AN INTEGRATED FRAMEWORK TO ANALYZE THE IMPLEMENTATION STRATEGIES FOR AGILE MANUFACTURING SYSTEM

THESIS

Submitted in fulfilment of the requirements of degree of

DOCTOR OF PHILOSOPHY

to

YMCA UNIVERSITY OF SCIENCE & TECHNOLOGY

by

RAHUL SINDHWANI

(Registration No. – YMCAUST/PH35/2012)

Under the supervision of

Dr. Vasdev Malhotra, Ph.D

(Associate Professor, YMCAUST, Faridabad)

Department of Mechanical Engineering

Faculty of Engineering and Technology

YMCA University of Science & Technology

Sec. – 6, Mathura Road, Faridabad, Haryana, India

JANUARY, 2017

.....dedicated

to

my beloved parents, wife and kids……

CANDIDATE'S DECLARATION

I hereby declare that the thesis entitled **AN INTEGRATED FRAMEWORK TO ANALYZE THE IMPLEMENTATION STRATEGIES FOR AGILE MANUFACTURING SYSTEMS** by **RAHUL SINDHWANI**, 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 YMCA University of Science & Technology Faridabad, during the academic year 2016-17, is bonafide record of my original work carried out under guidance and supervision of **Dr. VASDEV MALHOTRA, ASSOCIATE PROFESSR, DEPARTMENT OF MECHANICAL ENGINEERING, YMCA UNIVERSITY OF SCIENCE AND TECHNOLOGY, FARIDABAD, HARYANA, INDIA** and 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.

Rahul Sindhwani

Registration No. – YMCAUST/PH35/2012

CERTIFICATE OF THE SUPERVISOR

This is to certify that this Thesis entitled **AN INTEGRATED FRAMEWORK TO ANALYZE THE IMPLEMENTATION STRATEGIES FOR AGILE MANUFACTURING SYSTEM** by **RAHUL SINDHWANI**, 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 YMCA University of Science & Technology Faridabad, during the academic year 2016-17, is a bonafide record of work carried out under my guidance and supervision.

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

Dr. Vasdev Malhotra, Ph.D
Associate Professor
Department of Mechanical Engineering
Faculty of Engineering and Technology
YMCA University of Science & Technology
Faridabad- 121006, India

Dated:

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my Supervisor **Dr. Vasdev Malhotra, Associate Professor, Department of Mechanical Engineering, YMCA University of Science and Technology, Faridabad** for giving me the opportunity to work in this area. It would never be possible for me to take this thesis to this level without his innovative ideas and his relentless support and encouragement. I am grateful for his incisive comments and insightful suggestions that have helped me to remove many lacunae from this thesis.

I feel obliged to Dr. Varinder Kumar Mittal (Associate Professor) and Mr. Vipin Kaushik (Assistant Professor) in Mechanical Engineering Department, Amity University Uttar Pradesh, Noida), and all of my colleagues in Amity University Uttar Pradesh for his continuous support.

I owe thanks to all of my friends and colleagues for their help and co-operation at every step in this study. I thank all experts from industry and academia for their valuable inputs to the study. A very special expression of appreciation is regarded to my father, mother, wife and kids. Without their encouragement, patience, and understanding this endeavor would not have been possible. Last but not the least, I pray and thank to ALMIGHTY GOD for showering HIS divine blessings and giving me an inner strength and patience.

Rahul Sindhwani

ABSTRACT

Throughout history, manufacturing is going successive periods of great changes. New materials, new techniques, new technologies have always been at the root of these changes. Currently globalizing markets, demanding customers, congenial environment for foreign investment and other factors such as these have made "manufacturing" more complex. In the current environment, manufacturing has to be interpreted as consisting of multiple activities. There is a need to conceive, develop, manufacture, distribute, sell, maintain and dispose the products while following regulations on environment and keeping internal and external customers satisfied. Now, to sustain in 21^{st} century competitive manufacturing scenario, it is essential to implement Agile Manufacturing System (AMS). AMS is the science of a business system that integrates management, technology and workforce, making the system flexible enough for manufactures to switch over from production of one component to another component in a cost-effective manner within the framework of the system.

There are numerous attribute, sub-attribute, enabler, factor and barrier of Agile Manufacturing System (AMS) which play a dynamic role in its execution. In this research work, numerous attribute, sub-attribute, enabler, factor and barrier of AMS have been enlisted and analyzed. For this purpose, a literature review of AMS has been conducted for identification and to understand the vital role of attribute, sub-attributes, enablers, factors and barriers.

In this research work, firstly a questionnaire survey was conducted on AMS and the same was validated by Analysis of Variance (ANOVA) analysis. These attributes and sub-attributes of AMS have been analyzed and evaluated by Fuzzy Agility Index (FAI) approach for identification of agility level of an Indian industry. Afterwards, Interpretive Structural Modelling (ISM) and Total Interpretive Structural Modelling (TISM) approach have been applied to understand the relationship and dependency amongst factor and enabler of AMS. Furthermore, entropy approach has been applied for identification of AMS criteria weightage. In addition to, Multi Objective Optimization by Ratio Analysis (MOORA) and Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

methods have been applied to calculate the ranking of AMS facilitator. Lastly, Fuzzy Performance Importance Index (FPII) approach has been applied to calculate the performance index value of AMS barrier.

The study is highly significant for researchers working in the field of AMS and other similar systems as the study provides an exhaustive review of literature and traces the origin and evaluation of AMS. The study will help the future researcher in this area in improving the agility level of an Indian industry. Moreover, this study suggests an action plan for policy makers in government and industry to help AMS implementation in India.

Keywords: Agile Manufacturing System (AMS), Attributes, Sub-attributes, Enablers, Factors, Barriers, Facilitators, Analysis of Variance (ANOVA), Fuzzy Agility Index (FAI), Interpretive Structural Modelling (ISM), Total Interpretive Structural Modelling (TISM), Entropy approach, Multi Objective Optimization by Ratio Analysis (MOORA), Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Fuzzy Performance Importance Index (FPII)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

LlST OF ABBREVATIONS

ABBREVIATIONS	DESCRIPTION
AMS	Agile Manufacturing System
ANOVA	Analysis of Variance
FAI	Fuzzy Agility Index
ISM	Interpretive Structural Modelling
TISM	Total Interpretive Structural Modelling
MOORA	Multi-Objective Optimization on the basis of Ratio Analysis
VIKOR	Vlsekriterijumska Optimizacija I Kompromisno Resenje
FPII	Fuzzy Performance Importance Index
FMS	Flexible Manufacturing System
CIM	Computer Integrated Manufacturing
LM	Lean Manufacturing
JIT	Just In Time
MDT	Mean Down Time
IT	Information technology
DMS	Distributed Manufacturing System
MRP	Manufacturing Resource Planning
ABC	Activity Based Costing
ABM	Activity Based Manufacturing
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
ERP	Enterprise Resource planning
CIM	Computer Integrated Manufacturing
ITI	Information Technology Integration
PSM	Product Service Management
PLM	Product Life-Cycle Management
MCDM	Multi Criteria Decision Method
DOF	Degree of Freedom

LlST OF ABBREVATIONS

ABBREVIATIONS	DESCRIPTION
MS	Mean Square
SS	Sum of Square
FTV	Fuzzy Triangular Values
FAE	Fuzzy Agility Evaluation
AM	Agile Manufacturing
MICMAC	Matrice d'Impacts Croises-Multipication Applique an Classment
SSIM	Structure Self-Interaction Matrix
RM	Reachability matrix
RP	Rapid Prototyping
RMS	Reconfigurable Manufacturing System
AI	Artificial Intelligence
LPP	Linear Programming Problem
MF	Membership Function
TMF	Triangular Membership Functions
FS	Fuzzy Subset
EDM	Euclidean Distance Method
FTV	Fuzzy Triangular Value
CNC	Computer Numerical Control

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

In previous centuries, mass manufacturers were very much reliant on an invention industry to produce new products, and invention industries were often reliant on mass manufacturers to offer a ready market for their highly distinguished conceptions. This cooperation between mass manufacturers and inventions industry worked very well for an elongated time (Meyer, 2014). It was at the heart of America's economic success during the 20th century (Jin *et al.*, 2003). On the other hand Japanese enterprises figure out that if they persistently upgraded their process, they could attain both lesser costs and advanced quality than the distinctive mass manufacturers (Routroy *et al.*, 2015). By implementing an energetic process change, they could gain a substantial benefit over their contestants. This was so diverse from the ancient methods of doing things that it took American manufacturers a long time to figure out accurately what it was.

The practice that is followed in manufacturing business was established when circumstances were very dissimilar from the one prevailing today (Kettunen, 2009). Formerly, the manufacturing surroundings were mostly cost focused and based on great volume, low variability markets, with low level of opposition (Keenan, 2004). In this situation, we found that organization accounting methods established on financial measures of performance, and organization and industrial performance created on the request of division of labour, hierarchical control, centralization, de-skilling and so on worked reasonably well (Luo *et al.*, 2001).

The philosophical variations that are now happening in the market have already originated foremost variations in the way things are done in an industrial environment (Paulk, 2002; Nerur and Balijepally, 2007). Our confidence that the overview of new skill to decrease costs will assure enhanced competitiveness and profitability has been confronted by conceptions such as just-in-time manufacturing, concurrent engineering, and so on. Moreover, improved importance on excellence and flexibility meant that we have commenced to appreciate their reputation.

The following are the four essential conceptions underlying Agile Manufacturing System (AMS) - all four are commonly co-dependent (Misra *et al.*, 2012)

- To promote AMS, the approach should emphasize on methods to accomplish integration of organization, people and technology.
- To accomplish incorporation of organization, people and technology we need to improve interdisciplinary design approaches.
- It is the combination of organization, people and technology that delivers competitive benefit.
- There are many dissimilar methods of integration. Integration of technology is only one constricted view of integration

1.2 NEED OF AGILE MANUFACTURING SYSTEM

With marketplaces becoming extra vibrant and competition progressively being dependent on better quality and consumer approachability, the expansion of a suitable industrialized approach is likely to have direct influence on our existence, accomplishment and development. Thus, agile manufacturing system strategy should be concentrated on designing an enterprise. Various researchers BüyüKözkan *et al.*, 2004; Wadhwa *et al.*, 2007; Yauch, 2007; Kidd, 1995; Lee, 1998; Meade and Sarkis 1999 described that AMS is needed because of various benefits *i.e:*

- Quicker reaction to extremely variable consumer demand
- Enhanced productivity
- Prospect for system wise origination, learning and enhancement
- Developed product eminence
- Consumer preference is of extreme concern for agile organization
- Agile enterprise structure is conceived by dynamic market characteristics.

- Enhanced utilization of exclusive assets and better profit on speculation
- Ability to accept multi-venturing through a virtual enterprise concept
- The adaptability of an organization according to modification in its surroundings.
- Capability of arrangement with uninterrupted modification.
- Capable in functioning as a smart partner in a protracted and progressively supply network.

1.3 RESEARCH MOTIVATION

Manufacturing industries now days face progressively more indeterminate and unpredictable market demands. Design of the product and product requirement is changing rapidly due to customer dynamic demands. To sustain in today's competitive scenario, manufacturing enterprises need to retain capability to successfully adjust with the dynamically altering situation. Following are the some of the ground actualities that point out the implication of AMS in today's unstable market circumstances and encourage to research in this field.

- Prominent International Journal like International Journal of Production Research, International Journal of Production Economics, International Journal of Agile System and Management, International Journal of Advanced Manufacturing Technology etc. are entirely covering the matters associated with AMS.
- International and national conferences, workshops are being organized globally to address numerous topics associated with execution of agile manufacturing systems.
- Industries are fed up with manual labour difficulties and henceforth industries are concentrating on computerized processes.
- All over the globe, industries are concerned in agile manufacturing systems to encounter the challenges of contemporary dynamic marketplace.
- The current literature lacks in providing a perfect representation about the execution of agile manufacturing system.

1.4 OBJECTIVES OF THE STUDY

The objectives of this study are to:

- To identify various attributes, sub-attributes, factors, enablers and barriers of AMS with the help of literature survey
- To conduct a survey of Indian industries to find the agility level
- To find agility index level of Indian industries
- To develop a decision making structural model for AMS factors and enablers
- To find out the criteria's weightage and rank the facilitators of AMS
- To identify the performance index value for each AMS barriers

1.5 RESEARCH METHODOLOGY

The research techniques used in this research are as follows:

1.5.1 Questionnaire Based Survey

The questionnaire based survey approach is a proven approach to know the respondents perception related to different issue of a research problem. This has been used to gain broad insights in AMS implementation.

1.5.2 Analysis of Variance (ANOVA) Analysis

It is a very appropriate technique concerning investigators in the areas of engineering, manufacturing and management etc. With the help of this technique, we can validate that our data collected from questionnaire survey is significant or not.

1.5.3 Fuzzy Agility Index (FAI) approach

Agility means ability of an association to reply rapidly in accord with the changing requirements of the consumer. Agility of organizations can be measured by fuzzy agility index approach. This FAI approach is mainly the integration of performance rating and weightage importance of the elements.

1.5.4 Interpretive Structural Modelling (ISM) Approach

This approach is mainly used to deliver an essential knowledge of multifarious circumstances, as well as to provide a progress of action for resolving a problematic situation. In this approach a set of dissimilar; straight and circuitously variables are organized into a widespread methodical model. In this research ISM approach has been used for establishing driving and dependence power of factors affecting AMS

1.5.5 Total Interpretive Structural Modelling (TISM) Approach

Total interpretive structural modelling approach is used to provide the mutual contextual and systematic relationship between the elements. This technique is able to provide the interpretation of structural links in details. Level partitioning of the element has also been performed in this approach. In this study TISM approach has been applied to AMS enablers to identify the driving power and dependence power.

1.5.6 Entropy Technique

Entropy means the ordinary number of information available. This information is termed as weightage of that element. As the value of information availability is decreased the weight of that element will increase because in this existing environment less improbability will be desired. In this research entropy approach has been used to identify the weightage of the AMS criteria's.

1.5.7 Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) Method

This method is one of the multi criteria decision method which is mainly used to rank the variables. This is also used to optimize many issues at one time. It is very easy technique as compared to other multi criterion decision method which finally provides the benefits to industrial manager in taking the decisions amongst the various variables. MOORA has been used for calculating the ranking of AMS facilitators in this study.

1.5.8 Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) Analysis

This analysis is used to optimize and rank the multiple complex variables. This analysis provides the ranking on the basis of nearness to ideal solution. This analysis can also provide the ranking to each variable by using the weights of the criteria. In our study, VIKOR analysis is used for ranking the AMS facilitators.

1.5.9 Fuzzy Performance Importance Index (FPII) Approach

Fuzzy performance importance index approach is used to identify the performance index value of variable. This value represents the performance of that variable in that particular system. Fuzzy performance rating and fuzzy importance weightage is used to calculate the fuzzy performance index value. In this research, FPII approach has been used to calculate the fuzzy performance index value for AMS barrier.

1.6 SIGNIFICANCE OF THE STUDY

The increasing importance and significance of AMS in contemporary manufacturing atmosphere were studied through numerous research papers. Literature on numerous concerns like attributes, sub-attributes, enablers, factors and barriers has been considered. The fuzzy agility index approach has been applied for identifying the agility of an organization.

Afterwards, ISM and TISM approach has been executed for identifying the driving and dependence power for factors and enablers affecting AMS. Driving factors and enablers have further been analysed by Entropy Approach for identify the weightage of the criteria. MOORA method and VIKOR analysis have been applied to rank the facilitators. In this framework, performance index value for each barrier is identified by fuzzy performance index approach

The key contributions of this research are as follows:

- It shows existing status of research regarding execution of AMS
- With the application of fuzzy agility index approach, agility level of an Indian industry has been evaluated.
- ISM and TISM model have been developed for factors and enablers of AMS showing their managerial and academics implications for the implementation of AMS
- Weightage of the AMS criteria has been calculated by Entropy approach
- AMS facilitators have been ranked by MOORA method and VIKOR analysis
- Fuzzy performance importance index approach has been utilized to find out the performance index value for AMS barriers which helps in the evolution of AMS.

1.7 ORGANISATION OF THESIS

The organization of research scheme is depicted in figure 1.1.The research has been done in the following stages. The brief introductions of different chapters which are embodied in this research work are as follows:

Chapter 1: Introduction

This chapter contains the overview and need of agile manufacturing system in today's competitive scenario is discussed. Motivation of the research, objective of the study and research methodology adopted for attaining the objectives is discussed. Significance from the study has also been enlisted. This chapter present on overview of eleven chapters of the thesis. Finally it concludes with summary and conclusion.

Chapter 2: Literature Survey

In this step more than 350 research papers have been studied in the area of AMS. Out of these papers, more than 250 papers are found relevant to this research work. The attributes, sub-attributes, enablers, factors and barriers affecting AMS were finally identified from literature survey for further work.

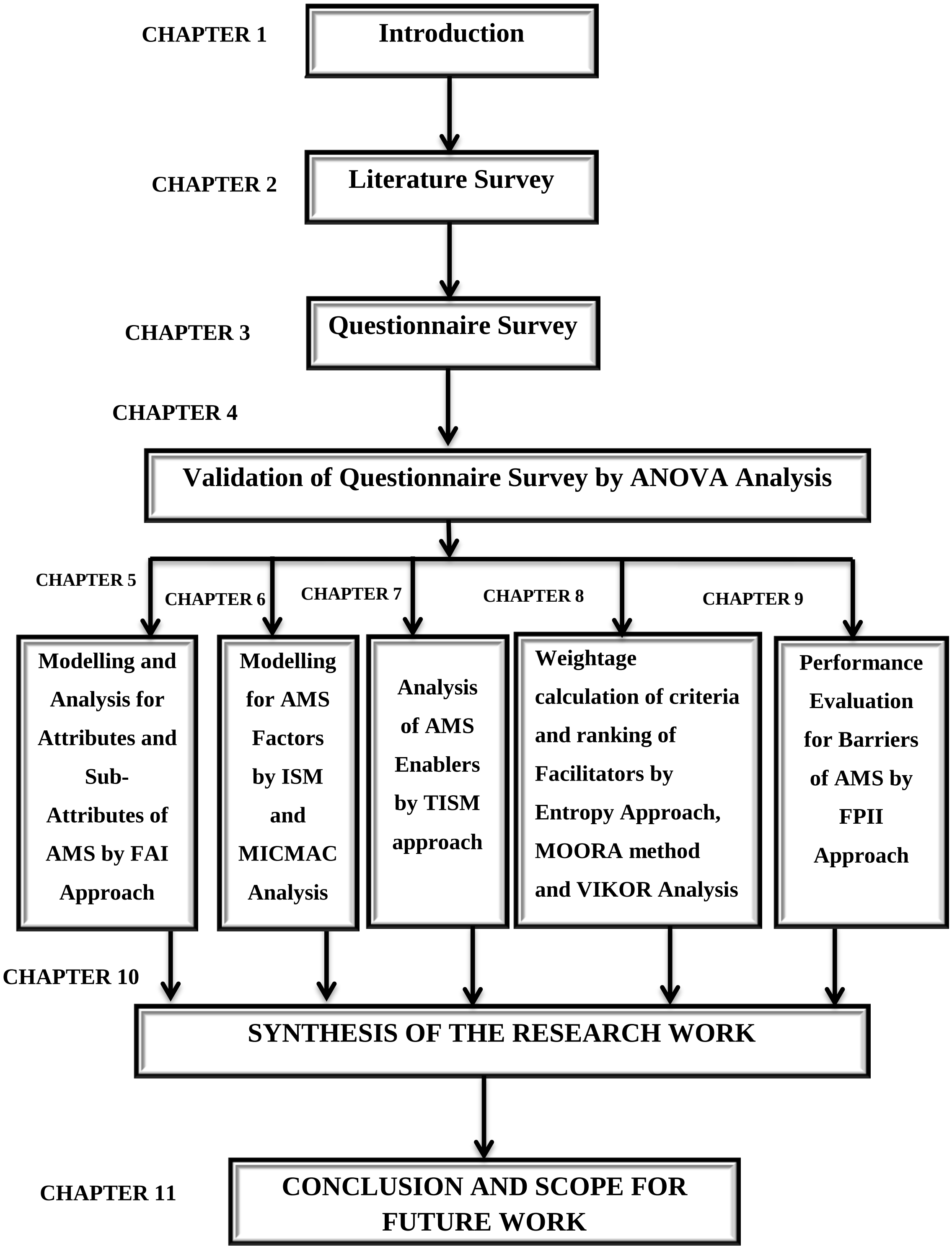

Figure 1.1: Plan of work

Chapter 3: Questionnaire Survey

This chapter covers the development of questionnaire which was prepared for finding attributes and sub-attributes affecting the AMS. Then across the country a survey was conducted and data collected from Indian companies. In this chapter development of questionnaire along with observation on the number of respondent industries is also discussed.

Chapter 4: Validation of Questionnaire Survey by ANOVA Analysis

This chapter validates the data collected from 151 Indian companies with the help of ANOVA analysis. In this chapter an overview of ANOVA analysis with methodology is also discussed.

Chapter 5: Modelling and Analysis for Attributes and Sub-Attributes of AMS by Fuzzy Agility Index Approach

This chapter firstly discusses the overview of fuzzy agility index approach and afterwards modelling for attributer and sub-attributes will be performed with the help of FAI approach. Finally, agility index of an Indian industry has been found. This agility index level is than checked for suitable level.

Chapter 6: Modelling for AMS Factors by ISM and MICMAC Analysis

On the basis of the extended literature review and discussion with the experts from industry and academia both; factors affecting AMS have been identified. In this chapter, ISM technique has been utilized for modelling and analysis of factors affecting AMS. The ISM model developed in this research provides the managers an opportunity to understand the driving and dependence power of the factors. In this model, managers can also get an insight into these factors and understand the relative importance and interdependence.

Chapter 7: Analysis of AMS Enablers by TISM approach

On the basis of the extended literature review and discussion with the experts from industry and academia, enablers who enable the AMS were identified. This research has provided an insight into the modelling and analysis of enablers affecting AMS. The TISM model developed in this research provides the managers an opportunity to understand the driving and dependence power of the enablers. In this model, managers can also get an insight into these enablers and understand the interpretation of relationships, relative importance and interdependence.

Chapter 8: Evaluation of Criteria Weightage and Facilitators Ranking by Entropy Approach, MOORA Method and VIKOR Analysis:

On the basis of the result outcome from chapter 6 and chapter 7 we get the seven main driving enablers and factors. These enabler and factors can be named as facilitators and then analyzed on the basis of beneficial and non-beneficial criteria. Two beneficial criteria *i.e.* agility and profit and two non – beneficial criteria *i.e.* resources and cost were identified after the extended literature review and discussion with the experts from the industry and academia. This chapter has provided an insight into the weightage calculation of criteria's with Entropy approach and ranks the facilitators by MOORA method and VIKOR analysis. This research basically has four objectives as following:

Chapter 9: Performance Evaluation for Barriers of AMS by FPII Approach:

On the basis of the extended literature review and discussion with the experts from industry and academia, barriers affecting AMS were identified. This chapter has provided an insight into the performance index value of barriers affecting agile manufacturing system. The fuzzy performance importance index approach has been used to measure the performance index value of each barrier separately. FPII approach used in this research provides the managers an opportunity to understand which of the barrier is necessary to be removed on priority basis. In this model, the managers can also get an insight into these barriers and understand the ranking of these barriers on the basis of performance index value of each barrier.

Chapter 10: Synthesis of the research work

In this research work, synthesis of the research is discussed. Different methodology discussed in this research is shown as linkage among the objectives.

Chapter 11: Conclusion, limitation & future scope of the research

In the last chapter of this thesis, the summary of the research, research finding, major contribution of the research along with key findings of the research and implication of research for industry and academician both is discussed. In this chapter, limitation and scope for further work with conclusion of the research work have been presented.

1.8 SUMMARY AND CONCLUSION

Today's global competitiveness has made the manufacturing industries to recognize the significance of AMS. But execution of AMS is not an easy work. There are certain attributes, sub-attributer, factors, enablers and barriers affecting AMS in the process. The factors and enablers not only affect the evolution process but also affect each other. The purpose of this study is to identify agility level of an Indian industry along with identification and analysis of factors, enablers, and barriers.

This chapter presents an introduction to this research work. Different issues related to implementation of AMS have been discussed briefly. Motivation of this research, objectives of the research, methodologies used in this research, a significance of the study and its organization are also presented in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In today's competitive scenario and rapid development of global marketplace, there is always a requirement of newer and updated manufacturing system. These updating manufacturing systems escalate the feasibility of manufacturer to move ahead in modern market (Yusuf and Adeleye, 2002). With this there is an improvement in relationship between customer and manufacturer which create a good bonding between each other.

Agile manufacturing system comes as an option for twenty first century manufacturing system (Ramesh and Devadasan, 2007). This AMS covers the response of the customer on priority basis. AMS is an innovation above additional industrial system such as cellular manufacturing systems, lean manufacturing systems and flexible manufacturing systems (Song and Nagi, 1997). Even though many Indian industries are still under the stage of lean manufacturing system. So, there is an urgent need to switch from lean manufacturing systems, flexible manufacturing systems to AMS.

Moradlou and Asadi, (2015) showed that in the innovative and developing AMS standard, where numerous organizations collaborate under mass customization, in which there is need of a technique which can manage the data flow between cooperating organizations. Due to this need they show that information technology integration is needed at every step of an organization.

Al Samman, (2014) have identified the agile manufacturing system drivers and deliberated on the collection of benefits that have appeared eventually as an effect of altering necessities of engineering procedures. The leading driving force of agile manufacturing system is variation. These changes are resultant of automation and cost consideration of manufacturing, widening of customers selection and expectancy, challenging significances, integrity & proactivity and attaining industrial prerequisite in cooperation. Current study also reveals the attribute of agile system which covers competence, technology, quality, partnerships, market and welfare by various means and attributes.

Pan and Nagi, (2013) according to author as we move toward the 21st century, success and survival in today's competitive scenario are more and more difficult. The ability to provenance of this competitiveness started from one basic term i.e. "change". The prominence is now ability to adapt to variations in the occupational situation and on market and consumer requirements. The emergent pattern is AMS which includes replying to variations and captivating benefit of variations over planned application of management and industrial approaches.

Frayret *et al.*, (2001) presents a planned structure for manipulative and functioning AMS. This outline permits integrated preparation, regulation and handling of all processes and eventualities in an active situation. This fragment encapsulates the administrative and cooperation policy. It contains of an active occupational technique to establish and activate industrial actions over the conformation, beginning and process of a dispersed system of answerable industrial hubs. Following, the thoughts primary to this premeditated outline as well as the methodological suggestions of such methodology, are demonstrated, and by means of a thorough case study stimulated by industrial partner of a motor coach.

The term "Agility" is demarcated as the capability of an organization to quickly reply to transformation in marketplace and consumers' request. Since its commencement, the conception of agility has grown manifold amongst organization and academician persons. Agility term is defined by different researchers as shown in table 2.1.

Table 2.1**:** Agility definitions by different researchers

Sr. No.	**Researchers**	**Definition of Agility**
1	Moradlou and Asadi, 2015	It is able to provide customer satisfaction, always prepared for market change, appreciating humanoid information and services, and founding virtual enterprise.
2	Al Samman, 2014	It is an aptitude to yield an extensive variety of short price; extraordinary excellence produces with diminutive principal periods in unpredictable portion dimensions, ready to make a product according to customer demand.
3	Pan and Nagi, 2013	It creates boundary in between organization and the marketplace. AMS behave as a leader to develop affordability and the professional predictions.
4	Shankarmani *et al.*, 2012	It is ready to respond the immediate changes in volumes and variability demand.
5	Carvalho *et al.*, 2011	It defined as with marketplace acquaintance and simulated organization to adventure commercial prospects in an unpredictable marketplace.
6	Mafakheri *et al.*, 2008	It suggests efficiently assimilating flexible manufacturing system and lean manufacturing system.
7	Hasan *et al.*, 2007	It is consider all term like consumer approachability and marketplace instability and necessitates precise competences.
8	Hopp and Oyen, 2004	It is an aptitude to have reflectiveness of request, rapid reply and corresponding processes.
9	Yusuf *et al.*, 2004	It defines as to produce advanced product and unbalanced request.

The central dynamic power behind agility is variation. However variation is not new; but today's variation is captivating and considerably rapid than forever. Commotion and improbability in the commercial situation have developed the foremost sources of disappointment in the industrial production (Shankarmani *et al.*, 2012; Sheridan, 1993). The quantity of variations and their category, provisions or distinguishing cannot be simply resolute and are perhaps unspecified. To assist executives in attaining enhanced agility, there have been abundant studies devoted to calculate the agility of an organization (Carvalho *et al.*, 2011; Towill and McCullen, 1999; Vernadat, 1999). Few researchers projected the integrated agility index technique; they define the agility index as a permutation of quantifying concentration level of agility competencies. So, agility index value of an organization is defined as:

$$(\text{AGILITY}_{\text{Index}}) = \sum_{j=1}^{N} Aij$$

Here; Agility of competency j of organization I is represented by A_{ij}

Literature of AMS was finding out by using Google Scholar databank. Papers were selected by using the keywords "Agile Manufacturing", "Agile Manufacturing System", and "Agility". Google scholar databank has been preferred due to its wider data reportage such as books, proceedings, journal papers, conference proceedings *etc.* Harzing and Wal, 2007 describe databank of Thomson ISI knowledge web strictly obey the methodological techniques so google scholar databank has been preferred during AMS literature. Beel *et al.* 2009, says google scholar databank have complete illustration especially in the field management topics.

Topic search in google scholar always provides the relevant research paper. Search has been done by topic and not by high cited journal to include in research. Literature survey includes conference proceedings paper, international and national journal papers, book chapter and in press paper. Shortcoming of this method is that before 1990 research is not digitalized, so not able to include in our research database.

In this chapter a systematic review of the literature on the agile manufacturing systems has been done. The objectives of the chapter are (i) to trace the evolution of agile manufacturing system, (ii) to identify agile manufacturing system attributes and sub-attributes, (iii) to identify agile manufacturing system enabler, (iv) to identify agile manufacturing system factors, (v) to identify agile manufacturing system barriers.

2.2 EVALUATION OF AGILE MANUFACTURING SYSTEM

The idea of AMS firstly seems in the twenty first century industrialized organizational policy description, circulated by the University of Iacocca. This description pronounced the consequences of a plan sponsored by the defense department of US, which cultivated into a meeting of high-ranking managers of the served US firms to deliberate upon the circumstances under which an organization will be operational in the future and the organization philosophies that should be implemented (Mafakheri *et al.*, 2008).

In spite of the pronounced attention still a lot of misperception occurs regarding the AMS. Till now, there is no globally accepted definition and nor is there any agreement among investigators about what is new definition of AMS (Yang and Li, 2002). There are some rules and regulations of lean manufacturing system, concurrent engineering, and flexible manufacturing systems (Yauch, 2007). Furthermore, the originality about AMS is that some concepts of it are multidimensional; it has commanded diverse researchers to give their own definition and not to limit only at a precise characteristic.

Development in manufacturing system with respect to time is as shown in figure 2.1 which represents that our manufacturing system started from mass production and further lead towards 21st century agile manufacturing system.

2.2.1 Mass Production

Mass production is also called stream production, continuous stream production, sequence production or sequential production. Mass production mentions the development of generating outsized alike product resourcefully (Hu, 2013). It is characteristically categorized by few kind of systematization, as through an assemblage link, to attain extraordinary capacity, the exhaustive industry of materials flow, cautious mechanism of superiority criterions.

The measurable base for mass fabrication was placed by the expansion of the machine-tool constructiveness *i.e.* the creation of machineries to create technologies (Tsuchiya and Kobayashi, 2004). However, few elementary strategies such as the lathe used for woodworking has been occurred for eras, their transformation into engineering apparatus tool proficient of cutting and modeling solid metal to exact acceptances was transported by a sequences of nine teeth era visionaries (Duray, 2002). With exactness apparatus, great number of indistinguishable fragments can be formed at little price and through less employees.

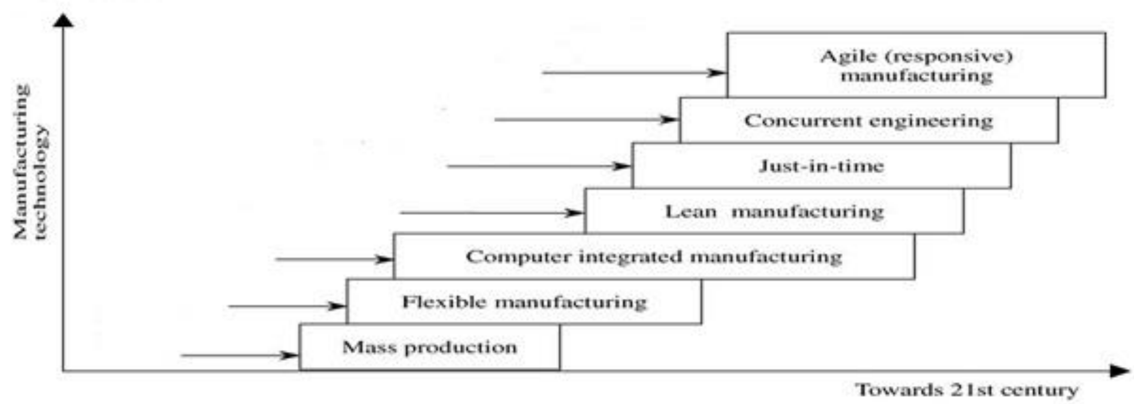

Figure 2.1 Development in manufacturing technology

2.2.2 Flexible Manufacturing System (FMS)

It is the type of manufacturing system in which some quantity of flexibility is attained which permits the organization to respond in the circumstance of variations, whether anticipated or non-anticipated (Yakimovich *et al.*, 2016). Flexible manufacturing system is normally divided in to section, and each section contains various sub-sections.

First section of FMS contains flexibility of the machine which shields the organization's capability to be transformed to yield different types of product (Chen *et al.*, 2014). It also provides the capability to transform the processes order implemented on a particular part.

Second section of FMS is known as flexibility in routing, which contains the capability to use numerous machineries to achieve the similar process on a portion of the part. This section also has a capability to facilitate significant variations, such as in capacity, magnitude, or competence (Saravanan *et al.*, 2016). The key benefits of flexible manufacturing system are as follows:

- Adjustable to fluctuations in the product being manufactured
- Capability to control unpredictable level of manufacturing process.
- Capability to handle the rapidly fluctuating manufacturing environment.
- Use of robots and computer numerical control machine in production provides the capability to produce high volume of productivity.
- Material handling system is handled by robotic cell and automatic guided vehicle which provides the easiness in handling the products.

2.2.3 Computer Integrated Manufacturing (CIM)

Integration of manufacturing processes with computer networking is known as computer integrated manufacturing. In this all the processes of manufacturing like designing, manufacturing, advertisement, inventory, accounting system, handling of the materials and equipment's, analysis and planning etc. all are transformed to computer networking (Błażewicz *et al.*, 2013). In computer integrated manufacturing system all the areas are firstly checked at precise level and then find out the possibility to transform.

Computer integrated manufacturing system is used to define the comprehensive computerization of an organization, which include all processes of a manufacturing plant (Zhang *et al.*, 2014). All these processes are controlled by computer and by digital information system. CIM include the various advanced techniques like computer aided design, computer aided manufacturing, computer numerical control, direct numerical control, computer aided process control, flexible machine system, automatic scheduling etc. Computer integrated manufacturing system is covering few activities completely on computer which makes it differ from other manufacturing system, those activities are as follows (Prasad 2000):

- Storage of data, recovery, handling and performance
- Appliances for detecting state and transforming procedures;
- Integrate the information handling device with the instrument/adaptation sections.

2.2.4 Lean Manufacturing (LM)

"Lean" term used in an organizational environment, defines a philosophy that integrates a assemblage of tool and methods into the commercial procedures to adjust time-period, humanoid resource, properties, and efficiency, while cultivating the superiority level of product and facilities to their consumers (Shah and Ward, 2003). On the other way, lean manufacturing is an incorporated organization, which includes the organization practice to remove the wastage and decrease the inconsistency of contractors, consumers and procedures (Anand and Kodali, 2008; Mostafa, 2013).

It is a manufacture preparation that deliberates on the disbursement of resources for any objective other than the formation of significance for the end consumer to be inefficient, and thus an objective for removal (Jones *et al.,* 2002). Functioning from the standpoint of the consumer who takes a product or facility, "worth" is well-defined as any act or procedure that a consumer would be prepared to pay for (Shah and Ward, 2003).

A non-exhaustive list of outfits to execute lean manufacturing are the Toyota way (Liker and Morgan, 2006), single minute exchange die (Dillon and Shingo, 1985), value stream mapping (Jones and Womack, 2002), Just in time, KANBAN (Sugimori *et al.*, 1977), Poka-Yoke (Shingo, 1986), Total Productive Maintenance (Nakajima, 1988) etc.

2.2.5 Just In Time (JIT)

Just in Time was introduced by Vice President of Toyota, Taiichi Ohno in 1960. The knowledge was dignified into a administrative organization, when Toyota required to encounter the specific request of consumers for dissimilar model and color with least interruption (Bookbinder and Locke, 2013). Just in Time is mentioned to as the Toyota production organization. After ten year of introduction of this manufacturing system; Toyota effectively executes this technique in the whole country.

In 1972, new techniques have been started to appeal in Japan. In mid-1970's, Japan companies have been started to implement these techniques (Kang and Bekkers, 2015). After successfully implementation of JIT in Japan, in early eighties JIT technique attract the whole world especially the United States. Many automotive industry and electronic industry of United States has started to implement JIT approach in early 1980's. Now JIT approach has pointed out 14 rules. Out of 14 rules, seven rules are oriented to 'respect of employee' and another seven rules are oriented to 'elimination of waste'. For successful implementation of JIT seven rules related to 'elimination of waste' are considered to be primary rules (Huson and Nanda, 1995).

2.2.6 Concurrent Engineering

Concurrent engineering is an effort procedure established on the parallelization of responsibilities (Zhu *et al.*, 2016). It discusses a methodology used in manufactured goods expansion in which purposes of strategy manufacturing, and other purposes are incorporated to decrease the lapsed time-period compulsory to carry a novel invention to the marketplace.

One of the significant causes for the enormous accomplishment of concurrent engineering is that by description; it re-defines the elementary design procedure arrangement that was mutual space for eras (Sapuan and Mansor, 2014). This was a arrangement created on a chronological policy movement, occasionally known as the 'Waterfalls Model'.

It expressively transforms outmoded technique and in its place chooses to practice what has been labelled an iterative or incorporated expansion technique (Demoly *et al.*, 2013). The alteration amongst these two techniques is that the concurrent engineering technique transfers in an entirely lined way by preparatory with user necessities and successively affecting to design, execution and supplementary step till you have a completed product.

2.2.7 Agile Manufacturing

Agile manufacturing system is 21st century manufacturing system whose primary goal is to complete the demand of the consumer while preserving high principles of superiority and monitoring the inclusive prices intricate in the fabrication of a precise product (Hasan et al., 2007). This technique is moving headed for enterprises working in an extremely economic situation, where minor disparities in presentation and manufactured goods conveyance can make an enormous modification in the extensive time period to a corporation's existence and repute amongst customers (Hopp and Oyen, 2004; Yusuf *et al.,* 2004). Agile manufacturing concept is near to lean manufacturing concept and flexible manufacturing concept. Some researcher also defines agile manufacturing as an integration of lean manufacturing system and flexible manufacturing systems (Carvalho *et al.*, 2011).

2.2.8. Comparison of Traditional Manufacturing System and Agile Manufacturing System

As agile manufacturing system is newly adopted manufacturing system and somewhere it differs from all other manufacturing system. Hence, it is necessitate to finding out the difference among traditional manufacturing system and agile manufacturing system. Many researchers have found the difference amongst traditional manufacturing system and agile manufacturing system which are as follows in table 2.2 (Devdasan *et al.*, 2012):

Table 2.2: Differences among traditional manufacturing system and Agile Manufacturing System (Devadasan *et al.*, 2012)

Sr. No.	**Criterion**	**Traditional Manufacturing System**	**Agile Manufacturing System**
1	Organizational structure	Vertical, Traditional and line organization	Flattened, and team managed organization
2	Devolution of authority	Lack of empowerment, centralized and informal authority	Self-autonomous and empowered authorities
3	Manufacturing set-ups	Rigid and long lasting manufacturing set-ups which are intolerable to changes.	Flexible and easily collapsible manufacturing set-ups which can quickly respond to the changes.
4	Status of quality	Customer satisfaction is the target	Customer delight is the target
5	Status of productivity	Stagnant productivity with no reasonable evaluation and improvement	Rapid increase in productivity with practically feasible evaluation, productivity and quality are integrated
6	Employee’s status	Existence of specialists. Employees are not exposed to other functions and skills. Employees are inflexible and ignorant to changes.	Learning employees, multi-skilled and multi-functional and self-committed
7.	Employees involvement	Very little involvement of employees in decision making. Ideas and knowledge of employees are seldom shared or utilized.	Fully empowered employees, ideas and knowledge of employees are fully utilized

Sr. No.	Criterion	Traditional Manufacturing System	Agile Manufacturing System
8	Nature of management	Autocratic and stagnant style of management.	Participation based management which is susceptible to changes and improvements.
9	Customers response adoption	Customer response adoption takes place very slowly due to beauracracy	Very fast and 100% response achieved
10	Product life cycle	Products produced have long life span but frequent failures and ineffective operations are encountered	Produced products have short life span but are free from failures. and are effectively operated.
11	Product service life	In case of failure of products it takes long time to repair. thus these products have long Mean Down Time (MDT)	In case of failure of products it takes very little time to restore the status que. Thus, these products have no or short MDT.
12	Design improvement	Design improvement is very rarely practised. Generally only modifications are made to the existing design.	Design improvement is very frequently and systematically practised by conducting experiment.
13	Production methodology	Production is dominated by internal manufacturing.	Production is dominated by main assembly of components and external manufacturing
14	Manufacturing planning	Manufacture planning is carried out for a long period which is cost ineffective in nature.	Manufacturing planning is carried for short period with the focus to adopt just in time purchase with zero or little investment.

