ANALYSIS OF PLANNING, DESIGN AND OPERATIONAL ISSUES OF FLEXIBLE MANUFACTURING SYSTEM

THESIS

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by

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DEDICATION

I dedicate this thesis to my mother

Smt. P. Lakshmi

Love you Maa

CANDIDATE'S DECLARATION

I hereby declare that this thesis entitled **ANALYSIS OF PLANNING, DESIGN AND OPERATIONAL ISSUES OF FLEXIBLE MANUFACTURING SYSTEM** by **PARINAM NAGA SANDHYA**, being submitted in fulfilment of the requirements for the Degree of Doctor of Philosophy in MECHANICAL ENGINEERING under Faculty of Engineering and Technology of J. C. Bose University of Science and Technology, YMCA, Faridabad, during the academic year 2018-19, is a bonafide record of my original work carried out under the guidance and supervision of **Dr. TILAK RAJ, PROFESSOR, DEPARTMENT OF MECHANICAL ENGINEERING** 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.

PARINAM NAGA SANDHYA
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CERTIFICATE OF THE SUPERVISOR

This is to certify that this thesis entitled **ANALYSIS OF PLANNING, DESIGN AND OPERATIONAL ISSUES OF FLEXIBLE MANUFACTURING SYSTEM** by **PARINAM NAGA SANDHYA**, submitted in fulfilment of the requirement for the Degree of Doctor of Philosophy in **MECHANICAL ENGINEERING** under Faculty of Engineering and Technology of J. C. Bose University of Science and Technology, YMCA, Faridabad, during the academic year 2018-19, 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 this university or in any other university.

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ABSTRACT

Globalized competition in the market has put up tremendous pressure on the manufacturing industries. Advancements in technology and the ever changing customer demands have made the manufacturing industries to upgrade their production systems as a necessity for their survival. Today, a high degree of flexibility as well as ability to reconfigure operations for new demands are required for meeting the customer's needs. Manufacturing industries are compelled to move away from traditional set ups to more responsive and dynamic ones. Product attributes like quality, reliability, flexibility, cost and the organizational ability to meet market pressures like delivery and service have come into focus. The manufactures today find competitive advantage through better design, improved customer satisfaction, quick response, faster new product introduction and other goals overshadowed in the past by the sole pursuit of cost reduction.

Such needs of the modern industries can be met with the adoption of advanced manufacturing systems like, flexible manufacturing systems (FMS). FMSs are the integrated manufacturing systems which can help the industries to achieve the goals of increasing profitability through the increase of productivity and flexibility. Thus, to improve productivity and increase the manufacturing flexibility, organizations are looking at FMS as a viable alternative to enhance their competitive edge.

A lot of research has been done in the field of flexible manufacturing systems. But still, there are many issues related to the design and performance of this advanced manufacturing system, which needs systematic research. With this goal, an effort has been made in the present research work to analyze the various planning, design and operational issues of FMS, especially in the Indian manufacturing environment.

In this work, the literature existing on planning, design, operational and other issues of FMS has been thoroughly studied. The perception of Indian manufacturing industries towards different issues and factors related to FMS have been analysed through questionnaire based survey. Various factors affecting the productivity of FMS are identified through the literature review and discussions with experts from industry and academia. These different factors affecting productivity of FMS are modelled using ISM and TISM techniques. Further, the quantification of the influence of FMS on the productivity of a firm is done using GTA technique.

Different issues concerned with the adoption of FMS are studied and a new methodology is developed for the conversion of a conventional manufacturing system into FMS. The strengths and limitations for adoption of advanced manufacturing systems in small and medium scale industries are identified and the feasibility analysis of FMS in small and medium scale industries is done. The different material handling issues in an FMS environment are identified and modelled in a hierarchical structure.

The major contributions of this research are given below:

- The present research provides a comprehensive review of literature and identifies contemporary issues related to design and development of FMS in Indian manufacturing industries.
- The inclination of Indian manufacturing industries towards different issues and factors related to FMS has been found out.
- Various measures related to productivity in FMS are identified and their interrelationships are analyzed. Their drive and dependence power have been analysed to identify the most significant key factors/measures affecting productivity.
- Quantification of the influence of FMS on the productivity of a firm is done. This gives a numerical index for showing how much is the productivity of any firm is influenced by the FMS installation. The mathematical model developed can be used as an aid to develop a suitable strategy for the implementation of FMS based on the intensity of different categories of factors.
- Feasibility analysis of FMS in small and medium scale industries is done.
- Different issues concerned with the adoption of FMS are studied and a new methodology is developed for the conversion of a conventional manufacturing system into FMS.
- The different material handling issues in an FMS environment are identified and they are modelled in a hierarchical structure to highlight the key issues.

Keywords: FMS; Flexible Manufacturing Systems; Advanced Manufacturing Systems; Productivity; Performance; Attributes; Issues; ISM; TISM; GTA; TOPSIS; AHP; MADM; Material Handling Systems; SMEs; Feasibility.

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LIST OF ABBREVIATIONS

S.No.	Description	Abbreviation
1.	Flexible Manufacturing System	FMS
2.	Machining System Block	MSB
3.	Workpiece Handling Block	WHB
4.	Tool Handling Block	THB
5.	Computer Control Block	CCB
6.	Automated Guided Vehicles	AGVs
7.	Interpretive Structural Modelling	ISM
8.	Total Interpretive Structural Modelling	TISM
9.	Graph Theoretic Approach	GTA
10.	Technique for Order Preference by Similarity to the Ideal Solution	TOPSIS
11.	Analytic Hierarchy Process	AHP
12.	Just In Time	JIT
13.	Total Productive Maintenance	TPM
14.	Total Quality Control	TQM
15.	Electric Discharge Machining	EDM
16.	Consistency Index	CI
17.	Consistency Ratio	CR
18.	Matrice d'Impacts croises-multipication applique´ an classment (cross-impact matrix multiplication applied to classification)	MICMAC
19.	Small and Medium Enterprises	SMEs
20.	Multi Attribute Decision Making	MADM
21.	Automated Storage and Retrieval System	AS/RS
22.	Direct Numeric Control	DNC
23.	Material Handling	MH
24.	Material Handling Systems	MHSs
25.	Computer Aided Design	CAD
26.	Computer Aided Manufacturing	CAM
27.	Material Resource Planning	MRP
28.	Structural Self Interaction Matrix	SSIM
29.	Reachability Matrix	RM

30.	Structural Equation Modeling	SEM
31.	Work-in-process	WIP
32.	Workpiece	W/P
33.	Numeric Control	NC
34.	Computer Numeric Control	CNC
35.	Productivity Index	PRO
36.	Permanent function of productivity factors matrix	Per P*
37.	Micro, Small and Medium Enterprises	MSME
38.	Government	Govt.
39.	Indian National Rupees	INR
40.	Gross Domestic Product	GDP
41.	Small Industries Development Organisation	SIDO
42.	National Small Industries Corporation	NSIC
43.	Entrepreneurship Development Institutions	EDIs
44.	Non Government Organizations	NGOs
45.	Small Scale Industries Board	SSIB
46.	Small Industries Development Bank of India	SIDBI
47.	Small Scale Industries	SSI
48.	Industrial Development Bank of India	IDBI
49.	Materiel Acquisition Plan	MAP
50.	Analytic Network Process	ANP
51.	Horse Power	HP
52.	Units per Man per Day	UMD
53.	Special Purpose Machines	SPMs
54.	Machining	M/C
55.	Materials Handling Industry of America	MHIA
56.	Operations Research	OR
57.	Multi Criteria Decision Making	MCDM
58.	Genetic Algorithm	GA
59.	Constraint Based Genetic Algorithm	CBGA
60.	Single Flexible Machine	SFM
61.	Flexible Manufacturing Cell	FMC
62.	Multi-machine Flexible Manufacturing System	MMFMC

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

The manufacturing environment has changed in the previous few decades like never before. The pace of change continues to accelerate and the organisations around the world are trying to catch up with it. Changing markets, consumer preferences, customer demands, new materials, processes and equipments have all influenced the working of industries. How companies have organised their manufacturing facilities to cope with this volatile environment has varied enormously. Successful companies today recognize that the ability to respond to new customer needs and seize market opportunities as they arise is crucial to their continued success [98]. Enterprises are continuously striving to improve in the area of product variety, quality, time to market, customer satisfaction, performance, profitability, employee morale etc. Timely and effective response to changing needs has become critical.

Traditional factories derived their competitive advantage from a combination of size, volume and standardisation [207]. But present day modern industries relay more on flexibility than on standardisation. Advanced technologies have fundamentally changed the nature of manufacturing and opened up opportunities for new styles of competition in many industries. The application of information technology, computers and telecommunications to all aspects of manufacturing is the key reason for the fundamental change towards achieving the goal of both variety and low cost. Today, variety and innovation have no longer to be traded off against productivity.

The drive towards world class industries has led to the development of flexible automation systems. Flexible automation through flexible manufacturing systems has changed the way in which the world class industries work. A flexible manufacturing system is a manufacturing philosophy which is able to produce a range of parts and handling flexible routing of parts instead of processing parts in a straight line through machines. It allows the industries to respond rapidly to new challenges and helps in achieving greater productivity and flexibility.

1.2 DIFFERENT STAGES OF DEVELOPMENT OF MANUFACTURING TECHNOLOGY

Looking back over the history and evolution of manufacturing technology, one can observe following three general stages of development in the utilisation of the basic factors of production [183]:

- In the first stage, manufacturing was dependent on human labour and human intelligence.
- The second stage saw the replacement of human labour by machines, while still relying on human intelligence.
- Today in the third stage, human intelligence is being replaced by artificial intelligence and integrated with machine labour.

The evolution to the third stage is made possible and/ or accelerated by the availability of low cost electronic computing and control, telecommunications and sophisticated measurement and sensor technologies.

These changes have been accompanied by systematic progression in manufacturing strategy as indicated in Figure 1.1.

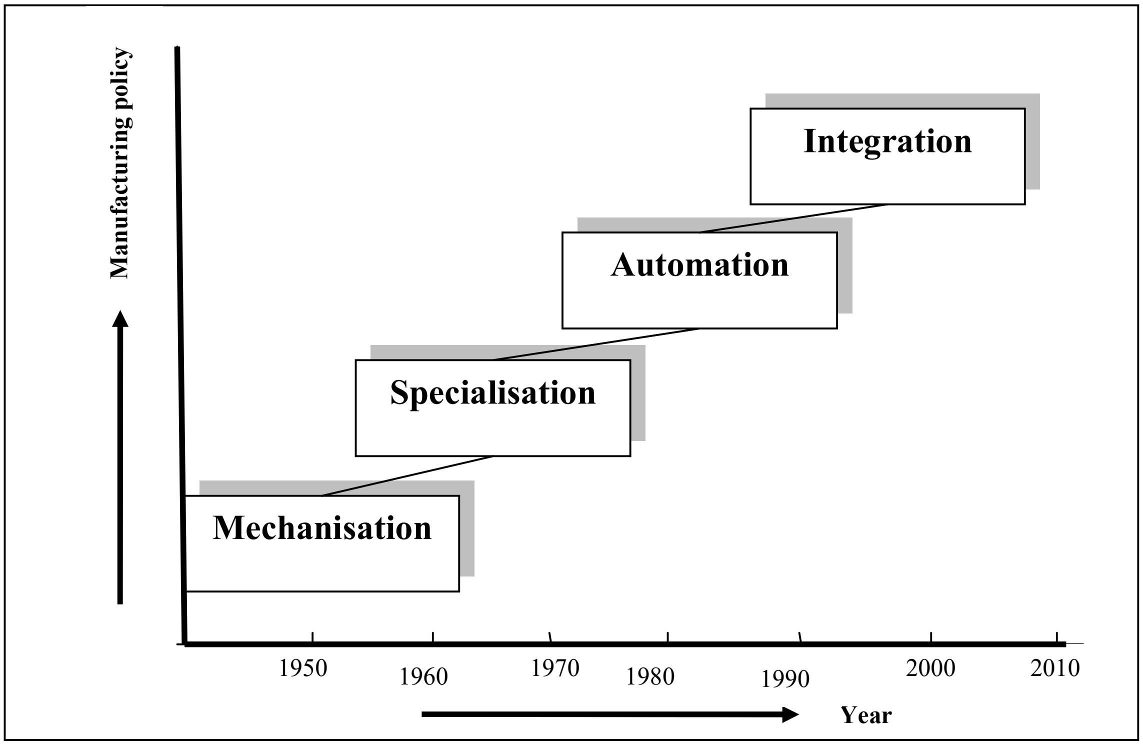

Figure 1.1: Different stages of development of manufacturing policy

1.3 CHANGING AIMS FOR PRODUCTION

Highly industrialised nations as well as developing countries like India are today facing the problems for their business like:

- Compressed product lifecycles and shorter market lifetimes
- Intensified competition
- An accelerated rate of technical development
- Declining profit margins
- Increased demands on the variety with quality products

Shorter market lifetimes and shorter innovation times lead to increasing demands on a company's preparedness, adaptability and versatility. The world class companies must therefore accept new business environment and pursue new strategies like,

- Develop new products with increased frequency.
- Offer a great number of variants.
- Attempt to shorten the delivery times.
- Reduce costs by all means.
- Ensure high quality during all phases of the product's lifetime. Embed the uniqueness of the product more and more deeply into the manufacturing process.
- Incorporate increasing level of product customisation.

