need to device innovative strategies for mitigating human resource barrier in their quest for green manufacturing. Manufactures need use agility and cost efficiency of green manufacturing to enhance consumer experience significantly for unlocking the barrier of customer acceptance.

10.5 LIMITATION AND SCOPE FOR FUTURE RESEARCH

Followings are significant limitaions of the present research

- The present research study uses DEMATEL and ANP to explore the causal relationship and strength of mutual influence among the enablers and enablers of green manufacturing. Other MCDM techniques can be used for analysis of relationship between various enablers and barriers of green manufacturing.

- Instead of GTMA different benchmarking methods can be employed for ranking and comparing environmental effectiveness of the manufacturing system.
- Various models have been developed on the basis of experts opinion which might have reflects their perception and business.

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APPENDIX- I

QUESTIONNAIRE

YMCA UNIVERSITY OF SCIENCE AND TECHNOLOGY
FARIDABAD (HARYANA)- 121006

Research Supervisors:

(i) Prof. Tilak Raj, YMCA University of Science and Technology, Faridabad, Haryana- 121006 (ii) Prof. Sandeep Grover, YMCA University of Science and Technology, Faridabad, Haryana- 121006

Subject: STUDY OF ISSUES RELATED TO GREEN MANUFACTURING

Dear Sir / Madam,

In view of global concern for environmental protection, adoption of newer environmentally friendly technologies are being implemented .Green manufacturing practices provide adoption of newer process and products for making operations environmentally benign.

As part of PhD research on “Study of Select Issues in Green Manufacturing”, a survey of Indian Industries has been taken up on various issues towards the adoption of Green Manufacturing. It is requested to kindly fill the enclosed questionnaire as observed in your organization. The response of the survey shall be confidential.

It will be highly appreciated if you can send the filled-in questionnaire within 15 days.

With warm regards,

Yours’ Sincerely,

(Sandeep Handa)
Research Scholar

Encl: 1. Questionnaire
2. Self-addressed envelope

SURVEY QUESTIONNAIRE

SECTION 1: ORGANIZATION PROFILE

(a) Name of the organization

(b) Address

(c) Nature of Operation .

Please put tick [✓] or type [T] in the appropriate box.

1. Total employees in your organization:
   (A) Less than 100 [ ] (B) 101 to 500 [ ] (C) 501 to 1000 [ ]
   (D) More than 1000 [ ]
2. Annual turnover of the organization (Rs. in Crore)……………………
   (A) Less than 10 [ ] (B) 10 to 50 [ ] (C) 50 to 100 [ ]
   (D) 100 to 500 [ ] (E) More than 00 [ ]
3. Number of different Production shops in your organization
   (A) Single [ ] (B) 2- 4 [ ] (C) 5-8 [ ] (D) More than 8 [ ]
4. Varieties of components manufactured in your organization
   (A) 1-5 [ ] (B) 6- 10 [ ] (C) 11- 20 [ ]
   (D) More than 20 [ ]

SECTION 2: RESPONSE RELATED TO MANUFACTURING

1. Please rate the following enablers towards the adoption of Green Manufacturing in your organization:

Sl. No.	**Enablers towards the adoption of Green Manufacturing**	**Very Low**	**Low**	**Moderate**	**High**	**Very High**
		1	2	3	4	5
1	Conducive regulatory mechanism					
2	Need of waste management					
3	Shareholders Pressure					
4	Economic benefits					
5	Eco innovations					
6	Collaborative supplier					
7	Market competition					
8	Customer demand					
9	Conservation of exhaustible resource					
10	Adept human resources					

2. Please rank the impact of following barriers towards the adoption of Green Manufacturing in your organization

Sl. No.	Barriers for adoption of Green Manufacturing	Very Low	Low	Moderate	High	Very High
		1	2	3	4	5
1	Uncertain Rate of Return					
2	Inadequate Management Commitment					
3	Employee Altitude and Resistance					
4	Complexity of Design					
5	Adaptability					
6	Integration					
7	Lack of Effective Environmental Enforcement					
8	Suppliers Resistance					
9	Long Gestation Period					
10	Customers’ Reluctance to Pay Higher Price					
11	High Cost of Compliance Certification					
12	Bank Reluctant to Fund Projects					
13	High Initial Capital Cost					
14	Inadequate Infrastructure					
15	Lack of Uniform Benchmarking Indices					
16	Mandating use Unviable Techniques					
17	Maintainability					
18	Lack of Flexibility					
19	Shareholder Pressure					
20	Lack of Experience Professional					

Thank you very much for your valuable feedback. Kindly forward your response in the self addressed envelope enclosed.

APPENDIX- II

BRIEF PROFILE OF THE RESEARCH SCHOLAR

Mr. Sandeep Handa is presently working as Senior Lecturer in the Department of Production Engineering, G. B. Pant Institute of Technology, Okhla, Phase III New Delhi, India. He had completed B.E. in Production and Industrial Engineering from Delhi College of Engineering in 1991. He had worked in HMT limited (Watch Factoy V), Ranibagh, District Nanital Uttarkhand in various capacities. He did his Masters' degree from Panjab University in 2010 and presently pursuing PhD from J. C. Bose University of Science and Technology, YMCA, Faridabad. He has more than 19 years of teaching and 09 years of Industrial experience in the field of Production Engineering and Industrial Management. Mechanical maintenance etc. He has published various research papers in different national and international journals of repute and conferences.

APPENDIX- III

LIST OF PUBLICATIONS OUT OF THESIS

LIST OF PUBLISHED PAPERS

Sl. No.	Title of Paper	Name of Journal where published	No.	Volume and Issue	Year
1	Innovation for green manufacturing,	International Journal of Engineering Sciences	ISSN (Online): 2277-9698		2012
2	Quest for environmental protection by integrated green manufacturing system	Proceedings of the National Conference on Trends and Advances in Mechanical Engineering, YMCA, Faridabad, Haryana	ISBN 978-93-5087-5742		2012
3	Analysis of Drivers for Green Manufacturing using ISM	INDUSTRIAL ENGINEERING JOURNAL	ISSN:2581-4915	12 (6)	2019
4	Evaluation of Critical Success Factors for Green Manufacturing Using Fuzzy TOPSIS	INDUSTRIAL ENGINEERING JOURNAL	ISSN:2581-4915	12 (9)	2019
5	Analysis of selected barriers in green manufacturing using AHP	International Journal of Engineering Sciences Paradigms and Researches	ISSN (Online): 2319-6564	Vol. 48, Special Issue	2019

LIST OF ACCEPTED PAPERS

Sl. No.	Title of Paper	Name of Journal where published	No.	Volume and Issue
1	An integrated approach for evaluating the enablers for green manufacturing using DEMATEL and Analytic Network Process	International Journal of Operational Research (IJOR), Inderscience	Article ID: IJOR 29944	Under Publication schedule

LIST OF COMMUNICATED PAPERS

Sl. No.	Title of the Paper	Name of Journal	Present Status	Year
1	Evaluation of environmental effectiveness of a manufacturing system using Graph Theoretical Matrix Approach	Int. J. of Process Management and Benchmarking,ISSN 1460-6739. Article ID: IJPMB-36651	Under review	2020