Sr. No.	Criterion	Traditional Manufacturing System	Agile Manufacturing System
15	Cost management	Traditional costing procedure is adopted (with classification namely prime and overhead cost).	Cost is managed using activity, strategy, quality and productivity based costing system.
16	Automation type	Direct and rigid automation is adopted.	Flexible, smart and adaptable automation is adopted.
17	Information technology (IT) integration	IT is directly integrated into the existing system.	IT is integrated after reengineering the existing system.
18	Change in business process	Very difficult to incorporate change in business processes, it is a almost impossible task.	The flexible set-up enables to effect changes in business processes economically and quickly.
19	Time management	Time is managed very efficiently.	Time is managed very efficiently.
20	Outsourcing	Only subcontracting is adopted.	Majority of the activities are outsourced. Supply chain management principles are adopted.

2.3 IDENTIFICATION OF ATTRIBUTES AND SUB- ATTRIBUTES OF AGILE MANUFACTURING SYSTEM

AMS execution process is not an easy work and transformation from customary manufacturing systems to agile manufacturing system is even extra problematic. Organization is facing various attributes and sub-attributes during transformation phase. In this section various attributes and sub-attributes affecting AMS have been identified through literature survey and brainstorming with industry and academia experts. Various attributes and sub-attributes of AMS are represented in fig. 2.2 and brief introduction about it are as follows:

2.3.1 Strategies

Extensive adoptions consider the re-configurability of the organization with the objective to oppose in the global marketplace by mass customization is precarious to make employment of diverse resources available for generating eminence product and managements. Strategies have always been the main attribute during execution process of agile manufacturing system (Gunasekaran, 1999). During the development of agile manufacturing system various strategies must be included *i.e* distributed manufacturing systems, concurrent engineering approach and virtual enterprises system.

2.3.2 Concurrent Engineering

During the execution process of agile manufacturing system; concurrent engineering approach has always been one of the most important strategies. Organizations consider it as one of the most important key sub-attribute of agile manufacturing (Bustelo and Avella, 2006). These accommodate concurrent structure processes, which can express the connection between organizations and customers.

2.3.3 Virtual Enterprises

AMS auxiliary execute the idea as rapid establishing of a simulated industry or effort in assessment of Industry Corporation to rapidly inform new belongings with the industry (Cheng *et al.,* 1998). It necessitates more transparent and comfortable information stream. Virtual enterprise provides an opportunity to industry by executing the instant customer demand.

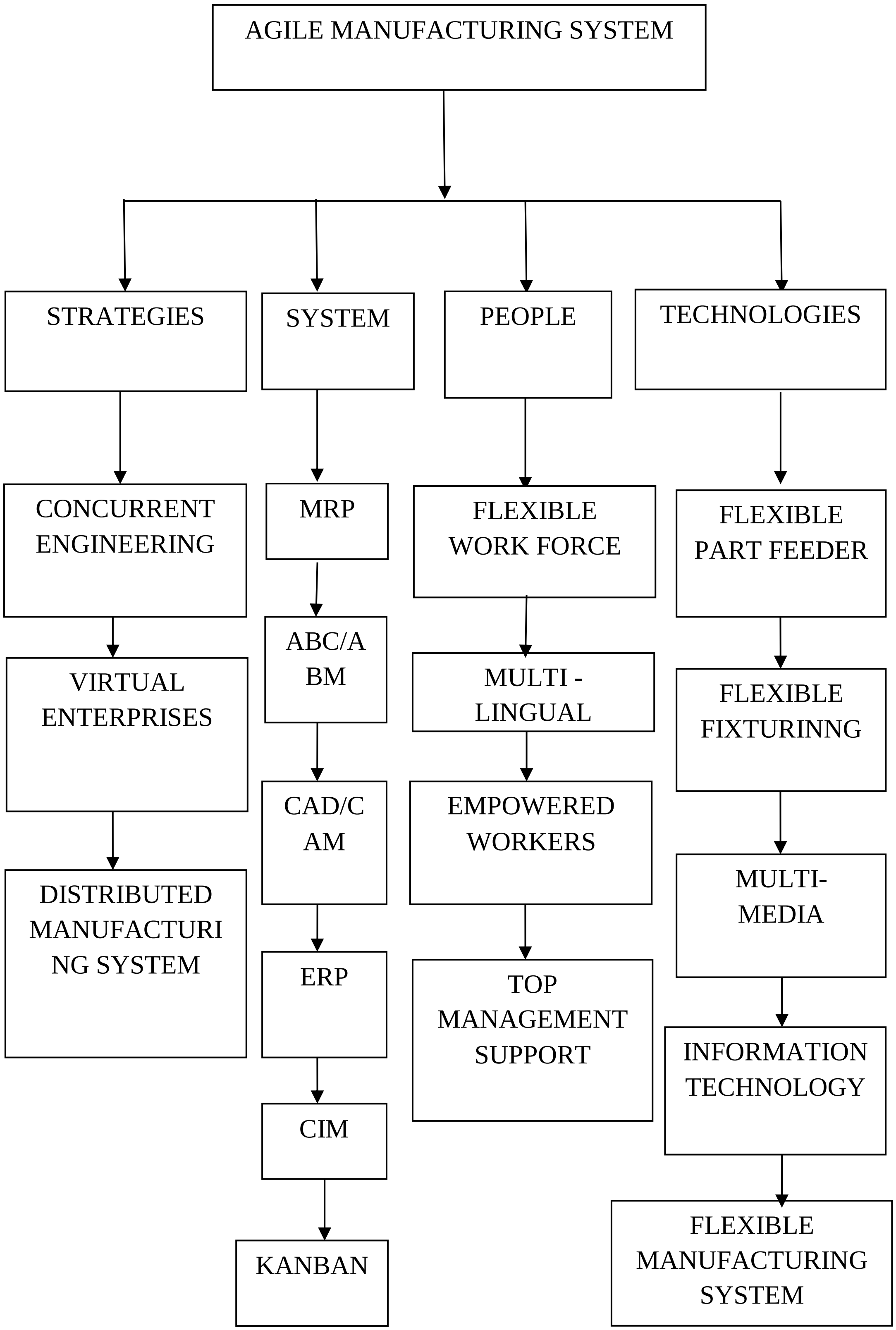

Figure **2.2**: Attributes and sub-attributes for AMS

2.3.4 Distributed Manufacturing System (DMS)

Distributed manufacturing system requires a dissimilar eminence organizational system environment (Gunaskeran, 1999). It demands only simple accounting systems which are able to reduce the problems due to gap in communication and difficulty in understanding the rule and regulations of global environment. This system is act as sub-attribute of agile manufacturing system.

2.3.5 System

A principal objective of AMS is to provide tailored product to respond the fluctuating market in a transitory period. To achieve this aim; altered product might be created by exploiting a congregation driven system. The operational procedure of this method lies in dynamic development of the structure. Gunasekaran (1999) recognize that this system is main and important attribute of AMS in which various sub-attributes such as decision supports system for numerous processes about development and controller like substantial demand, manufacturing planning for resources and manufacture scheduling regulator act as main pillar for AMS.

2.3.6 Manufacturing Resource Planning (MRP)

Manufacturing resource planning is a combination of result oriented system and communication system. This complete manufacturing system is help to management in execution of AMS. All ideas and methods are approachable in this system for AMS implementation (Shamsaddini *et. al.*, 2015). Operations research technique for optimization is also included in MRP (Babazadeh *et al.*, 2012). One of the most important reason to add this as a sub-attribute of AMS is that in MRP all information in regard to run the organization is stored in computer which always helps in future. MRP also help in numerous activities such as manufacturing, material selection, procuring, selection of inventory level *etc*. which is essential for AMS implementation.

2.3.7 Activity Based Costing (ABC)/Activity Based Manufacturing (ABM)

For today's competitive manufacturing environment; cost system such as activity based costing and activity based manufacturing is act an important sub-attribute. Irrespective of the appearances of agile innovativeness, the solicitation of activity based costing and manufacturing requires additional exploration (Gunasekaran, 1999). Due to customer dynamic demand and for fulfilling these demand in limited time period; ABC/ABM behave as a main attribute for AMS.

2.3.8 Computer Aided Design (CAD)/Computer Aided Manufacturing (CAM)

Computer aided design and manufacturing is an innovative technique that correspondingly play one of the important vital characters in obtaining the agility in any organization. (Bustelo and Avella, 2006). For moving towards new competitive scenario these CAD/CAM is necessary for any organization. Improvement in productivity and quality can easily achieved by this attribute (Pandey and Pattanaik, 2014). So, ABC/ABM plays a vital role in execution process of AMS.

2.3. 9 Enterprise Resource planning (ERP)

AMS require one computer based system which may attained all process of organization which includes inventory of raw material , product delivery date etc. (Gunasekaran, 1999). This computer based system can be achieved by enterprise resource planning. This system is linked with all databases of other organizations which helps in maintaining inventory level or complete the order timely (Shamsaddini *et al.*, 2015). This ERP system can also be applied on specific operation without disturbing whole organization. Due to all these reason ERP behaves like an important sub-attribute of AMS.

2.3. 10 Computer Integrated Manufacturing (CIM)

Computer integrated manufacturing means integration of individual manufacturing process with advance computer technology. Utilize each machine by applying computerized techniques; which finally helps in increasing agility of an organization (Pandey and Pattanaik, 2014).

2.3.11 KANBAN

KANBAN means sending the instruction card during each production steps. For achieving the right product at right time there in need of zero percent error in processing (Bustelo and Avella, 2006). So KANBAN plays a necessary role for achieving high agility level of an organization (Garbie *et al.,* 2014). Hence it acts as sub-attribute for agile manufacturing system.

2.3.12 People

People mean the persons who are responsible for productivity, profitability and all other aspects. It is the main resource of any organization for achieving high agility level (Cheng *et al.,* 1998). If peoples are able to handle every difficult problem knowledgably, then agility of an organization automatically increase. Hence, for implementation of AMS in any organization this attribute plays an important role.

2.3.13 Flexible Work Force

Flexible work force means the employee who is able to work in flexible manner. Flexible manner means the employee who is able to handle every situation in problematic condition (Goldsby *et al.,* 2006). This element is necessary for AMS because it includes the capability of employees to produce large production in minimum time (Gunasekaran *et al.,* 2008). Therefore, flexible work force can easily improve the agility level of organization. Hence flexible work force acts an important sub-attribute for AMS.

2.3.14 Multi Lingual

Multilingual workers act as a sub-attribute for AMS which comes under people attribute. Multilingual worker means the worker who is able to handle the global communication situation Gunasekaran (1999). In today’s competitive scenario business in not limited to one country, it is totally global. For communicating purpose there is always a need of multilingual employees. Therefore, this attribute helps in improving the agility level of an organization.

2.3.15 Empowered Workers

AMS can be functioned efficiently with the support of informative workforces such as workstation operator, architect, and project engineer (Gunaskeran, 1999). So, AMS is highly information technology concentrated; here is an essential to recover the efficiency of employee's information with the aim to attain agility in industry. Enabled employee is very expressive for manufacturers because existence depends on the buyer's initiative. If the buyer is happy, the buyer would endorse the organization to associates or others to buy the product from same organization (Wadhwa *et al.*, 2007). Gratitude of the humanoid factors is essential in responsive organization expansion.

2.3.16 Top Management Support

For creating new rule and regulation or to modify the old rule, there is always a need of top management support (Pan and Nagi, 2013). Agility level can only be achieved when support of the top management is with organization (Mishra, 2014). Top management support in achieving agility level act as power booster for inner workforce in achieving agility. For implementation of AMS; there is need to change some rules and regulation in each process which can only be possible with the help of top management support. Therefore, top management support act as an important sub-attribute for AMS.

2.3.17 Technologies

AMS is 21st century manufacturing system whose primary focus is to satisfy the customer demand in time with no compromise in quality. For achieving this goal there is a need of up to date technology (Wadhwa *et al.*, 2007). Without technology upgradation there is no possibility to sustain in such competitive scenario. Technology acts as an important attribute for achieving the agility level of organization. This attribute is essential for smooth execution process of AMS.

2.3.18 Flexible Part Feeder

To simulate the tools in numerous conveyors and to locate them according to machine vision there is need of flexible part feeder (Merat *et al.,* 2007). Particular hardware is installed separately in machine which helps in gripping the purpose and to interchange the assembly in less time. So, flexible part feeder acts as sub-attribute for AMS which helps in maintaining the agility level of an organization.

2.3.19 Flexible Fixturing

Flexible fixturing means changing the product from the production line in simple way. It is key essential sub-attribute for agile manufacturing system (Gunasekaran, 1999). With this sub-attribute lot of time will be saved which is necessary for achieving high agility level in organization. This sub-attribute conclusively increase the agility level in a substantially distributed accumulating situation

2.3.20 Flexible Manufacturing

In this competitive scenario; the manufacture approach shall be well-organized and sufficient to encounter the capacity and superiority necessities of consumers within a short time period. In order to grow such a competence agile manufacturing system; all principles are essential to be realistic (Kovach *et al.,* 2005). Agile manufacturing system is intended to associate the effectiveness of a production line and the flexibility of a shop floor to yield a diversity of product on a assembly of machineries (Jain and Raj, 2015). Flexible manufacturing system application will permit the manufacture of tailored and advanced yields by satisfying the superiority requests. So, for executing AMS in any organization flexible manufacturing is always act a main sub-attribute of AMS.

2.3.21 Information Technology

Twenty first century manufacturing system requires every process in integrated manner for which information technology act as an essential sub-attribute (Chakraborty and Mandal, 2014). Information technology helps in development of advanced production technology (Gunasekaran, 1999). Thus without IT, agility level of an organization is not achievable. Hence, information technology acts as a sub-attribute of AMS.

2.3.22 Multi- media

Agile manufacturing system is a system in which global communication with people is essential, to know the global market scenario, to know the people demand, to know about advanced manufacturing techniques at global level (Wadhwa *et al.,* 2007). All these demands of AMS can easily be attained by multi-media. Hence, accomplishing the competitive multi-media is act as sub-attribute of AMS.

2.4 IDENTIFICATION OF FACTORS AFFECTING THE AMS

After the extent literature survey and detailed discussion with industry and academia experts, factors affecting AMS have been identified. These AMS factors are as follows:

2.4.1 Organizational Structure

From previous many eras straight organizational structure has been obeyed in industry and academia sector. Though the effect of straight organizational structure on employees remained unstated but its effect on organization productivity and efficiency is very well understandable (Malhotra, 2014). In respect of it, flatter organization suggests an innovative conventional of organization activities; additional cooperation, fewer administration, improved communication, prospects for specialized expansion and superior employment contentment (Powell 2002). The efficiency of this modification unsympathetically is contingent on the arrogances and insights of the individuals occupied in flatter organizations (Kovach *et al.,* 2005). Virtuous organizational structures play an imperative part in magnificently execution of agile manufacturing system.

2.4.2 Information Technology Integration (ITI)

Integration of information technology shows a main and vital part in assimilating and attaching substantially separated industrialized businesses or organizations (Gunasekaran, 1999). Integration of information technology is possible only after the reengineering of the existing system (Chakraborty and Mandal, 2014). Different process in which paper work is included have to be removed by using IT integration (Singh *et al.,* 2011). In execution process of agile manufacturing system in an organization, information technology integration plays a vital role and it act as an important factor of AMS.

2.4.3 Outsourcing

Most of the processes are desired to subcontract in agile manufacturing system. Where tools and practices are not accessible, third parties shall be designated to subcontract the processes (Abdollahi *et al.*, 2015). AMS shall be considered in such a way that innovative products/ amenities are considered rapidly. So for accomplishing innovative invention or provision rapidly and at little price subcontracting is AMS factor.

2.4.4 Development of Design Methodology

Mathematical modelling and designing of outline for execution of agile manufacturing system and their authentication is a main factor (Pan and Nagi, 2013). Scientific demonstrating for AMS comprises expansion of a recognized and an incorporated illustration system. Execution of AMS mathematical model in s not an easy task, thus before implementation of AMS in organization there is need of proper planning in designing methodology. Hence, development of design methodology acts as important factor of AMS.

2.4.5 Convertibility

For measuring the performance of any manufacturing system, convertibility acts as an essential AMS factor (Malhotra 2014). It also helps in reducing the time in production and cost of the product (De Vor *et al.*, 1997). Finally, it helps in development of agility in agile manufacturing system. Hence convertibility acts as an important and essential factor in execution process of agile manufacturing system.

2.4.6 Scalability

Scalability is the ability to precisely correct the agility of an organization with minimum price and in minimum period over an enormous variety of manufacture capability (Meredith and Francis, 2000). The processes are significant when seeing the approachability of agile manufacturing system (Mohammed *et al.,* 2008). Manipulation of agile manufacturing system with the appearances of scalability; permits organization to control the variability in request permitting to marketplace.

2.4.7 Agile Work Force

The employees who are able to complete the work in particular given time in well-organized manner are known as agile workforce. It helps in significant manner for improving the agility of an organization (Pan and Nagi 2013). Agile workforces have capability to yield the product with least use of raw material and at condensed procedure principal time period and price (Gunasekaran *et al.*, 2002). Agility of an organization can easily be improved by agile workforces. Hence, agile workforce acts as an essential factor for execution of AMS.

2.4.8 Controls of Process Variations

Variation in product design is always demanded by consumers which include the fast changes in product design specification. Due to these changes every process like material handing time, product lead time automatically changed (Jain and Raj, 2015). So, control in process variation with proper designing is essential for high agility in an organization. Hence, controls of process variation play an important role of factor in an execution process of AMS.

2.4.9 Multi Lingual

Multi lingual is approximately that is accompanying with self-motivated employees Gunasekaran (1999). Multilingual employees are amalgamation of numerous potentials like dynamism, enthusiastic *etc.* So for magnificent changeover from traditional manufacturing systems to agile manufacturing system, multilingual workforce acts as an important key factor.

2.4.10 Top Management Support

Agility of an organization or industry can be easily improved by top management support. (Mishra, 2014 ; Raj *et al.,* 2008). Changes in rule and regulation for implementing agile manufacturing system in an organization can be handled by top management support (Pan and Nagi, 2013). To provide for the internal power to agile workforce is done by this factor only. However for complete implementation of AMS in an organization or industry, top management support acts as an essential factor.

2.4.11 Empowered Workers

AMS can be activated efficiently with the benefit of experienced employees such as design engineer, workshop manager, manufacturing engineer etc. (Gunaskeran, 1999). Just like an agile manufacturing system is much integrated information technology concentrated, it is pertinent to recover the acquaintance of an employee with the target to accomplish agility in organization. Authorized employee is actual expressive for manufacturers since endurance depend on the consumer's innovativeness. If the consumer is pleased, the consumer would endorse the company and promote to others to deal with that company (Sarkis, 2001). Hence, empowered worker acts as an essential factor for implementation of AMS in an organization.

2.4.12 Modular Design Approach

Failure in machine during production can cause increasing lead time, increase in cost of the product and delay in product delivery (Guneskaran *et al.,* 2002). Due to these shortfalls in machine; implementation of advanced design modular design methodology is essential. Afterwards, implementation of modular design approach can also reduce failure of machine (Yusuf *et al.,* 1999). Adoption of modular design approach finally helps in increasing the agility level of an organization. Hence, modular design approach is an essential factor of an AMS.

2.5 IDENTIFICATION OF ENABLERS FOR AMS

After the extensive literature; it has been evaluated that AMS enablers are helpful in the execution process of agile manufacturing system. Hence, the enablers who enable the agile manufacturing system are as follows:

2.5.1 Virtual Enterprise

It is a combination of essential abilities dispersed between different organizations, and then actual administrations focus on responding to quick market demand, cost reduction and quality (Singh *et al.*, 2015). One organization is not being able to complete the quickly changing requirement of market or customers. Tie-up with organizations is necessary step for increasing the agility of any organization so that virtual enterprise acts as significant enabler in execution process of agile manufacturing system.

2.5.2 Product Service Management (PSM)

An agile manufacturing company is required to provide its customers with products that will requires little or no service. In this regard, the concept of flexible design is brought to the attention of the researchers (Zhang *et al.,* 1999). So, PSM is an appropriate enabler in agile manufacturing environment *i.e.* to either eliminate or reduce the duration of product's service. This enabler will drive the manufacturer to improve the reliability of the products and strengthen the company's agile capabilities.

2.5.3 Flexible workforce

AMS can execute efficiently through the assistance of empowered employees or flexible workforce. Gunasekaran (2001) says flexible workforce is something that is associated with manpower whose is able to complete the multiple tasks. Flexible workforce means the workers are able to solve multiple problems. Enabler necessary for agility includes the capability to yield the product with least usage of raw materials and agile employees and condensed procedure for principal periods (Gunasekaran *et al.,* 2002).

2.5.4 Top Management Support

Gunasekaran, (2001) emphasized attaining agile manufacturing system necessitates essential fluctuations in each individual manufacturing process. This smooth modification in any association requires top management support in terms of essential methodological and monetary provision organized with worker authorization. It is necessary for execution process of agile manufacturing system because it gives helps in creating inner relations (Pan and Nagi, 2013). Hence, to increase the agility of an organization; top management support act as good enabler of AMS (Mishra, 2014).

2.5.5 Organizational structure

Over the year's previous horizontal organizational structures have been accepted in every organization. On the other side, flatter organization helps in improving the agility of an organization. Flatter organization system also helps in creating more cooperation, healthier communication, prospects for expert expansion and better employment gratification are originated which are accessible by AMS (Powell, 2002). Hence organization structure is act as an enabler in execution process of AMS.

2.5.6 Information Technology Integration

This enabler acts as very important enabler in integration of different manufacturing industries. Information technologies integrate the industries after rechecking each individual manufacturing process. The processes which are dependent upon the paper work can combine with information technology (Gunasekaran *et al.*, 2008). Hence, for achieving the high agility level in organization; information technology integration plays a role of enabler.

2.5.7 Man-Power Utilization

In today's scenario, customer's demands are fluctuating every day with respect to design, cost *etc.* To meet these ever-changing demands, industry needs to utilize manpower in proper way (Gunasekaran *et al.*, 2002). Agile team members are multi skilled and hardworking which can work in more efficient way. Under-utilization of manpower is behaved like one of the barriers in agile manufacturing system. So for improving the agility of the industry, utilization of man power is first and important step.

2.5.8 Pull production

AMS describe that product should not be 'Pushed' in the market; the demand of the product should be 'Pulled' from the consumer. This is possible when customer demand is calculated precisely and this can happen with the help of customer feedback. Agile manufacturing system is right platform for collecting customer response and feedback (Hallgren and Olhager, 2009). Agility of industries can only be achieved when exact information is available with industry regarding customer feedback and with its help ‘pulled’ manufacturing system can be achieved easily.

2.5.9 Product Life-Cycle Management (PLM)

PLM means maintaining the record of product till its disposal. In AMS, it is essential to collect information and knowledge of data over its entire life cycle. This practice has to be continued till its disposal. This PLM practice can be achieved with the help of IT, CAD, CAM and CIM (Coronado, 2003). Hence, PLM helps in achieving the agility of the organization and act as an enabler of AMS.

2.5.10 Optimal inventory

Maintaining zero inventories is not desirable in today scenario. Minimum reasonable inventory advantages reply rapidly to unexpected reduction or intensification in customer demands therefore supports in accomplishing agility (Gunasekaran, 2001). As per agile manufacturing system’s perception, thrive should be minimum reasonable inventory available all times which decrease the waiting period and lead period in circumstance of ambiguity. In today’s scenario, MRI is a more relevant philosophy and helps in achieving the agility of an organization. Hence, optimal level behaves as an enabler of agile manufacturing system.

2.5.11 Machine Utilization

Utilization of machine is primary step for any manufacturing system. This machine utilization can be improved by operations research techniques like scheduling. This machine utilization helps in increasing the production in short time period (Montazeri and Wassenhove, 1990). Machine utilization process by scheduling helps industry manager by maintaining the span time of machines. In such a competitive scenario; agility of an organization can be improved easily by proper machine utilization. Hence, machine utilization plays a vital role in implementation process of AMS.

2.6 IDENTIFICATION OF BARRIERS AFFECTING AMS

AMS execution process is not an easy task; various barriers are there which create problems in execution process of AMS. Hence barriers have been identified after the extent literature survey and discussion with researchers from both industry and academia. The barriers affecting agile manufacturing system are as follows:

2.6.1 Bottom-Out Production

Bottom-out production means producing the product in excess amount which is also known as overproduction. This overproduction may be caused by many reasons such as producing more products than actual demand due to wrong prediction, due to full utilization of permanent employees and due to overconfidence of management (Singh *et al.*, 2015). In most of the cases, this bottom out production is not informed by the employee to higher authority. So, controlling on overproduction can be done by putting an inventory method. This inventory method helps in overproduction which acts as a barrier for agile manufacturing system.

2.6.2 Excessive Stock

To maintain the stock in organization is a symbol of good company in last some decades. But in today's competitive scenario this excessive stock is act as barrier in execution of agile manufacturing system because this excessive stock use the land for stocking the products as well as money has already been blocked (Anand and Kohli 2008).. As per today's customer dynamic demand there is possibility of changing the product design as per customer demand. Afterwards, all stock acts as wastage for organization. Hence for maintaining the balance in an organization there is needed to obey the minimum inventory level method. Otherwise, excessive stock acts as a barrier in implementation process of agile manufacturing system.

2.6. 3 Waiting Time

Somewhat interruption in the dispensation of accomplishments cause breakdown of scheduling accomplishments of the business. In manufacturing system, postponements are order of day in numerous regions such as manufacture, advertising, management and plan. Slight interruption in the commencement of a procedure will move to their consequential phases disturbing their horizontal implementation (Anand and Kohli 2008). In order to evade such interruptions, a balanced agenda is to be ready. Additional imperfection free procedures necessitated to be industrialized and organized in the industry.

2.6.4 Logistic Charges

Conveyance is automatically approved in software emerging administrations by IT techniques. In the case of administrations going to the additional manufacturing segments, substantial treatment is considered by the corporal connotation of men and resources. This reasons the administrations to devote widespread quantity of period and cash on conveyance (Sullivan *et al.,* 2002). In many circumstances transport may see as an essential stage of dispensation. These conveyance necessities may be removed or reduced by spread ideas like cellular engineering and by exploiting CNC grounded machines center. These facilities permit the dispensation of resources by maintaining them inside a minor part. Hence, logistic charges also act as a barrier in implementation process of agile manufacturing system.

2.6.5 Processing

Although manufacture and facility focused on events mandatory to be handled to grow the result however dispensation seems to be a value addition action consisting numerous conditions with extended procedures which are central to the consumption of cash and time period (Dahlgaard *et al.,* 2006; Sullivan *et al.,* 2002). For illustration, a constituent made in casting shop essential to be processed in a workshop to create a machine constituent. Nevertheless a net designed constituent does not need machining process after establishing. Henceforth, the expedition for dropping and removing procedures in the society will remove the wastage.

2.6.6 Redundant Drift

In industry where the arrangement is not appropriately considered, persons are required to redundant drift through random paths (Herron and Hicks, 2008). In industrialized manufacturing ground the technique of enhancing the motion of persons has been mainly talked in study method technique (Dahlgaard *et al.,* 2006). Those ideologies are obligatory to be strategically organized to decrease or remove the motion of persons in the industry. The augmented motion of persons primes to the consumption of time period and occasionally cash also.

2.6.7 Imperfect Production

Imperfect portions in fabrication line are continuously represented as a key obstacle for AMS. To resist this obstacle, administrative or technical modelling is essential, such as ideas of 6-sigma can be executed in AMS (Mo, 2009). So, manufacture of unreliable portions is manageable by technical and management modeling. Hence, for improving agility there is need of imperfect production in an organization. Furthermore, imperfect product act as barrier in execution process of AMS.

2.6.8 Discrepancy in Resource Utilization

Major challenge during execution process of AMS is the appropriate exploitation of persons who are employed to accomplish the objective of consumer gratification (Herron and Hicks 2008). Key problem for the executive is that every time while assigning precise job with correct obligation to correct persons is require in an industry. These conditions can be simply controlled by executing AMS ideas which mostly emphasizes on satisfying consumer desire in smaller phase.

2.7 REVIEW ON METHODOLOGIES

After the extent literature and brainstorming with industry and academia persons, it is identified that AMS questionnaire survey, attributes, sub-attributes, factors, enablers and barriers can be analyzed and evaluated by numerous techniques. Hence, methods, approaches or techniques which can be used for evaluating purpose are as follows:

2.7.1 Analysis of Variance Approach

It is tremendously beneficial approach regarding investigators in the areas of industrial engineering, academia and in investigation of numerous additional restraints. This method is used when numerous illustration cases are integrated. The consequence of the alteration among the two sample mean which can be evaluated through t-test and z-test, but the trouble ascends when we ensue to inspect the implication of the alteration between additional than two cases at the identical period ((Kothari, 2004). Analysis of variance method permits us to achieve this assessment and as such is measured to be an essential instrument of exploration in the investigator hand. Exhausting this method, one can appeal implications about whether the samples taken from population have the same mean or not.

This ANOVA method is mainly divided in two parts namely one way ANOVA and muti-way ANOVA. One way ANOVA method is used to evaluate the different samples but on the basis of single factor. When we have to evaluate multi sample on the basis of more than factor than Multi-way ANOVA method is preferred.

2.7.2 Fuzzy Agility Index Approach

Fuzzy agility index method is used to categorize the level of agility of industry or somewhat industrialized industry. It characterizes inclusive industry agility level. Agility level of industry increases as agility index value increases (Yang and Li, 2002). Therefore, agility level of an organization can be representing by the value of fuzzy agility index. As per, fuzzy weighted average classification, the performance index value of sub-attributes can be representing as follows:

$$R_i = \sum_{k=1}^{n} (W_{ij} * R_{ij}) \Big/ \sum_{k=1}^{n} W_{ij} \qquad \text{(i)}$$

Here

Fuzzy weightage of importance for AMS sub-attributes is represent by W_{ij}

Fuzzy rating of performance for AMS sub-attributes is represent by R_{ij}

As, Fuzzy rating of performance for AMS attribute is represented by R_i and fuzzy weightage of the agile attributes is represented by W_i . Hence, agility index for agile manufacturing system is represented by

$$(\text{AGILITY}_{\text{INDEX}}) = \sum_{i=1}^{n} Ri * Wi$$

After the generation of fuzzy agility index value for attributes and sub-attributes for agile manufacturing system, this fizzy agility value must be checked with the linguist level whose membership role is equal or near to equal to the membership role of fuzzy agility index value for AMS.

2.7.3 Review of Interpretive Structural Modelling Approach

Interpretive structural modelling is developed by Warfield in 1973 which help in calculating the dependence and driving power of enablers, factors, barriers, element etc., affecting to system. This technique also helps in making the interactions between fundamentals amongst precise principles. ISM also supports in recognizing the circumstantial connection amongst the numerous components of the organization which describes the problems (Singh and Khamba, 2011). It is informational modelling as decision of the assembly elects; whether and exactly how the elements are associated with each other (Jain and Raj, 2015). It also supports to execute command and track the complication of relations amongst numerous essentials of an organization (Mohammed *et al.*, 2008).

ISM yields an organized model with systematic representation of the innovative difficult situation that can be connected efficiently to others in supplementary manner. ISM inspires issue investigation by permitting applicants to discover the competence of a projected list of organizations fundamentals or problem declarations for enlightening a stated condition (Malhotra, 2014). It acts as a useful technique by compelling contributors to improve a deep appreciative of the significance for a definite variable list and relationship (Mittal and Sangwan, 2011). It allows exploitation or strategy exploration by supplementary contributors in recognizing precise areas for strategy act which offer compensations or influence in following quantified purposes.

2.7.4 Review of Total Interpretive Structural Modelling Approach

This methodology benefits us in generating an association amongst the factors, enablers, and barriers of AMS. Since total interpretive structural modelling approach is produced from interpretive structural modelling approach, ISM methodology is not competent to clarify the explanation of organizational relationships and it is not completely lustrous in above surroundings (Jain and Raj, 2015). Consequently, to overcome the constraints of ISM technique, it needs to be inclusive to TISM. Consequent are the stages for total interpretive structural modelling as deliberated by Sushil (2012).

Total interpretive structural modelling procedure starts with the determination of factors, enablers, barriers and issues related to system. Afterward determination of issues, the primary step is one which differentiate the total interpretive structural modelling to interpretive structural modelling as in this we are recognizing the related circumstantial and interpretation correlation (Jayalakshmi and Pramod, 2015). After this the relation between the issues are converted into Structural Self-Interaction Matrix. Afterwards SSIM, initial reachability matrix will be generated. Final reachability matrix comes after checking the transitivity of initial reachability matrix. Partitioning of the level is done in last reachability matrix. Dependent on the relations given by portioning of level; a digraph is derived and also interface conditions is established with the assistance of diagraph. The consequential interface matrix and final digraph is transformed into total interpretive structural modelling by exchanging issue nodes with issue (Sushil, 2012; Jayalakshmi and Pramod, 2015). Lastly, established total interpretive structural modelling is patterned for theoretical inconsistency and essential alterations are finished.

2.7.5 Review of Entropy Approach

Concept of Entropy method first proposed by Shannon in 1948 (Shannon, 2001). In information theory term Entropy is known as the average amount of information (Shi-fei and Zhong-zhi, 2005). It is the uncertainty of information content and provides a scientific theory basis for modern information theory (Cover and Thomas, 1991). As with in decrease information entropy, weight of particular criteria increases because for taking decision in real world we prefer the value whose uncertainty level is low (Ji *et al.,* 2015). We applied the concept of entropy to determine the criteria weight.

Entropy method has following advantages compared to other MCDM method (Rhodes and Garside, 1995):

- Give minimum partisan result which is consistent with all the available data.
- Useful technique to investigate the validity of assumptions
- Easy to study and solve
- Simple mathematical calculation
- Less time consuming

This methodology has been successfully used by various researchers for optimization of micro scale manufacturing process (Beruvides *et al.,* 2016), product evaluation (Dashore *et al.,* 2013), cell phone evaluation (Akyene, 2012), probabilistic reasoning (Rhodes and Garside, 1995), supplier selection (Shemshadi *et al.,* 2011), order allocation (Ghorbani *et al.,* 2012), Risk assessment to hydropower station (Ji *et al.,* 2015).

2.7.6 Review of MOORA Method

MOORA method is also recognized as multi-attribute or multi-criteria optimization. MOORA method works simultaneously on optimization of many conflicting purposes focus to convinced criteria. Technique was presented in 2004 by Brauers and suggests that it is a technique in which we can optimize multi-objectives (Brauers *et al.,* 2006). It is used for solving composite resolution creating difficulties in the industrialized atmosphere. It is relatively simpler method than other MCDM method and calculation is stress-free which assist judgement creators to find more effective substitutes among various conflicting alternatives.

Advantages of this MOORA method in comparison with other MCDM method given by (Attri and Grover, 2014) is

- Easy to learn and solve as compare to other MCDM method
- Calculation is less time consumable, and

This methodology has been successfully used by various researchers for different production life cycle such as stages selection, selection of FMS, selection of supplier and welding processes (Attri and Grover, 2014), material selection (Karande and

Chakraborty, 2012), optimizing milling process (Gadakh 2010, Brauers *et al.*, 2008), privatization in a transition economy (Brauers *et al.*, 2006).

2.7.7 Review of VIKOR Analysis

VIKOR analysis is described by Opricovic in 1998 for optimization and ranking of complex system having multiple criteria (Opricovic 1998, Opricovic and Tzeng, 2002). Method focuses on evaluating ranking list of an available alternatives and stability of weight between the intervals of the compromise solution with initial given weight here derived by entropy method (Wei and Lin, 2008). This method relies on an evaluating the function that represents nearest to the ideal and give the ranking index based on the particular measure of closeness to the ideal solution.

Opricovic & Tzeng, (2004); Wei & Lin, (2008) describes various advantages of VIKOR analysis over other MCDM techniques Evaluation parameters are easily understandable and easy to calculate in such a way that

- Attitude of decision maker taken into consideration by changing v factor
- Final performance score is an aggregation of all the criteria and their relative weight

2.7.8 Review of Fuzzy Performance Importance Index Approach

This method has been engaged to extent the fuzzy performance importance index value for the barriers which affects the agile manufacturing systems. Agility assessment not only calculates exactly how agile an organization is but correspondingly, utmost essentially, assist executives to evaluate distinguishing capabilities and recognize the key problems for executing suitable development events ((Lee-Kwang and Lee, 1999). In order to recognize the key difficulties for enlightening the level of agility in an organization, a fuzzy performance importance index of agile barrier aptitude, which syndicates the performance importance and weightage essentials of each agile barrier (Karwowski and Mital, 1986). The lesser the fuzzy performance importance index value of AMS barrier, the lesser the degree of involvement for this barrier. Thus, the rank of FPII barrier is used for classifying the key problems ((Lee-Kwang and Lee, 1999).

2.8 RESEARCH GAP

During this research work, a lot of research papers related to AMS have been studied and it is found that there are some research gaps in the areas of implementation process of AMS. The following gaps are identified:

- The research on AMS till now; endeavours to start consciousness on the consequence and impending of AMS but very inadequate attempts have been made on the path to accomplish AMS in execution.
- Investigators were frequently concerned with manufacturing system and delivered only the common strategies to achieve agility for an organization without providing proper execution strategies.
- Literature related to the attributes, sub-attributes, barriers, enablers and factors of AMS is not readily available as not much work has been reported for these in AMS.
- Attribute, sub-attributes, barriers, enablers and factors of AMS needs to be modelled
- Relationship among the enablers and factor affecting AMS is not available in literature.
- Ranking for AMS facilitators is not available in literature.
- In the literature, performance index value measurement of AMS barriers is not available.
- In reality, there is existence of a widespread gap amongst the research endeavours and a comprehensive methodology which will ideally suit most industries in the process of rebuilding an AMS.

2.9 SUMMARY AND CONCLUSION

Afterwards the discussion it is considerably clear that the furthermost researchers have described the agile manufacturing system as theory based system; which are very problematic to be processed by industry experts. Many methodological problems related with agile manufacturing system execution are felt in today's competitive scenario and these technical difficulties decelerated the progress of AMS implementation. The execution process of AMS is very challenging task. The whole thing concerning its execution as well as it usage is not as simple as have been described in many research papers.The finest way of refereeing the possibility of AMS is organized knowledge about its industrialized viability.

In this chapter an evaluation of literature associated to execution process of AMS, evaluation, attributes and sub-attributes of AMS, factor, enablers and barriers disturbing the execution procedure of AMS have been described. These recognized attributes, sub-attributes, factors, enablers; barriers will deliver the enthusiasm and path for the existent work. The examination of these attributes, sub-attributes, factors, enablers and barrier for the acceptance and execution of AMS have been described in the succeeding sections.

CHAPTER 3

QUESTIONNAIRE SURVEY

3.1 INTRODUCTION

This chapter represents the methodology and outcomes of questionnaire based survey on agile manufacturing system. An aim of this survey was to evaluate the attributes and sub-attributes which effects execution process of AMS. Key interpretations have been described and deliberated which acts as the outcome from this survey. Few other characteristics such as questionnaire development and its administration have been included in this chapter.

3.2 QUESTIONNAIRE DEVELOPMENT

This questionnaire based survey was commenced to characterize various attributes and sub-attributed regarding acceptance and execution of agile manufacturing system in Indian scenario. All available literature survey on agile manufacturing system was used for the designing of the questionnaire survey. This questionnaire was also discussed with academician and industry experts in the area of AMS, during the expansion of the questionnaire. The response rates of the surveys are not passionate and respondent are very unenthusiastic to spare time in replying to such questionnaire. So, the questionnaire was premeditated in such a way that minimum efforts and time will require in filling the questionnaire.