1.4 FLEXIBLE AUTOMATION – A KEY CONCEPT

Companies which possess the ability to adapt themselves and to react rapidly to changes in their environment are in a better position than companies with fixed aims and means. The essential attributes like enhanced flexibility, greater versatility and higher quality can be attained primarily through the creation of new production conditions by means of computers, industrial robots and automation through the creation of direct information routes between design and production by means of data-processing techniques, and by choosing equipment and structuring production system in the right way.

In the present environment, it becomes essential to optimise flexibility and productivity. Short term flexibility has ability to adopt changes in existing product profile and long term flexibility requires additional ability to adopt new products. These objectives can be best achieved through 'Flexible Automation' which offers rapid response to product innovation, process innovation and shifts in demand. Flexible automation is much more cost effective than fixed automation for high variety production requirements.

There are two primary forces viz: Technology push and Competitive pull, driving a change in the way the manufacturers approach product innovation and product development. Whereas technology push is result of successful task automation by virtue of increase in availability and decrease in the cost of flexible automation technology, competitive pull is the outcome of change of external conditions.

The combination of technology push and competitive pull results in a new approach to effective manufacturing through flexible automation, Figure 1.2 [183].

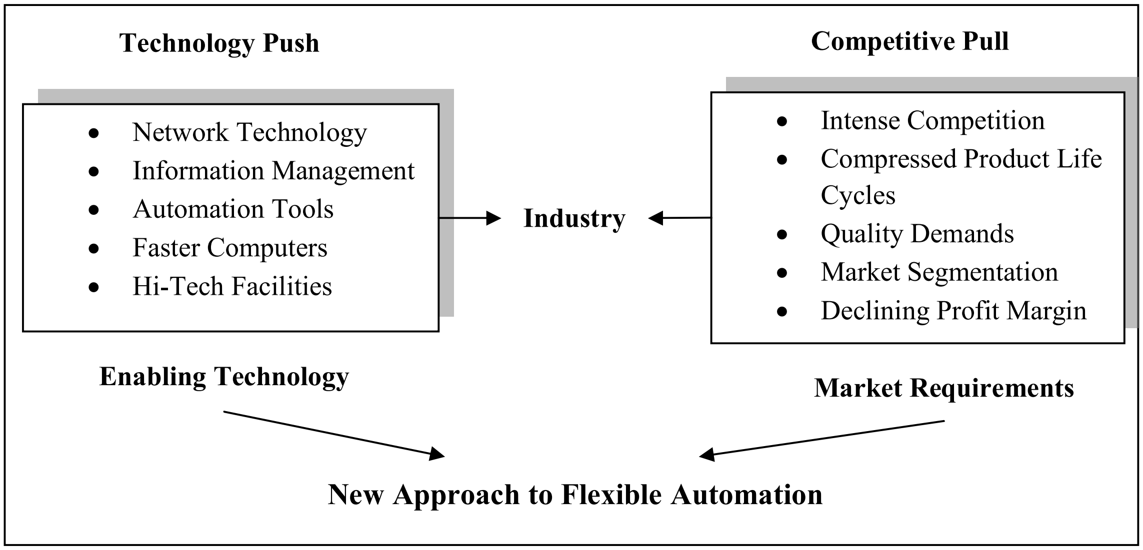

Figure 1.2: Drivers to new approach to flexible automation

1.5 FLEXIBLE MANUFACTURING SYSTEMS

Flexible automation concept has lead to a new philosophy of manufacturing called the 'Flexible Manufacturing Systems' which the companies worldwide are adopting today. The credit for the development of this technology goes to David Williamson, who was employed in the mid of 1960s by Molins. The concept was called "System 24" as it was believed that this production system will run continuously. FMS in its present form was first installed at Ingersoll-Rand, a USA company as a machining system [204].

1.5.1 Definitions of FMS

Some of the definitions of Flexible Manufacturing System are given below:

- "Flexible manufacturing System is an emergent technology which is appropriate for mid-variety, mid-volume type of production and comprises of multipurpose NC machines" [165].
- "A flexible manufacturing system is an integrated computer controlled system of automated material handling devices and computer controlled machine tools that can simultaneously process medium sized volumes of a variety of part types" [87].
- "A technology which will help achieve leaner factories with better response times, lower unit costs and higher quality under an improved level of management and capital control" [81].
- "Flexible Manufacturing is a system which combines micro electronics and mechanical engineering to bring economics of sale to batch work" [39].

A central on line computer controls the machine tools and other work stations and the transfer of components and tooling. The computer also provides monitoring and information control. This combination of flexibility and overall control makes possible the production of a wide range of products in small numbers. Figure 1.3 shows the suitability and application of FMS vis a vis other manufacturing systems like transfer lines, dedicated systems, etc [44].

1.5.2 Benefits of FMS

An FMS plant is able to accept random components and to work them up. The system's computer keeps track of tools, fixtures, handling and control systems, and also controls the manufacturing sequence to be followed. The detailed study of a plant based on FMS brings following encouraging results [112]:

- Quicker response to the market changes
- Shorter delivery times
- Saving in material cost
- Reduction in work-in-process
- Reduction in lead time

- Increase in machine utilisation
- Reduction in floor space
- Reduction in unit cost
- Increase in machine utilisation
- Unmanned operations in third shift
- Reduced setting up time
- Standardisation of technology
- Starting of Computer Integrated Manufacturing

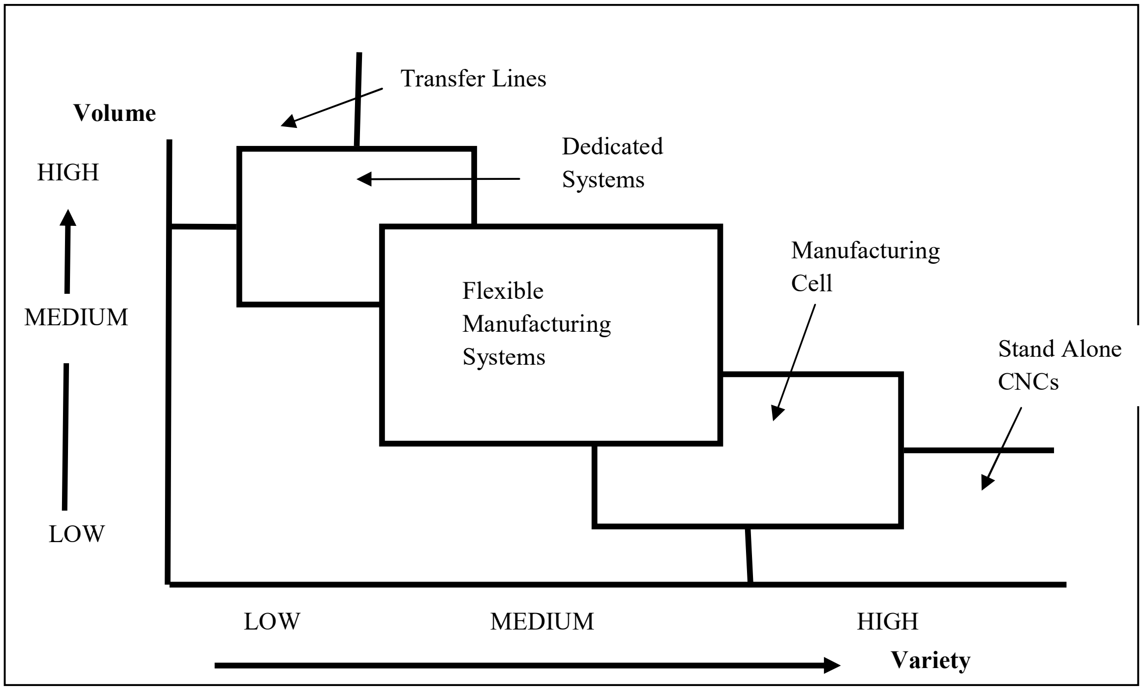

Figure 1.3: Spectrum of manufacturing systems

1.5.3 Components of FMS

The building blocks of an FMS system are Machining System Block (MSB), Workpiece Handling Block (WHB), Tool Handling Block (THB) and Computer Control Block (CCB), (Figure 1.4). There has to be compatibility between the four blocks for building an FMS. This implies that it should be possible to interface all the blocks for an integrated computer control of all the automated functions [183].

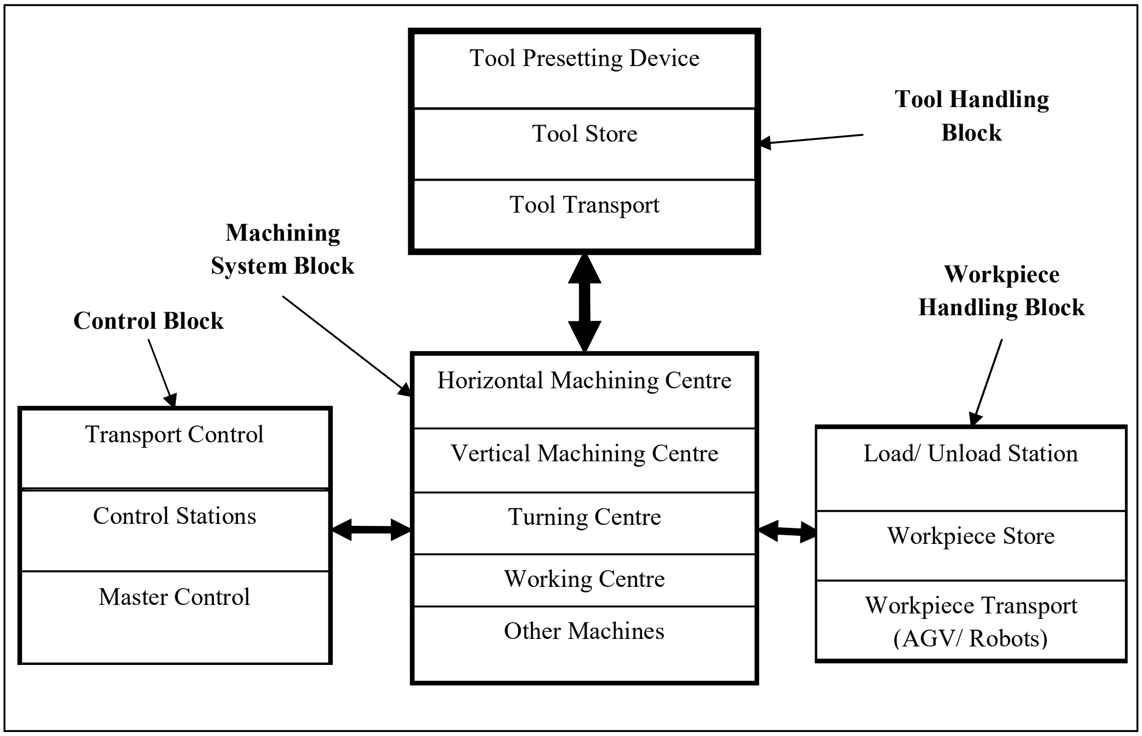

Figure 1.4: Building blocks of FMS

1.6 MOTIVATION FOR THIS RESEARCH WORK

It has been proved beyond doubt the social and economical well being of any nation depends directly on its technological advancements. The more a country is technologically strong, the more it is socially stable and economically strong. India which was once very stable socially and economically lags behind today because of many years of colonial suppression. It is still in the initial stages of adapting to the advanced manufacturing systems. The main reasons for this delay can be attributed to some of the factors which prevailed in Indian context until recently, like,

- Inertia in the mindsets for adopting changes quickly, hence starting late.
- Underutilization of the cheaply available manpower.
- Indian technological advancements have not been at par with those of the developed nations.
- Poor import/ export policies
- Poor quality and low reliability of the goods manufactured, as per international standards.

Indian mindset is a content one, but there is a fine line between contentment and lethargy and of late this line has dimmed. But now, again India as a nation has risen from this lethargic stage and is focussing on technological advancements to increase production, quality and cost effectiveness of the Indian products and services in the global market to catch up with the developed nations.

In today’s market, for survival, the Indian companies need to be able to produce a range of products at a lower cost in a short time. There is a need to change the present conventional manufacturing techniques with such type of production systems which adopts changes in minimum time and cost. So, manufacturing flexibility is the most sought after property of the modern production systems and can be attained by the adoption and implementation of flexible manufacturing systems.

With all the government policies like, ‘Skill India’, ‘Make in India’ and ‘Saksham Bharat, Sakshat Bharat’ etc, it is the high time that more attention and research be focussed on the topics like advanced manufacturing systems and especially the FMS. In view of the above, the motivation has been gained to address the topics like productivity improvement and adoption and implementation of FMS.

1.7 GAPS IN LITERATURE

Although much research work has been done in the area of flexible manufacturing systems, still some gaps in existing literature have been identified, like,

- The suitability and adaptation of FMS in developing countries where labour is very cheap and easily available is not properly covered.
- The methodologies for implementation and adoption of FMS are not well defined.
- Robots and AGVs are the main material-handling constituents of FMS. But, their costs of design and usage have not been compared with conventional material handling equipments operated by human labor in fast developing country like India.
- The issues related to FMS design and planning such as loading, scheduling, material handling, etc. have been discussed in the literature but not been addressed in a practical way.

- In the literature related to the performance of FMS, not much work has been reported for modeling of FMS productivity variables.
- The quantitative analysis of the effects of FMS on the performance of any organizations is not available.
- In the literature, factors affecting the productivity of FMS have not been categorized according to their driving power and dependence.

1.8 OBJECTIVES OF PRESENT WORK

Based on the above research gaps the main objectives identified for the present work are as follows:

- To study the literature existing on design, operational and planning issues of FMS.
- Identification of the various factors affecting the different issues of FMS.
- Analyse the perception of Indian manufacturing industries towards different issues and factors related to FMS through questionnaire based survey.
- Identification and modelling of different factors affecting productivity of FMS using ISM and TISM techniques.
- Quantification of the influence of FMS on the productivity of a firm using GTA technique.
- To study the different issues concerned with the adoption of FMS and to develop a new methodology for the conversion of a conventional manufacturing system into FMS.
- Conduct case studies to support the methodology developed for the conversion of a conventional manufacturing system into FMS.
- Feasibility analysis of FMS in small and medium scale industries.
- Identification of the different material handling issues in an FMS environment and modelling them in a hierarchical structure using ISM and TOPSIS.

1.9 RESEARCH METHODOLOGY

To achieve the above objectives, some methodologies that have been used in this work are given hereafter:

1.9.1 Questionnaire Based Survey

After exhaustive literature survey and discussions with the experts from industry and academia, a questionnaire was developed to assess the different issues and concerns of Indian manufacturing industries. The questionnaire also contained issues regarding the feasibility, implementation and performance of flexible manufacturing systems. The respondents were asked to indicate their views on a five point Likert scale. On this 1-5 scale, 1 was the least important and 5 was the most important, the other intermediate values vary in between correspondingly. The questionnaire was divided into three parts. Part 1 dealt with the company's profile, part 2 was the main section with the different issues concerned with the FMS and part 3 was related to the respondent's profile. The questionnaire was directed to 190 Indian manufacturing organisations. Based on the responses received the results were analysed and tabulated.

1.9.2 Interpretive Structural Modelling Technique (ISM)

Interpretive Structural Modelling is one of the intelligent administration strategies which help solve problems to help in decision making. In this technique the relationships between different items defining an issue are developed [16, 169]. In this technique, the judgements of the group decide whether the elements are connected or not and in what way the relation is. From these judgements a relationship is developed between a set of variables [4]. In this technique, a digraph depicts the specific relationships and overall structure between the variables.

1.9.3 Total Interpretive Structural Modelling Technique (TISM)

A TISM model is an up-gradation of Interpretive Structural Model (ISM). Infact, TISM is an extension of ISM technique. The interpretation of links in terms of how it operates is comparatively weak in ISM. To upgrade ISM to TISM, the interpretation of the nodes and links is added in the structural model. This TISM has higher applicability in real life situations [180].

1.9.4 Graph Theoretic Approach

GTA is a powerful tool that can be applied in various fields for synthesizing the interrelationship among different variables or subsystems and provides a synthesis score for the entire system. It also takes care of directional relationship and interdependence among different variables.

The following features highlight the uniqueness of this approach:

- It presents a single numerical index for all variables.
- It is a systemic methodology for conversion of qualitative factors to quantitative values.
- It permits the modeling of interdependence of factors under consideration.
- It allows visual analysis and computer processing.
- It leads to self analysis and comparison of different systems.

1.9.5 Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS)

TOPSIS was initially developed by Hwang and Yoon [28] and used by Lai et al. [206], and Yoon and Hwang [96]. TOPSIS is a MADM technique to identify solutions from a finite set of alternatives based upon simultaneous minimization of distance from an ideal point and maximization of distance from a nadir point. The ideal solution is a hypothetical solution for which all attribute values correspond to the maximum attribute values in the database comprising the satisfying solutions; the negative ideal solution is the hypothetical solution for which all attribute values correspond to the minimum attribute values in the database [155]. TOPSIS can incorporate relative weights of criterion importance.

1.9.6 Analytic Hierarchy Process (AHP)

The AHP technique is one of the approaches used in determining the relative importance of a set of attributes or criteria. AHP is designed to solve complex multi-criteria problems. It unites perception and purpose into an overall synthesis [188]. It does not require that the judgements be consistent or even transitive. In the AHP analysis, the degree of consistency of the judgements is computed [149]. The AHP is based on the innate human ability to make sound judgments about small problems. It facilitates decision-making by organizing perceptions, feelings, judgments and memories into a framework that exhibits the forces that influence a decision [125].

1.10 ORGANISATION OF THE THESIS

The details of the research carried out to achieve the objectives defined in section 1.8 are outlined in 11 chapters. The organization of the research work is depicted in Figure 1.5 and a brief description of the chapters is as given below:

- **Chapter I: Introduction**

  This chapter presents the general introduction of the manufacturing scenario of the world and introduces the flexible type of manufacturing systems. The need, suitability and benefits of flexible manufacturing system are highlighted. The motivation for this research is presented and the research gaps in this field are pointed out. The research objectives based on the gaps are presented and the methodologies used to achieve the same are discussed. Further, the organization of the whole research work is also presented.

- **Chapter II: Literature review**

  Flexible manufacturing systems are in practice for more than 60 years and its importance is still growing. So far a lot of research has been done in this field and presented in the form of papers and articles in reputed journals. To carry out this research, the work of previous researchers was thoroughly studied and reviewed. In this chapter the existing literature on different aspects of FMS is presented. The literature analysis is divided into four sections: (i) literature related to importance and adoption of FMS, (ii) identification of the factors related to the productivity of FMS, (iii) literature related to different planning, design and operational issues of FMS and (iv) literature related to the different methodologies used in this research work. Through this literature review the key issues related to the adoption, conversion, productivity and performance of FMS are identified which are further modelled in the subsequent chapters.

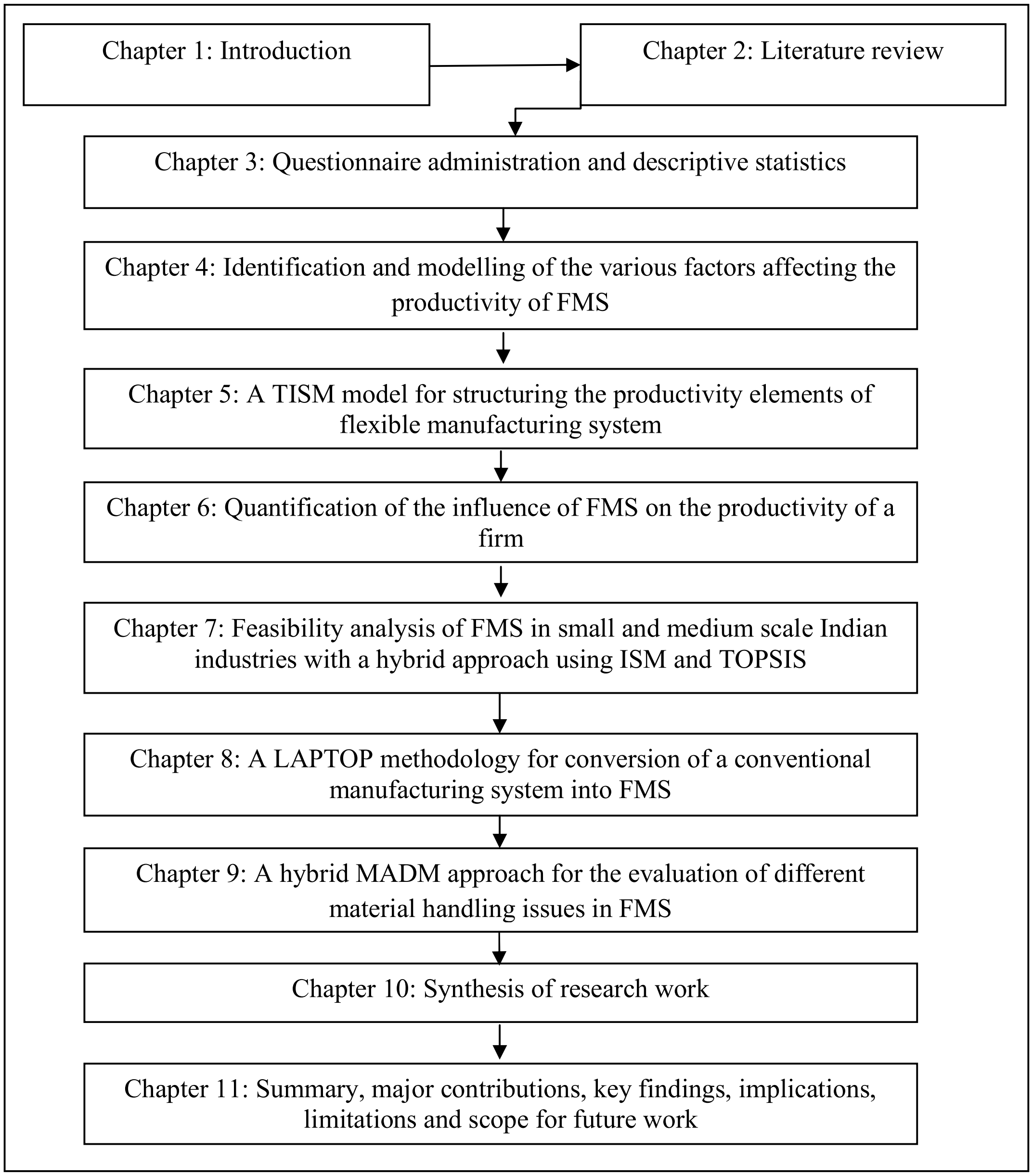

Figure 1.5: Organization of the research work

- **Chapter III: Questionnaire administration and descriptive statistics**

  A nationwide survey was conducted to know about the different issues related to FMS. This chapter presents the development of a questionnaire to conduct a nationwide survey of the different issues being faced by the manufacturing industries today. The survey questionnaire was floated to a number of large, medium and small scale industries. The survey collected the data about the perception of these industries about the different issues related to the design, planning and performance of FMS. The responses obtained from the industries were further discussed with some expert academicians in this field and analyzed and presented in this chapter for further use.

- **Chapter IV: Identification and modelling of the various factors affecting the productivity of FMS**

  In this chapter the various factors affecting the productivity of FMS are identified and modelled using Interpretive Structural Modeling technique to develop a hierarchical framework for them. Further, MICMAC analysis is done to find out their drive power and the dependence power.

- **Chapter V: A TISM model for structuring the productivity elements of flexible manufacturing system**

  The interpretation of the links in case of an ISM model is weak. By adding the interpretations of both the nodes and the links ISM can be upgraded as a Total Interpretive Structural Model (TISM). So the productivity factors are modelled using TISM technique in the chapter where the interpretation of both the links and the nodes is done to make the model more descriptive.

- **Chapter VI: Quantification of the influence of FMS on the productivity of a firm**

  An attempt has been made in this chapter to identify and categorize various productivity factors influenced by the implementation of FMS in a firm further these factors are quantitatively analysed to find their inhibiting strength using Graph Theory Approach (GTA). GTA is a powerful approach which synthesizes the inter-relationship among different variables or subsystems and provides a synthetic score for the entire system. So using this approach a numerical index is proposed in this chapter to evaluate and rank the various productivity factors so that the practising managers can have better focus.

- **Chapter VII: Feasibility analysis of FMS in small and medium scale Indian industries with a hybrid approach using ISM and TOPSIS**

The aim of this chapter is to find the feasibility of FMS in small and medium scale Indian industries. For this, in this chapter the various attributes of feasibility of FMS in small and medium scale Indian industries are presented. Further these attributes are modelled using Interpretive Structural Modelling (ISM) technique to show their relative importance. In order to validate the ISM model, the same attributes are evaluated using TOPSIS technique and the two results are compared and discussed. At the end, the key factors for making FMS feasible in SMEs are highlighted.

- **Chapter VIII: A LAPTOP methodology for conversion of a conventional manufacturing system into FMS**

  This chapter attempts to provide a new methodology for the stepwise conversion of a conventional manufacturing system into FMS. The identification of the various alternatives and their sub attributes to implement the proposed methodology is done and the best alternative of manufacturing based on FMS by means of a decision making tool, AHP in the present case, is selected. The proposed methodology is validated by a case study. Further, the implications of this research are discussed and directions for future research are suggested.