This questionnaire survey is designed in two sections. Section 1 represents the company profile such as number of employees, total turnover; number of models of your product being manufactured etc. is included in this section. Section 2 deals with two sub-sections, first is designed to calculate the importance weightage of attribute and sub-attributes for agile manufacturing system. This importance weightage is calculated in seven point linguistic terms as very high, high, fairly high, medium, fairly low, low and very low. These linguistic terms helps in finding out the weightage importance of attributes and sub-attributes affecting agile manufacturing system. Second sub-section of section 2 is designed for calculate the performance rating for sub-attributes. This performance rating of sub-attributes is evaluated in seven linguist terms as excellent, very good, good, fair, poor, very poor and worst. These linguistic terms helps in calculate the performance rating of sub-attributes affecting agile manufacturing systems.

3.3 DEVELOPMENT OF THE QUESTIONNAIRE

3.3.1 Targeted Industries for Questionnaire Organization

The questionnaire is organized on an Indian industry such as automobile sector; steel sector, engineering equipment’s, textile sector, manufacturing sector, process industry, gas turbine production industry, thermoplastic industry etc. are concentrated.

3.3.2 Administration of Questionnaire

The personal-contact, e-mail and postal assessment method are used for the organization of questionnaire survey. The questionnaire survey is mainly filled by higher authorities or decision makers like general managers, directors, chief executive officers, senior managers and executives etc. Mostly questionnaire surveys are filled by online (by using google sheet) and some are filled by sending personally the questionnaire form with covering letter to higher executives. One self-addressed envelope is also send with this survey form in order to get back the questionnaire form. As after the return of these questionnaire, it seems that mostly questionnaire was filled by senior executive while also some were filled by the others on behalf of higher executives.

3.4 SURVEY RESPONSE AND RESPONDENTS PROFILE

However the total 430 questionnaire survey forms were send for the AMS survey; out of which 172 questionnaire forms were received back furthermore again out of 172 forms, 21 questionnaires forms were incomplete which were rejected for further evaluation. Besides the rejected forms only remaining 151 questionnaires are used for analyzation which means response rate is 35.11 percent. As comparatively on the basis of Malhotra and Grover (1998), this percentage of the survey response is not low. According to the responses of the survey; section 1 company profile data of 151 respondents are represented in table 3.1.

Section 2 of the questionnaire survey which represents the importance weightage of attributes and sub-attributes in seven linguistic terms and performance rating of sub-attributes in seven linguistic terms are represented as per appendix-1.

Table 3.1: Data collection from responding companies

Sr. No.	Data Description	Range	Number of industry (out of 151)
1	Number of employees in organization	Less than100	25
		101-500	52
		501-1000	34
		More than 1000	40
2	Total turnover of the organization (Cr.)	Less than 10	22
		Between 10-50	40
		Between 50-100	28
		More than 500	61
3	Number of models of your product being manufactured	Between 1-5	21
		Between 6-10	51
		Between 11-20	34
		Above 20	45
4	Total number of components being manufactured inside the plant	Less than 20	34
		Between 20-50	52
		Between 50-100	39
		More than 100	26
5	The current productivity level in terms of units per man per day (approx.)	Less than 10	29
		Between 10-25	51
		Between 25-50	38
		More than 50	33

3.5 OBSERVATIONS ON THE NUMBER OF RESPONDENT INDUSTRIES

3.5.1 Regarding Number of Employees in an Organization

In questionnaire survey, we identified that 52 out of 151 industries means nearly 34% industries have number of employees in between 101-500. On the similar way, 40 out of 151 industries nearly 26% industries have more than 1000 employees. 34 out of 151 industries about 23% and 25 out of 151 nearly 17% industries have employees between 501-1000 and less than 100 respectively as shown in figure 3.1.

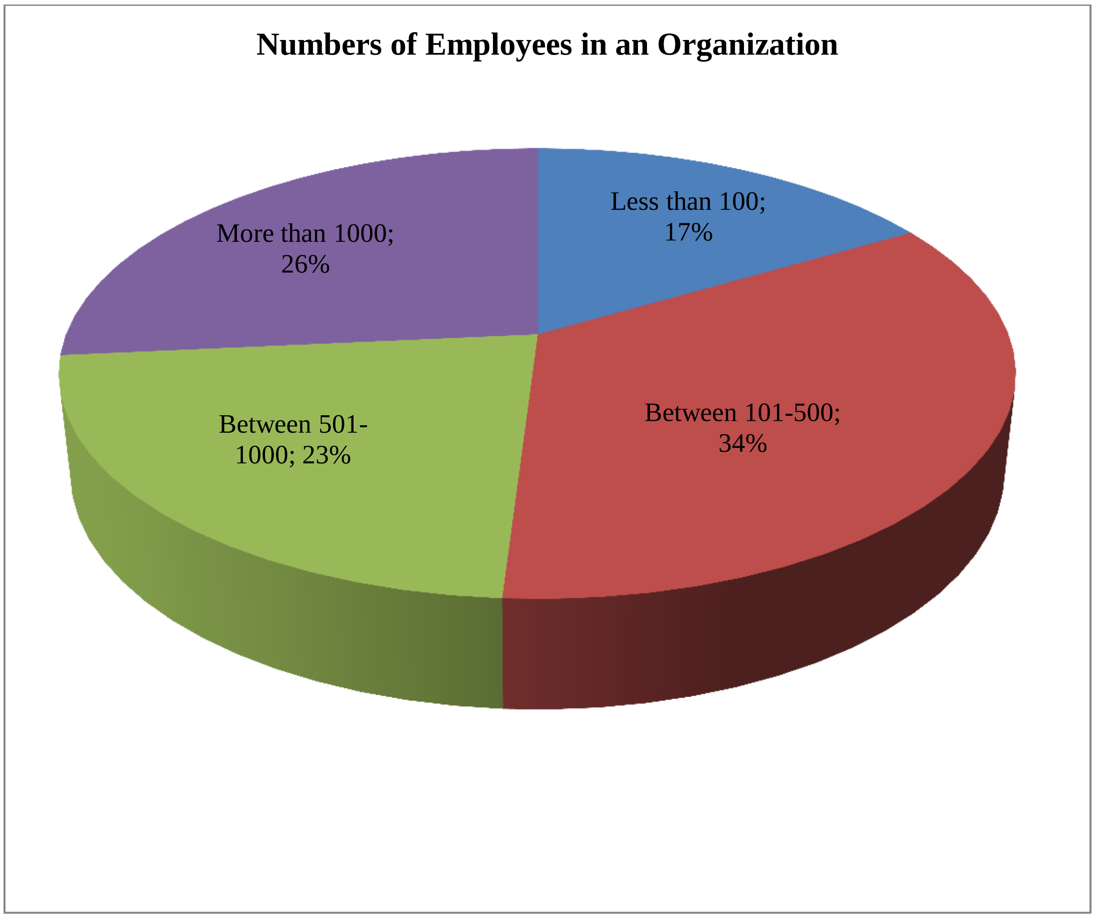

Figure 3.1: Numbers of employees in an organization

3.5.2 Regarding Turnover of an Organization

In respect to turnover of organization from 151 respondent industries, identified that 61 out of 151 about 40% industries have more than 500 Cr. turnovers while 40 out of 151 about 26% industries have turnover between 10-50 Cr. 28 out of 151 about 19% industries have turnover between 50-100 Cr. 22 out of 151 means only around 15% industries are lie in less than 10 Cr turnover category as shown in figure 3.2.

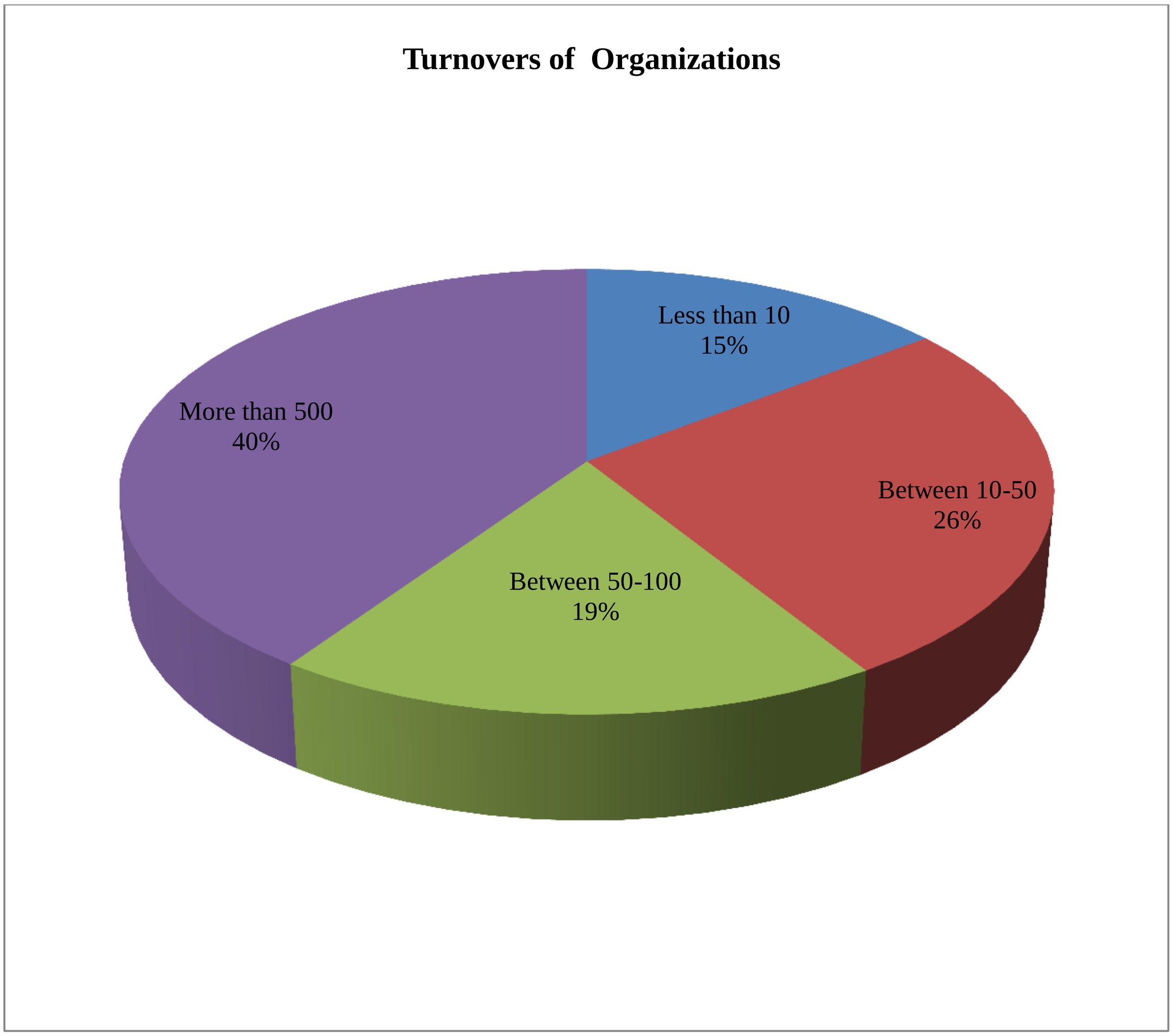

Figure 3.2: Turnover of organizations

3.5.3 Numbers of Different Models Produced in an Organization

In respect to number of different model produced in an organization identified that 51 out of 151 about 34% industries are producing 6-10 different models in an organization while 45 out of 151 about 30% industries are producing more than 20 models in an organizations. 34 out of 151 about 22% industries are producing between 11-20 models. 21 out of 151 means only around 14% industries are producing different models in between 1-5 as shown in figure 3.3.

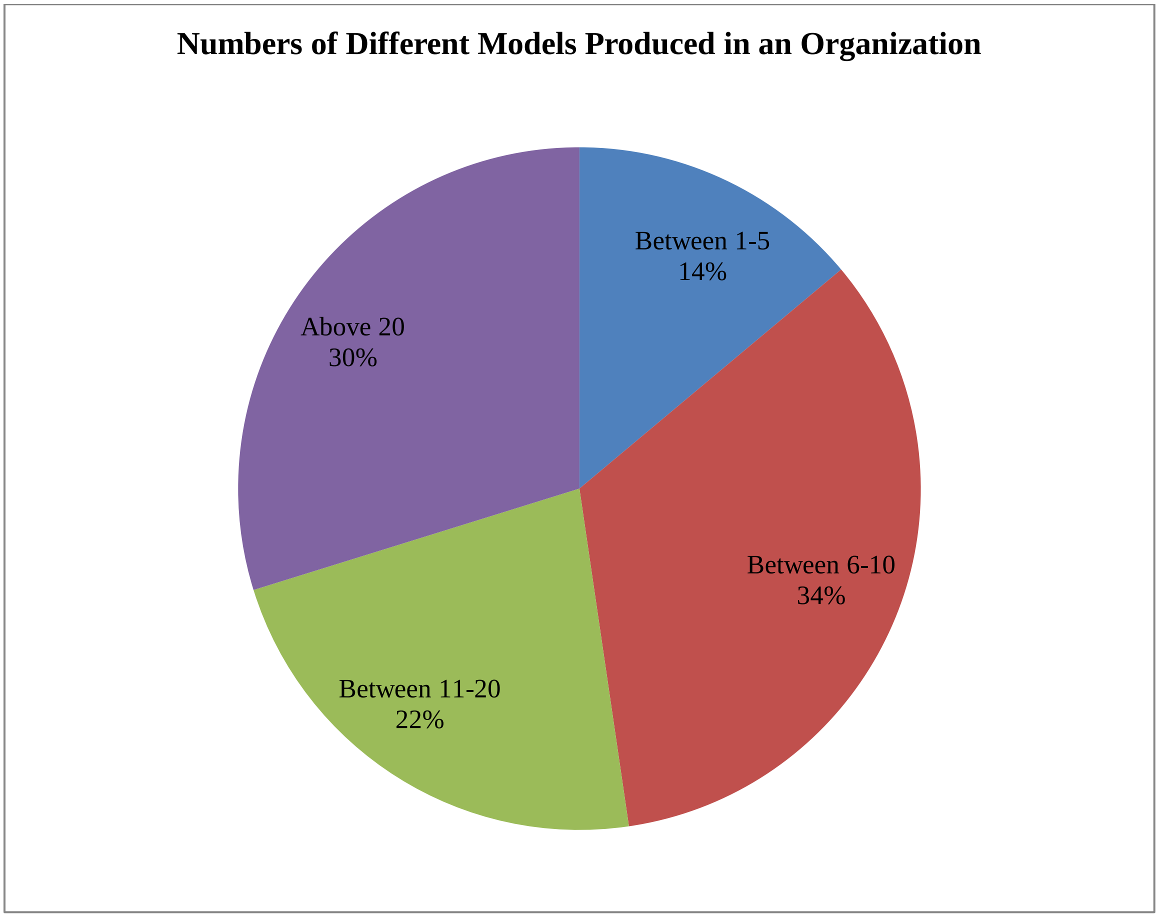

Figure 3.3: Number of different models produced by an organization

3.5.4 Number of Components Manufactured in an Organization

In respect to the number of components produced in an organization identified that 52 out of 151 about 34% industries are producing 20-50 number of components in an organization while 39 out of 151 about 26% industries are producing in between 50-100 components in an organizations. 34 out of 151 about 23% industries are producing less than 20 components. 26 out of 151 means only around 17% industries are producing more than 100 components as shown in figure 3.4.

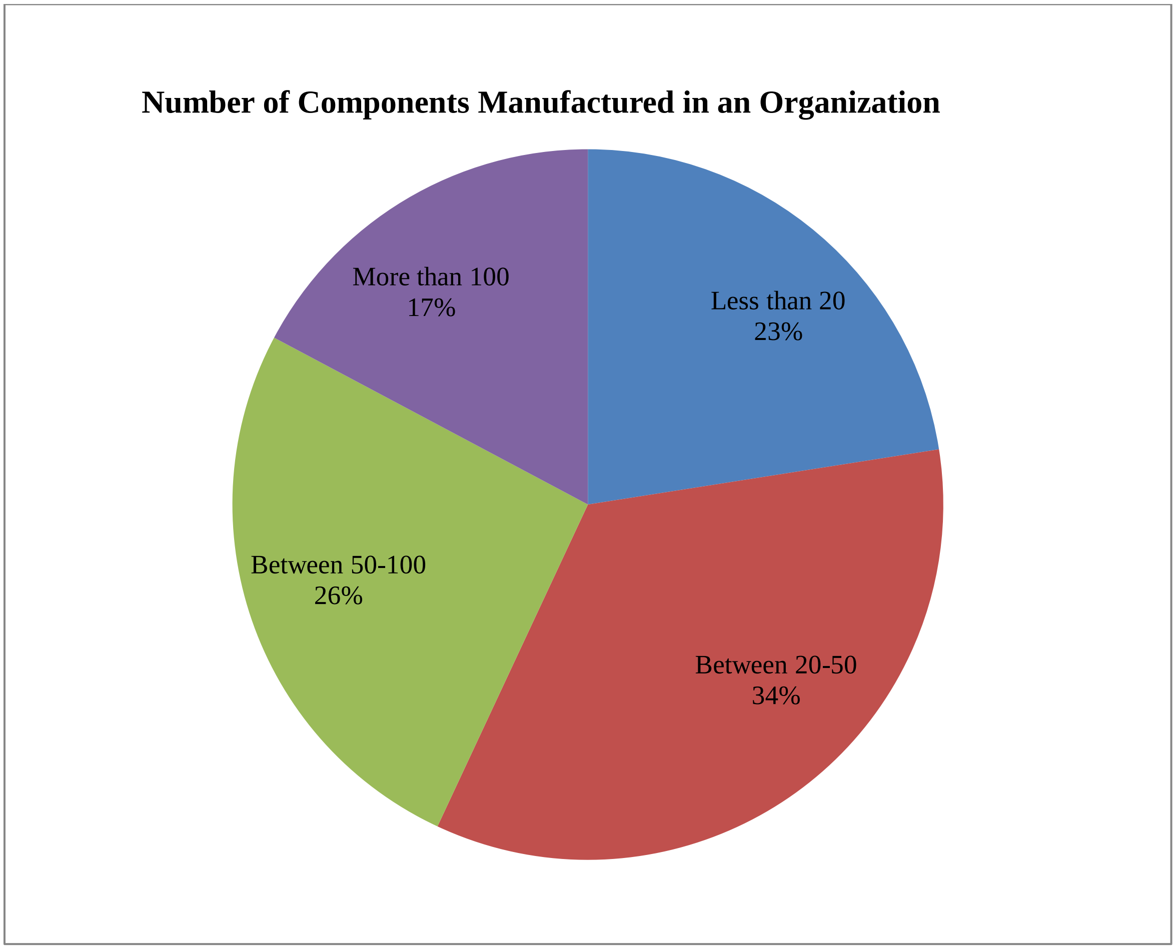

Figure 3.4: Number of components manufactured in an organization

3.5.5 Productivity Level of an Organization

The productivity level of an organization means that the number of product produced per men per day (approximately). In questionnaire survey, we identified that 51 out of 151 industries means nearly 34% industries have productivity level in between 10-25. On the similar way, 38 out of 151 nearly 25% industries have productivity level in between 25 to 50. 33 out of 151 industries about 22% and 29 out of 151 nearly 19% industries have productivity level more than 50 and less than 10 respectively as shown in figure 3.5.

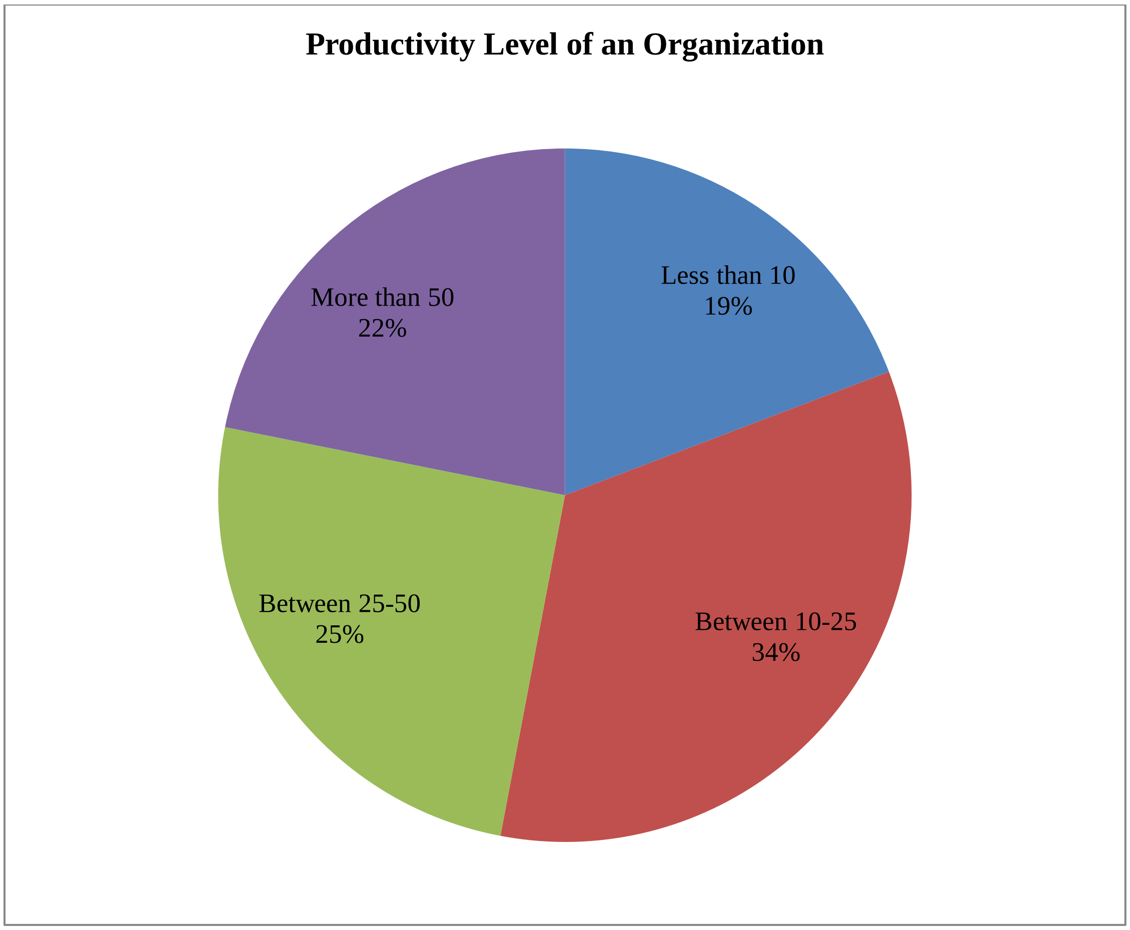

Figure 3.5: Productivity of an organization

3.6 CONCLUSIONS

From the questionnaire survey of 151 industries an examined results of the attributes and sub-attributes in terms of importance weightage and performance rating as per appendix 1. These 151 industries are categorized in five main types *i.e.* number of employees in an organization; turnover of an organization; number of different models produced by an organization; number of components manufactured by an organization; productivity level of an organization.

In our research; out of 151 respondent industries, maximum participation of an organization in each category is as follows: 34% industries have employees in between 101-500; 40% industries have more than 500 Cr. turnovers; 34% industries are producing 20-50 number of components in an organization; 34% industries have productivity level in between 10-25.

CHAPTER 4

VALIDATION OF QUESTIONNAIRE SURVEY BY ANOVA ANALYSIS

4.1 INTRODUCTION

Analysis of variance is an exceptionally convenient method regarding researchers in the fields of engineering, learning and in experiments of some further areas. It is used where different cases of sample are mainly elaborated. Importance between the two different samples can be evaluated by both t-test and z-test however main problem arises after we proceed towards to evaluate the importance between more than two samples (Kothari, 2004). This method helps in implementing this test and it acts as a significant instrument of investigation for the investigator. With the help of this method, individual can appeal suggestions about whether data have been taken from people having the same mean.

The term ‘Variance’ was firstly used by Professor R.A.Fisher in addition ANOVA term is also invented by him only further also explain its application and benefits in today’s scenario. After that however Professor Snedecor also helped in expansion of this method. This ‘ANOVA’ method is fundamentally a process for testing the variance between dissimilar groups of records for similarity (Kothari, 2004). “The essence of ANOVA is that the total amount of variation in a set of data is categorized down into two types, the amount which can be attributed to chance and the amount which can be attributed to specified causes” (Kothari, 2004; Christensen, 2011). The differences between samples and within samples can be exists. This ANOVA method includes in excruciating the difference for systematic purposes. So, it is a technique of examining the inconsistency to which a reaction matters into its several parts in respect to different sources of differences (Harnett & Murphy, 1980). The ANOVA principle is to assessment for changes amongst the means of the data by inspecting an extent of differences inside alone of these samples, comparative to the extent of differences amongst the sections. Now, we will take two population variances i.e. one based on within sample difference and other between samples differences. Afterwards these estimates are examined by F-Test and it is explored by given below formula.

$$F = \frac{\text{Mean Square between samples variance}}{\text{Mean Square within samples variance}}$$

Now, examined F-value will be compared with standard F-limit executed for known Degree of Freedom (DOF). Now if calculated F-Value is same or more than the F-Limit value (which is defined differ for different significant level value) then we can conclude that the difference between the data is significant (Stoline, 1981).

4.2 OVERVIEW OF ANOVA ANALYSIS

In one way ANOVA analysis, we include only one factor and afterwards we notice that the purpose for supposed factor to be significant is that some probable kind of examples can arise inside the factor. Then only we are able to find differences inside that particular factor. Various steps involve in this method are as follows (Kothari, 2004):

(i) Find the each sample mean i.e.

$$\bar{X}1, \bar{X}2, \bar{X}3, \bar{X}4 \ldots \bar{X}k \qquad \text{i)}$$

K represents the number of samples

(ii) Calculate the mean of the data collected as follows and it is represented in table 4.1:

$$\bar{\bar{X}} = \frac{\overline{x_1} + \overline{x_2} + \overline{x_3} + \cdots \ldots\ldots\ldots\ldots, \overline{x_k}}{\text{No.of samples (k)}} \qquad \text{ii)}$$

(iii) Sample mean deviation can be calculated from means of the sample and deviation square can also be calculated which can be multiplied by the quantity of objects in the consistent samples, and then attain their overall value. This is recognised as the SS between which is sum of squares for variance between the samples. This may be characterized as follows:

SS between = $n_1 \left(\bar{X}1 - \bar{\bar{X}}\right)^2 + n_2 \left(\bar{X}2 - \bar{\bar{X}}\right)^2 + \ldots\ldots + n_k \left(\bar{X}k - \bar{\bar{X}}\right)^2$ iii)

(iv) Now take the ration of above result and DOF inside the sample to find Mean Square (MS) inside the sample. This equation can be denoted by as follows: :

$$\text{MS between} = \frac{SS\ between}{(k-1)} \qquad \text{iv)}$$

DOF inside the samples is represented by (k-1).

(v) Attain the deviation of the value of the samples item for whole samples from consistent mean of the sample and evaluate the square of such deviations and then attain their whole value. This value is recognised as the sum of squares for variance and then finds their overall value. This sum is recognised as Sum of Square (SS) within i.e. the sum of squares for variance within samples. Metaphorically this may be engraved as:

SS within = $\sum(X_{1i} - \overline{X_1})^2 + \sum(X_{2i} - \overline{X_2})^2 + \ldots\ldots.. + \sum\left(X_{ki} - \overline{\overline{X_k}}\right)^2$ v)

i = 1, 2, 3…

(vi) Take the ration of SS within and DOF inside the samples to find out the MS inside the samples. This can be notated as below:

$$\text{MS within} = \frac{SS\ within}{(n-k)} \qquad \text{vi)}$$

DOF inside the samples is represented by (n-k)

Here total number of item in the entire sample is represented by n

And number of sample is represented by k

(vii) Total variance for sum of squares deviation can be calculated by adding the square of deviations. It can only be done when in the each data deviation in altogether sample is kept since the means of the sample mean. It may be denoted as follows:

$$\text{SS for total variance} = \sum\left(Xij - \bar{\bar{X}}\right)^2 \qquad \text{vii)}$$

Where i and j value is 1, 2, 3…

This SS for total variance must be same as the addition of step SS between and SS within.

Total variance DOF should be same as n-1; n representing total number of items. DOF for total variance will be addition of DOF between and within as follows:

$$(n-1) = (k-1) + (n-k) \qquad \text{viii)}$$

It represents ANOVA method preservative quality.

(viii) In conclusion, F-ratio can be calculated as per below formula i.e.

$$\text{F-ratio} = \frac{MS\ between}{MS\ within} \qquad \text{ix)}$$

Calculated result can be used to examine the variance between some means which is either beneficial or it is just fluctuation of samples. Now, for examining the F-value, check the F-critical value for specified DOF at changed levels of significance. Finally if calculated F-value is greater than or equal to F-critical value than we can conclude as differences taken is significant(which means that sample is not taken from same universe) and if calculated F-value is more on higher side which concludes that data is more definite and sure. If the deliberated F-value is fewer than the F-critical value at specified DOF then it means data is not significant (which means that there is a need to verify again the data resources) and finally according to that we need to come on conclusion.

4.3 METHODOLOGY

This section validates the data collected from questionnaire survey of 151 Indian companies with the help of ANOVA analysis.

Step 1: Convert the Linguistic value

First step for applying ANOVA analysis is to convert the linguistic variables into numerical values of collected data.

Step 2: Calculate the mean and variance

First step for ANOVA analysis of sample is to calculate the mean and variance of data collected from 151 Indian companies through questionnaire survey. The mean and variance has been calculated with help of equation i) and ii) as shown in table 4.1

Step 3: Calculate the SS between and MS between

Next step is to find out the sum of square between the samples by using equation iii) and iv) and in order to calculate, degree of freedom is taking as 39 by using formula k-1. SS between and MS between have been calculated and shown in table 4.2.

Table 4.1: Calculation of average and variance for collected data

Anova: Single Factor					
SUMMARY					
Sr. No.	*Groups*	*Count*	*Sum*	*Average*	*Variance*
1	Column 1	151	841	5.569536	1.286799
2	Column 2	151	822	5.443709	1.22181
3	Column 3	151	819	5.423841	1.352494
4	Column 4	151	800	5.298013	2.143929
5	Column 5	151	832	5.509934	0.904901
6	Column 6	151	817	5.410596	1.070287
7	Column 7	151	803	5.317881	1.218278
8	Column 8	151	812	5.377483	1.503223
9	Column 9	151	765	5.066225	1.302252
10	Column 10	151	797	5.278146	1.615453
11	Column 11	151	778	5.152318	1.183311
12	Column 12	151	777	5.145695	1.311965
13	Column 13	151	779	5.15894	1.65457
14	Column 14	151	808	5.350993	1.522649
15	Column 15	151	787	5.211921	1.39479
16	Column 16	151	797	5.278146	1.668786
17	Column 17	151	767	5.07947	1.700309
18	Column 18	151	759	5.02649	1.50596
19	Column 19	151	771	5.10596	1.668698
20	Column 20	151	778	5.152318	1.263311

Sr. No.	*Groups*	*Count*	*Sum*	*Average*	*Variance*
21	Column 21	151	816	5.403974	1.762384
22	Column 22	151	816	5.403974	1.762384
23	Column 23	151	825	5.463576	0.956998
24	Column 24	151	811	5.370861	1.194879
25	Column 25	151	823	5.450331	1.009183
26	Column 26	151	818	5.417219	1.111435
27	Column 27	151	796	5.271523	1.199117
28	Column 28	151	802	5.311258	1.215806
29	Column 29	151	791	5.238411	1.316115
30	Column 30	151	805	5.331126	1.342958
31	Column 31	151	793	5.251656	1.349581
32	Column 32	151	806	5.337748	1.198499
33	Column 33	151	799	5.291391	1.154525
34	Column 34	151	810	5.364238	1.433113
35	Column 35	151	824	5.456954	1.409801
36	Column 36	151	789	5.225166	1.855629
37	Column 37	151	802	5.311258	1.615806
38	Column 38	151	804	5.324503	1.673996
39	Column 39	151	826	5.470199	1.704106
40	Column 40	151	826	5.470199	1.810773

Step 4: Calculate the SS within and MS within

Sum of square within and Mean square within can be calculated by equation v) and vi). In this degree of freedom is taking as 6000 by using formula (n-k). SS within and MS within have been calculated and shown in table 4.2

Step 5: Calculate F- Ratio

F-ration can be calculated by taking the ratio of MS between and MS within (which have been calculated in step 3 and 4 respectively). F-ratio is represented in table 4.2 by using equation ix).

Table 4.2: F-critical value at 0.10, 0.05, 0.01 significant factor

Source of Variation	SS	df	MS	F	F crit (at 0.10)	F crit (at 0.05)	F crit (at 0.01)
Between Groups	101.3376	39	2.5984	1.8372	1.3004	1.4013	1.6041
Within Groups	8485.629	6000	1.4142				
Total	8586.967	6039					

Step6: Compare the calculated F-ration with F-critical value

In this step, we compare the calculated F-ration in step with F- critical value at different significant levels such as 0.01, 0.05, and 0.10 as shown in table 4.2. This F-critical value is fixed for different degree of freedom.

As per table 6.2 our calculated F-ration value is greater than F-critical value at all significant levels as on 0.01, 0.05, and 0.10.So, our data collected from questionnaire is significant.

4.4 CONCLUSION

This chapter concludes that data collected from 151 Indian manufacturing companies are significant. Data has been verified at different significant levels by ANOVA analysis as per table 6.2. After ANOVA analysis implementation on data collected from questionnaire survey, the calculated F-value is 1.8372 as per table 4.2. Now, this result has been checked at 3 significant levels 0.01, 0.05 and 0.10. Our F-value (1.8372) which is greater than the F-critical value 1.6041 (at 0.01 significant factors), F-critical value 1.4013 (at 0.05 significant factors) and F critical value 1.3004 (at 0.10 significant factors). This result validates that our data collected from questionnaire survey is significant.

CHAPTER 5

MODELLING AND ANALYSIS FOR ATTRIBUTES AND SUB-ATTRIBUTES OF AMS BY FAE APPROACH

5.1 INTRODUCTION

An organization always strives for an impeccable quality of its products, which is facilitated by improved productivity and eliminating wastage. Lean manufacturing bolsters an organizations capacity in producing the products, components and services in various volumes. Such a system allows an organization to produce high quality products and quint essential services and offer them to customers at low prices. This has been the trend for past some years (Carvalho *et al.,* 2011). But in today's competitive environment a customer's preference d to suit does not depends only upon the quality and pricing of a product but also on the new variations which tends to suit diverse discriminations. It means today's customer will not hesitate to pay a higher price if he/she is getting a new innovative product or services which meet his/her tastes (Yusuf *et al.,* 1999).

In a competitive and globalized environment, only those organizations are able to survive and thrive who can meet customer's dynamic demand? The trends have suggested that even those organizations who have implemented LM paradigm are either disappearing from the scene or are just on the verge of extinction, in such a competitive set-up of products (Routroy *et al.,* 2015). Thus need of hour is to implement flexible strategies in conjunction with lean manufacturing. This requirement aroused the interest of a cluster of academicians at University of Iacocca to define agility and address associated issues under the heading Agile Manufacturing (Hallgren and Olhager, 2009). Consequently a focal point for agility was started at University of Iacocca. This point noticeable the advent of exploration on AMS hence forth understanding and scope of AMS kept on increasing (Yusuf *et al.,* 1999).

Various techniques and concepts have been devised to control inventories in an efficacious manner which can easily be assessed e.g. stochastic models are used to ascertain order quantity including various methods for forcing request and different genres of ABC analysis (Shamsaddini *et al.,* 2015). Quite recently enterprises resources planning and manufacturing resources planning, management models have also been additional. As far as AMS concerned, it signifies primary changes in manufacturing and in administration attitudes and is not just a clubbing of techniques (Gunasekaran *et al.*, 2002). This necessitates a comprehensive change in doing businesses with emphasis on tractability and rapid adoption to varying market behavior. Flexible, lean and agile systems, the models of competitive manufacturing, have critically been analyzed in regard of attaining competitive attributes e.g. volume flexibility, production, leadership, quality, speed and cost (Garbie *et al.,* 2014).

Optimization has always been a primary goal which every organization aspires to achieve. This excellence can be mandated by adopting CAD/CAM and other best production practices which culminates into reducing lead times, improved quality and productivity (Pandey and Pattanaik, 2014). Flexibility, has gained a significant importance in the arena of manufacturing system (Jain and Raj, 2015). A major factor in this regard is the environment which greatly affects the productivity of manufacturing dispensation (Sanchez and Nagi, 2001). But such an environment is marked with high variability and volatility. Service provider capability to produce a high quality product will lead to customer satisfaction. The concept of quality is dynamic and is updated consistently as per customer's taste.

Many researchers have a complemented agile manufacturing with various attributes to reach at a comprehensive definition. Such an evolvement has provided us the most inclusive definition as "A paradigm that enables an organization to quickly react in accordance with the dynamic demands of the customers by making use of appropriate technologies and management models" (Sherehiy *et al.,* 2007). A manufacturing good should be of an impeccable quality while service delivery should be swift without cutting corners on excellence, production and operative cost. Hence, an organization aspiring to implement agile manufacturing in its production system should be able to every consumer/customer by providing flawless products and quick services. Such an evolution requires mass customization of products and services as per customer demands.

Researchers have suggested that the best of agile manufacturing paradigm can be brought out by adopting a number of technologies pertaining to the field (Sharifi and Zhang, 2001). It will further progress towards an intelligent amalgamation of FMS and LM (Sarkis, 2001). Implementation of LM may support the integration of AM in the organizations. Nevertheless, it does not mean that organizations who have not implemented LM cannot be implement AM. However, those organizations can also be implementing it by adopting criteria of AM.

Furthermore, many attributes and sub-attributes of AMS have been determined through literature survey in chapter 2. Attributes and Sub-Attributes selection is not only depend upon the literature survey; it also includes the brain storming with group of experts from education and industry. After brain storming and literature survey; 22 main attributes and sub-attributes have been recognized and evaluated by questionnaire analysis in chapter 3. Furthermore, in this chapter; attributes and sun-attributes are evaluated by Fuzzy Agility Evaluation (FAE) method. This method is superlative method for identify the agility index of any organization. The main reason of this evaluation is to help in implementing AMS to the managers and group of researchers of this field.

5. 2 FUZZY AGILITY INDEX APPROACH: AN OVERVIEW

This approach is used to examine agility of industries and produce the ranking and weights to create agility index of any industry. This FAI level will be checked by a suitable level of agility which is used to do development in enterprises. Steps for calculating FAI level is as follows:

a. Selection of criteria for assessment.
b. Identification of suitable linguistic parameters to evaluate the importance weights and performance rating.

c. Calculate the agility capabilities importance and performance with the help of linguistic parameters.
d. Linguistic terms approximation with the help of fuzzy numbers.
e. Cumulative the fuzzy performance ratings and fuzzy weights to calculate fuzzy agility index value.

Compare the calculated FAI level with and appropriate scale.

Step A:

It involves assessment of importance weights and performance ratings of agility capabilities with determination of appropriate linguistic scale. But linguistic terms and corresponding member function is generally criticized by fuzzy logic. Particularly, various general linguistic scale and corresponding member function have been recommended for linguistic evaluation (Chen and Hwang, 1992). Additionally, it is recommended that member function should not have crossed the nine levels, which is generally the discrimination of human limits (Karwowski and Mital, 1986). After the original study completed by Yang and Li (2002) they suggest the linguistic terms as below table 5.1

Table 5.1: Notation of linguistic variables for weightage and performance rating

Sr. No.	Linguistic Variable for Performance Rating	Notation used	Linguistic Variable for Weight age	Notation Used
1	Excellent	E	Very High	VH
2	Very Good	VG	High	H
3	Good	G	Fairly High	FH
4	Fair	F	Medium	M
5	Poor	P	Fairly Low	FL
6	Very Poor	VP	Low	L
7	Worst	W	Very Low	VL

Step B:

Determine the importance and performance of agility capabilities with linguistic variables by using questionnaire survey in chapter 3. Once these linguistic variables are defined with respect to company characteristics, profile, policy, practices and strategies, these linguistic variables can be used directly to evaluate the rating which symbolizes the performance degree of many agility capabilities.

C:

Table 5.2, 5.3 and 5.4 represents the steps used in conversion of linguistic variables into numerical values and these tables has been created on the basis of scale defined by Yang and Li (2002). This scales selection is very important because whole result is depends upon these scale. Table 5.2 represents the linguistic variables for performance rating in terms of Fuzzy Triangular Values (FTV). Table 5.3 represents the linguistic variables for importance weighting in terms of FTV. Table 5.4 represents the linguistic variables for FAI in terms of FTV.