- **Chapter IX: A hybrid MADM approach for the evaluation of different material handling issues in FMS**

  In this chapter the different issues related to material handling systems especially in advanced manufacturing systems like FMS are discussed. These issues are further modelled based on their importance using Interpretive Structural Modelling (ISM) approach. In order to validate the ISM model, the same issues are evaluated using TOPSIS technique and the two results are compared and discussed.

- **Chapter X: Synthesis of research**

  In this chapter the research work done so far is synthesized. A logical connection between the different methodologies used in the previous chapters is developed and their interconnection is shown.

- **Chapter XI: Summary, major contributions, key findings, implications, limitations and scope for future work**

  In this chapter the summary of the whole research work is presented. The key findings of this research are highlighted, clearly stating the implications of these findings for the academicians as well as the practising managers. The limitations of this research are also presented and the scope for the future work is discussed followed by the conclusion section.

1.11 CONCLUSION

The growing competition in the world market has forced the industries to adopt technologies like FMS because of the benefits associated with this system. But, the adoption and implementation of this system is a difficult task due to a number of technical as well as strategic issues. This research provides a comprehensive study and analysis of these different issues and also gives a concrete framework to study the feasibility, adoption and productivity issues of FMS. In this chapter a brief introduction to the FMS along with the outline of the research is given and the following chapters give the exact contributions of this research work.

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

The birth of flexible manufacturing systems (FMS) dates back to 1960's and much research has been carried out in this field since then. To accomplish the present research work, numerous research papers have been studied and the work done so far, in this field has been analyzed. This chapter presents a concise review of the literature studied to carry out this research. This literature review is presented in four sub-sections as, (i) literature related to importance, implementation and adoption of FMS, (ii) identification of the factors related to productivity in FMS, (iii) literature related to different planning, design and operational issues of FMS and (iv) literature related to the different methodologies used in this research.

2.2 LITERATURE RELATED TO IMPORTANCE AND ADOPTION OF FMS

Flexible Manufacturing Systems have been developed with the hope that they will be able to tackle new challenges like cost, quality, improved delivery speed and to operate to be more flexible in their operations and to satisfy different market segments [197]. Successful implementation of FMS could generate reduced labor costs, increased flexibility and product variety, productivity improvement, improved responsiveness, and increased machinery utilization [124]. The system achieves higher productivity and higher output because of increase in machine utilization rates and hence reductions in set-up times [3]. In an FMS, according to changing demand patterns, quantities of production can be adjusted easily [11]. Adjustments can be made in the production schedule to respond to rush orders and special customer requests [20]. Suri [161], stated it as a step towards achieving the dream of 'factory of the future'. A FMS is characterized by its ability to process many variations within a single-product family as well as ability to make rapid extensions of an existing product line [176].

So, the adoption of this flexible production technology is luring manufacturing managers worldwide. Most manufacturing organisations want to adapt to this highly attractive technology in a hurry to gain a competitive edge without caring for the suicidal repercussions of something acclaimed as the ultimate weapon of production technology [191]. FMS requires huge capital investment and is a complex system. Though FMS provides a lot of strategic and tactical benefits, yet all of these may not be possible with all installations. A manufacturing manager should know what are the specific benefits he is expecting from the FMS installation and what is the time span within which these benefits start coming in [165].

2.2.1 Literature Related to Adoption of FMS

Flexible manufacturing system has received huge attention in the literature over the last few decades. Flexible manufacturing system (FMS) is an automated manufacturing system consisting of multiple CNC machining centres and workstations, automated material handling and storage system and distributed computer system that is interfaced with all components in the system (Groover, 2008). The manufacturing technologies that comprise an FMS include, but are not limited to, NC (Numeric Control), CNC (Computer Numeric Control) or DNC (Direct Numeric Control) machining centres, robots, conveyors, AGVs (Automated Guided Vehicles), computers, and programmable logic controllers, etc. [164].

In the present market scenario, the demand and specifications of newer products rapidly change, FMSs with automation system can bring in these changes as quickly as possible to be able to fulfil market demands [11]. FMS addresses changes in work orders, production schedules, part-programs, and tooling for production of a family of parts [102]. The FMS automatically transfers pallets between workstations, storage system and loading/unloading system. The core of FMS system is sophisticated control software that can schedule production, manage and transfer programs, and run unmanned production. Installation of an FMS is usually a significant capital investment for the company but there are also many benefits: reduced factory floor space, increased machine utilization lower manufacturing lead times and high labour productivity [66].

Several studies are carried out to examine the potential benefits of FMS implementation. The common conclusion of these studies is that the advantages associated with the FMS implementation are numerous. Successful implementation of FMS could result in reduced labor costs, increased flexibility, improved productivity, greater responsiveness, and increased machinery utilization [103]. Many firms have installed FMSs and gained such benefits. However, many other firms have failed because of successful FMS implementation require lots of strategic planning and management. A number of studies have addressed the issues related to the success of an FMS installation and implementation, since FMSs are highly capital intensive and installation may take several years. According to those studies, management commitment, people involvement, technological changes, and organizational requirements are critical issues to the success of FMS implementation [65].

Every single flexible manufacturing system is basically unique and specially made for specific company. Managing and planning the production in the FMS is very complicated task because each machine can perform many different operations and several part types simultaneously, and each part may have alternative routes [202]. During the design process of flexible manufacturing system, the most complicated task is to find most rational structure for FMS and effective way to produce different parts according to the company's production needs and product types [10]. FMSs generally require conspicuous initial investments that are difficult to be justified, unless the tangible and intangible benefits arising from an increase of flexibility can be fully captured and quantified [52]. The main criteria to consider are cost of the FMS, payback period, throughput time, utilization rate, quality of results, etc.

In the literature, production system flexibility has been discussed with its industrial applications. According to Mohanty and Venkataraman [151], only 22% of the surveyed firms in India use flexible manufacturing. Rao and Deshmukh, [95] provided a strategic framework for implementing flexible manufacturing in India. Dangayach and Deshmukh, [60] pointed out that the level of utility of flexible manufacturing is 30% in multi-product manufacturing firms. Utilization of flexible manufacturing in India is not satisfactory [2]. Nayak and Ray, [118] studied the adoption of flexible equipments in Indian manufacturing firms and knowledge of flexibility reveal that the level of practical applications in India is not satisfactory.

Dixon [84] and Suarez et al., [45] carried out an empirical study for measuring flexibility in manufacturing. Chang et al., [163] investigated the empirical relationship between business strategy and manufacturing flexibility to investigate its effect on improvement of business performance. Chan [47] studied the effects of different levels of operation flexibility and dispatching rules on the performance of flexible manufacturing systems. Chan et al., [51] provided an approach to identify productive and counterproductive performance zones of an FMS at different flexibility levels while considering physical and operating characteristics and the results show that flexibility increase up to certain level is productive and further increase is counter-productive. Nayak and Ray [119] carried out an empirical investigation to find out the relationships between flexibility and performance in a bearing manufacturing firm in India. According to Chan et al., [51], the expected benefits from increasing the level of flexibility may not be achieved if the physical and the operating parameters of alternate machines have variations. If the variations are higher, then increase in flexibility level may be counter-productive. Nayak and Ray, [117] empirically investigated the relationship between flexibility and quality in an engine manufacturing firm in India. Son and park, [209] provided an economic measurement of productivity, quality and flexibility in advanced manufacturing systems.

All the studies had a broad scope, investigating different frameworks in performance of production systems and not focusing in detail on its implementation. The objective of this research is more focused, investigating the knowledge of FMS, the utility and methods for FMS conversion.

2.3 FACTORS AFFECTING THE PRODUCTIVITY IN FMS

Productivity means how much and how well we produce from the resources used [71]. Productivity is of vital importance to a company’s ability to compete and make profits over time. ‘Do more with less’ to optimise productivity gain is vital for companies in today’s increasing competitive world [111]. Productivity is a major factor in industrial performance and measures to increase it have been proven to improve profitability of the organization [54]. Productivity increase is achieved either by producing more output from the same amount of input, or with the requirement of fewer inputs for the same level of output [153].

FMS is important for modern manufacturing to increase productivity along with product diversification [74]. Therefore, some factors are identified from the literature, industry and the academia which affect the productivity of FMS. Description of these factors is given below:

1. Reduced direct labour cost

Range of direct cost reductions, based on a study done by Saloman and Biegel [36] varies between 3% and 66%. They attribute this wide range of direct cost savings to the ratio of the labor and materials components in the direct cost. The economic justification of this system is given by most of the studies which reported that the savings were significant. Not only the reduction in direct labour cost but some other impacts like reduction in skills of direct labour is also reported. Other than for the planning and scheduling the workparts, the direct labour is mainly used for loading and unloading the parts in the system. For productivity calculations in FMS, the indirect labour costs should also be weighed up and then the total and indirect labour cost savings should be calculated [208].

2. Reduced delivery times

The present manufacturing scenario of products with shorter life cycles, the FMS has become the most suitable manufacturing system because of its flexibility [19]. With FMS not only the processing time, but also the set-up time and change over time is reduced. The total time taken by the firm to finally deliver the product is called the manufacturing lead time [126] and in FMS this lead time is reduced. This means faster customer deliveries.

3. Increased output

With FMS installations, projects reported that throughput was increased. The number of completed parts is a measure of system performance. Researchers have been constantly improving performance of an FMS [46, 181]. In fact, significant increases in output are expected with unattended third shift and reduced human intervention of manufacturing operations. The higher productivity in an FMS is achieved because of increase in machine utilization rate which leads to lower set-ups so that the system achieves a higher output [3].

4. Better inventory control

There is reasonable support for the proposition that work-in-process (WIP) inventories are drastically reduced in FMS. The inventory of starting and finished parts can be reduced as well. Although, inventory reductions of the range of 60-80%

are reported [112], but still the FMSs have much more further potential for reduction in WIP if techniques like JIT or Kanban are also adopted with this.

5. Quick response to customers

FMS has better ability to respond to the changes in part design, changes in product mix and production schedule, machine break downs, and cutting tool failures. The system has more capability of quickly adding new parts and can [112]. Adjustments can be made in the production schedule to respond to rush orders and special customer requests.

6. Improved part quality

With the introduction of FMS, the product quality improves and the related costs like the costs associated with the scrap and rework, warranty and customer satisfaction are drastically reduced. Bayazit [124] has also stressed that quality affects the productivity as a factor in FMS. Better process consistency is achieved in a FMS which makes the system reliable for achieving the desired quality. Often, productivity and quality are referred to as two distinct measures which are to be achieved as performance goals. But, a significant part of any productivity measure should be quality. In fact increase in output levels at the cost of lower quality has no value.

It was proposed by Adam et al. [40] that the same conceptual framework of output and input of traditional productivity or efficiency can be used to measure the quality of production.

Quality Productivity = Number of good parts / Total cost to manufacture them

7. Improved workpiece processes

Groover [112] has identified that production is actually a sequence of operations. The strategy of combined operation involves reducing the number of distinct production machines or workstations through which the part must be routed. This is accomplished by performing more than one operation at a given machine, thereby reducing the number of separate machines needed. Since each machine typically involves a setup, as a consequence of this strategy setup time can usually be saved. Material handling effort and non-operational time are also reduced [207].

8. Reduced number of set-ups

Kaighobadi et al. [103] and Bayazit [124] have discussed that in FMS attempt is made to achieve maximum utilization of equipment by processing a variety of parts on the same equipment. Main objectives are to reduce requirement of different equipments for the same product and the related setup times [49].

9. Improved tool management

Cutting tools and various issues related to them also affect the performance of an FMS [187]. A standard feature in metal-cutting flexible manufacturing systems is automatic tool changing at the spindle. The total number of tools required to operate an FMS typically is much larger than the total tool storage capacity at the machines. So the decisions regarding number and sequence of cutting tools are made in advance. This is generally referred to as the tool management system [203]. The use of general-purpose tools has been suggested to increase the flexibility of a system both in terms of new product introduction and in scheduling the mix of part types to be produced [114, 67].

10. Reduced manual inspection

The FMS can run without human intervention for large time periods because of high level of automation [3]. In the most optimistic scenario, parts and tools are loaded into the system at the end of the day shift, and the FMS continues to operate throughout the night so that the finished parts can be unloaded the next morning [13, 49].

11. Reduced material handling

An FMS consists of a set of machine tools and a material handling system (MHS) linked by a network of computers controlling and interfacing with them. Unlike the traditional MHS, where a human element is involved in the transportation of materials between various locations, human intervention is almost non-existent in FMS [23]. This has been made possible by developments in guided-vehicle technology and computer controlled MHSs. There are various equipments used for material handling in FMS environment of which, the AGVs are the most popular. An automated guided vehicle system features battery powered, driverless vehicle moving on a guided path layout.

12. Improved layout of machinery

The layouts of FMS are evaluated and aspects vital in the designing of an FMS are identified [133]. In most FMS installations incoming raw material and workpieces are fixtured onto a pallet and then with the help of material handling system are moved to the workstations where they are processed. The traffic coordinator, which is a DMC computer, controls the flow of parts. The machine is never made idle by assuring that there is always a waiting part to be processed in the queue with a proper design of the system. To make the idle time of machine as short as possible, the pallet exchange times are made short. An important design aspect of these material handling systems is the coordination of the these with the workstations through the proper control systems to gain maximum machine utilization for increasing the productivity without compromising the flexibility of different equipments within a the least possible floor area [44].