Table 5.2: Performance rating for linguistic variables in terms of fuzzy triangular value

PERFORMANCE RATING (R)			
LINGUISTIC VARIABLES	**FUZZY TRIANGULAR VALUES**		
WORST (W)	0	0.5	1.5
VERY POOR (VP)	1	2	3
POOR (P)	2	3.5	5
FAIR (F)	3	5	7
GOOD (G)	5	6.5	8
VERY GOOD (VG)	7	8	9
EXCELLENT (E)	8.5	9.5	10

Table 5.3: Importance weighting for linguistic variables in terms of FTV

IMPORTANCE WEIGHTING (W)			
LINGUISTIC VARIABLES	**FUZZY TRIANGULAR VALUES**		
VERY LOW (VL)	0	0.05	0.15
LOW (L)	0.1	0.2	0.3
FAIRLY LOW (FL)	0.2	0.35	0.5
MEDIUM (M)	0.3	0.5	0.7
FAIRLY HIGH (FH)	0.5	0.65	0.8
HIGH (H)	0.7	0.8	0.9
VERY HIGH (VH)	0.85	0.95	1.00

Table 5.4: Fuzzy agility index for linguistic variables in terms of FTV

FUZZY AGILITY INDEX			
LINGUISTIC VARIABLES	**FUZZY TRIANGULAR VALUES**		
SLOWLY (S)	0	1.5	3
FAIRLY(F)	1.5	3	4.5
AGILE (A)	3.5	5	6.5
VERY AGILE (VA)	5.5	7	8.5
EXTREMELY AGILE (EA)	7	8.5	10

Step D:

Enterprise agility is characterized by FAI in such a way that with increase in agility, FAI will also increase. It means that determination of agility level is directly dependent upon MF. As per the definition of weighted fuzzy average, R_{ij} i.e. agility 2nd grade capability index, is determined as follows:

$$R_i = \sum_{k=1}^{n} (W_{ij} * R_{ij}) / \sum_{k=1}^{n} W_{ij} \quad \text{-----------} \quad \text{(i)}$$

Where Fuzzy performance rating is represented by R_{ij} and fuzzy importance weight is represented by W_{ij}.

Weightage and performance of each agility capability will be symbolized by R_i and W_i which mean agility index is represented by:

$$(\text{AGILITY}_{\text{INDEX}}) = \sum_{i=1}^{n} R_i * W_i \quad \text{----------------} \quad \text{(ii)}$$

Step E:

As FAI level has been calculated, for the purpose to find the agility level, this will further checked with linguistic label whose MF is equal to the MF of the fuzzy agility index from the expression set of label of agility.

Successive approximation technique with linguistic value is used for mapping the linguistic term with MF as described in figure. 5.1.

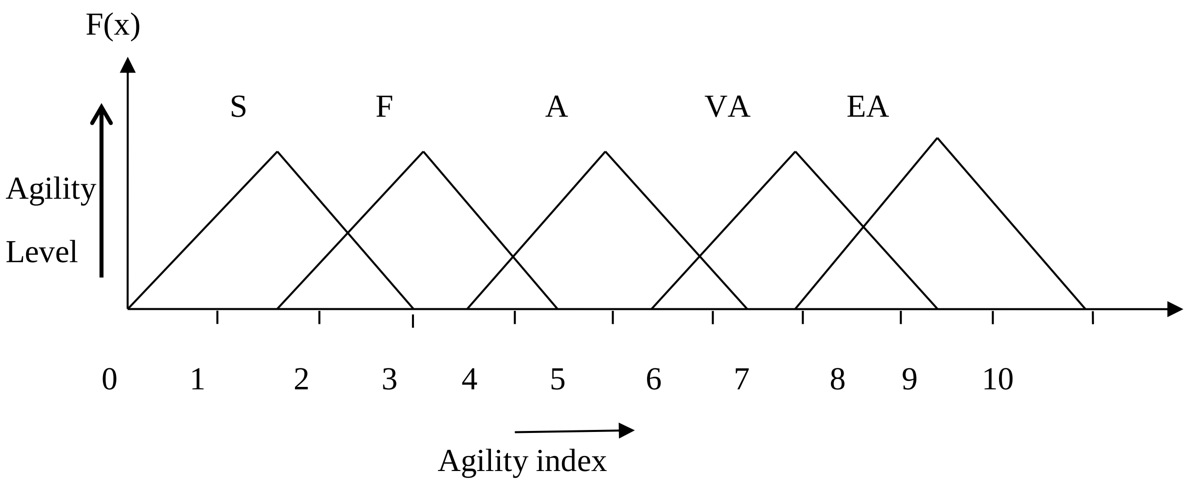

Figure 5.1: Fuzzy agility index matching with linguistic level

5.3 MODELING OF ATTRIBUTES AND SUB-ATTRIBUTES BY FUZZY AGILITY INDEX APPROACH

Model development will use the various steps as described below:

Step 1: Identification of Attributes and Sub-Attributes

Attributes and Sub-Attributes under the agile manufacturing system have been determined by brain-storming with industry and academia experts as well as from literature survey as represented in table 5.5.

.Table 5. 5: Attributes and sub-attributes of AMS

Attributes	Sub- Attributes
Strategies (AC_1)	Concurrent Engineering (AC_{11})
	Virtual Enterprises (AC_{12})
	Distributed Manufacturing System (AC_{13})
	Manufacturing Resource Planning (AC_{21})

System (AC_2)	Activity based Cost /Activity Based Manufacturing (AC_{22})
	Computer Aided Design / Computer Aided Manufacturing (AC_{23})
	Enterprise Resource Planning (AC_{24})
	Computer Integrated Manufacturing (AC_{25})
	KANBAN (AC_{26})
People (AC_3)	Flexible Work Force (AC_{31})
	Multi- Lingual (AC_{32})
	Empowered Workers (AC_{33})
	Top Management Support AC_{34})
Technologies (AC_4)	Flexible Part Feeder (AC_{41})
	Flexible Fixturing (AC_{42})
	Multi-media (AC_{43})
	Information technologies (AC_{44})
	Flexible Manufacturing System (AC_{45})

Step 2: Identification of apposite linguistic scale

Next step is to find out the appropriate linguistic scale to evaluate the importance weighting, rating of performance as well as fuzzy agility index which are shown in table 5.6.

Table 5.6: Performance rating, importance weightage and FAI in terms of linguistic variables

PERFORMANCE RATING (R)	**IMPORTANCE WEIGHTAGE (W)**	**FUZZY AGILITY INDEX (FAI)**
WORST (W)	VERY LOW (VL)	SLOWLY (S)
VERY POOR (VP)	LOW (L)	FAIRLY(F)
POOR (P)	FAIRLY LOW (FL)	AGILE (A)
FAIR (F)	MEDIUM (M)	VERY AGILE (VA)
GOOD (G)	FAIRLY HIGH (FH)	EXTREMELY AGILE (EA)
VERY GOOD (VG)	HIGH (H)	
EXCELLENT (E)	VERY HIGH (VH)	

Step 3: Performance and importance assessment of agility potential

In this assessment stage performance of various departments of an organization is evaluated in terms of linguistic variables by means of an objective questionnaire. In more common terms this is an assessment of performance and weighted importance of attributed and sub-attributes as represented in table 5.7.

Table 5.7: Importance weightage and performance rating measurement in linguistic terms

AC_i	AC_{ij}	R_{ij}	W_{ij}	W_i
AC_1	AC_{11}	G	FH	H
	AC_{12}	E	VH	
	AC_{13}	VP	FL	
AC_2	AC_{21}	W	L	FH
	AC_{22}	F	FH	
	AC_{23}	P	M	
	AC_{24}	VG	VH	
	AC_{25}	W	L	
	AC_{26}	E	H	
AC_3	AC_{31}	VP	FL	M
	AC_{32}	G	H	
	AC_{33}	F	FH	
	AC_{34}	E	H	
AC_4	AC_{41}	W	FL	VH
	AC_{42}	F	M	
	AC_{43}	VG	FH	
	AC_{44}	G	H	
	AC_{45}	VP	L	

Approximation of linguistic variables by fuzzy number logic

It includes the step of converting linguistic variables into numerical values as per table 5.2 and table 5.3 while it is shown in table 5.8.

Table 5.8: Importance weightage and performance rating measurement in terms of fuzzy number

AC_i	AC_{ij}	R_{ij}	W_{ij}	W_i
AC_1	AC_{11}	5-6.5-8	0.5-0.65-0.8	0.7-0.8-0.9
	AC_{12}	8.5-9.5-10	0.85-0.95-1.0	
	AC_{13}	1-2-3	0.2-0.35-0.5	
AC_2	AC_{21}	0-0.5-1.5	0.1-0.2-0.3	0.5-0.65-0.8
	AC_{22}	3-5-7	0.5-0.65-0.8	
	AC_{23}	2-3.5-5	0.3-0.5-0.7	
	AC_{24}	7-8-9	0.85-0.95-1.0	
	AC_{25}	0-0.5-1.5	0.1-0.2-0.3	
	AC_{26}	8.5-9.5-10	0.7-0.8-0.9	
AC_3	AC_{31}	1-2-3	0.2-0.35-0.5	0.3-0.5-0.7
	AC_{32}	5-6.5-8	0.7-0.8-0.9	
	AC_{33}	3-5-7	0.5-0.65-0.8	
	AC_{34}	8.5-9.5-10	0.7-0.8-0.9	

AC_4	AC_{41}	0-0.5-1.5	0.2-0.35-0.5	.85-0.95-1.0
	AC_{42}	3-5-7	0.3-0.5-0.7	
	AC_{43}	7-8-9	0.5-0.65-0.8	
	AC_{44}	5-6.5-8	0.7-0.8-0.9	
	AC45	1-2-3	0.1-0.2-0.3	

Step 5: Determination of FAI by aggregating fuzzy rating into fuzzy weights

Performance rating (R_i), according to According toFuzzy weighted average, is determined as

$$R_i = \sum_{k=1}^{n} (W_{ij} * R_{ij}) / \sum_{k=1}^{n} W_{ij}$$

As fuzzy performance rating and fuzzy importance weightage of the AMS attributes is represented by R_{ij} and W_{ij} respectively

R_1 = [{ (5-6.5-8)*(0.5-0.65-0.8) } + { (8.5-9.5-10) * (0.85-0.95-1.0) } + { (1-2-3)* (0.2-0.35-0.5) }] / [(0.5-0.65-0.8) + (0.85 – 0.95-1.0) + (0.2-0.35-0.5)]

R_1 = [(2.5-4.225-6.4) + (7.225-9.025-10) + (0.2 - 0.7 - 1.5) / [(1.55-1.95-2.3)]

R_1 = (9.925 – 13.95 – 17.9) / (1.55-1.95-2.3)

R_1 = (4.315-7.15 – 7.782) (iii)

R_2 = [{(0-0.5-1.5) * (0.1-0.2-0.3)} + {(3-5-7) * (0.5-0.65-0.8)} + {(2-3.5-5) * (0.3-0.5-0.7)} + {(7-8-9) * (0.85-0.95-1.0)} + {(0-0.5-1.5)*(0.1-0.2-0.3)} + {(8.5-9.5-10)*(0.7-0.8-0.9)} / [(0.1-0.2-0.3) + (0.5-0.6-0.8) + (0.3-0.5-0.7) + (0.85-0.95-1.0) + (0.1-0.2-0.3) + (0.7-0.8-0.9)]

R_2 = [14-21.3-28] / [2.55 – 3.25 – 4]

R_2 = [3.5- 4.27-6.9] (iv)

R_3 = [{ (1-2-3) * (0.2-0.35-0.5) } + { (5-6.5-8) * (0.7-0.8-0.9) } + { (3-5-7) * (0.5-0.65-0.8)} + { (8.5-9.5-10) * (0.7-0.8-0.9) }] / [(0.2-0.35-0.5) + (0.7-0.8-0.9) + (0.5-0.65-0.8) + (0.7-0.8-0.9)]

R_3 = [11.15 – 16.75-23.3] / [2.1-2.6-3.1]

R_3 = [3.539-6.44-7.10] (v)

R_4 = [{ (0-0.5-1.5) * (0.2-0.35-0.5) } + { (3-5-7) * (0.3-0.5-0.7) } + {(7-8-9) * (0.5-0.65-0.8)} + { (5-6.5-8) * (0.7-0.8-0.9) } + {(1-2-3) * (0.1-0.2-0.3)}] / [(0.2-0.35-0.5) + (0.3-0.5-0.7) + (0.5-0.65-0.8) + (0.7-0.8-0.9) + (0.1-0.2-0.3)]

R_4 = [8.0-13.475-20.55] / [1.8-2.5-3.2]

R_4 = (2.5-5.39-6.421) (vi)

Where W_i and R_i represents the agility weightage and performance rating respectively then agility index value can be calculated as below by using equation iii to equation vi

$$(\text{AGILITY}_{\text{INDEX}}) = \sum_{i=1}^{n} R_i * W_i$$

(AGILITY $_{\text{INDEX}}$) = [{ (4.315-7.15-7.782) * (0.7-0.8-0.9) } + { (3.5-4.27-6.9) * (0.5-0.65-0.8) } + { (3.539-6.44-7.10) * (0.3-0.5-0.7) } + { (2.5-5.39-6.421) * (0.85-0.95-1.0) }/ [(0.7-0.8-0.9) + (0.5-0.65-0.8) + (0.3-0.5-0.7) + (0.85-0.95-1.0)]

(AGILITY $_{\text{INDEX}}$) = (6.0-7.2-8.6)

Step 6: Matching FAI with a suitable level

To determine the agility level, the FAI as obtained in step 5 is matched with linguistic variables as shown in fig. 5.1. Hence, the enterprise falls under "VERY AGILE" category as represented in figure 5.2.

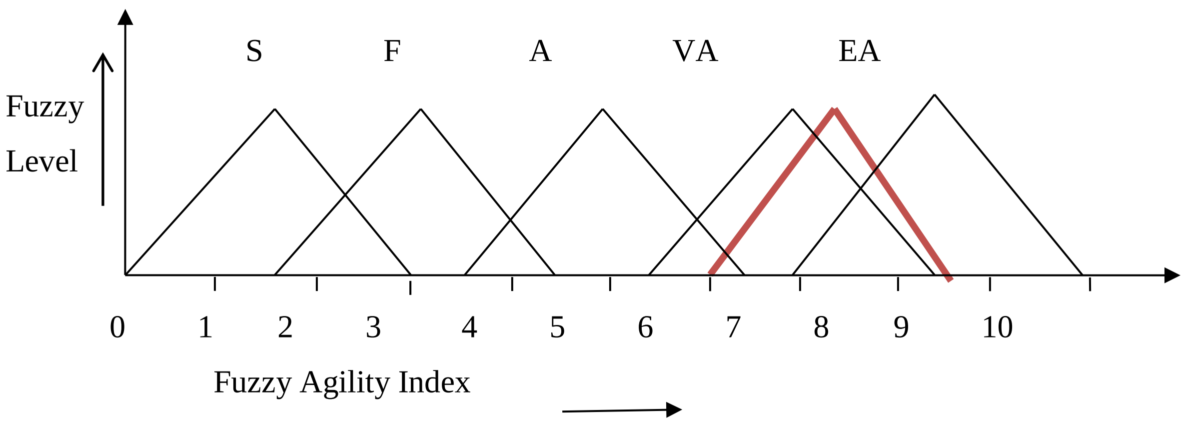

Figure 5.2: Fuzzy agility index match with calculated linguistic level

5.4 CONCLUSION

This chapter shown that effective and proper implementation of AMS on the basis of every attribute may prove to be very beneficial in generating fruitful insights for developing robust manufacturing system. This can be achieved by following FAI approach as represented in chapter through a series of steps. The value of agility index is of particular importance to the managers as it will help in making suitable improvements. It also establishes the facts that integration of manpower with robust AMS will produce incredible results. It has been thus observed that the company under observation falls under "very agile" and not "extremely agile" category.

Identification of product flexibility can be find out for Agile Manufacturing system. .

CHAPTER 6

MODELLING OF AGILE MANUFACTURING SYSTEM FACTORS BY ISM AND MICMAC ANALYSIS

6.1 INTRODUCTION

The successful implementation of Agile Manufacturing (AM) in any organisation is depending upon knowledge acquired, strategic skill adopted and certification achieved by the management (Routroy *et al.,* 2015). The absence of the foundational ingredient will categorize the organization into conventional organizational set-ups; such is the importance of the ingredient that, in their absence, any organization would not be able to acquire agility (Meredith and Francis, 2000). Hence, conventional organizations are not well equipped to implement AM in their manufacturing set-ups as they lack those indispensable ingredients (Dubey and Guneskaran, 2015). Another, aspect is the commitment and loyalty of the employees for their organization (Fullerton *et al.*, 2014; Sahin, 2000). In such industries integration of AM into manufacturing system is only moderately successful (Mishra, 2014). One more category is that of small organization where concentrated efforts of administration and workers culminates into a well-developed and coordinated assembly (Dubey and Guneskaran, 2015). Many organization carry out innumerable activities which in turn stress upon the implementation of AM essentials.

Implementation of AM in moderate or smart organization depends upon the agility level that has been achieved in such organisation (Guneskaran, 1999). This agility level is in turn central to the factors as per their driving and dependent capacity (Gunasekaran *et al.* 2002). Importance of economic factors in any organization has always played a major role but the race to achieve high quality and low price products has further catapulted the need for them to an altogether new height of competitiveness (Goyal and Grover 2013; Malhotra 2014). With the advents of multifunctional markets with dynamic nature, the product lines have been evolved multiple times in such a way that demand for quality is an ordinary affair in recent times(Attri *et al.,* 2013; Yusuf *et al.* 1999). The system is marginally susceptible to change in internal and external environment. AMS consists of a comprehensive analysis of every activity in an organization with major emphasis on productivity efficiency and effectiveness of its operations (Jain and Raj 2015). The most important fact of AMS lies in the fact that it eliminates and segregates the waste operations thereby improving the productivity and efficiency while increasing the profitability of the organization (Attri *et al.*, 2013; Aravind *et al.*, 2013). Since AMS still in an evolving stage and the scarcity of related literature in the arcs has made it elusive to the successfully implementation of the AMS (Susanti, 2004). This has been the vexed problem for academician and industrialist for many years. Thus only a sound understanding of key factors will permit an effective integration of AMS in a manufacturing system.

Consequently, a survey was conducted through a questionnaire- based approach in order to establish the importance of key factors required for implementing AMS. In this regard 12 factors of AMS were identified, studied and analysed upon through surveys to determine the importance from the perspective of man-power which could anger well for integration of AMS in an organization. In this chapter an effort is made to analyse the inter-relationship among the key factors by using Matrice d'Impacts Croises-Multipication Applique an Classment **(**MICMAC) analysis and ISM technique. It is pertinent to mention here that ISM is one of the best suited technique to identify and analyse the co-relation between different elements (Kumar and Sharma 2015; Jain and Raj 2015; Attri *et al.*, 2013). Further the factors were segregated into driving and dependent factors. This segregation and analysis of factors can play a key role in focussing the attention of researchers and practicing managers to conform the challenges passed by such factors during the implementation of AMS. Primary objectives of this chapter are (i) identification and ranking of factors which facilitate the transition of a conventional manufacturing system into AMS with regard to Indian industrial set-up (ii) to make a relationship between the factors by ISM technique (iii) analysis of factors with respect to driving power and dependence power by using MICMAC analysis (iv) to deliberate implication of AMS over managerial aspects and set course for future development with suggested changes.

6.2 AN OVERVIEW OF ISM APPROACH

Finding an optimal solution has always been a main step for every researcher. But the presence of large number of factors tends to accentuate the situation which is further aggravated by the complex inter-relationship among those factors (Jayant *et al.*, 2015). Since them factors have a direct or indirectly bearing on to the manufacturing system supporting a complex system. Various techniques have been developed and the one which is most preferred among such technique is ISM. ISM was first proposed by Warfield in 1973 and then developed it into a staunch methodology for solving complex issues with its basis on discrete and finite branch of mathematics (Malhotra 2014). He developed a mathematical language that has a wide scope in the problems having a set of elements in its structure (Singh and Khamba 2011; Talib *et al.*, 2011). ISM technique is pointed towards a clear understanding of belief of human being and recognition of the areas obvious to them (Raj *et al.*, 2008). Its strength lies in transformation of vague system into well-articulated and visible models (Jain and Raj 2015). Initially intended as a group learning technique, ISM today has its benefits in individual use (Jayant *et al.*, 2015). It is defined as an interpretive procedure concerned with the structuring of direct and indirect inter-related elements into an all-inclusive and comprehensive systematic model (Attri *et al.*, 2013).

6.2.1 ISM Methodology

ISM methodology forms the basis for establishing a contextual relationship between numerous elements constituting the system (Jain and Raj, 2015). It is also known as interpretive modelling as the relationship between variables is scrutinized by the judgements of the group (Singh *et al.*, 2011).

The foremost step in ISM is identifying the inter-related factors comprising the system and affecting it (Mittal and Sangwan, 2011). Next step is to establish contextual relationship between them and mapped into a Structure Self Interaction Matric (SSIM).

After obtaining SSIM, Reachability Matrix (RM) is developed and subjected to transitivity check. RM is then partitioned into differentiated level and its conical form is obtained with most one (1) factor in the lower diagonal and most zero (0) variables in the upper diagonal. Depending upon the interrelation depicted by RM all the transitive connection are removed and directed diagraph is obtained made (Talib *et al.*, 2011). This diagraph so obtained is developed into ISM Model with factor nodes replaced by statements (Raj *et al.*, 2008). The last step is to review the ISM model in regard of conceptual inconsistent and compulsory changes are introduced. The above stated steps are shown below in terms of a following figure 6.1.

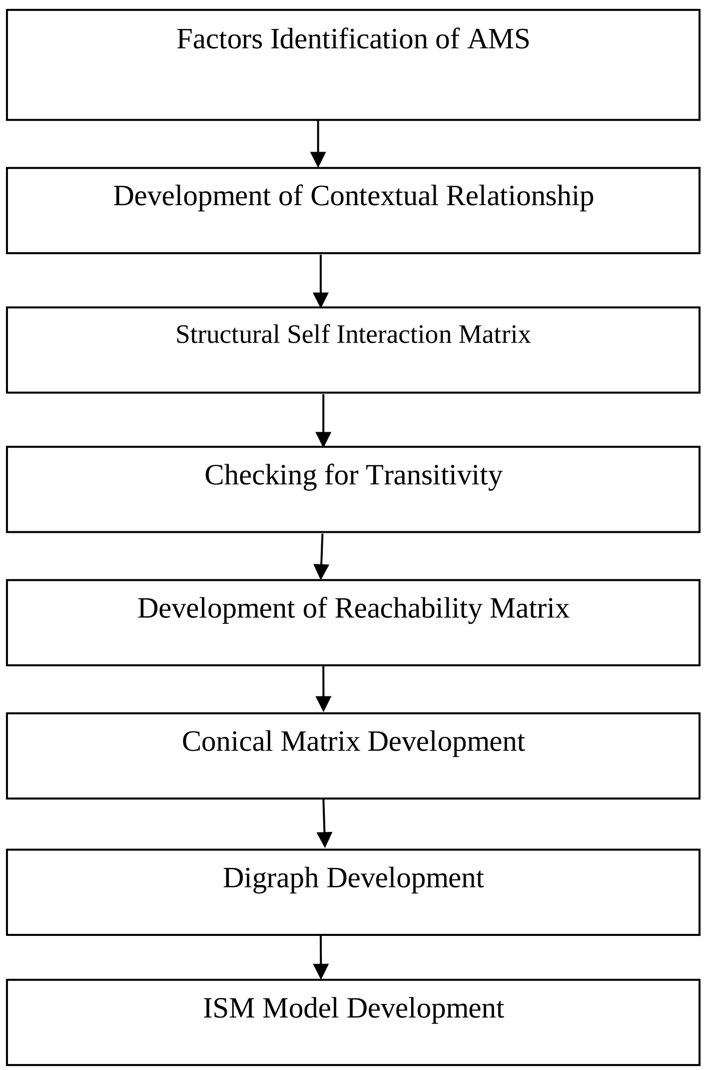

Figure 6.1: Flow diagram for ISM methodology

6.2.2 Advantages of ISM:

Some of the advantages described by Jain and Raj (2015); Mohammed *et al.*, (2008); Malhotra (2014); Jayant *et al.*, (2015); Mittal and Sangwan (2013); Mittal and Sangwan (2014) of this methodology are as follows:

- Implementation of suitable order and direction with regard to complex relationship existing between various factors comprised by the system.
- Helps in generation of a structured model or graphical description of the problem which is using to comprehend and can be communicated effectively.
- Allows the participants to perform issue analysis to check the suitability of elements proposed and bring about facts that highlight the current situation.
- It allows the participants to develop significant insights into the elements and their inter-relationship.
- It offers scope of analysis and provides therefore to participants in identifying the targeted areas where suitable action or analysis can be undertook in pursuing pre-defined objective.

On the other hand, the scope of ISM is not limited and it can also be effectively implemented in diverse areas of industry such as lean manufacturing system, green and sustainable manufacturing system, supply chain management, maintenance of railway department, decision control system (Jayant *et al.*, 2015; Mittal and Sangwan, 2013).

6.3 ANALYSIS OF AMS FACTORS WITH ISM APPROACH AND MICMAC ANALYSIS

The numerous stages, which central to the expansion of analysis, are demonstrated further down (Raj *et al.*, 2008)

Step 1: Documentation of factor affecting the organization

The factor affecting the organization has been recognized through literature review and takes suggestion from academia and industry experts as deliberated in chapter 2 are presented in table 6.1.

Table 6.1: Factors affecting AMS

Sr. No.	Factors in transition to AMS
1	Organizational Structure
2	Information Technology Integration
3	Outsourcing
4	Development of Design Methodology
5	Convertibility
6	Scalability
7	Agile Workforce
8	Controls of Process Variations
9	Multi Lingual
10	Top Management Support
11	Empowered Workers
12	Modular Design Approach

Step 2: Enlargement of Structural-Self Interactive Matrix

To cultivate SSIM, the subsequent four notations have been used to signify the path of inter- relationship amongst factor (*i* and *j*)

V explains that factor i will affect the factor j

A explains that factor j will affect the factor i

X explains that factor i and j will affect each other

O explains that factor i and j are isolated

Depending on the appropriate inter-relationships amongst factor, the SSIM has been established. To create this SSIM table, these factors relationships was elaborated in between the experts of industry and academia as shown in table 6.2.

Table 6.2: Structural self- interactive matrix for AMS factors

Factors	12	11	10	9	8	7	6	5	4	3	2
1	V	V	O	O	V	O	V	V	V	O	V
2	V	V	O	A	V	O	V	V	V	O	
3	V	V	O	A	V	O	V	V	O		
4	O	O	V	A	V	O	V	X			
5	V	V	V	A	V	O	O				
6	O	O	O	A	V	O					
7	O	O	V	A	O						
8	V	V	V	A							
9	O	O	V								
10	O	V									
11	O										

For analyzing the factor in SSIM development, the subsequent four traditions have been utilized to represent the inter-relationships amongst factor (i and j)

- Symbol V is allotted to cell (2, 11) since factor 2 affects or influence the factor 11.
- Symbol A is allotted to cell (3, 9) since factor 9 affects or influence the factor 3.
- Symbol X is allotted to cell (4, 5) since factors 4 and 5 affects or influence respectively to each other.
- Symbol O is allotted to cell (6, 11) since factors 6 and 11 are isolated.

Step 3: Expansion of the Reachability Matrix

The reachability matrix is attained from SSIM. RM specifies the inter-relationships amongst factor in the binary system. The numerous inter-relationships amongst factors represented by symbol *V*, *A*, *X*, and *O* used formerly in SSIM are substituted by binary numbers of 0 and 1. The subsequent procedures are used to supernumerary *V*, *A*, *X*, and *O* of SSIM to get RM.

- if the (*i*, *j*) item in the SSIM is *V*, then the (*i*, *j*) access in the RM develops 1 and the (*j*, *i*) access develops 0 .
- if the (*i*, *j*) item in the SSIM is *A*, then the (*i*, *j*) access in the RM develops 0 and the (*j*, *i*) access develops 1.
- if the (*i*, *j*) item in the SSIM is *X*, then the (*i*, *j*) access in the RM develops 1 and the (*j*, *i*) access develops 1.
- if the (*i*, *j*) item in the SSIM is *O*, then the (*i*, *j*) access in the RM develops 0 and the (*j*, *i*) access correspondingly develops 0.

The RM thus consequential is acknowledged as initial RM which is illustrated in table 6.3.

Table 6.3: Initial reachability matrix for AMS factors

Factors	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	0	1	1	1	0	1	0	0	1	1
2	0	1	0	1	1	1	0	1	0	0	1	1
3	0	0	1	0	1	1	0	1	0	0	1	1
4	0	0	0	1	1	1	0	1	0	1	0	0
5	0	0	0	1	1	0	0	1	0	1	1	1
6	0	0	0	0	0	1	0	1	0	0	0	0
7	0	0	0	0	0	0	1	0	0	1	0	0
8	0	0	0	0	0	0	0	1	0	1	1	1
9	0	1	1	1	1	1	1	1	1	1	0	0
10	0	0	0	0	0	0	0	0	0	1	1	0
11	0	0	0	0	0	0	0	0	0	0	1	0
12	0	0	0	0	0	0	0	0	0	0	0	1

- For (2, *11*) access in the SSIM is *V*, henceforth the (*i*, *j*) access in the RM develops 1 and the (*j*, *i*) access develops 0
- For (3, *9*) access in the SSIM is *A*, henceforth (*i*, *j*) access in the RM develops 0 and the (*j*, *i*) access develops 1.
- For (*4*, *5*) access in the SSIM is *X*, hereafter the (*i*, *j*) access in the RM develops 1 and the (*j*, *i*) access also develops 1.
- For (6, 11) access in the SSIM is *O*, henceforth (*i*, *j*) access in the RM develops 0 and the (*j*, *i*) access also develops 0.

Final RM is attained by employing the concept of transitivity. As per transitivity principle, if there are three elements in such a way that an inter-relationship holds between X and Y and inter-relationships is also held between Y and Z then automatically inter-relationships between X and Z will be held. Transitivity is represented by 1* and it is represented in final RM is displayed in table 6.4.

Table 6.4: Final reachability matrix for AMS factors

Factors	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	0	1	1	1	0	1	0	1*	1	1
2	0	1	0	1	1	1	0	1	0	1*	1	1
3	0	0	1	1*	1	1	0	1	0	1*	1	1
4	0	0	0	1	1	1	0	1	0	1	1*	1*
5	0	0	0	1	1	1*	0	1	0	1	1	1
6	0	0	0	0	0	1	0	1	0	1*	1*	1*
7	0	0	0	0	0	0	1	0	0	1	1*	0
8	0	0	0	0	0	0	0	1	0	1	1	1
9	0	1	1	1	1	1	1	1	1	1	1*	1*
10	0	0	0	0	0	0	0	0	0	1	1	0
11	0	0	0	0	0	0	0	0	0	0	1	0
12	0	0	0	0	0	0	0	0	0	0	0	1

Step 4: Partitioning the RM

Reachability set comprising horizontal factors and antecedent set comprising vertical factors, both can be obtained by find RM. Further, an intersection of these two sets is derived for every factor. A similarity index between reachability and intersection set permit a factor to reach top level in hierarchical structure of ISM. Such elements achieve top level in the hierarchical set up are identified and segregated.

Table 6.5: Level partitioning for AMS factors - Iteration 1

Factors	Reachability set	Antecedent Set	Intersection Set	Level
1	1,2,4,5,6,8,10, 11,12	1	1	
2	2,4,5,6,8,10,11,12	1,2,9	2	
3	3,4,5,6,8,10,11,12	3,9	3	
4	4,5,6,8,10,11,12	1,2,3,4,5,9	4,5	
5	4,5,6,8,10,11,12	1,2,3,4,5,9	4,5	
6	6,8,10,11,12	1,2,3,4,5,6,9	6	
7	7,10,11	7,9	7	
8	8,10,11,12	1,2,3,4,5,6,8,9	8	
9	2,3,4,5,6,7,8,9,10,11,12	9	9	
10	10,11	1,2,3,4,5,6,7,8,9,10,11	10	
11	11	1,2,3,4,5,6,7,8,9,10,11	11	I
12	12.	1,2,3,4,5,6,8,9,12	12	I

Since any top level element is not able to find any elements which is above its level succor the above mentioned process is repeated to find elements, in other words. This procedure is constant till the level of individually element is originated. These stages support to create the diagraph. In the existing case, partitioning of the reachability matrix is represented in table 6.5- 6.11.

Table 6.6: Level partitioning for AMS factors - Iteration 2

Factors	**Reachability set**	**Antecedent Set**	**Intersection Set**	**Level**
1	1,2,4,5,6,8,10	1	1	
2	2,4,5,6,8,10	1,2,9	2	
3	3,4,5,6,8,10	3,9	3	
4	4,5,6,8,10	1,2,3,4,5,9	4,5	
5	4,5,6,8,10	1,2,3,4,5,9	4,5	
6	6,8,10	1,2,3,4,5,6,9	6	
7	7,10	7,9	7	
8	8,10	1,2,3,4,5,6,8,9	8	
9	2,3,4,5,6,7,8,9,10	9	9	
10	10	1,2,3,4,5,6,7,8,9,10	10	II

Table 6.7: Level partitioning for AMS factors - Iteration 3

Factors	Reachability set	Antecedent Set	Intersection Set	Level
1	1,2,4,5,6,8	1	1	
2	2,4,5,6,8	1,2,9	2	
3	3,4,5,6,8	3,9	3	
4	4,5,6,8	1,2,3,4,5,9	4,5	
5	4,5,6,8	1,2,3,4,5,9	4,5	
6	6,8	1,2,3,4,5,6,9	6	
7	7	7,9	7	III
8	8	1,2,3,4,5,6,8,9	8	III
9	2,3,4,5,6,7,8,9	9	9	

Table 6.8: Level partitioning for AMS factors - Iteration 4

Factors	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,4,5,6	1	1	
2	2,4,5,6	1,2,9	2	
3	3,4,5,6	3,9	3	
4	4,5,6	1,2,3,4,5,9	4,5	
5	4,5,6	1,2,3,4,5,9	4,5	
6	6	1,2,3,4,5,6,9	6	IV
9	2,3,4,5,6,9	9	9	

Table 6.9: Level partitioning for AMS factors - Iteration 5

Factors	Reachability set	Antecedent Set	Intersection Set	Level
1	1,2,4,5	1	1	
2	2,4,5	1,2,9	2	
3	3,4,5	3,9	3	
4	4,5	1,2,3,4,5,9	4,5	V
5	4,5	1,2,3,4,5,9	4,5	V
9	2,3,4,5,9	9	9	

Table 6.10: Level partitioning for AMS factors - Iteration 6

Factors	Reachability set	Antecedent Set	Intersection Set	Level
1	1,2	1	1	
2	2	1,2,9	2	VI
3	3	3,9	3	VI
9	2,3,9	9	9	

Table 6.11: Level partitioning for AMS factors - Iteration 7

Factors	Reachability set	Antecedent Set	Intersection Set	Level
1	1	1	1	VII
9	9	9	9	VII

Step 5: Development of conical matrix

Conical matrix is established by integrate the factor in the similar levels, through rows and columns of the final RM. The drive power of factors is imitative by adding the quantity of one in the row and its dependence power by adding the quantity of one in the column. Subsequent, drive and dependence power positions are considered by providing utmost rank to the factors that have the extreme quantity of one in the row and column correspondingly as represented in table 6.12.

Table 6.12: Conical matrix for AMS factors

	11	12	10	7	8	6	4	5	2	3	1	9	**Drive Power**
11	1	0	0	0	0	0	0	0	0	0	0	0	1
12	0	1	0	0	0	0	0	0	0	0	0	0	1
10	1	0	1	0	0	0	0	0	0	0	0	0	2
7	1	0	1	1	0	0	0	0	0	0	0	0	3
8	1	1	1	0	1	0	0	0	0	0	0	0	4
6	1	1	1	0	1	1	0	0	0	0	0	0	5
4	1	1	1	0	1	1	1	1	0	0	0	0	7
5	1	1	1	0	1	1	1	1	0	0	0	0	7
2	1	1	1	0	1	1	1	1	1	0	0	0	8
3	1	1	1	0	1	1	1	1	0	1	0	0	8
1	1	1	1	0	1	1	1	1	1	0	1	0	9
9	1	1	1	1	1	1	1	1	1	1	0	1	11
Dependence Power	11	9	10	2	8	7	6	6	3	2	1	1	66/66

Step 6: Development of digraph

During the development of diagraph, the top level factors is located at the topmost of the digraph and second level factors is located at second position and so on, till the bottommost level is located at the bottom place in the digraph as shown in figure 6.2.

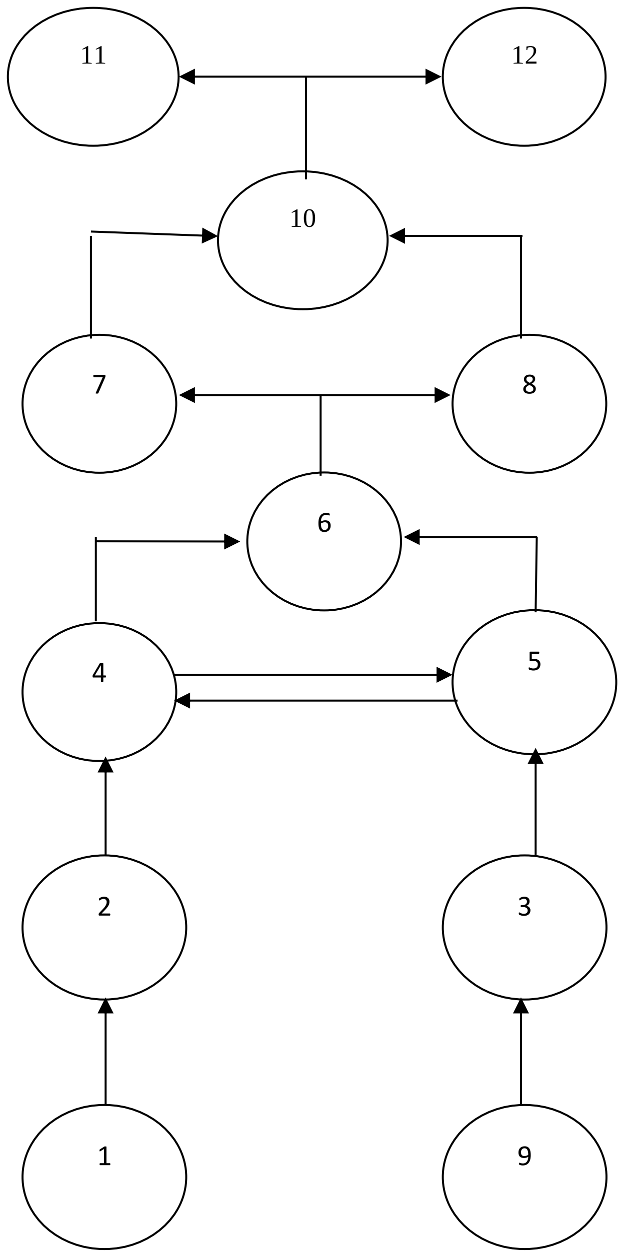

Figure 6.2: Digraph for AMS factors

Step 7: Development of ISM model

Subsequent stage is to translate the overhead defined diagraph into an interpretive structural modelling by substituting node of the components by factors as represented in figure 6.3.

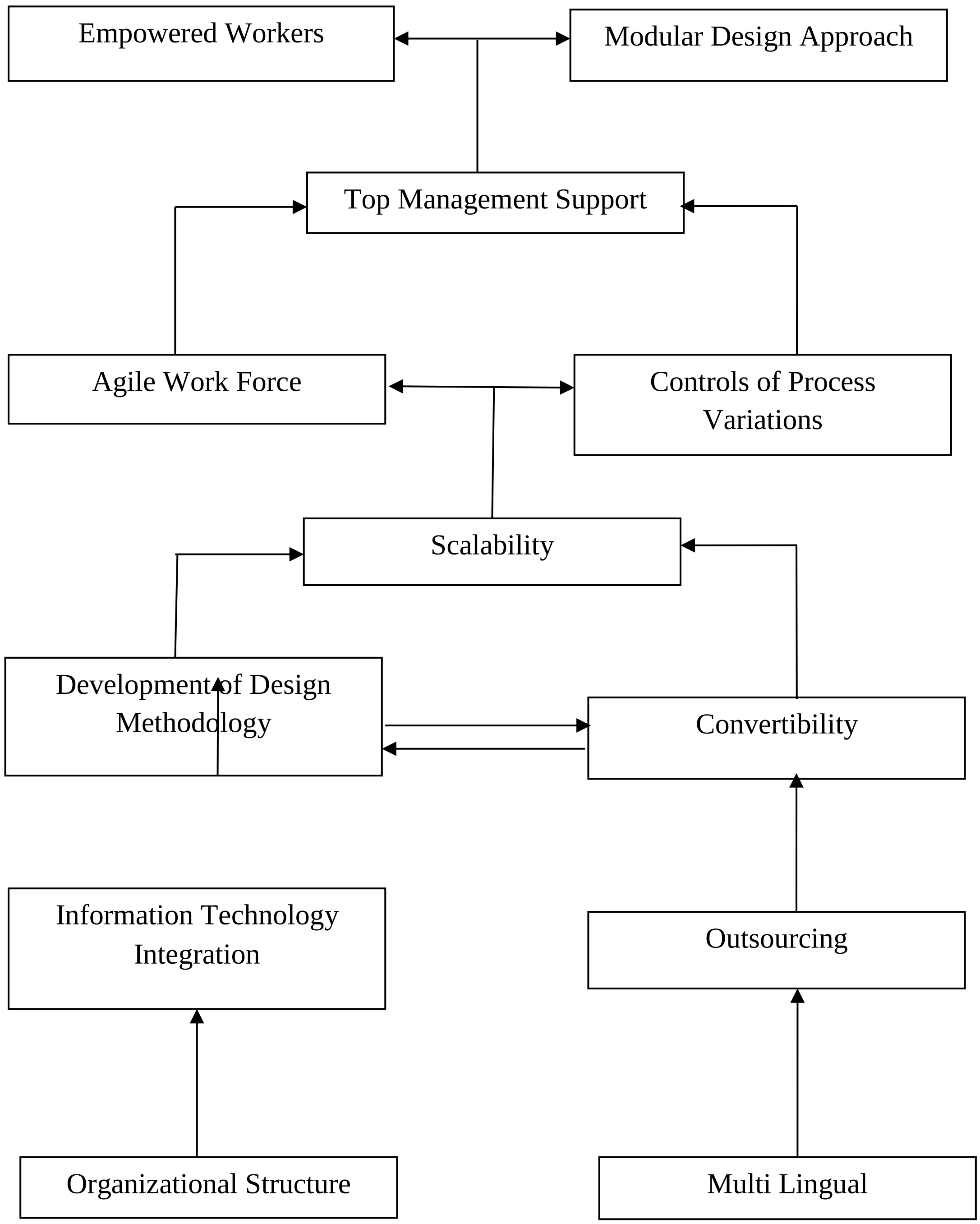

Figure 6.3: ISM Model for AMS factors

Interpretive structural modelling as represented in figure 6.3 shows that an organizational set-up and multilingual manufacturing system are high driving power factors which facilitate a steady implementation of AMS. It is further stated that framing of organizational structure should be done in horizontal/flattened way so as to allows execution and lower subordinates to share ideas, knowledge and information for better communication and co-ordination among the team members. Multi-lingual features allow a task to be completed within a given time frame and with a high degree of accuracy with maximum efficiency.