13. Plant modernization

With better layouts, lesser and newer machine tools, automated storage and retrieval systems, automatic guided vehicles for material handling, the overall plant is modernized. The use of modular and automatic pallet fixtures, multiple tool holders, NC and CNC makes FMS modern and advanced than the conventional manufacturing systems. With FMS there is an overall reduction in the amount of manual and clerical effort in product design, manufacturing planning and control, and the business functions of the system [112].

14. Reduced machine downtime

Increase in flexibility ensures maximum resource utilization [26]. FMS can handle different workpart configurations. The pallet fixtures used for the handling of parts are usually modular which can hold a variety of parts. Features like quick change over and rapid build up are incorporated into these fixtures which are fixed on the top of the pallets [112]. The base of pallet is designed for the material handling system. For rotational parts, industrial robots are often used to load and unload the turning machines and to move parts between stations [122].

15. Better control and documentation

Control is concerned with managing and controlling the physical operations of the FMS to implement the manufacturing plans. The flow of information is back and forth between the manufacturing control and the factory operations. Included in the manufacturing control function are shop floor control, inventory control and quality control. Advanced control functions in FMS also include safety monitoring, Maintenance and repair diagnostics and error detection and recovery. With NC, CNC and all, it is also easier to document and store the production data [112]. The graphical outputs of a computer aided design (CAD) system results in better documentation of the design data than what is practical with manual drafting. The engineering drawings are superior and more standardized. Much of the database to manufacture the product is also easily created.

These various variables like, the labour cost reduction, quality improvement, reduction in lead times, increase in outputs and quick response to the customers are the measures through which the productivity gains achieved with FMS can be gauged. The various strategic benefits achieved with the FMS installations like the increased flexibility and the reduced lead times may be more important in today's competitive market than the

The strategic benefits such as increased flexibility and reduced production lead times may well be more important factors for successfully competing in world markets than the financial savings achieved. Today cost accounting cannot be considered as the sole desirable objective of any manufacturing organization. The measures like the quality, productivity, flexibility, worker satisfaction and innovation are equally important to revitalize the manufacturing industries [44].

2.4 LITERATURE RELATED TO DIFFERENT PLANNING, DESIGN AND OPERATIONAL ISSUES OF FMS

The unique characteristic that distinguishes FMS from other factory automation technologies is the ability to achieve flexible automation i.e., the capacity to efficiently produce a great variety of part types in variable quantities [121]. FMS differs from the conventional systems in terms of flexibility in the flow of materials from one tool to another and performing the operations as per the required sequence

[152]. Each part can follow a variable route through the system. Flexibility is enabled in FMS by flexible and alternative production routes. Such alternative routes are made possible by different (or redundant) equipment types capable of performing the same operation or by different manufacturing processes that can be used to achieve the same final result [6]. In a nut shell, flexibility in material handling, in combination with multipurpose tools, makes it possible for a flexible manufacturing system to process a great diversity of parts [141].

However, managing the production of an FMS is more difficult than managing production lines or job shops because the additional flexibility-related degrees of freedom greatly increase the scope of decision variables [121]. Production planning and scheduling models arising in automated manufacturing environments exhibit several features not encountered in models developed for traditional production systems [12]. For instance, models of automated facilities typically include tooling constraints which reflect the possibility for a machine to use different tools in order to perform successive operations, within limits imposed by the size of the tool magazine. Also, these models often account for the existence of flexible material handling systems whose activities must be synchronized with the machining operations in order to optimize system utilization.

Numerous authors have discussed various issues regarding the planning, design and operation of FMS. The research problems raised by the adoption could be broadly classified into two problem areas: design problems and operation problems [27]. Adoption and implementation of FMS involves huge capital investment. Therefore it is important that the installation of this manufacturing system is preceded by thorough planning and proper design and the operation is characterised by good management of all resources. At the design stage, one is interested in specifying the system so that the desired performance goals are achieved. The operation problems are aimed at making decisions related to the planning, scheduling, and control of a given FMS. Nagarjuna et al., [121] broadly classifies the decisions involved in the management of an FMS as pre- and post-release decisions. FMS planning problem that deals with pre-arrangement of jobs and tools, before it begins to process, falls under pre-release decisions, whereas FMS scheduling problem, which considers the sequencing and routing of jobs at the time the system is in operation falls under post-release decisions. The different issues concerning the FMS are classified by Stecke [88] into four different categories as, (i) the design issues, (ii) the planning issues, (iii) the scheduling and control issues and (iv) the operational issues. These are discussed in the following sub-sections.

2.4.1 FMS Planning Issues

Pool et al., [35] defined planning as a sequence of actions that will transfer the initial world into one in which the goal description is true. FMS planning issues are those which have to be addressed before the FMS can begin to produce parts. At the planning stage, the various issues to be considered include [112]:

- Deciding the array of part types or families of parts.
- Processing requirements and selection of machine tools.
- Physical characteristics of the workparts
- Production Volume
- Number and type of flexibilities required

A family of parts to be processed in FMS is decided amongst all the parts being processes in the organization. This part type selection is made by considering the group technology philosophy or by any other similar technique. Part types which are compatible with each other may also be selected, in the sense that each type mainly utilizes different machine and so can be machined simultaneously and help attain a good overall system utilization. The due date criteria can also be considered for deciding the part types [88].

After, deciding the part types and noting their processing requirements, the selection of machine tools is done. The total processing requirements and total number of tool slots required from all machine types is also calculated. These machine and workstations are then grouped. These groupings are made with the help of total processing requirements, capacity available as per machine type and tool magazine. The physical characteristics of the workparts like the size, weight and the production volume are also the major planning issues as they influence the type of machine tools and the material handling equipments [112].

The specific types of the different flexibilities required or desired from the system are also planned at this stage. The amounts of each flexibility are also determined. Browne et al. [77] defined and described eight types of flexibilities that all FMSs theoretically can have. Buzacott [73] begins to quantify some of these flexibilities. It is both expensive and difficult to have all the flexibilities in all the systems. All FMSs actually have varying amounts of these. So, in the planning stage it is to be defined what are the specific flexibilities the system is going to inherent and in what amount, so that the system may be designed and controlled accordingly. The availability of funds, space, technology and skilled labour are also the issues which are to be considered during the planning phase.

2.4.2 FMS Design Issues

After the initial planning decisions, the design issues are addressed. The major design issues include [112]:

- Types of workstations
- Process routing variations and the FMS Layout
- Material handling system design
- Work-in-process and buffer capacity
- Number and types of tools
- Number and types of pallets and fixtures

As per the planned part types the number, types and position of the workstations including the processing workstations, load/unload stations, assembly, inspection, cleaning stations etc. are decided. As per the planning decision of how flexible the system is to be, the amount of automation into the system is decided. The layout of these workstations directly affects the amount of flexibility achieved by specifying the process and part routings, so the FMS layout design is made depending on the type of control strategies required. According to the chosen layout the primary and the secondary MHS are designed. Much considerations are involved in the design of the MHSs as they have a direct impact on the product lead time.

Further the level of WIP also affects the utilization and efficiency of FMS, so proper planning must be involved to determine the permissible WIP in the system. The buffer capacity has to be determined. Based on the turret capacity of the workstation and the processing requirements of the workparts the determination of the requirement of the number and types of cutting tools is done. Number of pallets and fixtures specifies the maximum number of parts that will be in the system. Too few pallets and fixtures lead to system under utilization and increases the waiting time, where as too many will cause system congestion and is an unnecessary expanse. Parts that differ too much in configuration and size also require different fixturing. So the optimum number of pallets and fixtures are to be decided as per the system requirements.

2.4.3 FMS Operational Issues

The operational issues in FMS are concerned with the strategies for running the FMS. These are the real time problems arising out of the changing customer orders, time of arrival of the order and the different processing requirements of the workparts. The operational issues are addressed after the FMS is installed to optimize the existing resources to meet the production requirements and achieve operational objectives. The main operational issues that must be handled regularly during the running of the FMS are [112]:

- Machine Loading
- Scheduling and dispatching
- Part routing
- Part grouping
- Tool management
- Pallet and fixture allocation

Loading involves the decision about the assignment of work to different machine tools in the manufacturing system for the purpose of machining [187].

A loading problem can be defined as,

‘‘given a set of parts to be produced, set of tools that are needed for processing the parts on a set of machines, and using a set of resources such as material handling systems, pallets and fixtures, how should the parts be assigned and tools allocated so that some measure of productivity is optimized’’[8].

Different components of FMS put different constraints in making a loading plan. These include, variety of machine tools, control system, cutting tools and tool magazine capacity, etc.

Scheduling is the allocation of resources over time to perform tasks [92]. The purpose of scheduling is to determine when to process which job and by which resources so that the production constraints are satisfied and the production objectives are met [70]. In view of the scheduling theory, a general FMS may be considered to be job shop with parallel machines and additional limited resources [187]. The development of effective and efficient FMS scheduling strategies remains an important and active research area. Scheduling in for an FMS is more difficult than in a conventional manufacturing environment. This is primarily due to versatile machines, which are capable of performing many different operations resulting in many alternative routes for part types, and also due to the systems' capacity for simultaneous part processing.

Part routing, grouping, tool, pallet and fixture allocations are the other operational issues which are to be considered. For part routing and grouping the various possibilities in the system are to be considered and the routes followed by other parts are also present a constraint. The different activities concerned with the allocation and the usage of the cutting tools come under the tool management [41].

Ever since the first article written by Stecke and Solberg [89] on the production planning problem of FMS has been published, a lot of research has been devoted in this area by various researchers. There are thousands of research articles on FMS loading and scheduling problems proposed by different authors at different times. The pioneering work by Steke [87, 88, 89], described the FMS planning problem into five sub problems i.e. (i) part selection, (ii) resource allocation, (iii) machine grouping, (iv) production ratio determination and (v) loading. Liu and Maccarthy [79] have identified and discussed five major factors influencing the FMS operational problems such as (i) system types such as a single flexible machine (SFM), a flexible manufacturing cell (FMC), a multi- machine flexible manufacturing system (MMFMS) and a multi-cell flexible manufacturing system (MCFMS), (ii) capacity constraints, (iii) job characteristics, (iv) production management environment and (v) scheduling criteria.

Based on the methodology followed, FMS operations literature could be classified in the following ways:

- Mathematical programming approach
- Multi-criteria decision making approach

- Heuristics oriented approach
- Control theoretic approach
- Simulation based approach
- Artificial intelligence (AI) based approach

There is also some cross fertilization among these approaches. For example, some AI based approaches use simulation to generate or evaluate schedules. In mathematical programming approach, the researchers have cast the problem into an optimization model. Due to the computational complexity of the problem, optimization techniques such as integer programming and mixed integer programming are not practical. Simulation and despatching heuristics are the two most commonly used solution methods for scheduling problems of reasonable sizes.

The first mathematical formulation for FMS-loading problem was given by Stecke [87]. The grouping and loading were formulated as non-linear 0–1 mixed integer programs. A heuristic model based on multi-stage programming approach was proposed by Nagarjuna et al., [121] to solve machine loading problem in random FMS. Kumar et al., [8], studied the simple genetic algorithm and proposed a new methodology, constraint-based genetic algorithm (CBGA) to handle a complex variety of variables and constraints in a typical FMS-loading problem. Roh and Kim [68] proposed a loading and scheduling model based on due- date with an automatic tool transporter. The model focused on the problems of part loading, tool loading, and part sequencing with the objective of minimizing the total tardiness. Chan and Swarnkar, [50] presented a fuzzy goal programming approach for the machine tool selection and operation allocation problem of FMS. Tiwari and Vidyarthi [106] proposed GA-based heuristic for solving machine-loading problem in FMS with an objective of minimization of system unbalance and maximization of throughput. Li et al., [34] proposed a mega-trend-diffusion technique to estimate the domain range of a small data set and produce artificial samples for training the modified back propagation neural network (BPNN). A simple FMS simulation model was constructed, it consisted of a load/unload station, three automatic guided vehicles (AGVs), four CNC machines, and four pairs of input/output buffers (IB/OB) for each CNC machine. A computer simulation model was proposed by Chan [42], in order to evaluate some control rules on the performance of flexible manufacturing system.

Three control rules: dynamic alternative routings, planned alternative routings, and no alternative routings, were proposed to control the selection of alternative routing for each part. Chan et al., [43] presented a simulation model of a flexible manufacturing system (FMS) which subjected to minimization three performance criteria simultaneously such as mean flow time (MFT), mean tardiness (MT), and mean earliness (MR). The FMS included five general-purpose machine workstations and one loading/unloading station.

A look at these available models indicates that these models solve the following problems:

- Selection problems
- Loading problems
- Work in process problems
- Part scheduling and allocation problems
- Dispatching problems
- Layout problems and
- Costing & investment problems

A review of the literature related to the different methodologies is given in next section.

2.5 LITERATURE RELATED TO THE DIFFERENT METHODOLOGIES USED

This section gives a review of the literature regarding the different methodologies used in this research work. The technique steps and the broad application areas are presented, as identified from the literature.

2.5.1 An Overview of ISM Approach

The presence of a large number of elements with interactions among these elements makes many issues or systems complex. The presence of directly or indirectly related elements complicates the structure of the system which may or may not be articulated in a clear fashion. It becomes difficult to deal with such a system in which structure is not clearly defined. Hence, it necessitates the development of a methodology which aids in identifying a structure within a system. Interpretive structural modelling is such a methodology [37, 189]. Interpretive Structural Modelling is a technique for giving a structure to the various directly or indirectly related attributes of any problem or issue. The ISM is an interactive learning process. In this technique, a systematic model is developed to depict the configuration of an intricate problem using words as well as graphics [100, 200, 186]. For identifying specific relationships between the items defining an issue or a problem, interpretive structural modelling is an established methodology [169, 16].

2.5.1.1 Steps involved in ISM methodology

There are two basic concepts which are essential to understand the ISM methodology. One is the concept of transitivity and the other is that of reachability. Transitivity can be explained with the following example. As shown in Figure 2.1, if element *i* relates to element *j* (i.e.*i*R*j*) and element *j* relates to element *k* (*j*R*k*), then transitivity implies element *i* relates to element *k* (*i*R*k*). Similarly, element *i, j and k* relates to element *m*. Transitivity is the basic assumption in ISM and is always used in this modeling approach [37, 162, 64]. It helps in maintaining the conceptual consistency. For example, in Figure 1, if the relationship between element *i* and element *k* is missing then with the help of transitivity rule one can modify the diagraph to incorporate this link. Similarly, in a situation like Figure 2.2, one can identify the conceptual inconsistency as element *j* leads to element *k* and element *k* leads to element *i*. In that case, element *i* leading to element *j* is conceptual inconsistency. The modeler can consult the expert if a situation of conceptual inconsistency is detected. Since, the ISM approach is based on expert opinion about these complex relationships, the literature only deals with the qualitative way to detect conceptual inconsistency [186].

The reachability concept is the building block of ISM methodology. Different identified elements are compared on a pair-wise basis with respect to their inter-relation. This information is represented in the form of binary matrix. If an element *i* reaches another element *j,* then entry in the cell (*i,j*) of the reachability matrix is 1 and if element *i* does not reach *j,* then entry in the cell (*i,j*) is 0. Some of the cells of the reachability matrix, because of this transitivity concept can be filled by inference [162]. In terms of matrix entries (*i,j*) = 1 and (*j,k*) = 1, imply (*i,k*) = 1. There is no need to make specific comparison between *i* and *k* since transitivity answers this comparison [189, 186].

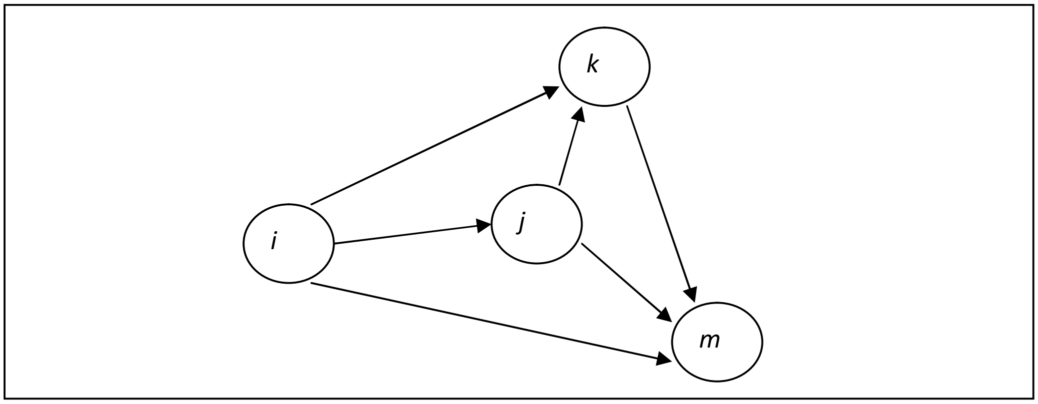

Figure 2.1: Transitivity digraph

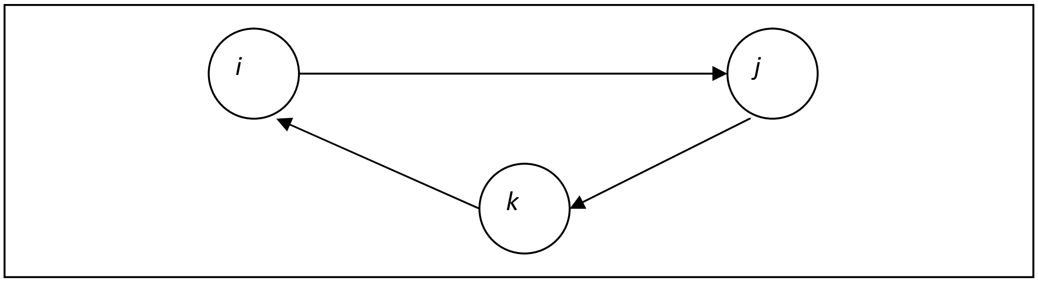

Figure 2.2: Intransitivity digraph

The stepwise methodology involved in ISM modelling is as follows [189, 186]:

Step 1: Identification of different variables related to a problem or issue, enlisted by a survey or group problem solving technique. After this, for examining the pairs of factors a contextual relationship is recognized between them.

Step 2: Developing a structural self-interaction matrix (SSIM) of the variables. This matrix indicates the pair-wise linking of the variables which is further tested for transitivity.

Step 3: From the SSIM a reachability matrix (RM) is developed.

Step 4: Partitioning of the reachability matrix into different levels.

Step 5: A conical matrix is developed with this reachability matrix by incorporating the maximum 0 entries in the upper diagonal half and most 1 entries in the lower half.

Step 6: With the help of the relationships depicted in the conical matrix, a digraph which is a directed graph is drawn. Further the transitivity links are removed from this digraph.

Step 7: ISM model is generated from this digraph by replacing the nodes of variables with variable statements.

Step 8: Finally, the conceptual consistency is for this ISM model checked and necessary modifications, if any are incorporated.

2.5.1.2 Applications of ISM approach

The application of ISM technique in analyzing different issues is very old. Literature shows that, Warfield [82]; Farris and Sage [37]; Watson [162], all have applied or elaborated this technique to model different issues. And it is still being used by the new researchers because of its simplicity. For example:

Table 2.1 gives a brief review of the ISM applications from the literature review.

Table 2.1: ISM applications found in the literature

S.No.	**Author(s)**	**Application**
1.	Ravi and Shankar [200]	Reverse logistic barriers to supply chains
2.	Bolanos et al. [140]	Strategic decision-making groups
3.	Singh et al. [146]	Successful implementation of advanced manufacturing techniques
4.	Raj et al. [189]	Modelling the enablers of FMS
5.	Thakkar et al. [86]	Evaluating and comparing supply chain relationships, in small and medium scale enterprise
6.	Raj et al. [190]	Barriers to transition to FMS
7.	Faisal [108]	Social responsibility in supply chains
8.	Khurana et al. [104]	Modelling the enablers for information sharing in Indian manufacturing industry
9.	Mudgal et al. [142]	Barriers of green supply chain practices.
10.	Luthra et al. [174]	Implementation of green supply chain

		management in automobile industry
11.	Govindan et al. [90]	Analysis of third party reverse logistics provider
12.	Attri et al. [139]	Barriers to TPM
13.	Mishra et al. [175]	Drivers of agile Manufacturing
14.	Saxena and Seth [17]	Supply chain risk and security management
15.	Nagar and Raj [24]	Critical success factors for implementation of humanised flexible manufacturing system in industries.
16.	Sharma and Bhat [171]	Supply chain agility enablers
17.	Upadhye et al. [123]	Implementation enablers for JIT in Indian Packaging Industry
18.	Poduval et al. [134]	Analyzing factors inhibiting implementation of Total Productive Maintenance
19.	Dixit and Raj [165]	Modelling the productivity variables of FMS
20.	Tripathi and Vinodh [147]	Analysis of sustainable manufacturing factors in Indian automotive component sector

2.5.2 An Overview of TISM

Many times we encounter the situations where a large number of elements or factors influence any system. There is usually direct or indirect interaction between these elements which makes the system complex. For instance, there are a number of factors which affect the productivity of FMS and these factors are mutually linked. So it becomes difficult to visualise any structure among these factors.

ISM is a technique which aids in identifying a structure within a system.ISM is a computer assisted interactive learning process whereby structural models are produced and studied. It shows the structure of a complex issue in a designed pattern employing graphics and words. ISM helps to impose levelling and hierarchy on the intricacy of relationships between different variables of a system [100, 16].

In ISM the interpretation of the diagraph can be done at the nodes and the links. In ISM the nodes define the different elements influencing the system. But the interpretation of links is comparatively weak in ISM. This is limited to interpreting the contextual relationship between the elements and the direction of relationship in a paired comparison [180]. The interpretation of the directed link in terms of how it operates is missing in ISM. The addition of the interpretation of all the links of an ISM model leads it to TISM. The TISM takes its predecessor to the next level by incorporating the interpretation of each observed relationship. The new approach improves upon the interpretive aspects of ISM by building a knowledge base of logical interpretations of each observable relationship. This repository of knowledge serves to bolster the interpretive aspects of ISM and makes the logic that drives the model more transparent and less likely to being interpreted incorrectly.

The basic steps for TISM are outlined below:

Step 1. Identify and the define factors: The first step is to identify and define the elements whose relationships are to be modeled.

Step 2. Defining the contextual relationship between these factors: After identifying the various factors, a contextual relationship is developed between them. This contextual relationship is developed based on how one factor influences the other.

Step 3. Giving interpretation of contextual relationships: In traditional ISM, the relationship between the various factors is developed without any interpretation being added to that but in TISM, the interpretation of the relationship is also clarified. Infact, it is at the commencement of this step that the study moves forward from the scope of traditional ISM to TISM.

Step 4. Interpretive logic of pair-wise comparison: In ISM, individual factors are compared. The only interpretation at this stage relates to the direction of the relationship. In order to upgrade ISM to TISM, interpretive matrices were used so as to fully interpret each paired comparison in terms of how that directional relationship operates in the system under consideration [180].

Step 5. Reachability matrix and transitivity check: A reachability matrix is created by the paired comparisons.

Step 6. Different levels are partitioned on reachability matrix. [82, 17]. It is done by determining the reachability and antecedent sets for all the factors. The factors in the top level of the hierarchy will not reach any factors above their own level. As a result, the reachability set for a top level factor will consist of the factor itself and any other factors within the same level which the factor may reach, such as components of a strongly connected sub-set

Step 7. Developing the digraph: A digraph is developed which is the graphical representation of the factors arranged in levels as per the relationships depicted in the reachability matrix. By investigating the interpretations from the knowledge base the transitive relationships are eliminated from the digraph. The only transitive relationships are taken whose interpretation is important.

Step 8. Developing interaction matrix and converting to interpretive matrix: A binary interaction matrix is developed through the final diagraph [155].

Step 9. Prepare TISM: With the help of the information obtained from the interpretive direct interaction matrix and diagraph the TISM is drawn. Interpretation of factors is added to the instead of nodes in the diagraph. Along the side of the particular link the interpretation from the interpretive direct interaction matrix is shown in the structural model. This results in the total interpretation of the structural model.

Step 10. It is widely believed that TISM may have a higher applicability in real life situations, which is why it was used for the purpose of this study.

2.5.3 Graph Theoretic Approach (GTA)

GTA is a powerful tool that can be applied to diverse fields. It synthesizes the inter-relationship among different variables or subsystems and provides a synthetic score for the entire system. Although there are a few other approaches available to perform similar tasks and GTA is more computationally intensive than most of them, still GTA has the following features which highlight its uniqueness over other similar approaches [185]:

- It presents a single numerical index for all the factors.
- It takes care of the directional relationship and interdependence among the factors and its sub factors.
- It is a systematic methodology for conversion of qualitative factors to quantitative values.
- Allows visual analysis as well as computer processing, and
- Leads to self analysis and comparisons of different organisations.

This approach consists of the following components:

- Digraph depiction

- Matrix depiction
- Permanent function calculation

The digraph gives the visual representation of the factors/variables and their interdependence. The matrix converts the digraph into mathematical form and the permanent function is a mathematical model which gives a numerical value.

2.5.3.1 Variables/ factors digraph

The interdependency between the various factors is shown with the help of a digraph. A digraph consists of a set of nodes P = $\{P_i\}$, with i = 1,2,3,.......M and a set of directed edges p = $\{p_{ij}\}$. Edges of the digraph show the interdependence between the factors and the node Pi represents the i^{th} factor. There will be as many number of nodes as are the number of factors. If a node i has a relative importance over another node j, then a directed edge or arrow is drawn from node i to node j (i.e. p_{ij}). A directed edge is shown from node j to i, if a node j has a relative significance over node i.