ISM also corroborates the fact that on effective implementation of AMS is also dependent upon high driving power factors like IT integration and outsourcing. As they are having high driving power hence they needs to be more devoted. Similarly a dynamic role is played by robust design methodology and conversion ability in AMS implementation. Agile work force, scalability and process control variation categorized as factors having moderate driving and dependence power comes below in the hierarchal set-up. Support from top management is one such factor which possesses high dependency and less driving power. Hence, it does not require greater attention as its impact on overall system is not that significant. Modular design approach and empowered workers are affected by factor existing on other levels; therefore these factors have highest depending and lowest driving power.

Step 8: Matrice d'Impacts Croises-Multipication Applique an Classment analysis

The main aim of MICMAC analysis is to analyze the driving and dependence power of the factor. Depending on the driving and dependence power of the factor has been categorized into four clusters as shown in figure 6.4.

- Cluster 1: Autonomous cluster;
- Cluster 2: Dependent cluster;
- Cluster 3: Linkage cluster;
- Cluster 4: Driving cluster.

Cluster 1: Autonomous cluster – This cluster contains those factors that have weak driving and dependence power. This cluster contains one factor namely agile work force (Factor 7).

Cluster 2: Dependent cluster- This cluster contains those factors that have low driving power and high dependence power. This cluster contains five factor namely i.e. scalability (factor 6), controls of process variations (factor 8), top management support (factor 10), empowered workers ((factor 11) and modular design approach (factor 12).

Cluster 3: Linkage cluster- This cluster contains those factors that have high driving and dependence power. In our study no factor comes under this cluster category.

Cluster 4: Driving cluster- This cluster contains those factors that have high driving power and low dependence power. In our study; six factors comes under this category namely organizational structure (factor 1), information technology integration (factor 2), outsourcing (factor 3), development of design methodology (factor 4), convertibility (factor 5), and multi lingual (factor 9).

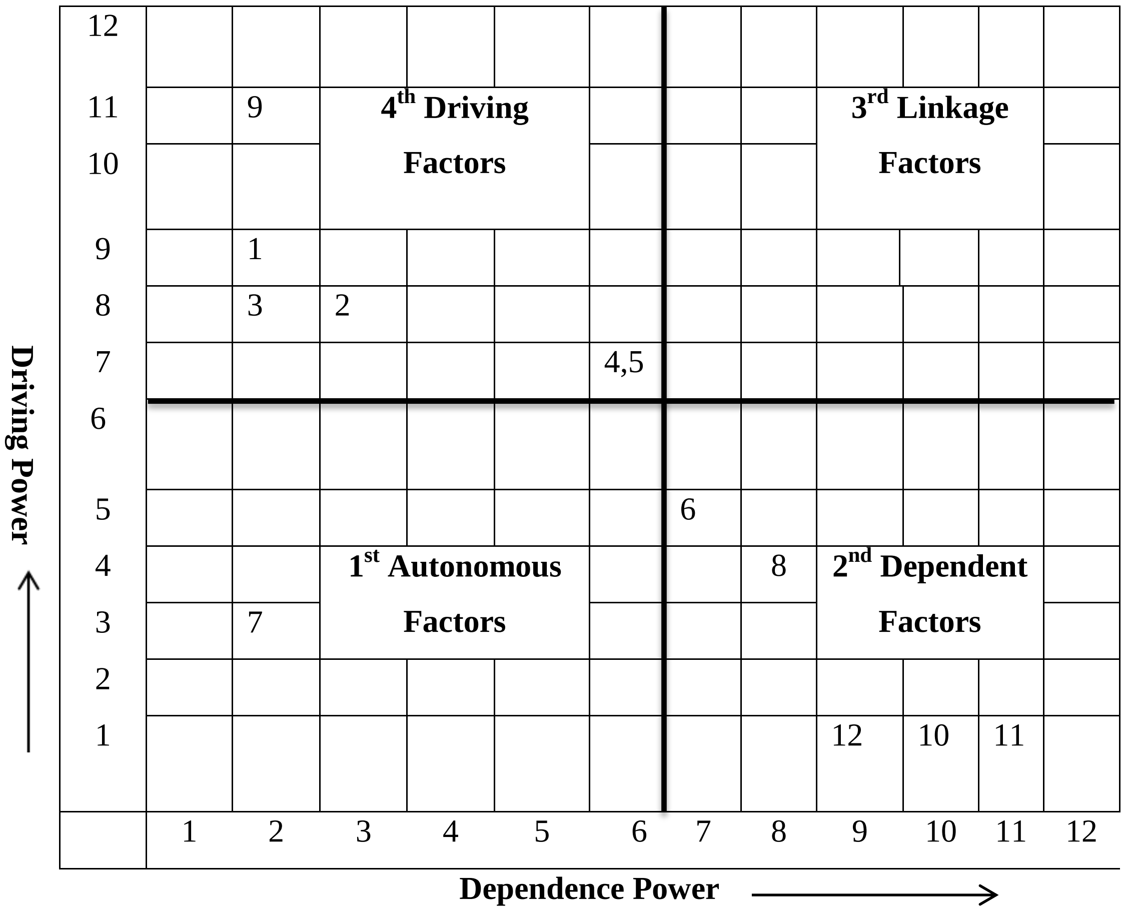

Figure 6.4: MICMAC analysis for AMS factors

6.4 CONCLUSION

This chapter presents the application of MICMAC analysis and ISM technique in an elaborative manner as shown in figure 6.3 and 6.4. The technique is applied in factors affecting the implementation of AMS in an organization manufacturing system. The model establishes the inter-relationship among these factors and also allows placing them in a hierarchical set-up which provides a method of selection of these factors on a priority basis with regard to implementation in an industrial set-up.

On the basis of results obtained, following conclusion can be drawn i) this study makes use of ISM and MICMAC analysis to carry out analysis on factors which affects the AMS ii) some factors have high driving power namely outsourcing, organizational structure, information technology integration, and multi-lingual essential to be taken care on a importance base iii) this research may prove beneficial to managers to concentrate on the transition from the conventional to agile manufacturing system iv) experience joined through this observational study may be served as a template of learning for management of manufacturing industries. The main focus of the chapter is to facilitate the implementation of AMS in an organizational set-up.

CHAPTER 7

ANALYSIS OF AGILE MANUFACTURING SYSTEM ENABLERS BY TISM APPROACH

7.1 INTRODUCTION

AMS is an innovative way that is used to signify the capability of manufacturing the products and facilities in constant varying surroundings (Gunasekaran, 1999). It is an evolving idea in engineering that ambition at accomplishing flexibility and approachability to the continuous varying marketplace requirements. Execution of AMS prototype has been a foremost idea of numerous industries (Gunasekaran *et al.,* 2008; Zhang *et al.,* 1999). AMS can be explained as the ability of alive and flourishing in a tough situation of constant and random modification by responding rapidly and efficiently in fluctuating marketplaces, determined by 'consumer-defined' product and amenities (Pandey and Pattanaik, 2014).

AMS does not characterize sequences of procedures much as it signifies an essential modification in executive attitude (Maskell, 2001; Cho *et al.,* 1996). Agile manufacturing system is not almost small-scale developments, but an exclusively changed method of doing work (Sushil, 2012). In 1991, rare idealistic investigators conceived the term agile manufacturing in University of Iacocca and give a lecture regarding topics under the field termed by them as agile manufacturing systems (Yusuf *et al.,* 1999; Hallgren and Olhager, 2009). Once the industrialized businesses started observing the numerous modifications in taste of consumers it developed a key topic to reply to their requirements (Monker, 1994; Sharp *et al.,* 1999). Then many investigators appreciated significance of AMS and did significant effort on this subject. Nowadays, AMS can be well-defined as the ability of enduring and flourishing in an inexpensive atmosphere of constant and changeable modification by responding rapidly and electively to varying marketplaces, determined by consumer-intended product and facilities (Cho *et al.,* 1996). Agility is frequently explained as the capability to flourish in a modest commercial atmosphere categorized by continuous and random modification (De Vor *et al.,* 1997; Goldman *et al.*, 1995; Gunasekaran, 1999).

AMS recommends that slighter scale, prefabricated manufacture amenities and collaboration amongst originalities would be the primary outline of attractiveness for the subsequent generations (Goldman *et al.*, 2008; Sahin, 2000). Agile stream is more realistically explained and thoroughly related with 'rapid response', but is usually mentioned to as a definitely dissimilar model to lean stream. Agile stream enablers are characterized by advanced product and unbalanced request, as usually originate in the style profound attire manufacturing (Stratton and Warburton, 2003; Naylor *et al.,* 1999). Deprived of the requirement of leanness, jump to agile manufacturing is not only mandatory, but also problematic to achieve (Gunasekaran, 2001).

Though, here is an essential for a general methodology to calculate and study agile manufacturing in real-life scenario. In opinion of the significance of this essential, this chapter analyzes the enablers which is identified through literature and brainstorming with people of industry and academia both in chapter 2 with total interpretive structural modeling and MICMAC analysis and developed a model to understand the interpretation of structural links and interrelationship between them. In industry the chief-executives/managing directors/general managers/work managers/senior executive members and in academia the scientists, professors and research scholars are included as experts for analyzing the inter-relationship among these enablers. The key aims of this chapter are as (i) to establish mutual relationship, relative importance and interdependence of each enabler with the help of TISM technique (ii) to analyze the AMS enabler by calculate driving power and dependence power with the help of MICMAC analysis.

7.2 AN OVERVIEW OF TISM

ISM is a methodology that gives relationships between elements among specific criteria that constitute problem related to the system and advantages in recognizing the circumstantial correlation amongst the numerous enablers of the organization which describes the concerns. It is explanatory because conclusion of the assembly adopts; whether and exactly how the enablers are related (Mittal and Sangwan, 2011; Singh and Sharma, 2015). Matawale *et al.,* (2013) developed a relationship among enablers for lean, agile and le-agile manufacturing system with ISM. Hasan *et al.,* (2007) identified numerous obstacles for AMS and establish a correlation amongst the dimensions of obstacles by the interpretive structural modelling. Hasan *et al.*, (2009) also introduced the enablers for agile manufacturing system and developed a systematic relationship among these enablers with ISM. But ISM is not able to explain the interpretation of structural links and it is not completely transparent in above cases. So, to overcome the limitations of ISM methodology, it is extended to TISM.

Following are the steps for TISM methodology as discussed by Sushil (2012); Jain and Raj (2015) and Jayalakshmi and Pramod (2015). First step is to find out the enablers who enable the organization that could be correlated to each other in an organization (Jain and Raj, 2015; Khatwani *et al.*, 2015). After identification of enablers, this is the main step which differ the TISM to ISM because in this we are identifying the mutual contextual and interpretation relationship. Now, next step is to convert relationship into structure self-interaction matrix. Afterwards, reachability matrix is established from structural self-interaction matrix and transitivity is checked for that matrix. In TISM, transitivity for the contextual relationship is considered as supposition. Now, level partitioning is done in final reachability matrix. Depending on the relationships given by level partitioning a digraph is drawn. Interaction matrix is developed with the help of diagraph. The resultant diagraph and interaction matrix is transformed into TISM model by substituting enabler nodes with enablers. In conclusion, established TISM model is checked for theoretical discrepancy and essential modifications are completed. All above described steps are demonstrated with the help of flow diagram as described in figure 7.1.

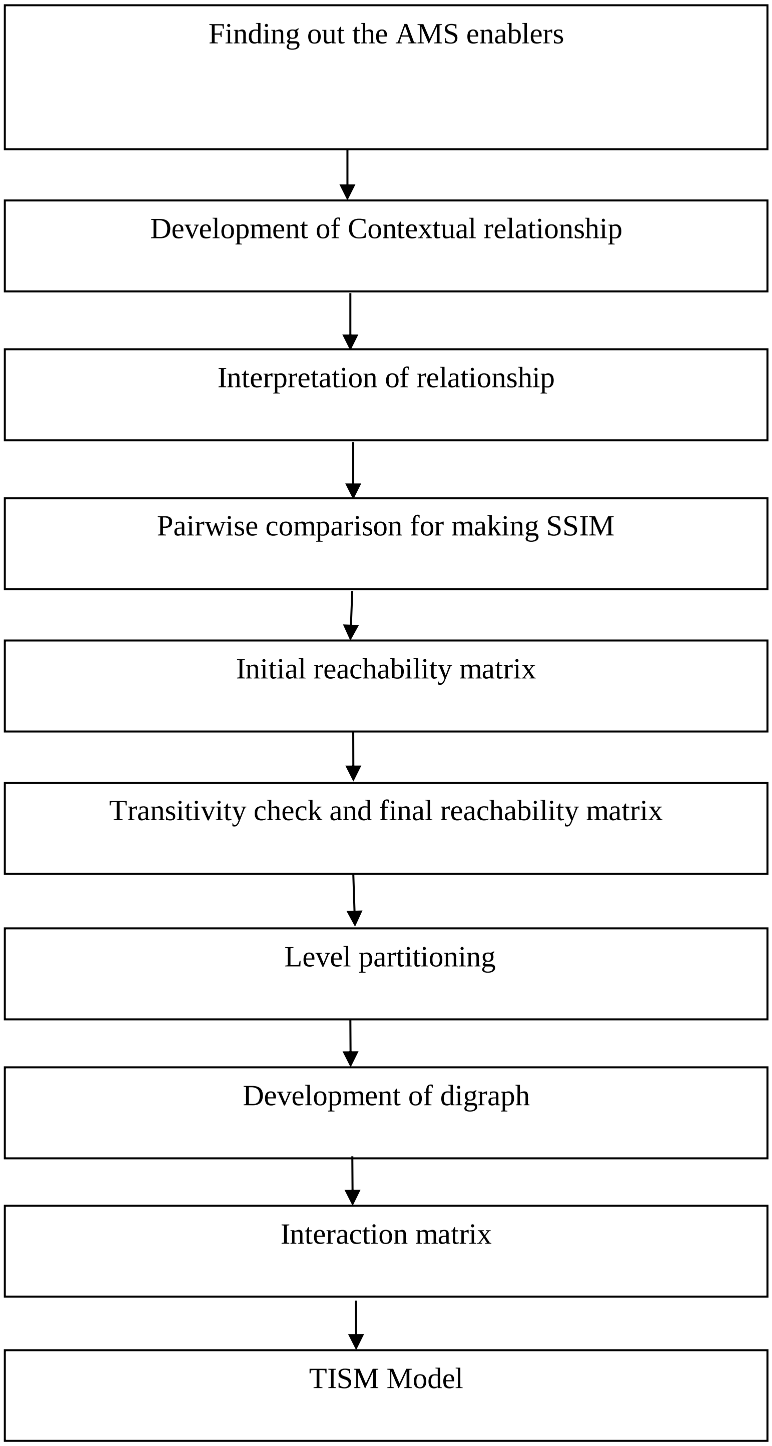

Figure 7.1: Flow diagram for TISM methodology

Furthermore, TISM approach has been magnificently used by numerous investigators in the areas of flexible manufacturing system (Jain and Raj, 2015; Dubey and Ali, 2014), productivity (Sandbhor and Botre, 2014), strategy execution (Srivastava and Sushil, 2013), telecom sector (Yadav, 2014), total quality management (Singh and Sushil, 2013), cloud computing (Sagar *et al*., 2013), pharmaceutical (Wasuja *et al.*,*201*2), education sector (Prasad and Suri, 2011), strategic management (Nasim, 2011).

7.3 MODELLING OF AGILE MANUFACTURING SYSTEM ENABLERS

The numerous phases, which help in the model development (Raj *et al.*, 2008) are explained below:

Step 1: Find out the enablers for AMS

The enablers encouraging the agile manufacturing system have been found by deep literature review and brainstorming with specialists from industry and academia both in chapter 2 as shown in table 7.1.

Table 7.1: Explanation of AMS Enablers in self-compiled manner

Sr. No.	Enablers	Explanation
1	Virtual enterprise (E_1)	Tie-up with core specialized industry for completion of quickly changing requirement of market or customers.
2	Product service management (E_2)	Produce a product with good quality so that would require little or no service in future.
3	Flexible workforce(E_3)	It is associated with manpower whose one is able to complete the multiple tasks and is able to solve multi problems.
4	Top management support (E_4)	Technical and financial support is essential for attaining agile manufacturing environment and this can be only achieved with help of top management support.

5	Organizational structure (E_5)	Better communication at each level and provide same opportunity to each employee is possible in only flatter organization. So it's right time to change the organization structure from horizontal to flatter organization.
6	Information technology integration (E_6)	Quickly changing requirements or demands of the customers cannot be achieved with the help of one industry. So to achieve customers' requirements there is a need to integrate the specialized industries which the help of information technology.
7	Man power utilization (E_7)	Proper utilization of manpower is required to escalate the agility of the organization and to complete the demands of the customer in short time period.
8	Pull production (E_8)	Pull production means 'pull' the customers in the market by producing a product of good quality with the help of customer feedback.
9	Product life-cycle management (E_9)	PLM means maintain record of the product from selling day to scrap day of the product with the help of information technology.
10	Optimal inventory (E_{10})	To respond the quickly increase or decrease demand of the customer zero inventory is not desirable. So responding customer on time and for maintaining inventory cost there is a need to maintain optimal level of the inventory *i.e.* known as MRI.
11	Machine utilization (E_{11})	Machine utilization means no waiting time for the machine which can optimize with the help of scheduling.

Step 2: Contextual relationship develop

To develop the AMS model, there is a need to find a type of contextual relationship between the enabler which is discussed above. The contextual relationship could be 'X should influence or help to enable Y' or 'Y should influence or help to enable X'. To obtain contextual relationship the enablers was discussed in group of experts from industry and academia both.

Step 3: Interpretation of relationship

This is main step of TISM in which we are finding how the relationship between enablers really works. In TISM description, how the enablers enhance or influence with each other and in what way they enhance or influence each other is considered but all these things is not considered in ISM. This interpretation of relationship is described as shown in appendix 2.

Step 4: Pair-wise comparison for SSIM

In this step pairwise comparison of enablers with answering the interpretive query as mentioned in the previous step which help in making self-structural interaction matrix. For each pair comparison, first enabler should be compared with all remaining enablers. For each enabler comparison, the entry should be 'Y' for relation and also reason is to be provide and 'N' for no relation. After comparing all enablers with each other, a paired relationship in the form of interpretive logic –knowledge base as per previous step, is obtained and is shown in table 7.2.

Table 7.2: Structural self- interactive matrix for AMS enablers

Enablers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
E_1		Y	N	N	N	Y	N	N	N	Y	N
E_2	N		N	N	N	N	N	Y	Y	N	N
E_3	N	Y		N	N	N	Y	N	N	N	Y
E_4	Y	Y	Y		Y	Y	Y	N	Y	N	N
E_5	N	N	N	N		Y	Y	N	N	N	N
E_6	Y	Y	N	Y	N		N	N	N	Y	N
E_7	N	N	N	N	N	N		N	N	N	Y
E_8	N	N	N	N	N	N	N		N	N	N
E_9	N	N	N	N	N	N	N	N		N	N
E_{10}	N	N	N	N	N	N	N	N	N		N
E_{11}	N	N	N	N	N	N	N	N	N	N	

Step 5: Initial reachability matrix

Knowledge based cell represented with 'Y' is replaced with '1' and cell represented with 'N' is replaced with '0'. Thus, consequential reachability matrix is called as initial reachability matrix as explained in table 7.3.

Table 7.3: Initial reachability matrix for AMS enablers

Enablers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
E_1		1	0	0	0	1	0	0	0	1	0
E_2	0		0	0	0	0	0	1	1	0	0
E_3	0	1		0	0	0	1	0	0	0	1
E_4	1	1	1		1	1	1	0	1	0	0
E_5	0	0	0	0		1	1	0	0	0	0
E_6	1	1	0	1	0		0	0	0	1	0
E_7	0	0	0	0	0	0		0	0	0	1
E_8	0	0	0	0	0	0	0		0	0	0
E_9	0	0	0	0	0	0	0	0		0	0
E_{10}	0	0	0	0	0	0	0	0	0		0
E_{11}	0	0	0	0	0	0	0	0	0	0	

Step 6: Transitivity check and final reachability matrix

Initial reachability matrix is further evaluated for transitivity. Transitivity is a relationship amongst three variables such that if relation amongst X and Y and relation amongst Y and Z then obviously relation amongst X and Z should be exist. Afterwards, initial reachability matrix is transformed into final reachability matrix by executing transitivity in initial reachability matrix. Table 7.4 represents the final reachability matrix in which transitivity is represented by *1**.

Table 7.4: Final reachability matrix for AMS enablers

Enablers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
E_1		1	0	*1**	0	1	0	*1**	*1**	1	0
E_2	0		0	0	0	0	0	1	1	0	0
E_3	0	1		0	0	0	1	*1**	*1**	0	1
E_4	1	1	1		1	1	1	*1**	1	*1**	*1**
E_5	*1**	*1**	0	*1**		1	1	0	0	*1**	*1**
E_6	1	1	*1**	1	*1**		*1**	*1**	*1**	1	0
E_7	0	0	0	0	0	0		0	0	0	1
E_8	0	0	0	0	0	0	0		0	0	0
E_9	0	0	0	0	0	0	0	0		0	0
E_{10}	0	0	0	0	0	0	0	0	0		0
E_{11}	0	0	0	0	0	0	0	0	0	0	

Step 7: Level partitioning

TISM based level partition is carried out same as ISM. Reachability set and antecedent sets for all the enablers are determined with the help of table 7.4. Intersection of the reachability and antecedent sets is found out. Top level in TISM hierarchy is obtained by those enablers whose reachability set and intersection set should be same. Top level enablers satisfying above condition should be removed from the table and repeat the exercise till all the levels are determined as shown in table 7.5.

Table 7.5: Level partitioning for AMS enablers (Iterations I-IV)

Enablers	Reachability set	Antecedent Set	Intersection Set	Level
E_1	1,4,6	1,4,5,6	1,4,6	III
E_2	2	1,2,3,4,5,6	2	II
E_3	3	3,4,6	3	III
E_4	4,5,6	4,5,6	4,5,6	IV
E_5	4,5,6	4,5,6	4,5,6	IV
E_6	4,5,6	4,5,6	4,5,6	IV
E_7	7,11	3,4,5,6,7,11	7,11	I
E_8	8	1,2,3,4,6,8	8	I
E_9	9	1,2,3,4,6,9	9	I
E_{10}	10	1,4,5,6,10	10	I
E_{11}	7,11	3,4,5,7,11	7,11	I

Step 8: Development of diagraph

As per the reachability matrix, relationship of the directed links is drawn for the enablers in the form of graph. In this transitive relationship is eliminating step by step after examining the interpretation from the knowledge based. Only important transitive links considered based on their interpretation and shown in figure 7.2

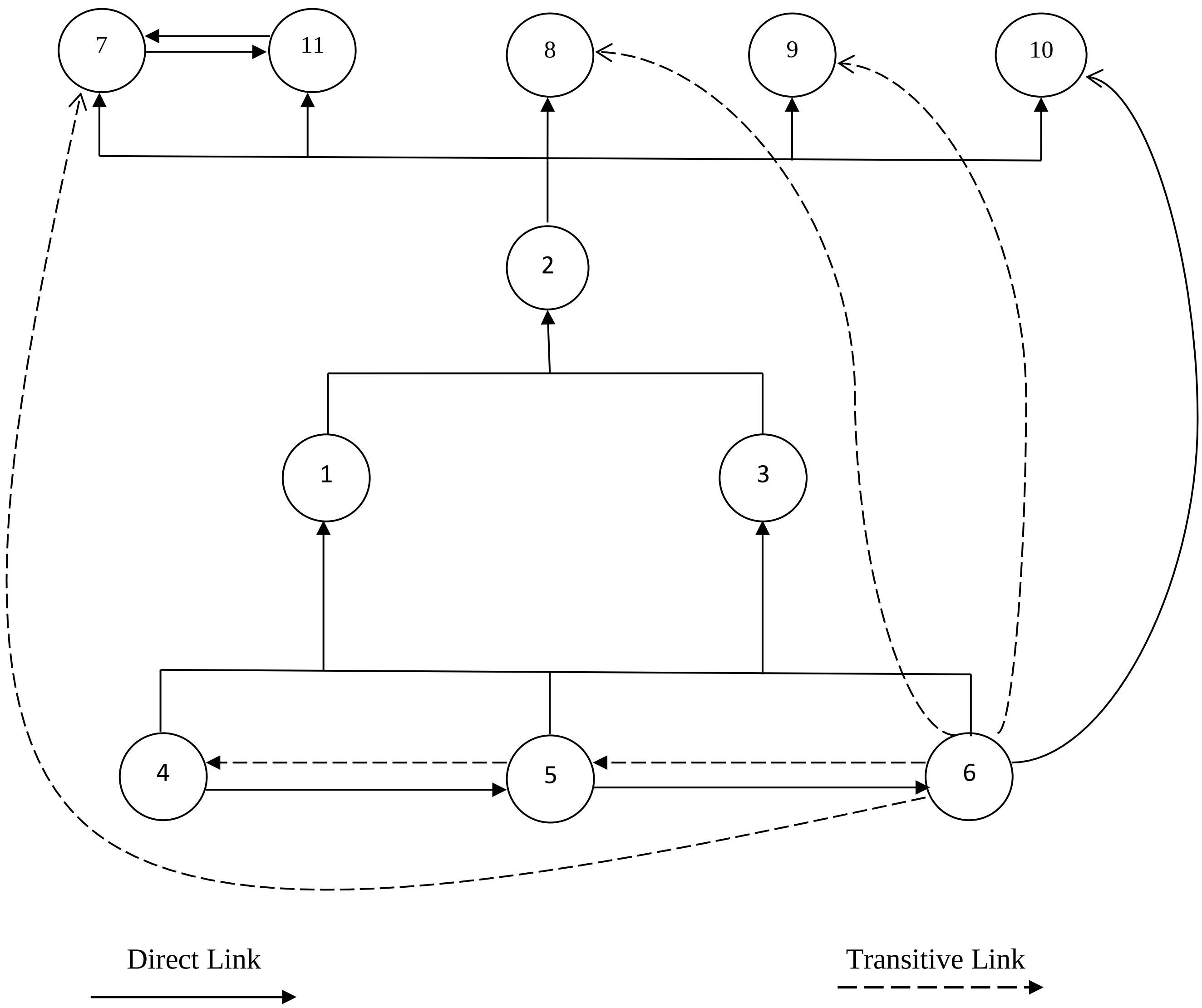

Figure 7.2: Digraph for AMS enablers

Step 9: Interaction matrix

In interaction matrix, diagraph is converted into a binary interaction matrix form by changing all the interaction by 1 entry. The cell with ‘1’ entry in interaction matrix is interpreted with the help of knowledge base as shown in table 7.6 in which bold number represent direct link and italic number represent significant transitive link.

Table 7.6: Interaction matrix for AMS enablers

Enablers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
E_1		**1**	0	*0*	0	0	0	*0*	*0*	0	0
E_2	0		0	0	0	0	0	**1**	**1**	0	0
E_3	0	**1**		0	0	0	0	*0*	*0*	0	0
E_4	**1**	0	**1**		**1**	0	0	*0*	0	*0*	*0*
E_5	***1***	*0*	0	*1*		**1**	0	0	0	*0*	*0*
E_6	**1**	0	***1***	0	*1*		*1*	*1*	*1*	**1**	0
E_7	0	0	0	0	0	0		0	0	0	**1**
E_8	0	0	0	0	0	0	0		0	0	0
E_9	0	0	0	0	0	0	0	0		0	0
E_{10}	0	0	0	0	0	0	0	0	0		0
E_{11}	0	0	0	0	0	0	**1**	0	0	0	

Step 10: Total interpretative structural modelling

TISM model consist with the help of Interaction matrix and diagraph. Nodes in the diagraph are replaced with interpretation of elements and TISM model is shown in figure 7.3.

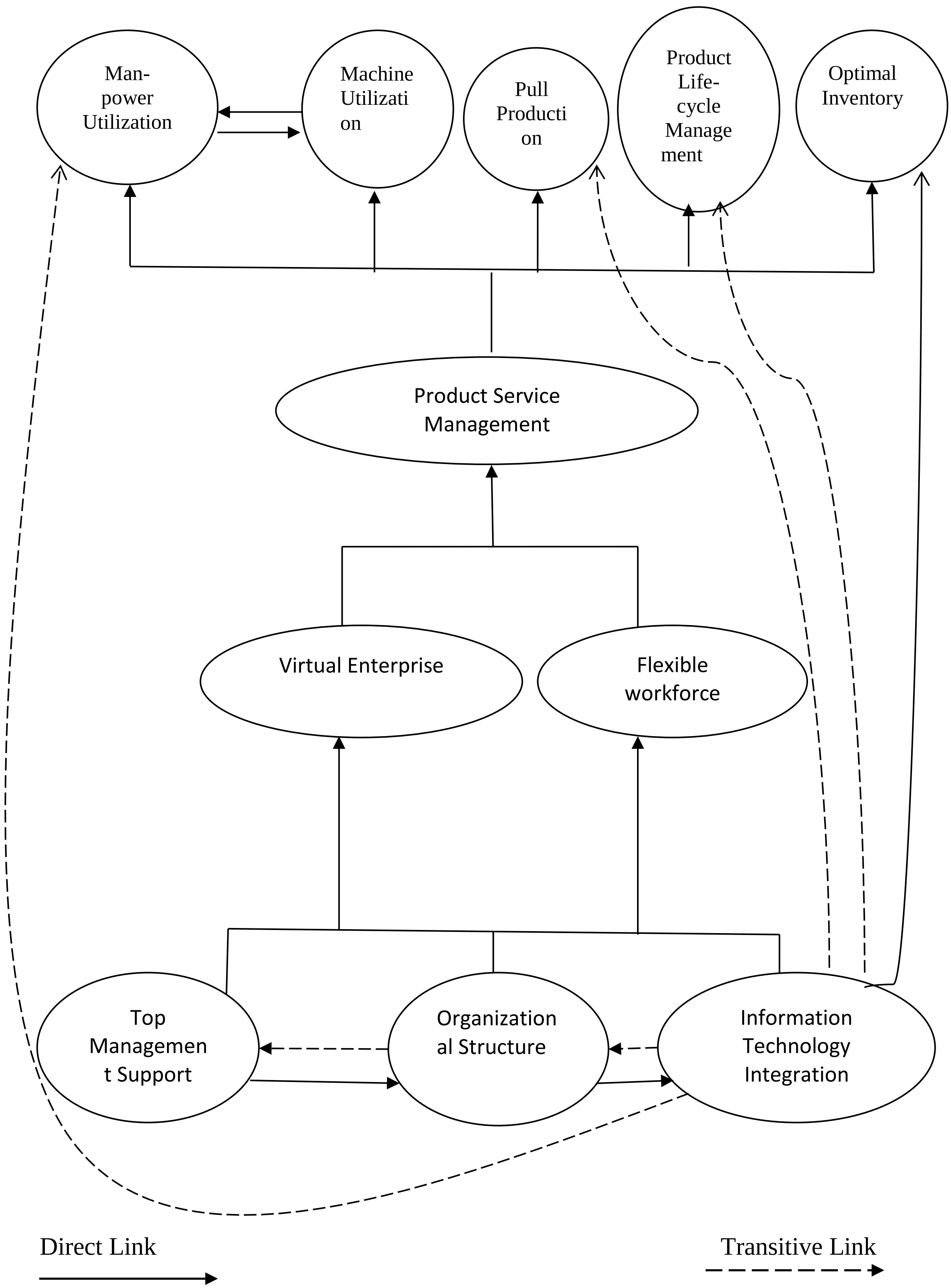

Figure 7.3: TISM Model for enablers of AMS

Step 11: MICMAC analysis

Matrice d'Impacts Croises-Multipication Applique an Classment is known as MICMAC analysis whose meaning is cross-impact matrix multiplication applied to classification. Afterwards, AMS enablers have been divided into four clusters i.e. autonomous cluster, dependent cluster, linkage cluster and driving cluster which is depends upon the driving and dependence power of AMS enabler. Table 7.4 represents the cluster-wise characterization of AMS enablers. Main aim is to evaluate the AMS enablers in term of driving power and dependence power by MICMAC analysis.

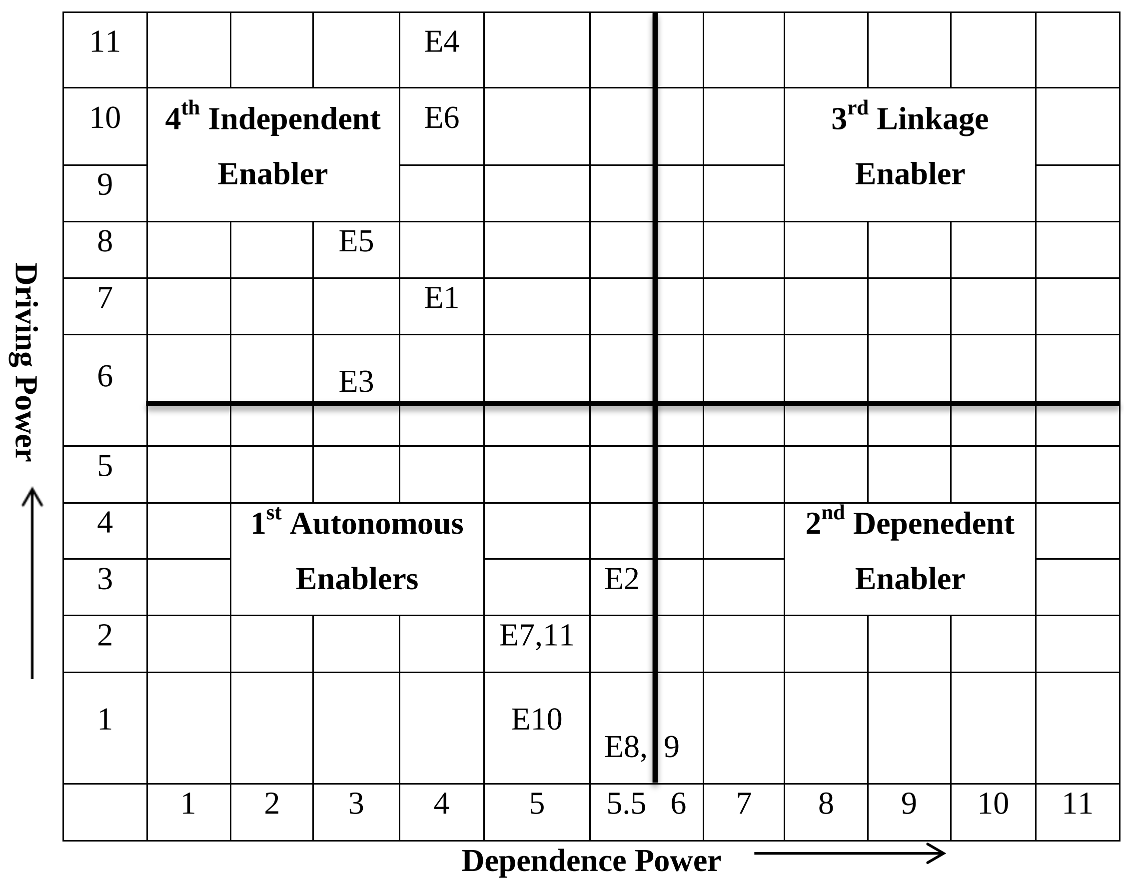

Figure 7.4: MICMAC analysis for AMS enablers

Cluster 1: Autonomous cluster – This cluster contains those enablers who have weak driving and dependence power. This cluster contains three enabler's namely man-power utilization (enabler 7), optimal inventory (enabler 10), and machine utilization (enabler 11).

Cluster 2: Dependent cluster- This cluster contains those enablers who have low driving power and high dependence power. This cluster contains three enabler's namely product service management (enabler2), pull production (enabler 8), product life-cycle management (enabler 9). All enablers in this cluster are on border line means as they little weak in dependence power it moves in autonomous cluster.

Cluster 3: Linkage Cluster- This cluster contains those enablers who have high driving and dependence power. In our study no enabler comes under this cluster category.

Cluster 4: Driving enablers- This cluster contains those enablers who have high driving power and low dependence power. In our study; five enablers comes under this category namely virtual enterprise (enabler 1), flexible workforce (enabler 3), top management support (enabler 4), organizational structure (enabler 5), and information technology integration (enabler 6).

7.4 CONCLUSION

The present model identifies the influence of enabler, mutual relationship, relative importance and interdependence of enablers with the help of TISM and MICMAC analysis. Integrated model of AMS has been developed by using TISM and MICMAC analysis. This model can be used as an aid to develop a suitable strategy for the designing and implementation of AMS in any organization. This conclusion will permit organization to efficiently exploit their resource to focus consideration on the greatest substantial enabler. These results will provide insight into the enablers that influence the choice of agile manufacturing system. Organization will also achieve the competitiveness, customer satisfaction and environmental concern *etc.* from the above findings which will help in moving towards advanced manufacturing practices.

Afterwards; depending upon the outcomes attained from the research, the subsequent activities are recommended to execute the agile manufacturing system in today's competitive scenario a) for complete the quickly changing requirements or demands of the customer in short time-period, tie-up with specialized core industry is necessary step. It means virtual enterprise is first step towards implementation of AMS in any organization b) the organizational structure in the industry should be in flattened way so that every employee of the organization can share his knowledge or ideas with higher subordinates c) Utilization of man-power and machine act as one of the important enabler in implementation process of AMS. It helps in producing good quality products and also decreases the waiting time for quickly changing requirement of the customers for the product. So, proper utilization of both machine and man-power makes the organization more agile.

CHAPTER 8

WEIGHTAGE CALCULATION OF CRITERIA AND RANKING OF AMS FACILITATORS BY ENTROPY APPROACH, MOORA METHOD AND VIKOR ANALYSIS

8.1 INTRODUCTION

The global manufacturing environment is generally afflicted with a tendency of reduced rate of output and is not commensurable with the quantum of investment being made to maintain the quality and quantity. The most immediate reason behind this imbalance is the grave competition confronting the manufacturing sector globally along with the inability to grapple with increased expectations of customized demands of targeted customers with impeccable quality. In order to compete in rapidly changing scenario and to obtain high quality products at low cost require changing in manufacturing system (Routroy *et al.,* 2015). This challenge mandates to each industry to choose right manufacturing system. This can be accomplished by the espousal of new manufacturing system called agile manufacturing system (Montgomery and Levine 1996). AMS takes into the account the merits of both the earlier system *i.e.* flexible manufacturing system and lean manufacturing system (Malhotra, 2014; Wu *et al.,* 1999). Thus AMS has shown immense potential and garnering significant attention of researchers and industrialist.

Sherehiy *et al.*, 2007 gives the most comprehensive definition of AMS as “A paradigm that facilitates an organisation to quickly react in accordance with the dynamic demands of the customers by making use of appropriate technologies and management models”. It is imperative to note that the emphasis is not only on the flexible technology of the system but also on the managerial aspects. Jung *et al.,* (1996) explained as the “capability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by ‘customer-defined’ products and services”. The efficacy of AMS lies in its profound ability to respond and meet the customer demands swiftly.