This developed digraph helps the experts to visualize and analyze the any given environment, but as the number of variables and their interrelationships increase, the digraph becomes complex. In such cases the digraph is represented in matrix form.

2.5.3.2 Matrix representation of variables/ factors

A matrix is a convenient and useful way of representing a digraph for computer processing. Matrices can be easily used for the mathematical manipulations. A digraph can be represented by a binary matrix (p_{ij}), where p_{ij} shows the relative importance amongst the factors i and j such that, p_{ij} = 1, if the i^{th} factor is more important than the j^{th} factor and p_{ij} = 0, for vice versa [155].

In general, if there are M number of contributing categories of factors and interdependencies exist among all of these categories and there are no self loops, i.e. p_{ii} = 0, then the matrix, P is written as:

$$P = \begin{array}{c|cccccc} \text{Factors} & P_1 & P_2 & P_3 & \ldots & \ldots & P_m \\ \hline P_1 & P_1 & p_{12} & p_{13} & \ldots & \ldots & p_{1m} \\ P_2 & p_{21} & P_2 & p_{23} & \ldots & \ldots & p_{2m} \\ P_3 & p_{31} & p_{32} & P_3 & \ldots & \ldots & p_{3m} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ P_m & p_{m1} & p_{m2} & p_{m3} & \ldots & \ldots & P_m \end{array} \qquad \text{.......(2.1)}$$

2.5.3.3 Permanent representation of productivity factors matrix

To have a unique representation of the above digraph and matrix a permanent function of the productivity factors is calculated. As given by Jukat and Ryser [201] the permanent function is widely used in the combinatorial mathematics as a standard matrix function. Quantitative value of the effect of variables/ factors is obtained by this permanent function by substituting the values of P_i and p_{ij} in matrix P. This multinomial representation includes all the information regarding critical factors as it does not contain any negative sign thus no information is lost.

2.5.3.4 Applications of GTA

This technique has been used widely by the researchers in the past because of its inherent simplicity. Some examples of its applications in the past in different fields are presented in Table 2.2.

Table 2.2: Applications of GTA

S.No.	Author (s)	Applications
1.	Agarwal and Rao [199]	Identification and isomorphism of kinematic chains.
2.	Gandhi and Agarwal [188]	Failure mode effect analysis
3.	Wani and Gandhi [101]	Development of maintainability index of mechanical systems
4.	Rao and Gandhi [157]	Selection, identification and comparision of metal cutting fluids
5.	Grover et al. [167]	Quantifying TQM environment
6.	Grover et al. [168]	Human factors in TQM

7.	Rao and Padmanabhan [156]	Selection of industrial robots
8.	Faisal et al. [109]	Risk mitigation in supply chain environment
9.	Jangra et al. [91]	Performance evaluation of the carbide compacting die manufactured by wire EDM
10.	Raj and Attri [185]	Quantifying barriers to implementing TQM
11.	Raj et al. [192, 191]	Feasibilty of transition to FMS and Evaluation of the intensity of barriers in the implementation of FMSs
12.	Saha and Grover [159]	Website performance factors evaluation
13.	Dev et al. [120]	Combined cycle power plant efficiency analysis
14.	Mishra [150]	Structural modelling and analysis of world-class maintenance system

2.5.4 Review of the Literature Regarding TOPSIS

The acronym TOPSIS stands for Technique for Order Preference by Similarity to the Ideal Solution. TOPSIS was initially developed by Hwang and Yoon [28] and used by Lai et al. [206], and Yoon and Hwang [96]. It is based upon simultaneous minimization of distance from an ideal point and maximization of distance from a nadir point. The ideal solution is a hypothetical solution for which all attribute values correspond to the maximum attribute values in the database comprising the satisfying solutions; the negative ideal solution is the hypothetical solution for which all attribute values correspond to the minimum attribute values in the database [155] TOPSIS can incorporate relative weights of criterion importance.

2.5.4.1 The TOPSIS Methodology

The main steps involved in the improved TOPSIS technique for the finding the most wanted variable from given set of variables is described as follows [155]:

Step 1: Determine the goal and related variables.

Step 2: A matrix is created based on the information obtained about the variables. Each row of this matrix is allocated to one variable and each column to one criteria. So performance data for n alternatives over k criteria is obtained. Raw measurements are usually standardized; converting raw measures X_{ij} into standardized measures S_{ij}, using the equation (2.2).

$$S_{ij} = X_{ij} / \left((\sum_{i=1,j=1}^{n,k} ({X_{ij}}^2))^{1/2} \right) \qquad \text{........ (2.2)}$$

Step 3: Now a set of importance weights w_k is developed for each of the criteria. The weights are decided such that the set of weights w_k (k = 1, 2,…, n) and $\sum w_k$ =1. The basis for these weights is reflective of relative importance of these criteria. The relative importance weights of the criteria can be assigned arbitrarily by the decision maker. In this work the weightage of rating is calculated by using following criteria:

$$Normalised\ weight\ of\ each\ importance = \frac{Total\ of\ each\ importance}{Grand\ total\ of\ all\ importance} \quad \text{.... (2.3)}$$

Step 4: By multiplying each element of the column of the matrix S_{ij} with its associated weight w_k the weighted normalized matrix W_{ij} is obtained. Hence, the elements of the weighted normalized matrix W_{ij} are expressed as:

$$W_{ij} = w_k S_{ij} \qquad . \text{......(2.4)}$$

Step 5: Identify the ideal attribute i.e. the most desirable attribute on each criterion, S+. The ideal attribute is the maximum value of each rating column of weighted matrix.

Step 6: Identify the nadir attribute i.e. reverse extreme desirable attribute on each criterion, S-. The nadir attribute is the minimum value of each rating column of weighted matrix.

Step 7: Develop a distance measure over each criterion to both ideal (D+) and nadir (D-). The distance from ideal can be calculated using equation (2.5).

$$D_t^+ = \left\{ \sum_{j=1}^{k} (W_{ij}^- \ S_j^+)^2 \right\}^{1/2} \qquad i = 1,2,3 \ldots\ldots n \qquad \text{.......(2.5)}$$

and the distance from nadir can be calculated using equation (2.6).

$$D_t^- = \left\{ \sum_{j=1}^{k} (W_{ij}^- \ S_j^-)^2 \right\}^{1/2} \qquad i = 1,2,3 \ldots\ldots n \qquad \text{........(2.6)}$$

Step 8: A ratio R used to express the relative closeness of a variable to the ideal variable. So, R_i can be expressed as equal to the distance to the nadir divided by the sum of the distance to the nadir and the distance to the ideal, as shown in equation (2.7).

$$R_i = \frac{D_i^-}{D_i^- + D_i^+} \qquad i = 1,2,3 \ldots .. n \qquad \ldots\ldots\ldots(2.7)$$

Step 9: A set of alternatives is made in the descending order in this step, as per the value of R_i showing the most desirable and least desirable variable. R_i may also be called as overall or composite performance score of variable A_i.

2.5.4.2 Applications of TOPSIS

Some of the application in which TOPSIS has been applied is given in Table 2.3.

Table 2.3: Applications of TOPSIS

S.No.	Author(s)	Application
1.	Agrawal et al. [198]	Selection of grippers in flexible manufacturing
2.	Kim et al. [58]	Investment opportunities for advanced manufacturing system
3.	Parkan and Wu [30]	Robot selection
4.	Deng et al. [63]	Company performance comparision
5.	Hao and Xie [97]	Bidding evaluation of manufacturing enterprises
6.	Wang and Chang [182]	Evaluating initial training aircraft
7.	Kannan et al. [57]	Selection of reverse logistics provider
8.	Yang and Sun [55]	New personalized recommendation technique
9.	Chen et al. [31]	Personnel selection based on multi-type information environment
10.	Latpate [154]	Supplier selection problem in supply chain Management
11.	Jain and Raj [196]	Evaluation of flexibility in FMS
12.	Ziaei et al. [115]	Performance improvement of water pump manufacturing system

2.5.5 Literature Related to the Application of AHP Technique in Decision Making

The Analytic hierarchy process (AHP), developed by Saaty, [184] is one of the multi-criteria decision making methods that simplifies a multifaceted issue into hierarchical order [113]. The AHP is based on the innate human ability to make sound judgments about small problems. It facilitates decision-making by organizing perceptions, feelings, judgments and memories into a framework that exhibits the forces that influence a decision [125]. The AHP technique is one of the approaches used in determining the relative importance of a set of attributes or criteria. AHP is designed to solve complex multi-criteria problems. It unites perception and purpose into an overall synthesis [188]. It does not require that the judgements be consistent or even transitive. In AHP analysis the degree of consistency of opinions is calculated [149]. AHP incorporates the evaluations of all decision- makers into a final decision, without having to elicit their utility functions on subjective and objective criteria, by pair-wise comparisions of the alternatives [25]. The AHP has been widely used and much research publications are available related to the applications of AHP in decision making [194, 211, 124, 29, 48, 129].

The AHP methodology can be explained by the following three steps [184]:

Step 1: Structuring the hierarchy.

The approach of the AHP involves decomposition of the decision problem into different hierarchy levels with a view to accomplishing the stated objective of the problem. So in the first step, group related components and structure them into a hierarchical order that reflects functional dependence of one component or a group of components on another.

Step 2: Performing paired comparisons between elements/decision alternatives.

In the second step a pair- wise comparison matrix of the relative importance of the hierarchy elements at each level with respect to the overall objective of the problem is constructed. In this matrix the entries indicate the strengths with which one element dominates another using a method for scaling of weights of the elements in each of the hierarchy levels. These values are used to determine the priorities of the elements of the hierarchy reflecting the relative importance among entities at the lowest levels of the hierarchy [48]. The scale used for comparisons in AHP enables the decision maker to incorporate experience and knowledge intuitively [136] and indicates how many times an element dominates another with respect to the criterion. A nine-point scale given by Saaty [184] can be used for entering the values in this matrix. The decision maker can express his preference of importance between each pair of elements verbally as equally, moderately more, strongly more, very strongly and extremely more. These descriptive preferences would then be translated into numerical values 1, 3, 5, 7, 9, respectively, with 2, 4, 6 and 8 as intermediate values for comparisons between two successive qualitative judgments. Reciprocals of these values are used for the corresponding transposed judgments [124]. So in this step n(n-1)/2 comparisons are made, where n is the number of elements, all the diagonal elements are equal to 1 and the other elements will simply be reciprocals of the earlier comparisons.

Step 3: Synthesizing results.

Synthesize these priorities to obtain the global priorities. For this perform calculations to find the maximum Eigen value, Consistency Index (CI) and Consistency Ratio (CR). If the inconsistency exceeds 0.10 value, the comparison process in step 2 is repeated till these values are in the desired range otherwise the decision is taken based on the normalised values for each alternative. The ranking of each alternative is calculated by multiplying each value in weight from the sub-criteria column by the respective value in the criteria weight column, then multiplying by the value for each respective alternative and summing the results [188]. Select the alternative with the highest priority.

2.6 CONCLUSION

Although it is very good for the manufacturing organizations to adopt and implement FMS, but deep understanding of the different issues related to its planning, design, operation and performance is must for gaining its maximum benefits. In this chapter the various dominant issues related with the FMSs have been reviewed. A critical look at the available literature indicates that there are still various issues which need to be addressed towards design and development of an effective FMS. These can provide an important direction for the further research to be carried out in this field.

In literature productivity gain is mentioned as an advantage of FMS implementation, but what are the specific variables which affect this productivity gain is not specified. The various productivity factors are also not structured and modelled to show their interrelationship. In this research work these factors are identified and modelled. The studies related to the implementation of FMS lack in showing in a clear and precise way the feasibility of FMS in developing countries like India. Also there is a need to develop a stepwise methodology for adoption of FMS in traditional factories. The adoption and implementation issues of the FMS should be further analyzed according to Indian industrial environment to achieve the maximum profits. These issues identified in this chapter provide the impetus for carrying out this current research.

CHAPTER III

QUESTIONNAIRE ADMINISTRATION AND DESCRIPTIVE STATISTICS

3.1 INTRODUCTION

In this chapter, a questionnaire based survey report is presented with the objective of examining the perception of Indian manufacturing industries towards different issues related to FMS. Key observations from the survey have been discussed and analyzed. The development of the questionnaire and its administration is also discussed.

3.2 QUESTIONNAIRE DEVELOPMENT AND ADMINISTRATION

A survey was undertaken to find out the present major concerns and the status of FMS in Indian manufacturing industries. For this purpose, a questionnaire was designed and developed related to the major issues regarding FMS from literature survey and discussions with experts from industry and academia. The questionnaire was developed on a five point (1 to 5) Likert scale. The questionnaire was divided into three parts. Part 1 dealt with the company's profile, part 2 was the main section with the different issues concerned with the FMS and part 3 was related to the respondent's profile.

The questionnaire was directed to 190 Indian manufacturing organisations, out of which only 67 filled questionnaires were received. Four questionnaires were incompletely filled and were discarded. So, for further analysis only 63 questionnaires were used. This gives a response rate of 33.15%.