It is a commonly observed that companies have been swarming up the market with a multitude of products/models without deliberating on the dynamics of ever evolving business environment. Serrador and Pinto (2015) states “Motorola's multibillion-dollar Iridium project could be considered a success on the basis it was ‘on time’ and ‘on budget’ from an engineering point of view, but was a catastrophic commercial failure because it did not adjust to what was being learned about the changing business environment”.

As in conclusion of chapter 6 and 7 identified the driving enablers and factors which are act as facilitator in implementation of AMS. Furthermore, now system approach is requires ranking and studying these facilitators of AMS in respect of its criteria which have a substantial effect in real-world organizations. In view of the importance of this need, this chapter attempts to study 7 facilitators and 4 criteria substantiated with exhaustive literature review and corroborated by elaborative discussion among industry and academia experts. In this endeavor facilitators have been evaluated on the basis of two criteria *i.e* beneficiary and non-beneficiary criteria. Agility (C1), Profit (C2) comes under beneficiary criteria as it provides output in terms of benefit, while Resources (C3) and Capital Investment (C4) are expressed as non-beneficiary criteria because they do not contribute directly to the benefit of the industry. This paper analyses these criteria with Entropy approach and rank the facilitators by MOORA method and VIKOR analysis. The 7 AMS facilitators identified through chapter 6 and 7 respectively are given below in table 8.1 with references.

Table 8.1: Agile manufacturing system facilitators

Facilitators	**References**
Virtual Enterprise (F1)	Abdollahi *et al.*, 2015; Dubey and Gunasekaran, 2015; Malhotra, 2014; Vinodh and Aravindraj 2012 ; Cheng *et al.*, 1998
Flexible Workforce (F2)	Gunasekaran *et al.*, 2008; Goldsby *et al.*, 2006; Gunasekaran, 2001; Meredith and Francis, 2000.
Top Management Support (F3)	Mishra, 2014; Pan and Nagi, 2013; Raj *et al.*, 2008; Yusuf *et al.*, 1999.
Organizational Structure (F4)	Malhotra, 2014; Powell, 2002; Vinodh and Aravindraj, 2012; Yang and Li, 2002.
Information Technology Integration (F5)	Chakraborty and Mandal, 2014; Singh *et al.*, 2011; Gunasekaran, 1999; Richards, 1996.
Flexibility in System (F6)	Malhotra, 2014; Vinodh and Aravindraj, 2012; Abdel *et al.*, 2000; Maler *et al.*, 2003; Vinodh and Aravindraj, 2012; Youssef, 1992.
Development Of Design Methodology (F7)	Pan and Nagi, 2013; Vinodh and Aravindraj, 2012; Sherehiy *et al.*, 2007; Sarkis 2001, Mo, 2009.

The main objectives of this chapter are (i) to calculate the weightage of the criteria affecting facilitators of AMS by Entropy approach (ii) to map the ranks of AMS facilitators calculated with the help of MOORA method and VIKOR analysis in order to deduce the most significant facilitator for implementing the AMS.

8.2 METHODOLOGY

The literature shows that various researchers have been focusing on finding out the enablers, barriers, facilitators, attributes and sub-attributes of AMS (Routroy *et al.,* (2015); Dubey and Gunasekaran (2015); Malhotra (2014); Elmoselhy (2015); Gunasekaran (1999); Yusuf *et al.,* (1999); and while some had focused on finding the inter-relationship between them Beruvides *et al.*, (2016); He *et al.,* (2001). However there is also a need to find out the weightage of criteria and ranking of facilitators for effective implementation of AMS. Entropy approach method is used to find out the criteria weightage which is then used to rank the facilitator by MOORA method and VIKOR analysis to further accomplish the objectives of this research as depicted in figure 8.1. The aforementioned methods are separately discussed as follows.

8.2.1. Entropy Technique

Shannon (2001) stated concept of entropy method firstly proposed in 1948. In information theory, the term entropy is known as the average amount of information (Shi-fei & Zhong-zhi, 2005). It is the uncertainty of information content and provided a scientific basis for modern information theory (Cover and Thomas, 2012). With the decrease in information entropy, weight of particular criteria is increased because when it comes to take decision in real world a value of low uncertainty level is preferred (Ji *et al.,* 2015). This concept of entropy serves the deterministic basis for criteria weightage. The viability of entropy method over other multi criteria decision method (MCDM) (Rhodes and Garside, 1995) is mentioned as follows:

- Give minimum partisan result which is consistent with all the available data.
- Useful technique for investigate the validity of assumptions
- Easy to study and solve

- Simple mathematical calculation
- Less time consuming

This methodology has been successfully used by various researchers for optimization of micro scale manufacturing process (Beruvides *et al.*, 2016), product evaluation (Dashore *et al., 2013),* cell phone evaluation (Akyene, 2012), probabilistic reasoning (Rhodes and Garside, 1995), supplier selection (Shemshadi *et al.*, 2011), order allocation (Ghorbani *et al.*, 2012*)*, and for risk assessment to hydropower station (Ji *et al.*, 2015).

8.2.2. MOORA Method

MOORA stands for Multi-Objective Optimization on the basis of Ratio Analysis (Attri and Grover, 2014; Mandal and Sarkar, 2012; Mishra *et al.*, 2015). It is also known as multi-attribute or multi-criteria optimization. This method works simultaneously in optimization of many conflicting goals. Brauers *et al.*, (2008) suggests that with this technique the multi-objectives can be optimized. It is used for solving multifarious complications in advanced manufacturing scenario. It is a relatively simple method vis-a-vis MCDM method with easier calculation which helps the decision makers to find more effective alternatives among the various conflicting alternatives.

Advantages of this MOORA method in comparison with other MCDM method given by Attri & Grover (2014):

- Easy to learn and solve as compared to other MCDM method
- Calculation is less time consuming

This methodology has been successfully used by various researchers for ranking of different production life cycle such as stages selection, flexible manufacturing system selection, welding process selection, supplier selection Attri & Grover (2014), material selection Karande & Chakraborty (2012), optimizing milling process Gadakh, (2010), Gadakh *et al.*, (2013), privatization in a transition economy Brauers *et al.*, (2008).

Figure 8.1: Methodology for ranking of AMS facilitators

8.2.3. VIKOR Analysis

VIKOR stands for Vlsekriterijumska Optimizacija I Kompromisno Resenje. VIKOR analysis is described by Opricovic in 1998 for optimization and ranking of complex system having multiple criteria (Opricovic, 1998; Opricovic & Tzeng, 2002; Opricovic & Tzeng, 2004). This method provides ranking to all available alternatives while the initial weight is derived by entropy method (Wei & Lin, 2008; Shariari, 2016; Vinodh *et al.*, 2013). This method relies on evaluating the function that represents nearest to the ideal and give the ranking index based on the particular measure of closeness to the ideal solution (Singh & Khamba, 2011).

Opricovic & Tzeng, (2004); Wei & Lin, (2008) describes various advantages of VIKOR analysis over other MCDM techniques:

- Evaluation parameters are comprehensive and easy to calculate
- Attitude of decision maker taken into consideration by changing v factor
- Final performance score is an aggregation of all the criteria and their relative weight

Based on the above described methodology, the weightage of criteria and ranking of the facilitators can be measured.

8.3 WEIGHT ALLOCATION TO CRITERIA BY ENTROPY APPROACH

In this section, weight allocations to criteria using Entropy approach suggested by Soleimani & Zarepisheh (2009); Lihong *et al., 2008*; Wang & Lee (2009) are described below:

Step 1: Ranking to facilitators contrary to criteria

First step for calculating the weight of criteria is to rank the facilitators with respect to its criteria. This ranking is done only after the extant brain-storming with experts from industry and academia both. This ranking is done with the help of Likert scale from 1 to 5. 1 is representing less dependency as 5 is representing high dependency on respected criteria. This ranking is shown as per table 8.2 from column 2 to 5.

Table 8.2: Weight allocation to criteria by Entropy approach

Facilitator/Criteria	Value Assigned to Facilitators				Normalized Facilitators			
	C1	**C2**	**C3**	**C4**	**C1**	**C2**	**C3**	**C4**
F1	4	2	2	2	0.1538	0.0952	0.0870	0.0870
F2	4	4	4	4	0.1538	0.1905	0.1739	0.1739
F3	3	3	3	3	0.1154	0.1429	0.1304	0.1304
F4	3	4	2	2	0.1154	0.1905	0.0870	0.0870
F5	2	3	4	4	0.0769	0.1429	0.1739	0.1739
F6	5	3	4	4	0.1923	0.1429	0.1739	0.1739
F7	5	2	4	4	0.1923	0.0952	0.1739	0.1739
N_j					0.9793	0.9834	0.9801	0.9801
$1-N_j$					0.0207	0.0166	0.0199	0.0199
W_j					0.2684	0.2159	0.2578	0.2578

Step 2: Normalization of a matrix

Normalization of facilitators is requiring before proceeding on any further calculation. Many researchers used various different methods for normalizing the matrix. Various methods like Weitendorf ratio method, Total ratio method, Stop ratio method, Schärlig ratio method, Körth ratio method, Jüttler ratio method *etc* are used by various researchers for normalizing the matrix (Rhodes & Garside, 1995). For this research work total ration method is preferred due to its simplicity and ease of calculation. Normalization of matrix by total ration approach is described by equation 1 as follow:

$$\text{Xij} = \frac{\text{Xij}}{\sum_{\text{i}=1}^{\text{m}} \text{Xij}} \quad (\text{j}=1, 2, 3\ldots..\text{n}) \qquad \text{(i)}$$

By using above equation normalization of matrix is done as per table 8.2 from column 6 to 9.

Step 3: Calculation of N_j value for each criteria

Before calculate the criteria weightage there is a need of Nj value. Nj value for each criteria is calculated after normalization of facilitators by using equation 2.

$$N_j = -k \sum_{i=1}^{n} X_{ij} * \ln\left(X_{ij}\right) \qquad j = 1,2.\ldots\ldots m \qquad \text{(ii)}$$

Where k = 1/ ln (n)

N_j value of each criteria is shown in table 8.2 by using equation (ii).

Step 4: Criteria weight calculation

Criteria weight calculation is done by equation 3 by using Nj value of each criteria. This W_j value represents the weightage of each criteria with respect to its facilitators. Criteria weightage is represented in table 8.2.

$$w_j = \frac{1-N_j}{\sum_{j=1}^{n}(1-N_j)} where\ j = 1, \ldots, n. \qquad \text{(iii)}$$

After the calculation by using equation (iii), beneficiary criteria *i.e.* Agility (C1) and Profit (C2) achieve 0.2684 and 0.2159 weightage respectively which means both of these criteria achieved 48.43% of total weight. Non beneficiary criteria *i.e.* Resources (C3) and Capital Investment (C4) achieve 0.2578 each which is achieving 51.56%. It means beneficiary and non-beneficiary criteria are getting nearly equal weightage under AMS

8.4. RANKING OF FACILITATORS BY MOORA METHOD AND VIKOR ANALYSIS

In this step the ranking of facilitator with respect to its criteria weightage is ascertained by MOORA method and VIKOR analysis separately.

8.4.1. Ranking of facilitators by MOORA method

Steps involved in ranking of facilitators by MOORA approach are as follows (Attri & Grover, 2014; Karande & Chakraborty, 2012; Gadakh, 2010; Gadakh *et al.,* 2013).

Step 1: Value assigned and Normalization of AMS Facilitators

The ranking involves assigning the values and normalization of AMS facilitators. This step has already been accomplished in section 8.3 during calculation of weight of criteria by entropy approach as shown in table 8.2.

Step 2: Assessment of Facilitators (Y_i)

For assessment of multiple criteria, normalized value added to all beneficial criteria (case of maximization) and subtract from all non-beneficial criteria (case of minimization). The final equation for Y_i is

$$Y_i = \sum_{j=1}^{g} Xij - \sum_{j=g+1}^{n} Xij \qquad \text{iv)}$$

Where g is the number of beneficial criteria, (n-g) is the number of non-beneficial criteria and Y_i is the normalized assessment value for i^{th} facilitators. In some cases, it is often observed that some goals are more important than the others. In order to give more importance to a goal, it could be multiplied with its corresponding weight (significance coefficient) (Brauers *et al.* 2008). When these criteria weights are taken into consideration then new equation for Y_i is

$$Y_i = \sum_{j=1}^{g} Wj * Xij - \sum_{j=g+1}^{n} Wj * Xij \quad (j=1, 2, 3\ldots..n) \qquad \text{(v)}$$

Where, W_j is the weight of j^{th} goal.

In our case criteria weight is calculated in previously mentioned section 8.3, so these beneficial and non-beneficial criteria are multiplied by corresponding weight. This normalized assessment is done by using equation (v) and calculation is shown in table 8.3.

Table 8.3: Ranking of AMS facilitators by MOORA method

Ranking of AMS Facilitator by MOORA Method						
Facilitators /Criteria with weightage	**Resources (0.2684)**	**Capital Investment (0.2159)**	**Agility (0.2578)**	**Profit (0.2578)**	**Y_i Value**	**Rank**
F1	0.1538	0.0952	0.0870	0.0870	0.0170	2
F2	0.1538	0.1905	0.1739	0.1739	-0.0073	5
F3	0.1154	0.1429	0.1304	0.1304	-0.0054	3
F4	0.1154	0.1905	0.0870	0.0870	0.0273	1
F5	0.0769	0.1429	0.1739	0.1739	-0.0382	7
F6	0.1923	0.1429	0.1739	0.1739	-0.0072	4
F7	0.1923	0.0952	0.1739	0.1739	-0.0175	6

Step 3: Ranking of AMS facilitators

The Y_i value can be positive or negative depending on the calculation as per equation (v) and it is shown in the table 8.3. Thus the best facilitators have the highest Y_i value while the other facilitators have the lowest Yi value. Facilitator 1 and 4 got the positive Yi value which means these are purely beneficial facilitators and all other facilitators got the negative Yi value which means F2, F3, F5, F6 and F7 require more input for getting significant output. As F4 has 0.0273 and F1 has 0.0170 Y*i* value therefore, F4 and F1 will have first and second rank respectively. Other facilitators got ranking accordingly as shown in table 8.3.

8.4.2. Ranking of facilitators by VIKOR analysis

VIKOR analysis brings-about an inclusive solution by using utility weight. The attitude of decision-makers can be reflected by adjusting utility weight. It can also determine a compromise solution to reflect the attitude of most decision makers (Wei & Lin, 2008). This method is successfully used by various researchers to select a location and analysis of environments (Tzeng *et al.*, 2002), supplier selection (Sanayei *et al.*, 2010), planning of land use (Chang and Hsu, 2009).

Wei and Lin (2008); Tzeng *et al.*, (2002) describe steps involved in VIKOR analysis is as follows:

Step 1: Calculate the normalized value

Normalization of AMS facilitator is done by using equation 1 in above section during the ranking calculation of AMS facilitator by MOORA Approach as shown in table 8.3.

Step 2: Calculation of E_i value

This step includes the calculation of E_i value, which represents the distance of each AMS facilitator from the positive ideal solution.

E_i value for beneficial criteria:

$$Ei = \sum_{j=1}^{n} Wj[(Xijmax - Xij) / (Xijmax - Xijmin)] \quad \text{(vi)}$$

E_i value for non-beneficial criteria:

$$Ei = \sum_{j=1}^{n} Wj[(Xij - Xijmin) / (Xijmax - Xijmin)] \quad \text{(vii)}$$

E_i value of each AMS facilitator is calculated by using equation (vi) and (vii) and shown in table 8.4.

Step 3: Calculation of F_i value

It includes calculation of F_i value, which shows the distance rate of the i^{th} alternative to the negative ideal solution.

F_i value for beneficial criteria:

$$F_i = \text{Maximum of } [Wj(Xijmax - Xij) / (Xijmax - Xijmin)] \quad (i=1, 2....., n) \qquad \text{(viii)}$$

F_i value for non-beneficial criteria:

$$F_i = \text{Maximum of } [Wj(Xij - Xijmin) / (Xijmax - Xijmin)] \quad (i=1, 2....., n) \qquad \text{(ix)}$$

F_i value of each AMS facilitator is calculated by using equation (viii) and (ix) and represented in table 8.4.

Step 4: Calculation of P_i value

P_i value represents the negative attitude of AMS facilitators it means minimum value of Pi comes as best facilitator and higher value of it comes up as weakest facilitator.

$$P_i = v\,[(E_i - Eimin) / (Eimax - Eimin)] + (1 - v)\,[(Fi - Fi\ min) / (Fi\ max - Fi\ min)] \qquad \text{(x)}$$

Here we assume VIKOR constant v = 0.5. When the v is larger than 0.5, the index of Pi will tend to majority agreement; when v is less than 0.5, the index Pi will indicate majority negative attitude; in general, v = 0.5, i.e. compromise attitude of evaluation experts. Pi value of each facilitator is calculated by using equation (x) as shown in table 8.4.

Table 8.4: Ranking of AMS facilitators by VIKOR analysis

Facilitator/ Criteria	Normalized Facilitators				E_i	F_i	P_i	Rank
	C1 (0.2684)	C2 (0.2159)	C3 (0.2578)	C4 (0.2578)				
F1	0.1538	0.0952	0.0870	0.0870	0.2720	1	0.10207	2
F2	0.1538	0.1905	0.1739	0.1739	0.7595	1	0.42982	6
F3	0.1154	0.1429	0.1304	0.1304	0.7562	1	0.42757	5
F4	0.1154	0.1905	0.0870	0.0870	0.1202	0.5	0	1
F5	0.0769	0.1429	0.1739	0.1739	0.8639	1	0.5	7
F6	0.1923	0.1429	0.1739	0.1739	0.5158	1	0.26595	3
F7	0.1923	0.0952	0.1739	0.1739	0.5970	1	0.32057	4

Step 5: Ranking

An ordinal ranking of Pi shows the final preference. Thus, the best facilitators has the lowest Pi value, as Pi value increases, ranking of facilitators will also increase. Ranking of AMS facilitators is represented in table 8.4. Table 8.4 represent Pi value of organizational structure (F4) is zero and its minimum in all values of facilitators, hence it occurs at first rank. Ranking of other facilitators is done accordingly and represented in table 8.4.

8.5. RESULT AND DISCUSSION

This section compares the results obtained from MOORA method and VIKOR analysis. Both the approaches provide the ranking of AMS facilitators. Y_i value calculated by MOORA method is represented by dotted line and P_i value calculated by VIKOR analysis is represented by solid line in figure 8.2. Higher Y_i and lowest P_i values represent best facilitator and vice versa. Y_i and P_i value of all facilitators provide us a succinct way to compare the results of MOORA method and VIKOR analysis.

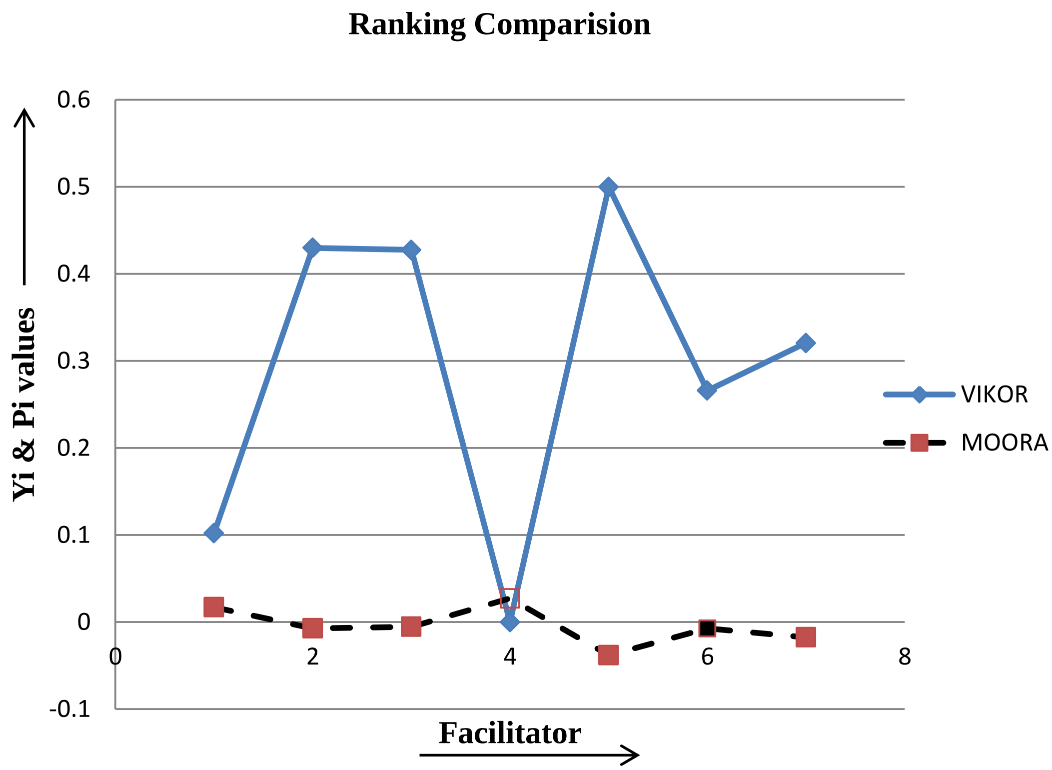

Figure 8.2: Comparison of AMS facilitators ranking

This graph examines the facilitators which have minimum gap between Y_i and P_i values as best facilitator and vice versa. Organisational structure (facilitator 4) achieved highest Y_i value as 0.0273 and lowest P_i value as 0. Therefore it occurs at first rank in comparison with all other facilitators. After organisational structure, facilitator 1 (virtual enterprise) gets Y_i value as 0.0170 and P_i value as 0.1020 which indicates that facilitator 1 achieves second rank in all facilitators. Facilitator 5 (information technology integration) have maximum distance between Y_i and P_i value as shown in figure 2, which signifies that facilitator 5 is less effective among all facilitators. The final ranking of all facilitator is done accordingly with the help of graph in figure 8.2 and accessible in table 8.5.

Table 8.5: Final ranking of AMS facilitators with comparison of MOORA method and VIKOR analysis

Facilitator	**Y*i* Value**	**P_i**	**Rank**
F1	0.0170	0.102075	2
F2	-0.0073	0.429826	6
F3	-0.0054	0.427576	5
F4	0.0273	0	1
F5	-0.0382	0.5	7
F6	-0.0072	0.265951	3
F7	-0.0175	0.320576	4

This ranking of AMS facilitators can be used as an aid to develop a suitable strategy for designing and implementation of AMS in any organization. This finding will allow the management to efficiently utilize their resources to focus attention on the most significant facilitator. These results will provide an insight into the facilitator that influences the choice of AMS. Organization will also achieve the competitiveness, customer satisfaction and environmental concern *etc.* from the above findings which will help in moving towards advanced manufacturing practices.

8.6. CONCLUSION

The application of entropy approach, MOORA method and VIKOR analysis on facilitators of AMS identified from the exploration of extant literature and discussion with experts from academia and industry yielded a ranking which is presented in table 8.5. There is a dearth of empirical literature on AMS as it is relatively a new concept. An initial analysis of facilitators will help the policy makers to understand the potential of actual implementation of AMS in Indian manufacturing industry. The present work provides the weightage of criteria and ranking of AMS facilitators, which will help in identifying the significant facilitators which should be given primary consideration during the course of implementation of AMS in order to make the manufacturing system efficacious.

Based on the results obtained from the study, the following actions are suggested to foster the AMS implementation in Indian manufacturing industry (i) the organization structure should be designed in such a way that it should be flattened and decentralized organization and there should be a provision of imparting education and providing training to teams for empowerment with no compromise on agility (ii) for developing a new product line, the companies should outsource those activities which require technologies and processes not available with them and these tie-ups would result in improved and expeditious conception of new product/ services (iii) IT and ITes should be promoted to improve the efficiency of the system and it will not only reduce the humungous paper work but also liberate the system from limitations of space required to store the same. It can only be possible by the business process reengineering (iv) continuous experiments should be undertaken on frequent and systematic basis in order to meet the evolving needs for design development and this can be achieved by adopting rapid prototyping technology, and concurrent engineering *etc.*

CHAPTER 9

PERFORMANCE EVALUATION FOR BARRIERS OF AMS BY FPII APPROACH

9.1 INTRODUCTION

Today's competitive market set challenges to modern industries for adopting newer and economic manufacturing processes. Basically market value is active and existing only on demand and supply rule specifically on customer demand. Increased prospective of today's customer is more challenging for now a day's manufacturing industry (Malek *et al.,* 2000). To stay in today competitive scenario, industries are required to become upgrade by implement agile manufacturing system (Gunasekaran and Yusuf, 2002). AMS is essentially a combination of flexible manufacturing system, Rapid Prototyping (RP) and Reconfigurable Manufacturing System (RMS) (Sherehiy *et al.* 2007). AMS is also expressed as it is a method which provides fast and effective decisions for both industries and customers (Iftikhar *et al.*, 2013; Raj *et al.,* 2008). For complete the requirement of the customer, it is necessary to keep the agility of manufacturing and design (Sanchez and Nagi 2001; Vinodh and Arvindraj 2012). AMS is essentially focused on volatile market scenario which helps in prospering the industry (Singh *et al.,* 2015). Agility in manufacturing can also be written as capability to prospering in regular and unexpected changes in market scenario, sustain in crumbing and international market which is totally focused on high performance and quality product demand, produce the minimum cost product and provide customer focused services.

Now a days, AMS research is mainly focused on optimization and high level control methods such as advanced design of the product, commercial followers and understanding of culture (Singh *et al.,* 2015; Vinodh and Arvindraj 2012). Few researchers have been focused till now towards study of barriers in the way of implementation of AMS (Ismail *et al.*, 2011). AMS designing is not an easy task and problem comes in front during the designing and implementation (Malhotra, 2014). Some barriers have been identified by various researchers such as waiting-time, production bottom out, stocks perfuse and utilization discrepancy in resources obstruct in effective AMS implementation. (Anand and Kodali, 2008; Dahlgaard and Park 2006; Herron and Hicks 2008). As per our understanding, in previous years researchers have not been investigated these barriers. Hence, in this chapter an effort has been done in investigating the power of barriers during AMS designing and implementation. After the investigation about the strength of barriers, the organization authorized person can take final decision for overwhelming the effect of barriers; which helps in implementation of AMS in any organization.

Hence, fuzzy performance importance index method is suggested in this chapter for the barriers analysis. Furthermore, mostly literature measures various barriers as individual entity affecting to AMS and also they did not find out the strength of each barrier also. So, in this chapter an effort has been done to measure the strength of individual barrier by FPII approach. This chapter objective is (i) to calculate the strength of these barriers by using FPII approach (ii) to produce a distinct index value to each AMS barrier.

9.2 AN OVERVIEW OF FPII APPROACH AND FUZZY RANKING METHOD

A FPII approach and Fuzzy Ranking Method is used to analyze and calculate the performance index value of the barriers. Overview of this FPII approach and fuzzy ranking method is as below. Fuzzy Logic is one more class of Artificial Intelligence. It was mentioned by a famous scientist that humanoid intellectual and choices are depend on “Yes” / “No” reasoning, or “1” / “0” logic. It has been contended that humanoid philosophy does not constantly follows crispy “Yes” / “No” logic, but is regularly vague, qualitative inexactness, and fuzzy in nature.

On the basis of humanoid fuzzy thinking nature, Lofti a computer science researcher at the University of California, Berkeley, investigated the fuzzy set theory or “fuzzy logic” in 1965. In the starting, it was extremely investigated by the researchers that Fuzzy Logic captured the imagination, of the entire new discipline of Artificial Intelligence (AI). The general methodology or guidelines is the alike; hence, it is mainly known as “fuzzy expert system”.

9.2.1 Fuzzy set theory

In this judgment creating circumstances, high uncertainties and very high volume of degree of fuzziness are integrated in the set of data. It is challenging to create the reliability data due to several restrictions e.g. occurrence of failures of component, humanoid inaccuracies and financial contemplations. Furthermore, if data availability is there, it may be inaccurate so this condition can create uncertainty. Additionally, adversative working situations and the impulses of industrial manufacture procedures disturb the individual part of system. Though, it can be challenging or even not possible to create balanced database to provide all working and ecological circumstances. This theory also helps in making a database for supervision the problems. This theory was initiated by Zadeh and afterwards in 1970 Bellman and Zadeh jointly provide few fuzzy set theories applications in various judgmental creating steps in fuzzy circumstances.

During the 1976 to 1978 time period; one of the fuzzy optimization method like Linear Programming Problem (LPP) with several cases like single and multiple objective is presented by Zimmerman. Afterwards, it has been applied to various real situation problems where fuzziness survives. In literature, fuzzy set theory is used in different uncertainty cases. Various researchers have been used this theory to handle maintenance decision problem. Cheng in 1994 elaborated the application of grey theory to create critical evaluation. But this theory is mainly used in engineering system failure cases, however it still exist in hypothetical time period of research. During the hypothetical time period of research to engineering practical research time many work has already been completed. The main fuzzy set theory concepts are described as below:

9.2.2 Fuzzy sets

Fuzzy sets include the substances which mainly fulfill exact situations of MF. In this case, mainly two things can possible, whether a particle belongs or particle is not belonging to existing set. Characteristics functions can also be represented by a crisp set "A". For this one method is also proposed which is mainly depend on fuzzy linguistic model for selecting the maximum operating preservative technique for the individual component of the system.

$$M_A / u = \{0,1\}.$$

$$M_A(x) = \begin{cases} 1 \ \ if \quad x \in A \\ 0 \ \ if \quad x \notin A \end{cases}$$

Here: Universe of discourse is represented by U

Element of U is represented by X

Crisp set is represented by A

Characteristic function is represented by M

However, fuzzy set include the things which fulfil indefinite properties of MF it means membership of a thing in a fuzzy set can be fractional. Conflicting to standard set, fuzzy set include numerous degree of memberships function on constant time period [0, 1],

Here: No membership function is represented by '0'

Full membership function is represented by '1'

Statistically, the MF a fuzzy set Ã is represented by:

$$\mu_{\tilde{A}}(x): U \rightarrow [0, 1]$$

Here, Degree of membership of element x in fuzzy set Ã is represented by $\mu_{\tilde{A}}(x)$

9.2.3Membership Function (MF)

Many MF like as gamma, triangular, rectangular and trapezoidal may be used for reliability analysis. Fuzzy number is a convex fuzzy number sets which is mainly categorized by a known interim of actual number; each one is represented by MF between 0 and 1.

Though, Triangular Membership Functions (TMF) is mainly use for computing and understanding the reliability information because of their easiness and recognizes ability. However, using extra complex number, like Gaussian and trapezoidal one, allow an additional exact explanation of the problems under examination. On the other hand; they create more computational difficulty without giving substantial benefit. Additional feature that enhances to the range decisions of TFN lie in their comfort to signify the MF efficiently and to include the decision circulation of numerous professionals. This is not accurate for complex MFs like as trapezoidal function. For example, inexact or imperfect data like as up/down failure rate *e.g.* about 3 or in between 4 and 6 is soundly described by triangular member function.

A TMF is stated here by well-ordered triple Ã = (l, m, u) representative, separately, the lesser value, the medium value, and the higher value of a TMF. To determination of fuzzy set in relations of essential fuzzy set, the idea of α cut is used. They are essential in execution of mathematics processes along with crisp set. α Cut of a crisp set Ã signified by $\tilde{A}_\alpha$, is the fuzzy sets included of altogether element x of creation of dissertation for which association of better than or equivalent to α is represented by:

$$A_\alpha = \{x \in X \mid \mu\tilde{A}(x) \geq \alpha\}$$

9.2.4 Linguistic Variables

When variable values are representing in words or natural sentences and may be in artificial language is known as linguistic variables. When result is inaccurately or imprecisely stated, the authorities would basically say's that the option of incidence of a specified result is "'low", " fairly high", and "high". To estimation of such individual results linguistic variables are used. So to make the fuzzy results of the elements and their consistent weights of position, linguistic variable are used to evaluate and calculate the event by expending well-stated fuzzy MF's. A linguistic variables are categorized by (X, T, U, M)

Here: The fuzzy linguistic variables are represented by X

The combination of linguistic value that X can take is represented by T

The crisp value of quantitative linguistic variables X is represented by U

The rule which establish the relationship between T and U is represented by M

9.2.5 Fuzzy Numbers

X is the collections of object, known as universe, whose variables are represented by x. The Fuzzy Subset (FS) A in X is considered by a MF's $f_A(X)$ is related through individual component x in X and a actual numbers in period [0,1]. The FS, A is called a fuzzy digit if A is convex and here exist precisely single actual numbers with $f_A(A) = 1$. Around there are numerous methods to signify fuzzy number; now we practice TFN.

TFN, A can be represented by a threesome (a,b,c).

So, now MF f_A(x) is represented as below:

$$f_A(x) = \begin{Bmatrix} \dfrac{x-a}{b-a} & a \leq x \leq b \\ \dfrac{x-c}{b-c} & b \leq x \leq c \\ 0 & otherwise \end{Bmatrix}$$

9.2.6 Fuzzy Arithmetic Operation

Assume A_1 and A_2 are the TFN, where

A_1 (a_1, b_1 , c_1) and

A_2 (a_2, b_2 , c_2)

The TFNs arithmetic operations such as additions, subtraction, multiplication and division operation of A_1 and A_2 are explained as below:

Addition: $$A_1 \oplus A_2 = \left(a_1 + a_2, b_1 + b_2, c_1 + c_2\right)$$

Subtraction: $$A_1 \Theta A_2 = \left(a_1 - c_2, b_1 - b_2, c_1 - a_2\right)$$

Multiplications: assume k is act as scalar value

$$k \otimes A_1 = \begin{cases} \left(ka_1, kb_1, kc_1\right), \ k > 0 \\ \left(kc_1, kb_1, ka_1\right), \ k < 0 \end{cases}$$

If a1≥0, a2≥0 $$A_1 \otimes A_2 = \left(a_1 a_2, b1b2, c1c2\right)$$

Division If a1≥0, a2≥0

$$A_1 \emptyset A_2 \approx \left(\frac{a_1}{c_2}, \frac{b_1}{b_2}, \frac{c_1}{a_2}\right)$$

However multiplications and divisions operation on TFN's is not essentially produce a TFN, TFN estimation can be used for numerous real-world applications. TFN are suitable for count the imprecise data about the maximum result oriented difficulties comprising of our individual choices such ranking for originality, character and management. The main motive for consuming TFN's can be specified as their instinctive and effectual demonstration.

9.2.7 Euclidean Distance Method (EDM)

EDM consist of computing the distance from particular crisp number to individually of the crisp number signify the usual- linguistic communication sets. The distance among the crisp number calculated by fuzzy agility Index and respective crisp number members can be determined as:

$$d(FAI, AL_i) = \left\{\sum_{x \in p}(f_{FAI}(x) - f_{ALi}\,(x))^2\right\}^{1/2}$$

9.2.8 Defuzzification of Triangular Fuzzy Numbers

It is the concession of a fuzzy number to exact magnitude, like as fuzzy-Fication is the adaptation of an exact magnitude to a fuzzy number. Here may be condition wherever the amount produced of a fuzzy procedure requests to be a only scalar number as disparate to a fuzzy sets.

9.2.8.1 Types of Defuzzification Methods

There are six types of defuzzification method. They are

A) Maximum Membership Principle

This is moreover recognized as the height method and this principle is somewhere restricted to peaky output function. This principle is represented in mathematical expression as below:

$$\mu_c\,(x) \geq \mu_c\,(x) \text{ for all } x \in x$$

B) Centroid Method

Centroid method is also known by different name such as center of gravity and center of area which is the maximum predominant and actually interesting of altogether the defuzzification technique. This method is represented in mathematical expression as below:

$$x^* = [\,\int \mu_i\,(x)\,dx\,] \,/\, [\,\int \mu_i\,(x)\,dx$$

C) Weighted average method

For regular output MF, weighted average method is more suitable as comparison to other method. This method is molded by weighing individual MF in the result by its particular extreme membership significance. This method is represented in term of algebraic expression as below:

$$Z^* = [\sum\mu_c(\check{z}).\ \check{z}] / [\sum\mu_c(\check{z})]$$

D) Mean – Maximum Membership

Mean- Maximum Membership Method is also known as middle of maxima which is nearly related to the maximum membership principle. It is suppose that the position of the supreme MF can be non-unique. Mathematical expression for this method is as below:

$$Z = (a + b) / 2$$

E) Center of Sums

Center of Sums procedure includes the algebraic sum of the distinct output crisp sets in its place of their unification. Defuzzified value of z* is represented by the below equation:

$$z* = \int z \sum_{k=1}^{n} \mu_{c_k}(z)dz \Big/ \int \sum_{k=1}^{n} \mu_{c_k}(z)dz$$

F) Center of Largest Area

Let it be the fuzzy output set has two convex sub region, formerly the gravity center of the convex crisp sub-region include the major area is used to acquire the de-fuzzified value of the result. It is mathematically represented as below

$$z* = \int \mu_{c_m}(z)zdz \Big/ \int \mu_{c_m}(z)dz$$

9.2.9 Fuzzy Performance Importance Index Approach

During the calculation of Fuzzy performance importance index, the weights of importance W_i will counterbalance the performance rating in evaluation process of FPII. It is nearly not possible to find out the main actual problems means whose is low in performance rating and high in importance.

Let it be, W_i is on upper side so there is need to find out the transformation i.e. [(1, 1, 1) – W_i] which is low. Subsequently, for individual agile barrier there is need to find out performance index value by below equation:

$$FPII_i = W_i' * R_i$$

Here

$$W_i' = (1,1,1) - W_i$$

Fuzzy importance weight of the agile barrier i is represented by W_i
Fuzzy performance rating of the agile barrier i is represented by R_i

Now with the help of above formula we can easily find out the performance index for each agile barrier. Subsequently crisp number do not continually produce a completely well-ordered seta as actual number so, altogether the agile barrier must be ranked by FPII approach.

9.2.10 Fuzzy Ranking Method (Chen And Hwang's Left And Right)

Numerous approaches have been established to rank fuzzy numbers (Kwang and Lee 1999). The ranking of the fuzzy number can also be evaluated by this method; subsequently it is not only conserves the position direction but also consider the complete position of individual fuzzy number.

According to Chen and Hwang's left-and-right fuzzy-ranking method, for de-fuzzifying a fuzzy number, Maximizing and minimizing fuzzy set are mathematically expressed as below:

$$f_{max}(x) = \begin{cases} x, & 0 \le x \le 10, \\ 0, & otherwiswe \end{cases}$$

$$f_{min}(x) = \begin{cases} 10 - x, & 0 \le x \le 10, \\ 0, & otherwise \end{cases}$$

TFN's for FPII is defined as

$f_{FPII} : R \rightarrow [0\ ,10]$, with TMF, the left and right score of FPII is represented as below:

$$U_R(FPII) = \sup[f_{FPII}(x) \wedge f_{max}(x)]$$

$$U_L(FPII) = \sup[f_{FPII}(x) \wedge f_{min}(x)]$$

In conclusion, Final ranking of fuzzy performance importance index can also be attained by integrating the right and left score. FPII final score in mathematical expression is represented as below.

$$U_T(FPII) = [U_R(FPII) + \ 10 - U_L(FPII)]/2$$

Here: Left ranking score is represented by U_L

Right ranking score is represented by U_R

Total score is represented by U_T

9.3 MODEL FOR AMS BARRIER BY FPII AND FUZZY RANKING METHOD

Numerous steps used in development of this model are explained as below:

Step1: Identification of AMS barriers

AMS barriers have been found out by deeply literature survey and brain- storming with experts from industry and academia as discussed in chapter 2.

Step 2: Selection of proper linguistic scale

For find out the performance rating and importance weight of the agile barriers there is a need to find out the proper linguistic scale. In fuzzy logic, linguistic terms and repective MF is always evaluated in best way (Karwowski and Mital, 1986). In past years, mostly used linguistic term and respective MF have been projected for linguistic assessment. A Fuzzy Triangular Value (FTV) of linguistic variables for performance ratings and importance weightage is employed as per table 9.1 and 9.2.

Table 9.1: FTV of linguistic variables for performance rating

PERFORMANCE RATINGS (R)			
LINGUISTIC VARIABLES	**FUZZY TRIANGULAR VALUES**		
NOT AT ALL (NL)	0	0	3
SMALL (SM)	0	3	5
SOME (S)	2	5	8
LARGE (L)	5	7	10
VERY LARGE (VL)	7	10	10

Step 3: Measure the performance rating and weightage importance

To calculate the performance rating and weightage importance of each AMS barrier using semantic expressions with support of questionnaire. When the variable for examining the performance rating and weightage importance of the AMS barriers are prescribed as per the industry rules and regulations, industry outline, industry features, business change and routines, facts about market competition, professionals' understanding and information, the professionals can straightly employ the linguistic term atop to measure the ratings which characterize the performance degree for AMS barriers. Performance rating and importance weightage for AMS barriers determined from industry and academia experts are as per table 9.3.

Table 9.2: FTV of linguistic variables for importance weightage

IMPORTANCE WEIGHTING (W)			
LINGUISTIC VARIABLES	**FUZZY TRIANGULAR VALUES**		
NIL(NL)	0	0	0.3
LOW (L)	0	0.3	0.5
MEDIUM (M)	0.2	0.5	0.8
HIGH (H)	0.5	0.7	1
VERY HIGH (VH)	0.7	1	1

Table 9.3: Performance rating and weightage importance measurement

Barriers (B_i)	**Performance Rating (R_i)**	**Importance Weightage (W_i)**
B_1	L	VH
B_2	L	VH
B_3	SM	M
B_4	L	VH
B_5	S	H
B_6	VL	VH
B_7	SM	H
B_8	L	H

Step4: Proximate the linguistic term by fuzzy number

In this step, the transformation of linguistic variables into numerical terms as represented in table 9.4. This conversion is performed on the basis of table 9.1 and 9.2. FTV of linguistic variable for importance weightage and rating of performance are shown in table 9.4

Table 9.4: FTV of importance weightage and performance rating

Barriers (B_i)	**Performance Rating (R_i)**	**Importance Weightage (W_i)**
B_1	(5,7,10)	(0.7,1,1)
B_2	(5,7,10)	(0.7,1,1)
B_3	(0,3,5)	(0.2,0.5,0.8)
B_4	(5,7,10)	(0.7,1,1)
B_5	(2,5,8)	(0.5,0.7,1)
B_6	(7,10,10)	(0.7,1,1)
B_7	(0,3,5)	(0.5,0.7,1)
B_8	(5,7,10)	(0.5,0.7,1)

Step5: Measure the performance with FPII approach

Performance index value for individual AMS barrier is found below. Index value for Barrier 1 (B1) is obtained as below:

$$FPII_1 = [(1, 1, 1) - (0.7, 1, 1)] * (5, 7, 10)$$
$$= (0, 0, 3)$$

In similar way the FPII value of each barrier is calculated as shown in table 9.5.

Step 6: Ranking the barriers by Fuzzy Ranking Method

Final ranking of each AMS barriers have been by using below formula:

$$U_R(FPII) = \sup[f_{FPII}(x) \wedge f_{max}(x)] = 9.685$$

$$U_L(FPII) = \sup[f_{FPII}(x) \wedge f_{min}(x)] = 9.685$$

Therefore, the final score of AMS barriers can be identified by integrating the *left* and *right* score respectively.

Hence, FPII total score is calculated as below:

$$U_T(FPII) = [U_R(FPII) + 10 - U_L(FPII)]/2 = 5$$

Here: Left ranking score is represented by U_L

Right ranking score is represented by U_R

Total score is represented by U_T

Moreover, according to this computation table 9.5 represent ranking of each barrier.

Table 9.5: FPII value and ranking of AMS barriers

Barriers (B_i)	Aggregated Fuzzy Performance Rating	(1,1,1) – Importance Weightage	Fuzzy Performance Importance Index (FPII)	Ranking score
B1	(5,7,10)	(0,0,0.3)	(0,0,3)	5
B2	(5,7,10)	(0,0,0.3)	(0,0,3)	5
B3	(0,3,5)	(0.2,0.5,0.8)	(0,1.5,4)	1.25
B4	(5,7,10)	(0,0,0.3)	(0,0,3)	5
B5	(2,5,8)	(0,0.3,0.5)	(0,1.5,4)	1.25
B6	(7,10,10)	(0,0,0.3)	(0,0,3)	5
B7	(0,3,5)	(0,0.3,0.5)	(0,0.9,2.5)	0.95
B8	(5,7,10)	(0,0.3,0.5)	(0,2.1,5)	5

To obtain the few difficulties, scale 2.0 was benchmarked as the management origin to differentiate which serious barrier need to be augmented. Afterwards, table 9.5 shows that the 3 agile barriers have a lesser performance than the origin, recognized as B3, B5 and B7. Afterwards, as per the result, administrators can choose accordingly agility providers from table 9.5 to appliance enhanced agility hierarchy.

9.4 RESULT, DISCUSSION AND CONCLUSIONS

The practical significance of FPII on AMS barriers recognized from the contemplation of literature and brain storming with connoisseur from education and industry as projected in table 9.5. However very few research papers are available as AMS are comparatively new so the beginning analysis of the barriers will support the policy makers to grasp the idea of capability of actual performance with Indian manufacturing industry. The introduced model supplies the performance index value amongst numerous AMS barriers, which further will enhance to find the cause barrier which should be considered first in order to have speedy implementation among industry.

The outcomes attained from this chapter, the succeeding action are recommended to adoptive the implementation of AMS in Indian industry i) companies should focus firstly on delay in the manufacturing process because this can cause the execution of AMS in all stages ii) transportation barrier is also causes the organization to spend extensive amount of time and money in it, so there is need to eliminate or minimize this barrier by using enterprise resource planning and Computer Numerical Control (CNC) based machining iii) control in production of defective parts is the necessary step for successfully and effectively implementation of agile manufacturing system, so minimizing the effect of defective parts production is necessary.

CHAPTER 10

SYNTHESIS OF RESEARCH WORK

10.1 INTRODUCTION

Agility is one of the most precarious dimensions of improving the effectiveness of the industry. Due to new advancement in technology and customer demands industries are forced towards agile manufacturing systems. The agility of the industry can be achieved only after the implementation of AMS but this implementation process is not an easy task. However, it is very important to investigate various attributes, sub-attributes, barriers, enablers and factors affecting the implementation of AMS. In this chapter, study which has been carried out in relation to these attributes, sub-attributes, enablers, barriers and factors are explained.

10.2 SYNTHESIS OF RESEARCH WORK

Research described during thesis work concerns the examination of few issues regarding the AMS implementation. Specified objectives in chapter 1 were successfully carried out and achieved objective are as follow:

- The understandings on points regarding AMS implementation have been established.
- Actual gaps in circumstance of acceptance and execution of AMS have been recognized.
- Main attributes, sub-attributes, enablers, barriers and factors for evolution of AMS have been recognized through literature survey and brain storming with industry and academia experts.
- Preferences towards acceptance and execution of AMS for Indian industries have been extended.
- Agility Index level of Indian industries has been identified.

- Driving power and dependence power of AMS factors and enablers have been established.
- Weightage of criteria's and ranking of AMS facilitators have been analyzed.
- Performance index value for each AMS barriers has been established.
- For smooth AMS evaluation; interrelationship model between identified factors and enablers have been established.

For accomplishing the above described objectives, diverse approaches used in the contemporaneous research are shown in table 10.1. The studies established in this research are as follows:

10.2.1 Literature Review

A widespread literature review was carried out through which execution process of AMS and diverse issue regarding it, was studied. An enormous number of research papers were studied concerning different issue related to the problems. The comprehensive study of attributes, sub-attributes, enablers, factors and barriers, FAI approach, ISM, TISM, Entropy Approach, MOORA Method, VIKOR analysis, FPII approach have been reported in chapter 2. The main prominence was placed on the documentation of numerous attributes, sub- attributes, enablers, factors and barriers for acceptance and execution of AMS.

10.2.2 Questionnaire Development and Validation

The study in chapter 3 and chapter 4 has been planned to produce the opinion of Indian organizations concerning about essential issues regarding acceptance and execution of AMS. Results of the questionnaire survey exposed the important enabler and factors manipulating the AMS implementation. After the questionnaire survey, importance weightage of attributes and sub-attributes have been identified. Performance rating of sub-attributes have also been identifies through questionnaire survey which finally helped in finding out the agility index of the Indian industry. This questionnaire survey output also helped in development of ISM and TISM model for enablers and factors.

Table 10.1: Diverse approaches used in contemporaneous research

Objectives	Methodology	Study No.
To recognize the significance of numerous concerns regarding agile manufacturing system.	Literature survey, brain storming and expert opinion from industry and academia both.	1
To observe the insight of Indian industry towards issue regarding the acceptance and execution of AMS and validate it.	Questionnaire based survey and ANOVA analysis.	2
To find the agility index for Indian industry.	Fuzzy Agility Index approach	3
Modeling the AMS factors affecting design and execution	Interpretive Structural Modelling	4
Study the AMS enablers affecting design and implementation	Total Interpretive Structural Modelling	5
To find the weightage of the criteria and rank the facilitator	Entropy Approach, MOORA Method and VIKOR analysis	6
To provide the performance index value to each AMS barrier	Fuzzy Performance Importance Index Approach	7

10.2.3 Agility Index Evaluation for Indian Industry

The study in chapter 5 presents the agility index of Indian industry. This agility index value has been produced on the basis of the performance rating and importance weightage of attributes and sub-attributes. Agility index value for Indian industry has been developed by fuzzy agility index approach.

10.2.4 Modelling the Factors and Enablers by ISM and TISM Approach

The study in chapter 6 and 7 has been planned to develop the ISM and TISM models. These models have been established on the base of factors and enablers recognized through the literature review, brainstorming and experts opinion with industry and academia both. Interpretive structural model and total interpretive structural model were developed for AMS factors and enablers respectively. Interrelation between factors and enablers has also been identified from this model. Factors and enablers have also been categorized in levels on the basis of driving and dependence power. This evocative analysis helps the manager in finding out the mutual relationship between factors and enablers. Understanding from this model will help the managers in tactic preparation from executing the AMS.

10.2.5 Evaluation of Criteria Weightage and Facilitators Ranking

The study in chapter 8 has been planned to find out the criteria weightage and ranking of facilitators. This criteria's affecting AMS has been identified through literature survey and brain storming with industry and academia experts. Entropy approach was used for find out the weightage of the criteria's. Key factors and enablers identified through ISM and TISM model has given the name as facilitators. Ranking of these enablers has been done by MOORA method and VIKOR analysis separately. Final ranking was established after integrating the MOORA method and VIKOR. This final ranking of AMS facilitators helps the industry managers in AMS implementation.

10.2.6 Performance Index Evaluation for AMS Barriers

Chapter 9 provides the performance index value to each AMS barrier. These AMS barriers have been identified through the literature survey and with experts opinion. Fuzzy performance importance index approach was used to calculate the performance index value. Final ranking of these index values is done by fuzzy ranking method (Chen and Hwang's left and right rule). These ranking helps the manager in taking the decision to tackle the barriers.

10.3 CONCLUSION

Synthesis of this research reported in this research has been presented in this chapter. Flow diagram for integration of all used methodologies is presented in figure 10.1. Conclusion, limitation and future scope was presented in next chapter.

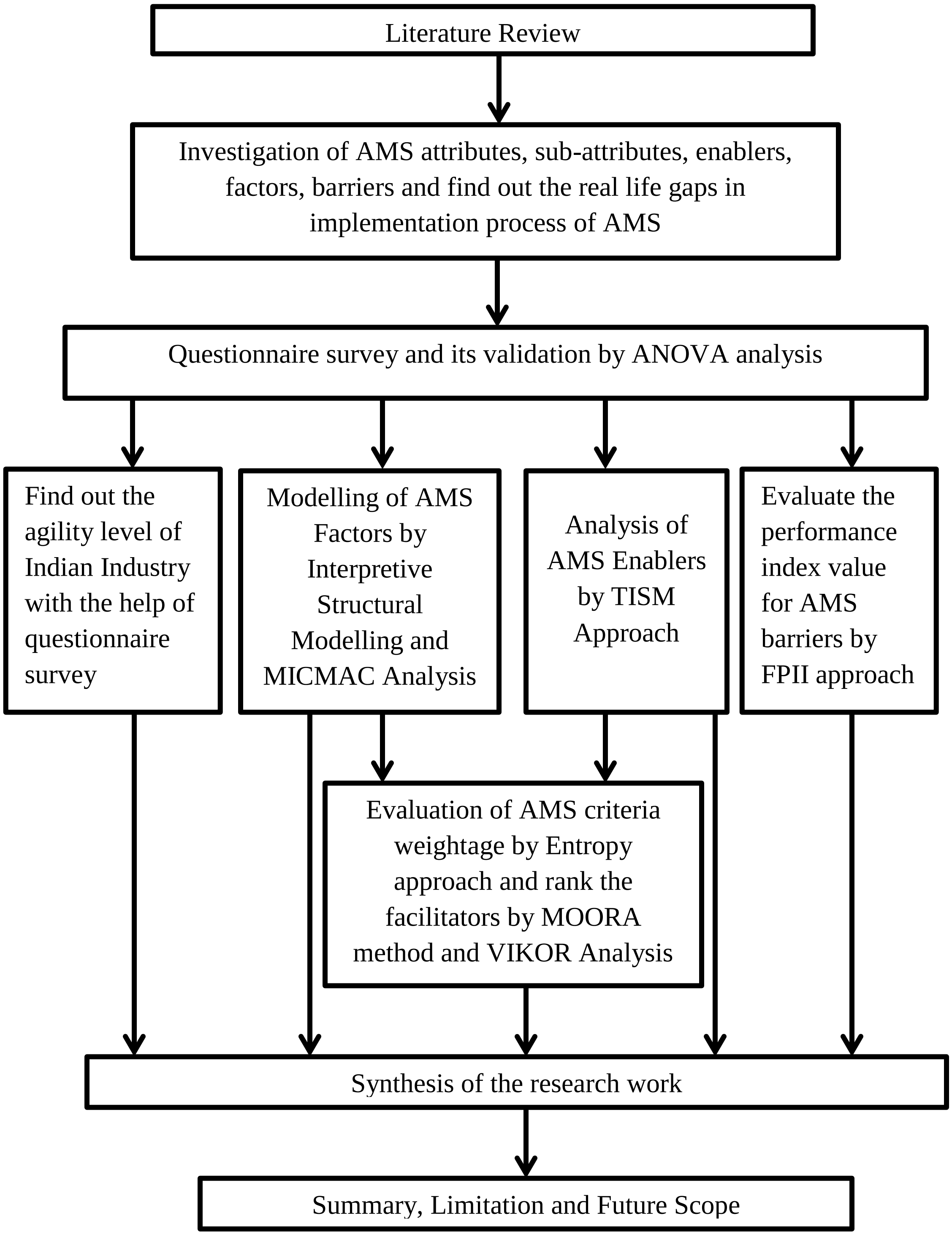

Figure 10.1: Synthesis of the research work

CHAPTER 11

CONCLUSION, LIMITATIONS AND FUTURE SCOPE

11.1 INTRODUCTION

High competitive scenario emphasizes the Indian industry to adopt agile manufacturing system. From last many years; researcher explored the various factors, enablers and barriers but till now execution and adoption of AMS is a very challenging task. This is only due to research gap occurring amongst the hypothetical studies carried till date and practical expectancy of decision makers in industry. Very few implementation of AMS mainly in developing country like India, motivate the researcher to analyze and evaluate the AMS attributes, sub-attributes, factors, enablers and barriers. In the the last chapter of this thesis, the summary of the research, major contribution and key finding of the research, major implication and limitation of the research with future scope and conclusion of the research work have been presented.

11.2 SUMMARY OF THE WORKDONE

This section signifies the work done towards accomplishing the research objectives is presented. The core work done commenced in this research includes the following

- The widespread literature survey was accompanied to find out the attributes, sub-attributes, factors, enablers and barriers in the area of AMS.

- After the literature survey and brainstorming with the industry and academia personnel, a questionnaire was deliberated to stimulate reactions from the industry experts. Reactions from the industry were used, which helps in comprehend the preference of the Indian industry towards execution and implementation of AMS.

- Results of the questionnaire survey were validated by ANOVA analysis.

- Agility of Indian industry was found by fuzzy agility index approach.

- Interpretive structural modelling and total interpretive structural modelling was used for analysing and evaluating the interrelationship between factors and enablers.

- Entropy approach was applied for calculating the weightage of the AMS criteria.

- MOORA method and VIKOR analysis have been applied for calculating the ranking of AMS facilitators.

- Fuzzy performance importance index approach has been applied for calculating the performance index values of AMS barriers.

11.3 MAJOR CONTRIBUTION OF RESEARCH

The major contributions made through this research are given below

- The present research provides a widespread evaluation of the literature and current research issue regarding AMS implementation.

- Various attributes, sub-attributes, factors, enablers and barriers are identied which affect in implementation strategy of AMS.

- Agility level of Indian industry has been identified.

- Mutual relationships among factors have been identified by interpretive structural modelling approach.

- With the TISM modelling interpretation relationship between the enablers of AMS have been developed.

- The driving power and dependence power of the factors and enablers have been evaluated by interpretive structural modelling and total interpretive structural modelling.

- Major factors and enablers affecting the AMS implementation have been isolated.

- Weightage of AMS affecting criteria's have been identified by Entropy approach.

- Ranking of AMS facilitators have been done by MOORA method and VIKOR analysis

- Performance index value for each barrier has been calculated for each barrier of AMS with fuzzy performance importance index approach.

11.4 KEY FINDING OF THE RESEARCH

The key finding emerges from this research are as follows:

- Implementation of fuzzy agility index on attributes and sub-attributes affecting AMS cleared out that our Indian companies are lacking behind in achieving the complete agility level. It offers a prospect to target alongside the best practices regarding agile manufacturing systems.

- An insight into the ISM model and MICMAC analysis of factors affecting AMS find out that organizational structure, information technology integration, and outsourcing, development of design methodology, convertibility and multi-lingual are having high driving power and low dependency power. These identified factors may be treated as key enabler in implementation strategy of AMS.

- With the TISM modelling and MICMAC analysis for enablers of AMS identified that virtual enterprise, flexible work-force, top-management support, organizational structure and information technology integration are having high driving power and low dependency power. These identified enablers may be treated as key enabler in implementation strategy of AMS.

- The levels of different factors and enablers have been found by ISM and TISM approach.

- Organisational structure and multilingual factors deliberated as higher driving power than the other factors such as development design methodology, outsourcing *etc.*

- Top management support, information technology integration enablers deliberated as higher driving enabler than other enablers such as pull production, machine utilization *etc.*

- Agility criteria attain maximum weightage after implementation of entropy weightage approach.

- Organizational structure and Virtual enterprise attain first and second rank after implementation of MOORA method and VIKOR analysis.

- Discrepancy in resource utilization, waiting time and processing are the main barrier that crossed the threshold value and need a prior attention than other barriers.

11.5 IMPLICATION OF RESEARCH

The outcomes of the research have resourced to prepared some essential influences to the literature. These judgement contracts with some essential and extensively deliberated concerns correlated to execution of AMS. The main influences of this research are as follows:

- A significant involvement of this exploration to literature is the identification of gaps in the current research in the area of AMS. Complete list of research gap in the field of agile manufacturing system was not reported earlier as per our understanding. The findings of this research have led to strong contribution to the literature of "Agile Manufacturing System".

- These findings deal with some important and widely discussed factors, enablers, criteria's and barriers related to agility and agile manufacturing. Interrelationship among factors and enablers has also been discussed.

- The analysis reveals that placing proper emphasis on these factors and enablers are the key to enhance the agility and hence competitiveness of a company.

- A performance index value has been proposed to each AMS barrier.

- Agile manufacturing system is found as the best manufacturing among all feasible alternatives.

11.5.1 Implication for the Academicians

Few important suggestions for academicians, which have developed from this research, are given below:

- ❖ The study on various issues related to agility and agile manufacturing presented in this research provide insight for further research in this area.

- Literature on agility and agile manufacturing will be helpful to researchers in carrying out research in these areas.

- Fuzzy Agility Index (FAI) approach can be used by academician for identifying agility level of the institutes.

- ANOVA analysis is used to validate the questionnaire which can be used as an important tool for the academicians in their research

- ISM and TISM methodology helps to impose order and direction on the complexity of relationships among elements of a system, so ISM and TISM may be used by researchers for establishing relationships and also identifying the level of the various elements of a system/environment.

- A Fuzzy Performance Importance Index (FPII) has been employed which combines the performance rating and importance weight of each agility element capability, represents an effect which will contribute to the agility level of an organization. This may motivate academicians to apply FPII in other agile manufacturing related decision making process.

- In this research, various methods such as Entropy, MOORA, VIKOR have been dealt to evaluate criteria weightage and facilitators ranking. Such synthesis, are very important in order to determine the issues regarding the agile manufacturing.

11.5.2 Implications for the Managers

Managers those who are decision makers in the industrialized area can develop beneficial identifications from the observed study presented in the research are as follows:

- Managers may take driving factors and driving enablers identified by ISM, TISM and MICMAC analysis as on first priority for improving the agility of the industry.

- Managers may use ranking of facilitators find out by MOORA method and VIKOR analysis for implementation of AMS in an industry

- Managers may find the application of FPII useful for making selection of reducing the effect of AMS barrier.

- The managers should have clearly visualized the implementation procedure of AMS

11.6 LIMITATION AND SCOPE FOR FURTHER WORK

This section provides the limitation in this research and affords some suggestions for future research. It is essential to openly recognize the limitations of the research which are as follows:

- As this research focus on Indian industry with wide range of sector, products and sizes of industry, these differences can create variability in the responses. So, it would be good if study will do on particular sector, product or sizes of industry.

- There is a need to further explore the role of these key factors and enablers for particular industry for better improving the agility index of industry.

- Contextual relationship developed in ISM and TISM model has been developed with expert opinion, which may have introduced some element of bias.

Although this research has a deliberated effect on execution of AMS yet forthcoming research may be attentive on to make this execution easier. However, the research work can be extended to following directions:

- More number of attributes and sub-attributes affecting the AMS can be identified for more clarity in agility index value.

- Extension of factors and enablers affecting AMS is possible to develop ISM model and TISM model.

- ISM model for factors affecting AMS and TISM model for enabler of AMS has been developed. This model has not been statistically validated. So, these models can be validated by structural equation modelling.

- Other multi-criteria decision making techniques like AHP, ANP and GTA approach can be applied on identified factors and enablers of AMS.

- Simulation technologies can be developed for easier and accurate implementation of AMS

- Case study can be carried out to examine the impact of key factor and key enablers in different practical situations.

- There is a need to create a relationship between the agile manufacturing system and green manufacturing system.

11.7 CONCLUSION

The main focus of this thesis work is to provide the easy way to implement agile manufacturing system in Indian industry. The research conceded out in this thesis to emphases on some significant concerns related to AMS. In the present work the attributes, sub-attributes, factors, enablers and barriers related to AMS have been deliberated and some gaps regarding these in the hypothetical research have been acquainted.

The way of acceptance and execution of AMS in Indian industry is not an easy task. There are various concerns which deliberately affect the acceptance and execution of AMS. These concerns are attributes, sub-attributes, factors, enablers and barriers which are having high relationship to AMS implementation. A number of attributes, sub-attributes, factors, enablers and barriers have been recognized in the contemporaneous work and effort has been made to evaluate the nature.

Agility index value for Indian industry have been identified which concludes that Indian industries do not comes under “complete agile” category. Relationship among factors and enablers has been established by interpretive structural modelling approach and total interpretive structural modelling approach respectively. From the interpretive structural modelling for factors identified that organizational structure factor and multilingual factor have high driving power and low dependency power which signify that manager has to first focus on these factor for easy implementation of AMS. Afterwards, total interpretive structural modelling for enablers identified that the top management support and information technology integration enablers deliberated as higher driving and low dependency power than other identified enablers. So, decision makers also firstly focus on these enablers for execution of AMS.

These driving factor and enablers are predominantly known as facilitators of AMS. AMS criteria’s has been weighted by entropy approach which concludes that agility criteria attain highest weightage among other criteria’s for industry. Afterwards, facilitators are ranked by MOORA method and VIKOR analysis which delivers that organizational structure and virtual enterprise attain first and second rank in other facilitators. Fuzzy performance index value to each AMS barriers has been assigned by FPII approach and ranks the each barrier by fuzzy ranking method. This ranking provides that discrepancy in resource utilization, waiting time and processing is the main barrier that crossed the threshold value and need to prior attention than the other barriers.

REFERENCES

- Abdel-Malek, L., Das, S. K., & Wolf, C. (2000), 'Design and implementation of flexible manufacturing solutions in agile enterprises', International Journal of Agile Management Systems, Vol. 2, No. 3, pp. 187-195.

- Abdollahi, M., Arvan, M., & Razmi, J. (2015), 'An integrated approach for supplier portfolio selection: Lean or agile?', Expert Systems with Applications, Vol. 42, No. 1, pp. 679-690.

- Akyene, T. (2012), 'Cell phone evaluation base on entropy and TOPSIS', Interdisciplinary Journal of Research in Business, Vol. 1, No. 12, pp. 9-15.

- Al Samman, T. A. S. (2014), 'Modelling Lean, Agile, Leagile Manufacturing Strategies: An Fuzzy Analytical Hierarchy Process Approach For Ready Made Ware (Clothing) Industry In Mosul, Iraq', International Journal of Advances in Engineering & Technology, Vol. 7, No. 3, pp. 1091.

- Anand, G., & Kodali, R. (2008), 'Selection of lean manufacturing systems using the PROMETHEE', Journal of Modelling in Management, Vol. 3, No. 1, pp. 40-70.

- Aravind R.S., Sudheer, A., Vinodh, S., & Anand, G. (2013), 'A mathematical model to evaluate the role of agility enablers and criteria in a manufacturing environment', International Journal of Production Research, Vol. 51, No. 19, pp. 5971-5984.

- Attri, R., Grover, S., Dev, N., & Kumar, D. (2013), 'An ISM approach for modelling the enablers in the implementation of Total Productive Maintenance (TPM)', International Journal of System Assurance Engineering and Management, Vol. 4, No. 4, pp. 313-326.

- Attri, R., Dev, N., & Sharma, V. (2013), 'Interpretive structural modelling (ISM) approach: an overview', Research Journal of Management Sciences, Vol. 2, No. 2, pp. 3-8.

- Attri, R., Grover, S., Dev, N., & Kumar, D. (2013), 'Analysis of barriers of total productive maintenance (TPM)', International Journal of System Assurance Engineering and Management, Vol. 4, No. 4, pp. 365-377.

- Attri, R., & Grover, S. (2014), 'Decision making over the production system life cycle: MOORA method', International Journal of System Assurance Engineering and Management, Vol. 5, No. 3, pp. 320-328.

- Babazadeh, R., Razmi, J., & Ghodsi, R. (2012), 'Supply chain network design problem for a new market opportunity in an agile manufacturing system', Journal of Industrial Engineering International, Vol. 8, No. 1, pp. 1-8.

- Beel, J., Gipp, B., & Wilde, E. (2009), 'Academic Search Engine Optimization (aseo) Optimizing Scholarly Literature for Google Scholar & Co.', Journal of scholarly publishing, Vol. 41, No. 2, pp. 176-190

- Beruvides, G., Quiza, R., & Haber, R. E. (2016), 'Multi-objective optimization based on an improved cross-entropy method. A case study of a micro-scale manufacturing process', Information Sciences, Vol. 334, pp. 161-173.

- Błażewicz, J., Ecker, K. H., Pesch, E., Schmidt, G., & Weglarz, J. (2013), 'Scheduling computer and manufacturing processes', Springer Science & Business Media.

- Bookbinder, J. H., & Locke, T. D. (2013), 'Simulation analysis of just-in-time distribution', International Journal of Physical Distribution & Materials Management.

- Brauers, W. K. M., & Zavadskas, E. K. (2006), 'The MOORA method and its application to privatization in a transition economy', Control and Cybernetics, Vol. 35, No. 2, pp. 445.

- Brauers, W. K. M., Zavadskas, E. K., Peldschus, F., & Turskis, Z. (2008), 'Multi-objective decision-making for road design', Transport, Vol. 23, No. 3, pp. 183-193.

- Bustelo, D., & Avella, L. (2006), 'Agile manufacturing: Industrial case studies in Spain', Technovation, Vol. 26, No. 10, pp. 1147-1161.

- BüyüKözkan, G., DerelＩ, T., & Baykasoğlu, A. (2004), 'A survey on the methods and tools of concurrent new product development and agile manufacturing', Journal of Intelligent Manufacturing, Vol. 15, No. 6, pp. 731-751.

- Carvalho, H., Duarte, S., & Cruz Machado, V. (2011), 'Lean, agile, resilient and green: divergencies and synergies', International Journal of Lean Six Sigma, Vol. 2, No. 2, pp. 151-179.

- Chakraborty, A., & Mandal, P. (2014), 'Understanding challenges of supply chain sustainability in Asia', International Journal of Process Management and Benchmarking, Vol. 4, No. 1, pp. 51-68.

- Chang, C. L., & Hsu, C. H. (2009), 'Multi-criteria analysis via the VIKOR method for prioritizing land-use restraint strategies in the Tseng-Wen reservoir watershed', Journal of Environmental Management, Vol. 90, No. 11, pp. 3226-3230.

- Chen, S. J., & Hwang, C. L. (1992), 'Fuzzy multiple attribute decision making methods. In Fuzzy Multiple Attribute Decision Making', Springer Berlin Heidelberg, pp. 289-486.

- Cheng, K., Harrison, D. K., & Pan, P. Y. (1998), ‘Implementation of agile manufacturing—an AI and Internet based approach’, Journal of Materials Processing Technology, Vol. 76, No. 1, pp. 96-101.

- Cho, H., Jung, M., & Kim, M. (1996), ‘Enabling technologies of agile manufacturing and its related activities in Korea’, Computers & Industrial Engineering, Vol. 30, No. 3, pp. 323-334.

- Chen, Y., Li, Z., & Zhou, M. (2014), ‘Optimal supervisory control of flexible manufacturing systems by Petri nets: A set classification approach’, IEEE Transactions on Automation Science and Engineering, Vol. 11, No. 2, pp. 549-563.

- Christensen, R. (2011), ‘Plane answers to complex questions: the theory of linear models’, Springer Science & Business Media.

- Coronado, A. E. (2003), ‘A framework to enhance manufacturing agility using information systems in SMEs’, Industrial Management & Data Systems, Vol. 103, No. 5, pp. 310-323.

- Cover, T. M., & Thomas, J. A. (2012), Elements of information theory, John Wiley & Sons.

- Dahlgaard, J. J., & Mi Dahlgaard-Park, S. (2006), ‘Lean production, six sigma quality, TQM and company culture,’ The TQM magazine, Vol. 18, No. 3, pp. 263-281.

- Dashore, K., Pawar, S. S., Sohani, N., & Verma, D. S. (2013), ‘Product Evaluation Using Entropy and Multi Criteria Decision Making Methods’, International Journal of Engineering Trends and Technology (IJETT), Vol. 4, No. 5, pp. 2183-2187.

- Demoly, F., Dutartre, O., Yan, X. T., Eynard, B., Kiritsis, D., & Gomes, S. (2013), 'Product relationships management enabler for concurrent engineering and product lifecycle management', Computers in Industry, Vol. 64, No. 7, pp. 833-848.
- Devadasan, S. R., Sivakumar, V., Murugesh, R., & Shalij, P. R. (2012), 'Lean and Agile Manufacturing: Theoretical, Practical and Research Futurities', PHI Learning Pvt. Ltd.

- DeVor, R., Graves, R., & Mills, J. J. (1997), 'Agile manufacturing research: accomplishments and opportunities', IIE transactions, Vol. 29, No. 10, pp. 813-823.

- Dillon, A. P., & Shingo, S. (1985). A revolution in manufacturing: the SMED system. CRC Press.

- Dubey, R., & Ali, S. S. (2014), 'Identification of flexible manufacturing system dimensions and their interrelationship using total interpretive structural modelling and fuzzy MICMAC analysis', Global Journal of Flexible Systems Management, Vol. 15, No. 2, pp. 131-143.

- Dubey, R., & Gunasekaran, A. (2015), 'Agile manufacturing: framework and its empirical validation', The International Journal of Advanced Manufacturing Technology, Vol. 76, No. 9-12, pp. 2147-2157.

- Duray, R. (2002), 'Mass customization origins: mass or custom manufacturing?', International Journal of Operations & Production Management, Vol. 22, No. 3, 314-328.

- Elmoselhy, S. A. (2015), 'Implementing the Hybrid Lean-Agile Manufacturing System Strategically in Automotive Sector', SAE International Journal of Materials & Manufacturing, Vol. 8, No. 2, pp. 592-601.

- Frayret, J. M., D'Amours, S., Montreuil, B., & Cloutier, L. (2001), 'A network approach to operate agile manufacturing systems', International Journal of Production Economics, Vol. 74, No. 1, pp. 239-259.

- Fullerton, R. R., Kennedy, F. A., & Widener, S. K. (2014), 'Lean manufacturing and firm performance: The incremental contribution of lean management accounting practices', Journal of Operations Management, Vol. 32, No. 7, pp. 414-428.

- Gadakh, V. S. (2010), 'Application of MOORA method for parametric optimization of milling process', International Journal of Applied Engineering Research, Vol. 1, No. 4, pp. 743.

- Gadakh, V. S., Shinde, V. B., & Khemnar, N. S. (2013), 'Optimization of welding process parameters using MOORA method', The International Journal of Advanced Manufacturing Technology, Vol. 69, No. 9-12, pp. 2031-2039.

- Garbie, I. H., & Al-Hosni, F. S. (2014), 'New evaluation of petroleum companies based on the agility level in gulf area', International Journal of Industrial and Systems Engineering, Vol. 18, No. 4, pp. 528-572.

- Ghorbani, M., Bahrami, M., & Arabzad, S. M. (2012), 'An integrated model for supplier selection and order allocation; using Shannon entropy, SWOT and linear programming', Procedia-Social and Behavioral Sciences, Vol. 41, pp. 521-527.

- Goldman, S., Nagel, R., and Preiss, K. (1995), 'Agile Competitors and Virtual Organization: strategies for enriching the customers', New York, NY: Van Norstand Reinhold.

-

- Goldsby, T. J., Griffis, S. E., & Roath, A. S. (2006), 'Modeling lean, agile, and leagile supply chain strategies. Journal of business logistics', Vol. 27, No. 1, pp. 57-80.

- Goyal, S., & Grover, S. (2013), 'Manufacturing system's effectiveness measurement by using combined approach of ANP and GTMA', International Journal of System Assurance Engineering and Management, Vol. 4, No. 4, pp.404-423.

- Gunasekaran, A. (2001), 'Agile manufacturing: the 21st century competitive strategy', Elsevier.

- Gunasekaran, A. (1999), 'Agile manufacturing: a framework for research and development', International journal of production economics, Vol. 62, No. 1, pp. 87-105.

- Gunasekaran, A., Lai, K. H., & Cheng, T. E. (2008), 'Responsive supply chain: a competitive strategy in a networked economy', Omega, Vol. 36, No. 4, pp. 549-564.

- Gunasekaran, A., Tirtiroglu, E., & Wolstencroft, V. (2002), 'An investigation into the application of agile manufacturing in an aerospace company', Technovation, Vol. 22, No. 7, 405-415.

- Hallgren, M., & Olhager, J. (2009), 'Lean and agile manufacturing: external and internal drivers and performance outcomes', International Journal of Operations & Production Management, Vol. 29, No. 10, pp. 976-999.

- Harzing, A.W. and Wal, R.V.D., (2007), Google Scholar as a new source for citation analysis, Ethics in Science and Environmental Politics, Vol. 8, No. 1, pp. 1-13.

- Harnett, D. L. D. L., & Murphy, J. L. (1980), 'Introductory statistical analysis', (No. 04; QA276, H3 1980.).

- Hasan, M. A., Shankar, R., & Sarkis, J. (2007), 'A study of barriers to agile manufacturing,' International Journal of Agile Systems and Management, Vol. 2, No. 1, pp. 1-22.

- Hasan, M. A., Shankar, R., Sarkis, J., Suhail, A., & Asif, S. (2009), 'A study of enablers of agile manufacturing', International Journal of Industrial and Systems Engineering, Vol. 4, No. 4, pp. 407-430.

- He, D., Babayan, A., & Kusiak, A. (2001), 'Scheduling manufacturing systems in an agile environment' Robotics and Computer-Integrated Manufacturing, Vol. 17, No. 1, pp. 87-97.

- Herron, C., & Hicks, C. (2008), 'The transfer of selected lean manufacturing techniques from Japanese automotive manufacturing into general manufacturing (UK) through change agents', Robotics and Computer-Integrated Manufacturing, Vol. 24, No. 4, pp. 524-531.

- Hopp, W. J., & Oyen, M. P. (2004), 'Agile workforce evaluation: a framework for cross-training and coordination', Iie Transactions, Vol. 36, No. 10, pp. 919-940.

- Hu, S. J. (2013), 'Evolving paradigms of manufacturing: From mass production to mass customization and personalization', Procedia CIRP, Vol. 7, pp. 3-8.

- Huson, M., & Nanda, D. (1995), 'The impact of just-in-time manufacturing on firm performance in the US', Journal of Operations Management, Vol. 12, No. 3, pp. 297-310.

- Iftikhar, A., Khan, M., Alam, K., Imran Jaffery, S. H., Ali, L., Ayaz, Y., & Khan, A. (2013), 'Turbine blade manufacturing through rapid tooling (RT) process and its quality inspection', Materials and Manufacturing Processes, Vol. 28, No. 5, pp. 534-538.

- Ismail, H. S., Poolton, J., & Sharifi, H. (2011), 'The role of agile strategic capabilities in achieving resilience in manufacturing-based small companies', International Journal of Production Research, Vol. 49, No. 18, pp. 5469-5487.

- Jain, V., & Raj, T. (2015), 'Evaluating the intensity of variables affecting flexibility in FMS by graph theory and matrix approach', International Journal of Industrial and Systems Engineering, Vol. 19, No. 2, pp. 137-154.

- Jayalakshmi, B., & Pramod, V. R. (2015), 'Total interpretive structural modeling (TISM) of the enablers of a flexible control system for industry', Global Journal of Flexible Systems Management, Vol. 16, No. 1, pp. 63-85.

- Jayant A, Azhar M, Singh P (2015), 'Interpretive structural modeling (ISM) approach: a state of the art literature review', Int J Res Mech Eng Technol, Vol. 5, No. 1, pp. 15–21.

- Jones, Dan, and Jim Womack (2002), 'Seeing the whole', Lean Enterprise Institute, Brookline.

- Ji, Y., Huang, G. H., & Sun, W. (2015), 'Risk assessment of hydropower stations through an integrated fuzzy entropy-weight multiple criteria decision making method: A case study of the Xiangxi River', Expert Systems with Applications, Vol. 42, No. 12, pp. 5380-5389.

- Jin-Hai, L., Anderson, A. R., & Harrison, R. T. (2003), 'The evolution of agile manufacturing', Business Process Management Journal, Vol. 9, No. 2, pp. 170-189.

- Jung, M., Chung, M. K., & Cho, H. (1996), 'Architectural requirements for rapid development of agile manufacturing systems', Computers & industrial engineering, Vol. 31, No. 3, pp. 551-554.

- Kang, B., & Bekkers, R. (2015), 'Just-in-time patents and the development of standards', Research Policy, Vol. 44, No. 10, pp. 1948-1961.

- Karande, P., & Chakraborty, S. (2012), 'Application of multi-objective optimization on the basis of ratio analysis (MOORA) method for materials selection', Materials & Design, Vol. 37, pp. 317-324.
- Karwowski, W., & Mital, A. (1986), 'Development of a safety index for manual lifting tasks', Applied ergonomics, Vol. 17, No. 1, pp. 58-64.

- Kettunen, P. (2009), 'Adopting key lessons from agile manufacturing to agile software product development—A comparative study', Technovation, Vol. 29, No. 6, pp. 408-422.

- Keenan, F. (2004, May), 'Agile process tailoring and problem analysis (APTLY). In Proceedings of the 26th International Conference on Software Engineering (pp. 45-47). IEEE Computer Society.

- Khatwani, G., Singh, S. P., Trivedi, A., & Chauhan, A. (2015), 'Fuzzy-TISM: A fuzzy extension of TISM for group decision making', Global Journal of Flexible Systems Management, Vol. 16, No. 1, pp. 97-112.

- Kidd, P. T. (1995), 'Agile manufacturing: forging new frontiers', Addison-Wesley Longman Publishing Co., Inc.

- Kothari, C. R. (2004), ‘Research methodology: Methods and techniques’, New Age International.

- Kovach, J., Stringfellow, P., Turner, J., & Cho, B. R. (2005), ‘The house of competitiveness: the marriage of agile manufacturing, design for Six Sigma, and lean manufacturing with quality considerations’, Journal of Industrial Technology, Vol. 21, No. 3, pp. 1-10.

- Kumar, S., & Sharma, R. K. (2015), ‘An ISM based framework for structural relationship among various manufacturing flexibility dimensions’, International Journal of System Assurance Engineering and Management, Vol. 6, No. 4, pp. 511-521.

- Lee, G. H. (1998), ‘Designs of components and manufacturing systems for agile manufacturing’, International Journal of Production Research, Vol. 36, No. 4, pp. 1023-1044.

- Lee-Kwang, H., & Lee, J. H. (1999), ‘A method for ranking fuzzy numbers and its application to decision-making’, IEEE Transactions on Fuzzy Systems, Vol. 7, No. 6, pp. 677-685.

- Liker, J. K., & Morgan, J. M. (2006), ‘The Toyota way in services: the case of lean product development’ The Academy of Management Perspectives, Vol. 20, No. 2, pp. 5-20.

- Lihong, M., Yanping, Z., & Zhiwei, Z. (2008, December), ‘Improved VIKOR Algorithm Based on AHP and Shannon Entropy in the Selection of Thermal Power Enterprise's Coal Suppliers, International Conference on Information Management, Innovation Management and Industrial Engineering, Vol. 2, pp. 129-133, IEEE.

- Luo, Y., Zhou, M., & Caudill, R. J. (2001), 'An integrated e-supply chain model for agile and environmentally conscious manufacturing', IEEE/ASME Transactions On Mechatronics, Vol. 6, No. 4, pp. 377-386.

- Malek, L.A., Das, S.K., Wolf, C. (2000) 'Design and implementation of flexible manufacturing solutions in agile enterprises', International Journal of Agile Management Systems, Vol. 2 No. 3, pp.187-195.

- Mafakheri, F., Nasiri, F., & Mousavi, M. (2008), 'Project agility assessment: an integrated decision analysis approach', Production Planning and Control, Vol. 19, No. 6, pp. 567-576.

- Maler-Speredelozzi, V., Koren, Y. H. S. J., & Hu, S. J. (2003), 'Convertibility measures for manufacturing systems', CIRP Annals-Manufacturing Technology, Vol. 52, No. 1, pp. 367-370.

- Malhotra, V. (2014), 'Modelling the barriers affecting design and implementation of reconfigurable manufacturing system', International Journal of Logistics Systems and Management, Vol. 17, No. 2, pp. 200-217.

- Malhotra, M. K., & Grover, V. (1998), 'An assessment of survey research in POM: from constructs to theory', Journal of operations management, Vol. 16, No. 4, pp. 407-425.

- Mandal, U. K., & Sarkar, B. (2012), 'Selection of best intelligent manufacturing system (ims) under fuzzy moora conflicting mcdm environment', International Journal of Emerging Technology and Advanced Engineering, Vol. 2, No. 9, pp. 301-310.

- Maskell, B. (2001), 'The age of agile manufacturing', Supply Chain Management: An International Journal, Vol. 6, No. 1, pp. 5-11.

- Matawale, C. R., Datta, S., & Mahapatra, S. S. (2013), ‘Interrelationship of capabilities/enablers for lean, agile and leagile manufacturing: an ISM approach’, International Journal of Process Management and Benchmarking, Vol. 3, No. 3, pp. 290-313.

- Meade, L. M., & Sarkis, J. (1999), ‘Analyzing organizational project alternatives for agile manufacturing processes: an analytical network approach’, International Journal of Production Research, Vol. 37, No. 2, pp. 241-261.

- Merat, F. L., Barendt, N. A., Quinn, R. D., Causey, G. C., Newman, W. S., Velasco, V. B., ... & Jo, J. Y. (1997, April), ‘Advances in agile manufacturing. In Robotics and Automation’, Proceedings, IEEE International Conference on (Vol. 2, pp. 1216-1222). IEEE.

- Meredith, S., & Francis, D. (2000), ‘Journey towards agility: the agile wheel explored’, The TQM Magazine, Vol. 12, No. 2, pp. 137-143.

- Meyer, B. (2014), ‘Agile methods. In Agile! (pp. 133-143). Springer International Publishing

- Mishra, R. P. (2014), ‘Structural modelling and analysis of world-class maintenance system: a graph theoretic approach’, International Journal of Process Management and Benchmarking, Vol. 4, No. 1, pp. 69-88.

- Mishra, S., Sahu, A. K., Datta, S., & Mahapatra, S. S. (2015), ‘Application of fuzzy integrated MULTIMOORA method towards supplier/partner selection in agile supply chain’, International Journal of Operational Research, Vol. 22, No. 4, pp. 466-514.

- Misra, S., Kumar, V., Kumar, U., Fantazy, K., & Akhter, M. (2012), ‘Agile software development practices: evolution, principles, and criticisms’, International Journal of Quality & Reliability Management, Vol. 29, No. 9, pp. 972-980.

- Mittal, V. K., & Sangwan, K. S. (2011), 'Development of an interpretive structural model of obstacles to environmentally conscious technology adoption in Indian industry', In Glocalized Solutions for Sustainability in Manufacturing (pp. 383-388). Springer Berlin Heidelberg.

- Mittal, V.K., & Sangwan, K.S., (2013), 'Assessment of hierarchy and inter-relationships of barriers to environmentally conscious manufacturing adoption', World Journal of Science, Technology and Sustainable Development, Vol. 10, No. 4, pp. 297-307.

- Mittal, V.K., & Sangwan, K.S., (2014), 'Modeling drivers for successful adoption of environmentally conscious manufacturing', Journal of Modelling in Management, Vol. 9, no. 2, pp. 127-140.

- Mo, J. P. (2009), 'The role of lean in the application of information technology to manufacturing', Computers in industry, Vol. 60, No. 4, pp. 266-276.

- Mohammed, I. R., Shankar, R., & Banwet, D. K. (2008), 'Creating flex-lean-agile value chain by outsourcing: An ISM-based interventional roadmap', Business Process Management Journal, Vol. 14, No. 3, pp. 338-389.

- Monker, P. M. (1994), 'Search for agile manufacturing', Manufacturing Engineering, Vol. 113, No. 5, pp. 40-43.

- Montazeri, M., & Wassenhove, L. N. (1990), 'Analysis of scheduling rules for an FMS', The International Journal of Production Research, Vol. 28, No. 4, pp. 785-802.

- Montgomery, J. C., & Levine, L. O. (Eds.). (1996), 'The transition to agile manufacturing: staying flexible for competitive advantage', Asq Press.

- Moradlou, H., & Asadi, M. (2015), 'Implementation of Agile Manufacturing Principles in Small and Medium Enterprises (SMES)', Journal of Modern Processes in Manufacturing and Production, Vol. 4, No. 3, pp. 31-44.

- Mostafa, M. M. (2013), 'More than words: Social networks' text mining for consumer brand sentiments', Expert Systems with Applications, Vol. 40, No. 3, pp. 4241-4251.

- Nasim, S. (2011), 'Total interpretive structural modeling of continuity and change forces in e-government', Journal of Enterprise Transformation, Vol. 1, No. 2, pp. 147-168.

- Nakajima, S. (1988), 'Introduction to TPM: Total Productive Maintenance.(Translation)', Productivity Press.

- Naylor, J. B., Naim, M. M., & Berry, D. (1999), 'Leagility: integrating the lean and agile manufacturing paradigms in the total supply chain', International Journal of production economics, Vol. 62, No. 1, pp. 107-118.

- Nerur, S., & Balijepally, V. (2007), 'Theoretical reflections on agile development methodologies', Communications of the ACM, Vol. 50, No. 3, pp. 79-83.

- Opricovic, S. (1998), 'Multicriteria optimization of civil engineering systems', Faculty of Civil Engineering, Belgrade, Vol. 2, No. 1, pp. 5-21.

- Opricovic, S., & Tzeng, G. H. (2002), 'Multicriteria planning of post-earthquake sustainable reconstruction', Computer-Aided Civil and Infrastructure Engineering, Vol. 17, No. 3, pp. 211-220.

- Opricovic, S., & Tzeng, G. H. (2004), 'Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS', European journal of operational research, Vol. 156, No. 2, pp. 445-455.

- Pandey, R., & Pattanaik, L. N. (2014), 'A fuzzy QFD approach to implement reverse engineering in prosthetic socket development', International Journal of Industrial and Systems Engineering, Vol. 17, No. 1, pp. 1-14.

- Pan, F., & Nagi, R. (2013), 'Multi-echelon supply chain network design in agile manufacturing', Omega, Vol. 41, No. 6, pp. 969-983.

- Prasad, B. (2000), 'Converting computer-integrated manufacturing into an intelligent information system by combining CIM with concurrent engineering and knowledge management', Industrial management & Data systems, Vol. 100, No. 7, pp. 301-316.

- Prasad, U. C., & Suri, R. K. (2011), 'Modeling of continuity and change forces in private higher technical education using total interpretive structural modeling (TISM)', Global Journal of Flexible Systems Management, Vol. 12, No. 3/4, pp. 31.

- Paulk, M. C. (2002), 'Agile methodologies and process discipline', Institute for Software Research.

- Powell, L. (2002), 'Shedding a tier: flattening organisational structures and employee empowerment', International Journal of Educational Management, Vol. 16, No. 1, pp. 54-59.

- Raj, T., Shankar, R., & Suhaib, M. (2008), 'An ISM approach for modelling the enablers of flexible manufacturing system: the case for India', International Journal of Production Research, Vol. 46, No. 24, pp. 6883-6912.

- Ramesh, G., & Devadasan, S. R. (2007), ‘Literature review on the agile manufacturing criteria’, Journal of Manufacturing Technology Management, Vol. 18, No. 2, pp. 182-201.

- Rhodes, P. C., & Garside, G. R. (1995), ‘Use of maximum entropy method as a methodology for probabilistic reasoning’, Knowledge-Based Systems, Vol. 8, No. 5, pp. 249-258.

- Richards, C. W. (1996), ‘Agile manufacturing: beyond lean?’, Production and Inventory Management Journal’, Vol. 37, No. 2, pp. 60.

- Routroy, S., Potdar, P. K., & Shankar, A. (2015), ‘Measurement of manufacturing agility: a case study’, Measuring Business Excellence, Vol. 19, No. 2, pp. 1-22.

- Sagar, M., Bora, S., Gangwal, A., Gupta, P., Kumar, A., & Agarwal, A. (2013), ‘Factors affecting customer loyalty in cloud computing: A customer defection-centric view to develop a void-in-customer loyalty amplification model’, Global Journal of Flexible Systems Management, Vol. 14, No. 3, pp. 143-156.

- Sahin, F. (2000), ‘Manufacturing competitiveness: Different systems to achieve the same results’, Production and Inventory Management Journal, Vol. 41, No. 1, pp. 56.

- Sanchez, L. M., & Nagi, R. (2001), ‘A review of agile manufacturing systems’, International Journal of Production Research, Vol. 39, No. 16, pp. 3561-3600.

- Sandbhor, S., & Botre, R. (2014), ‘Applying total interpretive structural modeling to study factors affecting construction labour productivity’, The Australasian Journal of Construction Economics and Building, Vol. 14, No. 1, pp. 20.

- Sanayei, A., Mousavi, S. F., & Yazdankhah, A. (2010), ‘Group decision making process for supplier selection with VIKOR under fuzzy environment’, Expert Systems with Applications, Vol. 37, No. 1, pp. 24-30.

- Sapuan, S. M., & Mansor, M. R. (2014), ‘Concurrent engineering approach in the development of composite products: a review’, Materials & Design, Vol. 58, pp. 161-167.

- Saravanan, M., Kumar, S. G., & Srinivasan, R. (2016), ‘Sheep flock heredity algorithm to solve the loop layout problem in flexible manufacturing system’, International Journal of Enterprise Network Management, Vol. 7, No. 3, pp. 260-271.

- Sarkis, J. (2001), ‘Benchmarking for agility’, Benchmarking: An International Journal, Vol. 8, No. 2, pp. 88-107.

- Serrador, P., & Pinto, J. K. (2015), ‘Does Agile work?—A quantitative analysis of agile project success’, International Journal of Project Management, Vol. 33, No. 5, pp. 1040-1051.

- Shamsaddini, R., Vesal, S. M., & Nawaser, K. (2015), ‘A new model for inventory items classification through integration of ABC–Fuzzy and fuzzy analytic hierarchy process’, International Journal of Industrial and Systems Engineering, Vol. 19, No. 2, pp. 239-261.

- Shannon, C. E. (2001), ‘A mathematical theory of communication’, ACM SIGMOBILE Mobile Computing and Communications Review, Vol. 5, No. 1, pp. 3-55.

- Shah, R., & Ward, P. T. (2003), ‘Lean manufacturing: context, practice bundles, and performance’, Journal of operations management, Vol. 21, No. 2, pp. 129-149.

- Sharifi, H., & Zhang, Z. (2001), ‘Agile manufacturing in practice-Application of a methodology’, International Journal of Operations & Production Management, Vol. 21, No. 5/6, pp. 772-794.

- Shemshadi, A., Shirazi, H., Toreihi, M., & Tarokh, M. J. (2011), ‘A fuzzy VIKOR method for supplier selection based on entropy measure for objective weighting’, Expert Systems with Applications, Vol. 38, No. 10, pp. 12160-12167.

- Sherehiy, B., Karwowski, W., & Layer, J. K. (2007), ‘A review of enterprise agility: Concepts, frameworks, and attributes’, International Journal of industrial ergonomics, Vol. 37, No. 5, pp. 445-460.

- Shi-fei, D., & Zhong-zhi, S. (2005), ‘Studies on incidence pattern recognition based on information entropy’, Journal of Information Science, Vol. 31, No. 6, pp. 497-502.

- Shingo, S. (1986), ‘Zero quality control: Source inspection and the poka-yoke system’, CRC Press.

- Shankarmani, R., Pawar, R., Mantha, S. S., & Babu, V. (2012), ‘Agile Methodology Adoption: Benefits and Constraints’, International Journal of Computer Applications, Vol. 58, No. 15, pp. 31-37

- Shariari, M. (2016), ‘Agile Supplier Selection In Sanitation Supply Chain Using Fuzzy VIKOR Method’, Journal of Optimization in Industrial Engineering, Vol. 10, No. 21, pp. 19-28.

- Sharp, J. M., Irani, Z., & Desai, S. (1999), ‘Working towards agile manufacturing in the UK industry’, International Journal of production economics, Vol. 62, No. 1, pp. 155-169.

- Sheridan, J. H. (1993), ‘Agile manufacturing: stepping beyond lean production’, Industry Week, Vol. 242, No. 8, pp. 30-46.

- Singh, A., Singh, K., & Sharma, N. (2015), ‘Agile in global software engineering: an exploratory experience’, International Journal of Agile Systems and Management, Vol. 8, No. 1, pp. 23-38.

- Singh, H., & Khamba, J. S. (2011), ‘An interpretive structural modelling (ISM) approach for advanced manufacturing technologies (AMTs) utilisation barriers’, International Journal of Mechatronics and Manufacturing Systems, Vol. 4, No. 1, pp. 35-48.

- Singh, M., Khan, I. A., & Grover, S. (2011), ‘Selection of manufacturing process using graph theoretic approach’, International Journal of System Assurance Engineering and Management, Vol. 2, No. 4, pp. 301-311.
- Singh, R. K., & Sharma, P. B. (2015), ‘TISM-Based Model to Evaluate the Flexibility Index of a Supply Chain’, In Systemic Flexibility and Business Agility (pp. 323-342). Springer India.

- Singh, A. K., & Sushil. (2013), ‘Modeling enablers of TQM to improve airline performance’, International Journal of Productivity and Performance Management, Vol. 62, No. 3, pp. 250-275.

- Soleimani-Damaneh, M., & Zarepisheh, M. (2009), ‘Shannon’s entropy for combining the efficiency results of different DEA models: Method and application’, Expert Systems with Applications, Vol. 36, No. 3, pp. 5146-5150.

- Song, L., & Nagi, R. (1997), 'Design and implementation of a virtual information system for agile manufacturing', IIE transactions, Vol. 29, No. 10, pp. 839-857.

- Srivastava, A. K., & Sushil. (2013), 'Modeling strategic performance factors for effective strategy execution', International Journal of Productivity and Performance Management, Vol. 62, No. 6, pp. 554-582.

- Stoline, M. R. (1981), 'The status of multiple comparisons: simultaneous estimation of all pairwise comparisons in one-way ANOVA designs', The American Statistician, Vol. 35, No. 3, pp. 134-141.

- Stratton, R., & Warburton, R. D. (2003), 'The strategic integration of agile and lean supply', International Journal of Production Economics, Vol. 85, No. 2, pp. 183-198.

- Sullivan, W. G., McDonald, T. N., & Van Aken, E. M. (2002), 'Equipment replacement decisions and lean manufacturing', Robotics and Computer-Integrated Manufacturing, Vol. 18, No. 3, pp. 255-265.

- Sugimori, Y., Kusunoki, K., Cho, F., & Uchikawa, S. (1977), 'Toyota production system and kanban system materialization of just-in-time and respect-for-human system', The International Journal of Production Research, Vol. 15, No. 6, pp. 553-564.

- Susanti, E. C. (2014), 'The antecedence of customer loyalty in traditional restaurants in East Java, Indonesia', International Journal of Process Management and Benchmarking, Vol. 4, No. 1, pp. 22-35.

- Sushil, S. (2012), 'Interpreting the interpretive structural model', Global Journal of Flexible Systems Management, Vol. 13, No. 2, pp. 87-106.

- Talib, F., Rahman, Z., & Qureshi, M. N. (2011), 'An interpretive structural modelling approach for modelling the practices of total quality management in service sector', International Journal of Modelling in Operations Management, Vol. 1, No. 3, pp. 223-250.

- Towill, D. R., & McCullen, P. (1999), 'The impact of agile manufacturing on supply chain dynamics', The international journal of Logistics Management, Vol. 10, No. 1, pp. 83-96.

- Tsuchiya, H., & Kobayashi, O. (2004), 'Mass production cost of PEM fuel cell by learning curve', International Journal of Hydrogen Energy, Vol. 29, No. 10, pp. 985-990.

- Tzeng, G. H., Tsaur, S. H., Laiw, Y. D., & Opricovic, S. (2002), 'Multicriteria analysis of environmental quality in Taipei: public preferences and improvement strategies', Journal of environmental Management, Vol. 65, No. 2, pp. 109-120.

- Vinodh, S., & Aravindraj, S. (2012), 'Agility evaluation using the IF–THEN approach', International Journal of Production Research, Vol. 50, No. 24, pp. 7100-7109.

- Vinodh, S., Varadharajan, A. R., & Subramanian, A. (2013), 'Application of fuzzy VIKOR for concept selection in an agile environment', The International Journal of Advanced Manufacturing Technology, Vol. 65, No. 5-8, pp. 825-832.

- Vernadat, F. B. (1999), 'Research agenda for agile manufacturing', International Journal of Agile Management Systems, Vol. 1, No. 1, pp. 37-40.

- Wadhwa, S., Mishra, M., & Saxena, A. (2007), 'A network approach for modeling and design of agile supply chains using a flexibility construct', International Journal of Flexible Manufacturing Systems, Vol. 19, No. 4, pp. 410-442.

- Wang, T. C., & Lee, H. D. (2009), ‘Developing a fuzzy TOPSIS approach based on subjective weights and objective weights’, Expert Systems with Applications, Vol. 36, No. 5, pp. 8980-8985.

- Wasuja, S., Sagar, M., & Sushil. (2012), ‘Cognitive bias in salespersons in specialty drug selling of pharmaceutical industry’, International Journal of Pharmaceutical and Healthcare Marketing, Vol. 6, No. 4, pp. 310-335.

- Wei, J., & Lin, X. (2008, October), ‘The multiple attribute decision-making VIKOR method and its application. In 2008 4th International Conference on Wireless Communications’, Networking and Mobile Computing (pp. 1-4). IEEE.

- Wu, N., Mao, N., & Qian, Y. (1999), ‘An approach to partner selection in agile manufacturing’, Journal of Intelligent Manufacturing, Vol. 10, No. 6, pp. 519-529.

- Yadav, N. (2014), ‘Total interpretive structural modelling (TISM) of strategic performance management for Indian telecom service providers’, International Journal of Productivity and Performance Management, Vol. 63, No. 4, pp. 421-445.

- Yakimovich, B., Korshunov, A., & Vladislav, S. (2016), ‘Increasing of the Efficiency of Flexible Manufacturing System’, Procedia Engineering, Vol. 149, pp. 581-585.

- Yang, S. L., & Li, T. F. (2002), ‘Agility evaluation of mass customization product manufacturing’, Journal of Materials Processing Technology, Vol. 129, No. 1, pp. 640-644.

- Yauch, C. A. (2007), ‘Team-based work and work system balance in the context of agile manufacturing’, Applied Ergonomics, Vol. 38, No. 1, pp. 19-27.

- Youssef, M. A. (1992), ‘Agile manufacturing: a necessary condition for competing in global markets’, Industrial Engineering-New York then Atlanta Norcross-American Institute of Industrial Engineers Incorporated, Vol. 24, pp. 18.

- Yusuf, Y. Y., & Adeleye, E. O. (2002), ‘A comparative study of lean and agile manufacturing with a related survey of current practices in the UK’, International Journal of Production Research, Vol. 40, No. 17, pp. 4545-4562.

- Yusuf, Y. Y., Sarhadi, M., & Gunasekaran, A. (1999), ‘Agile manufacturing:: The drivers, concepts and attributes’, International Journal of production economics, Vol. 62, No. 1, pp. 33-43.

- Yusuf, Y. Y., Gunasekaran, A., Adeleye, E. O., & Sivayoganathan, K. (2004), ‘Agile supply chain capabilities: Determinants of competitive objectives’, European Journal of Operational Research, Vol. 159, No. 2, pp. 379-392.

- Zhang, L., Luo, Y., Tao, F., Li, B. H., Ren, L., Zhang, X., & Liu, Y. (2014), ‘Cloud manufacturing: a new manufacturing paradigm’, Enterprise Information Systems, Vol. 8, No. 2, pp. 167-187.
- Zhang, J., Gu, J. and Duan, Z.C. (1999), ‘Object-oriented modeling of control system for agile manufacturing cells’, International Journal of Production Economics, Vol. 62, pp. 145–153.

- Zhu, A. Y., von Zedtwitz, M., Assimakopoulos, D., & Fernandes, K. (2016), ‘The impact of organizational culture on Concurrent Engineering, Design-for-Safety, and product safety performance’, International Journal of Production Economics, Vol. 176, pp. 69-81.

APPENDIX-1
QUESTIONNAIRE

From: Rahul Sindhwani

Research Scholar, Ph.D, YMCAUST, Faridabad

9971270808 (m); rahul.sindhwani2006@gmail.com

Subject: - Dissertation work on "**AN INTEGRATED FRAMEWORK TO ANALYZE THE IMPLEMENTATION STRATEGIES FOR AGILE MANUFACTURING SYSTEM**"

Respected Sir/ Ma'am,

Please find enclosed a questionnaire based on attributes and sub-attribute of Agile Manufacturing System. Agile manufacturing is a term applied to an organization that has created the process, tools and training to enable it to respond quickly to customer needs and market changes while still controlling cost and quality.

Agile manufacturing is an approach to manufacturing which is focused on the needs of customers while maintaining high standards of quality and controlling the overall costs involved in the production of a particular product. This approach is geared towards companies working in a highly competitive environment, where small variations in performance and product delivery can make a huge difference in the long term to a company's survival and reputation among consumers.

The purpose of this questionnaire is to identify the agility of the organization and as well as relative importance and difficulty in implementation of various parameters and on the basis of this data to identify the suitable parameter for an organization to improve agility. This study is a part of my dissertation work leading to P.hD degree in Department of Mechanical Engineering under the supervision of **Dr. Vasdev Malhotra, Associate Professor**, Department of Mechanical Engineering, YMCA University of Science & Technology, Faridabad. I request you to kindly have the questionnaire filled up and mailed to me at your earliest convenience. I assure you that your response will kept strictly confidential.

Thanking you in anticipation

Your's truly

(RAHUL SINDHWANI)

SECTION –A (ORGANIZATION PROFILE)

1 (a) Name of the organization ………………………………………..

(b) Type of business …………………………………………………

(c) Department…………………………………………………….

(d) Name……………………………………………………………..

(e) Post…………………………………………………………….

2. Please indicate the number of employees at your organization :

a) Less than 100 ☐
b) Between 101-500 ☐
c) Between 501-1000 ☐
d) More than 1000 ☐

3. Please indicate the total turnover of your organization in Rs of Crores:

a) Less than 10 ☐
b) Between 10-50 ☐
c) Between 50-100 ☐
d) More than 500 ☐

4. Please indicate the number of models of your product being manufactured:

a) Between 1-5 ☐
b) Between 6-10 ☐
c) Between 11-20 ☐
d) More than 20 ☐

5. Please indicate the total number of components being manufactured inside the plant

a) Less than 20 ☐
b) Between 20-50 ☐
c) Between 50-100 ☐
d) More than 100 ☐

6. The current productivity level in terms of units per man per day is approximately

a) Less than 10 ☐
b) Between 10-25 ☐
c) Between 25-50 ☐
d) More than 50 ☐

IMPORTANCE WEIGHTAGE OF ATTRIBUTES FOR AGILE MANUFACTURING SYSTEM

IMPORTANCE WEIGHTING OF ATTRIBUTE → ATTRIBUTES ↓	VERYHIGH	HIGH	FAIRLYHIGH	MEDIUM	FAIRLY LOW	LOW	VERY LOW	AGILE MANUFACTURING SYSTEM
STRATEGIES								
SYSTEM								
PEOPLE								
TECHNOLOGIES								

IMPORTANCE WEIGHTAGE OF SUB-ATTRIBUTES FOR AGILE MANUFACTURING SYSTEM

WEIGHTING → ATTRIBUTE / SUB- ATTRIBUTE ↓	VERYHIGH	HIGH	FAIRLYHIGH	MEDIUM	FAIRLY LOW	LOW	VERY LOW	ATTRIBUTE
Concurrent Engineering								Strategies
Virtual Enterprises								
Physically Distributed Manufacturing System								
MRP -II (Manufacturing Resource Planning)								System
Activity Based Cost (ABC)/ Activity Based Management (ABM)								
CAD / CAM								
ERP								
CIM								
KANBAN								
Flexible Work Force								People
Multi-Lingual								
Empowered Workers								
Top Management Support								
Flexible Part Feeder								Technologies
Flexible Fixturing								
Multi-Media								
Information Technology								
Flexible Manufacturing System								

PERFORMANCE RATING OF SUB-ATTRIBUTES FOR AGILE MANUFACTURING SYSTEM

RATING ATTRIBUTE ⇨ SUB- ATTRIBUTE ⇩	EXCELLENT	VERY GOOD	GOOD	FAIR	POOR	VERY POOR	WORST	ATTRIBUTE
Con-Current Engineering								**Strategies**
Virtual Enterprises								
Physically Distributed Manufacturing System								
Manufacturing Resource Planning (MRP)								**System**
Activity Based Cost (ABC)/ Activity Based Management (ABM)								
Computer Aided Design (CAD) / Computer Aided Manufacturing (CAM)								
Enterprise Resource Planning (ERP)								
Computer Integrated Manufacturing (CIM)								
KANBAN								
Flexible Work Force								**People**
Multi-Lingual								
Empowered Workers								
Top Management Support								
Flexible Part Feeder								**Technologies**
Flexible Fixturing								
Multi-Media								
Information Technology								
Flexible Manufacturing System								

APPENDIX 2

INTERPRETATION OF RELATIONSHIP FOR AMS ENABLERS

Interpretations of Relationship for AMS Enablers are as follows:

Sr. no.	**Enabler no.**	**Paired Comparison of Enabler**	**Y/N**	**In what way an enabler will influence or help in enabling the other enabler. Give reason in brief**
E_1 Virtual Enterprise				
1	E1 E2	Virtual Enterprise is influencing or helps in enabling the Product service management	Y	Quality of the product will improve with the help of specialized industry tie-up.
	E2-E1	Product service management is influencing or helps in enabling the virtual enterprise	N	
	E1-E3	Virtual Enterprise is influencing or helps in enabling the Flexible workforce	N	
	E3-E1	Flexible workforce is influencing or helps in enabling the Virtual Enterprise	N	
	E1-E4	Virtual Enterprise is influencing or helps in enabling the Top management support	N	
	E4-E1	Top management support is influencing or helps in enabling or influence the Virtual Enterprise	Y	For tie up with other industry top management support is very necessary.
	E1-E5	Virtual Enterprise is influencing or helps in enabling the Organizational structure	N	
	E5-E1	Organizational structure is influencing or helps in enabling the Virtual Enterprise	N	
	E1-E6	Virtual Enterprise is	Y	Tie-up with core industry

		influencing or helps in enabling the information technology integration		influence the information technology.
	E6-E1	Information technology integration is influencing or helps in enabling the Virtual Enterprise	Y	Virtual enterprise is possible only when information technology integration happened in industry.
	E1-E7	Virtual Enterprise is influencing or helps in enabling the Man power utilization	N	
	E7-E1	Man power utilization is influencing or helps in enabling the Virtual Enterprise	N	
	E1-E8	Virtual Enterprise is influencing or helps in enabling the Pull production	N	
	E8-E1	Pull production is influencing or helps in enabling the Virtual Enterprise	N	
	E1-E9	Virtual Enterprise is influencing or helps in enabling the Product life cycle management	N	
	E9-E1	Product life cycle management is influencing or helps in enabling the Virtual Enterprise	N	
	E1-E10	Virtual Enterprise is influencing or helps in enabling the Optimal inventory	Y	Easy to maintain inventory level after virtual enterprise.
	E10-E11	Optimal inventory is influencing or helps in enabling the Virtual Enterprise	N	
	E1-E11	Virtual Enterprise is influencing or helps in enabling the Machine utilization	N	
	E11-E1	Machine utilization is influencing or helps in enabling the Virtual	N	

		Enterprise		
E_2 Product service management				
2	E2-E3	Product service management is influencing or helps in enabling the Multilingual	N	
	E3-E2	Flexible workforce is influencing or helps in enabling the Product service management	Y	For improvement in quality of product flexible workforce is necessary.
	E2-E4	Product service management is influencing or helps in enabling the Top management support	N	
	E4-E2	Top management support is influencing or helps in enabling the Product service management	Y	For improvement in quality of the product top management support plays an important role
	E2-E5	Product service management is influencing or helps in enabling the Organizational structure	N	
	E5-E2	Organizational structure is influencing or helps in enabling the Product service management	N	
	E2-E6	Product service management is influencing or helps in enabling the Information technology integration	N	
	E6-E2	Information technology integration is influencing or helps in enabling the Product service management	Y	After IT integration of the industry quality of the product is upgrade.
	E2-E7	Product service management is influencing or helps in enabling the Man-power utilization	N	
	E7-E2	Man-power utilization is influencing or helps in enabling the Product service management	N	
	E2-E8	Product service management is influencing or helps in enabling the Pull production	Y	Good quality of the product always 'pull' the customers
	E8-E2	Pull production is influencing or helps in	N	

		enabling the Product service management		
	E2-E9	Product service management is influencing or helps in enabling the Product life-cycle management	Y	Good quality of the product reduces the work of management which enables PLM.
	E9-E2	Product life-cycle management is influencing or helps in enabling the Product service management	N	
	E2-E10	Product service management is influencing or helps in enabling the Optimal inventory	N	
	E10-E2	Optimal inventory is influencing or helps in enabling the Product service management	N	
	E2-E11	Product service management is influencing or helps in enabling the Machine utilization	N	
	E11-E2	Machine utilization is influencing or helps in enabling the Product service management	N	
3. Flexible workforce				
	E3-E4	Flexible workforce is influencing or helps in enabling the Top management suppport	N	
	E4-E3	Top management support is influencing or helps in enabling the Flexible workforce	Y	Good workforce only is recruited with the help of top management support only.
	E3-E5	Flexible workforce is influencing or helps in enabling the Organizational structure	N	
	E5-E3	Organizational structure is influencing or helps in enabling the Flexible workforce	N	
	E3-E6	Flexible workforce is influencing or helps in enabling the Information	N	

		technology integration		
	E6-E3	Information technology integration is influencing or helps in enabling the Flexible workforce	N	
	E3-E7	Flexible workforce is influencing or helps in enabling the Man-power utilization	Y	Flexible workforce always give result so man-power utilization is always improve.
	E7-E3	Man-power utilization is influencing or helps in enabling the Flexible workforce	N	
	E3-E8	Flexible workforce is influencing or helps in enabling the Pull production	N	
	E8-E3	Pull production is influencing or helps in enabling the Flexible workforce	N	
	E3-E9	Flexible workforce is influencing or helps in enabling the Product life-cycle management	N	
	E9-E3	Product life-cycle management is influencing or helps in enabling the Flexible workforce	N	
	E3-E10	Flexible workforce is influencing or helps in enabling the Optimal inventory	N	
	E10-E3	Optimal inventory is influencing or helps in enabling the Flexible workforce	N	
	E3-E11	Flexible workforce is influencing or helps in enabling the Machine utilization	Y	Good worker can only use the machine in proper way.
	E11-E3	Machine utilization is influencing or helps in enabling the Flexible workforce	N	
4. Top management support				
	E4-E5	Top management support is	Y	Selection of organization

		influencing or helps in enabling the Organizational structure		structure is depending upon the management.
	E5-E4	Organizational structure is influencing or helps in enabling the Top management support	N	
	E4-E6	Top management support is influencing or helps in enabling the Information technology integration	Y	Integration decision is depend upon the management.
	E6-E4	Information technology integration is influencing or helps in enabling the Top management support	Y	Integration gives better product which influences the management.
	E4-E7	Top management support is influencing or helps in enabling the Man-power utilization	Y	Decision regarding man-power is done by management only.
	E7-E4	Man-power utilization is influencing or helps in enabling the Top management support	N	
	E4-E8	Top management support is influencing or helps in enabling the Pull production	N	
	E8-E4	Pull production is influencing or helps in enabling the Top management support	N	
	E4-E9	Top management support is influencing or helps in enabling the Product life-cycle management	Y	Maintaining the record of product from selling to scrap is decided by management.
	E9-E4	Product life-cycle management is influencing or helps in enabling the Top management support	N	
	E4-E10	Top management support is influencing or helps in enabling the Optimal inventory	N	
	E10-E4	Optimal inventory is influencing or helps in enabling the Top management support	N	

	E4-E11	Top management support is influencing or helps in enabling the Machine utilization	N	
	E11-E4	Machine utilization is influencing or helps in enabling the Top management support	N	
5. Organization structure				
	E5-E6	Organization structure is influencing or helps in enabling the Information technology integration	Y	Better organization always enables IT integration.
	E6-E5	Information technology is influencing or integration helps in enabling the Organization structure	N	
	E5-E7	Organization structure is influencing or helps in enabling the Man-power utilization	Y	Better organization structure motivate the employee for more work which enables man-power utilization
	E7-E5	Man-power utilization is influencing or helps in enabling the Organization structure	N	
	E5-E8	Organization structure is influencing or helps in enabling the Pull production	N	
	E8-E5	Pull production is influencing or helps in enabling the Organization structure	N	
	E5-E9	Organization structure is influencing or helps in enabling the Product life-cycle management	N	
	E9-E5	Product life-cycle management is influencing or helps in enabling the Organization structure	N	
	E5-E10	Organization structure is influencing or helps in enabling the Optimal inventory	N	
	E10-E5	Optimal inventory is	N	

		influencing or helps in enabling the Organization structure		
	E5-E11	Organization structure is influencing or helps in enabling the Machine utilization	N	
	E11-E5	Machine utilization is influencing or helps in enabling the Organization structure	N	
6.Information technology integration				
	E6-E7	Information technology integration is influencing or helps in enabling the Man-power utilization	N	
	E7-E6	Man-power utilization is influencing or helps in enabling the Information technology integration	N	
	E6-E8	Information technology integration is influencing or helps in enabling the Pull production	N	
	E8-E6	Pull production is influencing or helps in enabling the Information technology integration	N	
	E6-E9	Information technology integration is influencing or helps in enabling Product life-cycle management the	N	
	E9-E6	Product life-cycle management is influencing or helps in enabling the Information technology integration	N	
	E6-E10	Information technology integration is influencing or helps in enabling the Optimal inventory	Y	Information technology integration helps in maintaining the inventory level to optimum level.
	E10-E6	Optimal inventory is influencing or helps in enabling the Information technology integration	N	
	E6-E11	Information technology	N	

		integration is influencing or helps in enabling the Machine utilization		
	E11-E6	Machine utilization is influencing or helps in enabling the Information technology integration	N	
7. Man-power utilization				
	E7-E8	Man-power utilization is influencing or helps in enabling the Pull production	N	
	E8-E7	Pull production is influencing or helps in enabling the Man-power utilization	N	
	E7-E9	Man-power utilization is influencing or helps in enabling the Product life-cycle management	N	
	E9-E7	Product life-cycle management is influencing or helps in enabling the Man-power utilization	N	
	E7-E10	Man-power utilization is influencing or helps in enabling the Optimal inventory	N	
	E10-E7	Optimal inventory is influencing or helps in enabling the Man-power utilization	N	
	E7-E11	Man-power utilization is influencing or helps in enabling the Machine utilization	Y	Utilization of man-power gives result in a form of proper machine utilization.
	E11-E7	Machine utilization is influencing or helps in enabling the Man-power utilization	Y	Scheduling of machine gives result in a form of better man-power utilization.
8. Pull production				
	E8-E9	Pull production is influencing or helps in enabling the Product life-cycle management	N	
	E9-E8	Product life-cycle management is influencing	N	

		or helps in enabling the Pull production		
	E8-E10	Pull production is influencing or helps in enabling the Optimal inventory	N	
	E10-E8	Optimal inventory is influencing or helps in enabling the Pull production	N	
	E8-E11	Pull production is influencing or helps in enabling the Machine utilization	N	
	E11-E8	Machine utilization is influencing or helps in enabling the Pull production	N	
9. Product life-cycle management				
	E9-E10	Product life-cycle management is influencing or helps in enabling the Optimal inventory	N	
	E10-E9	Optimal inventory is influencing or helps in enabling the Product life-cycle management	N	
	E9-E11	Product life-cycle management is influencing or helps in enabling the Machine utilization	N	
	E11-E9	Machine utilization is influencing or helps in enabling the Product life-cycle management	N	
10. Optimal inventory				
	E10-E11	Optimal inventory is influencing or helps in enabling the Machine utilization	N	
	E11-E10	Machine utilization is influencing or helps in enabling the Optimal inventory	N	

APPENDIX 3
BRIEF BIOGRAPHY OF THE CANDIDATE AND SUPERVISOR

About the author (Rahul Sindhwani)

Rahul Sindhwani is an Assistant Professor in Mechanical Engineering Department of Amity University Uttar Pradesh and research scholar in Mechanical Engineering Department with specialization (Production & Industrial Engineering) in YMCA University of Science and Technology, Faridabad, India. He has passed his B.Tech. in Mechanical Engineering from Kurukshetra University, India in 2008 and M.Tech. in Mechanical Engineering from Kurukshetra University, India in 2010 with distinction and Gold Medal. His area of expertise is Lean and Agile Manufacturing. He has published 10 research articles in various international journals of repute.

About the supervisor (Dr. Vasdev Malhotra)

Dr. Vasdev Malhotra is working as an Associate Professor in Mechanical Engineering Department in YMCA University of Science and Technology, Faridabad, India. He passed his BE in Mechanical from NIT, Kurukshetra, India in 2000 with honours, ME in Mechanical Engineering specialization (production) from Guru Nanak Dev Engg. College Ludhiana, India in 2008 with distinction and completed his PhD degree in January 2012. His area of expertise is Advanced Manufacturing. His published research papers are more than 70 and his research papers are accepted/ published in International Journal of Process Management and Benchmarking, Benchmarking: An International Journal, International Journal of Service and Operation Management, International Journal of Material and Manufacturing System, International Journal of Machine Intelligence, International Journal of Engg. Science and Technology, International Journal of Applied Engg. and Research, Journal of Udyog Pargati and international conferences and published a book.

APPENDIX 4

LIST OF PUBLICATIONS OUT OF THESIS

List of Published Paper in International Journal

Sr. No.	Title of the Paper	Name of Journal where published	Volume & Issue No.	Year	Pages
1	Modelling the attributes affecting design and implementation of agile manufacturing system	International Journal of Process Management and Benchmarking (Inderscience)	Vol.6, No. 2	2016	216-234
2	Modelling And Analysis Of Agile Manufacturing System By ISM And MICMAC Analysis	International Journal of System Assurance Engineering & Management (Springer)	DOI: 10.1007/s13198-016-0426-2	2017	1-11
3	A Framework to Enhance Agile Manufacturing System: A Total Interpretive Structural Modelling (TISM) Approach	Benchmarking : An International Journal (Emerald)	Vol. 24, No. 2 DOI 10.1108/BIJ-09-2015-0092	2017	1-23
4	Barriers Evaluation for Agile Manufacturing System with Fuzzy Performance Importance Index Approach	International Journal of Agile Systems and Management (Inderscience)	Vol. 9, No. 4	2016	292-301
5	Lean and Agile Manufacturing System Barriers	International Journal of Advance Research and Innovation	Vol. 3, No. 1	2015	110-112
6	Overview And Drivers Of Agile Manufacturing System: A Review.	International Journal of Marketing and Technology	Vol. 3, No. 12	2015	144-154
7	Twenty Criteria Agile Manufacturing Model.	International Journal of Emerging Technology and Advanced Engineering	Vol. 5, No. 1	2015	182-185
8	Agile Manufacturing Through Management Driver	International Journal Of Advanced Research In Engineering And Technology	Vol. 6, No. 4	2015	34-40

List of Published Paper in International Conference

Sr. No.	Title of the Paper	Name of Conference	Year of Conference	Place of Conference
9	An Overview of Agile Manufacturing System	International Conference on Sustainable Development through Research in Engineering and Management (SDREM-2016)	December 26-27, 2016	YMCAUST, Faridabad, Haryana

List of Communicated Paper

Sr. No.	Title of the Paper	Name of Journal	Present Status	Year
10	An Integrated Approach for Implementation of Agile Manufacturing System in an Indian Manufacturing Industry	SADHNA- Academy Proceeding in Engineering Science (SPRINGER) Impact Factor: 0.349	Under-Review	2016