Based on these 63 questionnaires the data of the responding organizations is presented in Table 3.1.

Table 3.1 Descriptive data of the responding organizations

S.No.	Data description	Value ranges	Number of organizations
1.	Annual turnover (in Crores of Rs.)	Less than 10	13
		10-50	7
		50-100	22
		More than 100	21
2.	Number of employees	Less than 100	20

		101-500	09
		501-1000	13
		1001-3000	7
		More than 3000	14
3.	Department	Production	21
		Quality	08
		Marketing	20
		Others	14

3.3 ANALYSIS OF THE SURVEY DATA

This section presents the analysis of the survey data for the various issues related to FMS.

3.3.1 Major Concerns being faced by the Organizations Today

Before the implementation of any advanced manufacturing systems, it is necessary to know the present majors concerns of the organizations. Table 3.2 shows the survey data of the major concerns faced by the industries today. The table shows producing quality goods (mean = 3.873), vendor lead times (mean = 3.857) and poor utilization of equipments and resources (mean = 3.698) are the major concerns of present day industries. The other problems being faced are also shown in the Table 3.2 and Figure 3.1 with their mean score of responses.

Table 3.2: Data for the major concerns of industries today

S. No.	Major concerns	Mean	Rank
1.	High or rising overhead costs	2.905	11
2.	Producing high quality standards	3.873	1
3.	Introducing new products on schedule	3.476	6
4.	High or rising material cost	3.031	9
5.	Availability of qualified workers	2.889	12
6.	Inability to deliver on time	2.920	10
7.	Poor sales forecast	2.857	13
8.	Falling behind in new process technology	3.608	4
9.	High or rising inventories	3.507	5
10.	Yield problems and rejects	3.253	8
11.	Vendor lead times	3.857	2
12.	Indirect labour productivity	3.269	7
13.	Poor utilization of equipments and resources	3.698	3

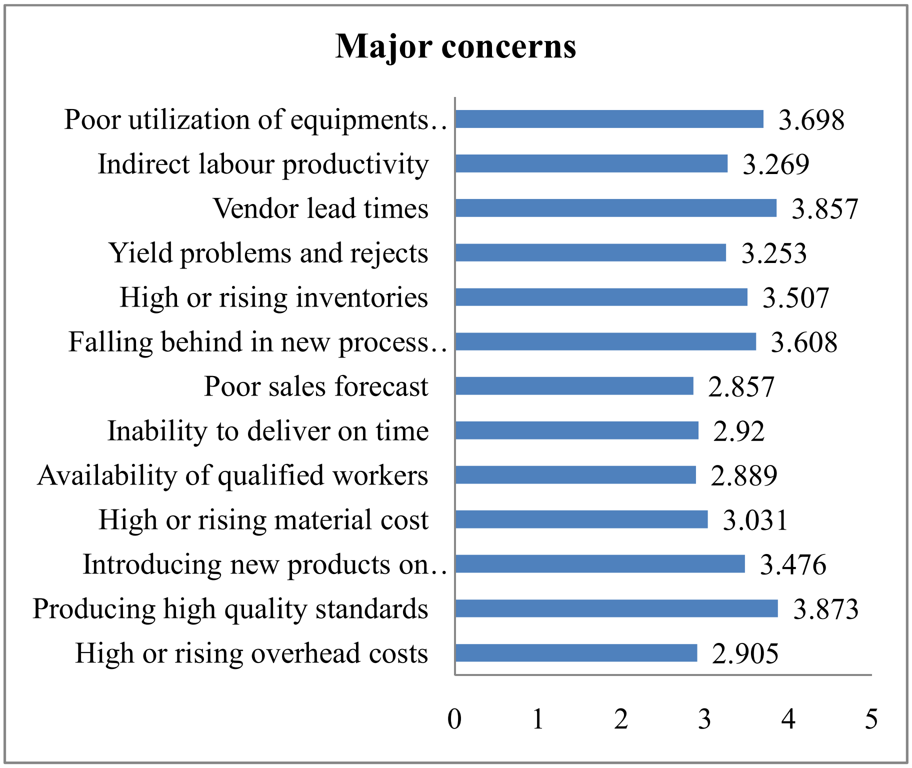

Figure 3.1: Data for the major concerns of industries today

3.3.2 Competitive Priorities

To sustain in the market every organization has certain competitive priorities, and the organizations adopt newer techniques to attain these. The Table 3.3 shows the survey results of the competitive priorities of the companies. Market share (mean = 3.380), consistent quality (mean = 3.539) and fast and dependable deliveries (mean = 3.460) are the major priorities of the present day organizations. The survey results of other priorities are also given in Table 3.3 and Figure 3.2.

Table 3.3: Data for the competitive priorities of the industries

S.No.	Competitive priorities (Ability to provide)	Mean	Rank
1.	Consistent quality	3.539	2
2.	High performance products	3.365	4
3.	Fast and dependable deliveries	3.460	3
4.	Low prices	2.968	6
5.	Rapid design changes	3.031	5
6.	After sales service	2.634	8
7.	Rapid volume changes	2.904	7
8.	Market share	3.380	1

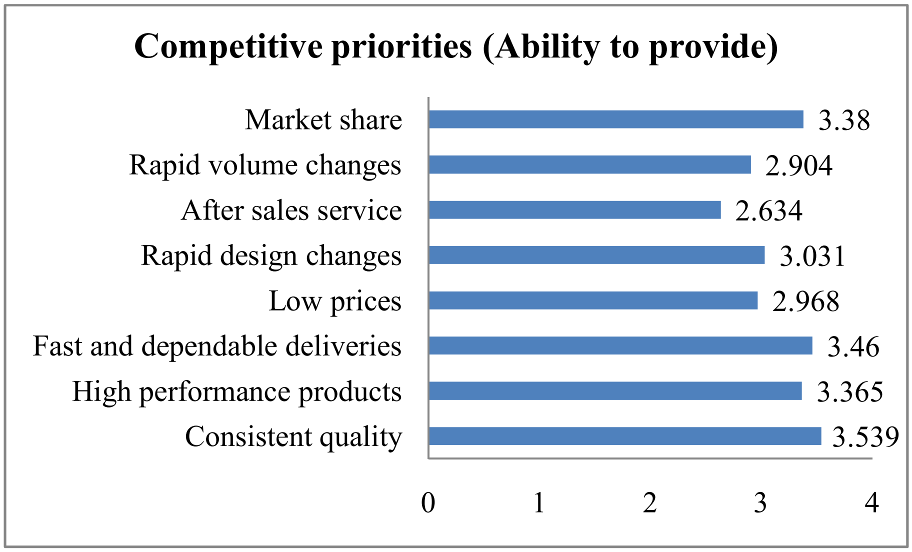

Figure 3.2: Data for the competitive priorities of the industries

3.3.3 Important Action Plans as per Vision/Mission Policies

The framework for the working of any organization is laid in its vision and mission statement. It is the vision and mission policies of the organization which define whether or not it wants to adopt newer and advanced manufacturing systems for its working. The survey results of the action plans as per the vision and mission policies of the organisation are tabulated in Table 3.4 and Figure 3.3. Lead time reduction (mean = 4.269), worker safety (mean = 3.825) and statistical process control (mean = 3.793) are the major action plans.

Table 3.4: Data for the action plans as per the vision/ mission policies

S.No.	Action plans	Mean	Rank
1.	Direct labour motivation	3.285	10
2.	Production and inventory control systems	3.571	7
3.	Automating jobs	3.587	6
4.	Integrating information systems in manufacturing	3.206	12
5.	Supervisor training	3.253	11
6.	Manufacturing reorganisation	3.047	15
7.	Lead time reduction	4.269	1
8.	Improving vendor quality	3.539	8
9.	Statistical process control	3.793	3
10.	Zero defects	3.142	13
11.	Improving new product introduction capability	2.952	17

12.	Process improvements	3.634	5
13.	Flexible manufacturing systems	3.714	4
14.	Quality circles	2.634	19
15.	Reducing set up times	3.111	14
16.	Worker Safety	3.825	2
17.	Giving workers a broader range of tasks	2.778	18
18.	Improvement in physical working conditions	3.492	9
19.	Supplier- customer integration	2.968	16

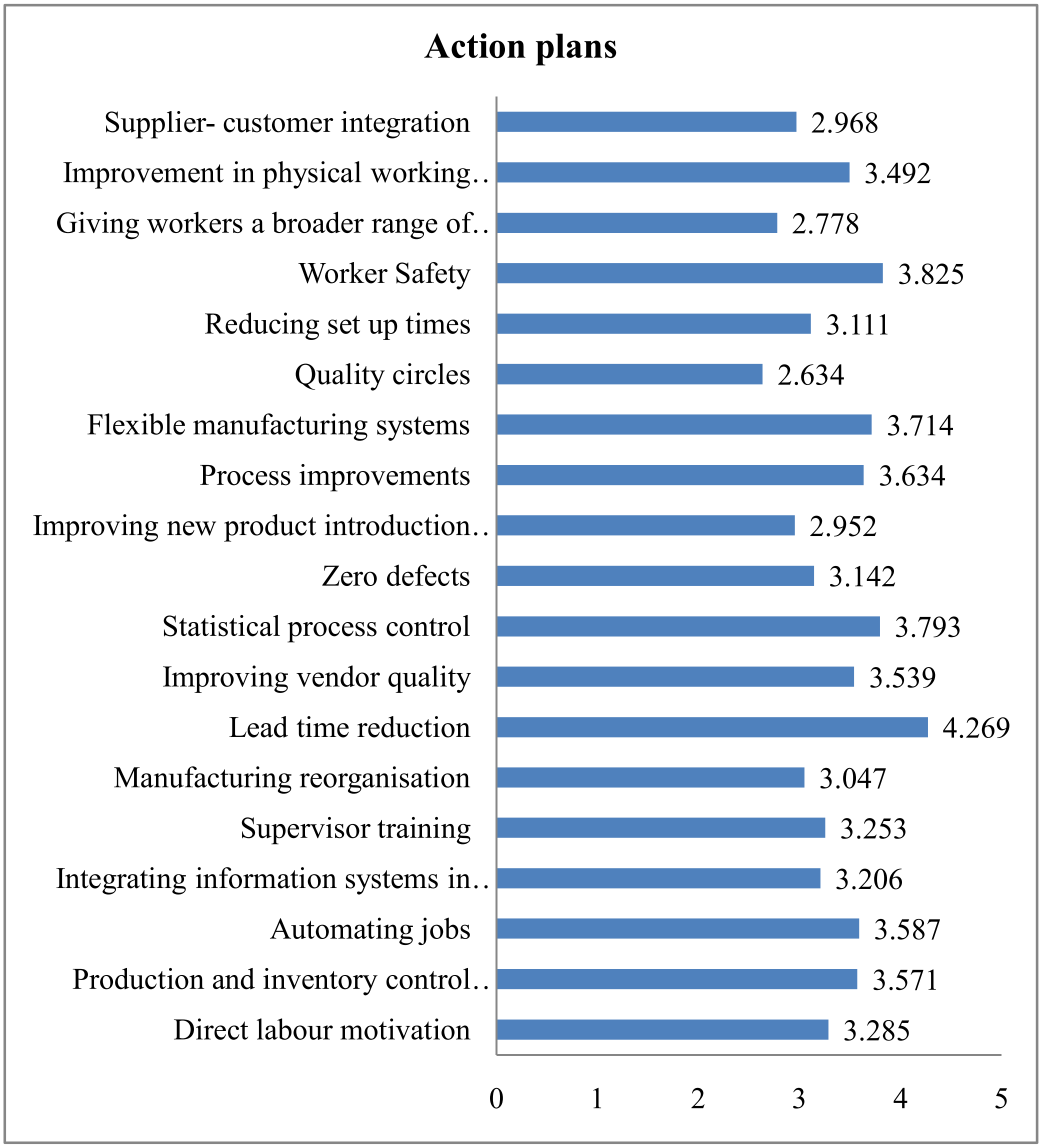

Figure 3.3: Data for the action plans as per the vision/ mission policies

3.3.4 Critical Success Factors of FMS

There are some driving factors which enable the implementation of newer systems like FMS easily. The availability of these with the organisations is critical for the adoption of FMS. Table 3.5 and Figure 3.4 shows the major success factors of FMS. As per the survey results, the team building (mean = 3.650), availability of funds (mean = 3.634) and capability of process and production changes (mean = 3.428) are the top rankers for success of FMS.

Table 3.5: Data for the critical success factors of FMS

S.No.	Success factors of FMS	Mean	Rank
1.	Type of company/Product	3.222	5
2.	Availability of funds	3.634	2
3.	Availability of Technology	2.889	8
4.	Vision and Mission policy of the company	3.269	4
5.	Multi skilled and flexi manpower	3.047	6
6.	Availability of space	2.809	10
7.	Availability of vendors	2.857	9
8.	Development of effective FMS strategy	2.968	7
9.	Team Building	3.650	1
10.	Capability of process and production changes	3.428	3

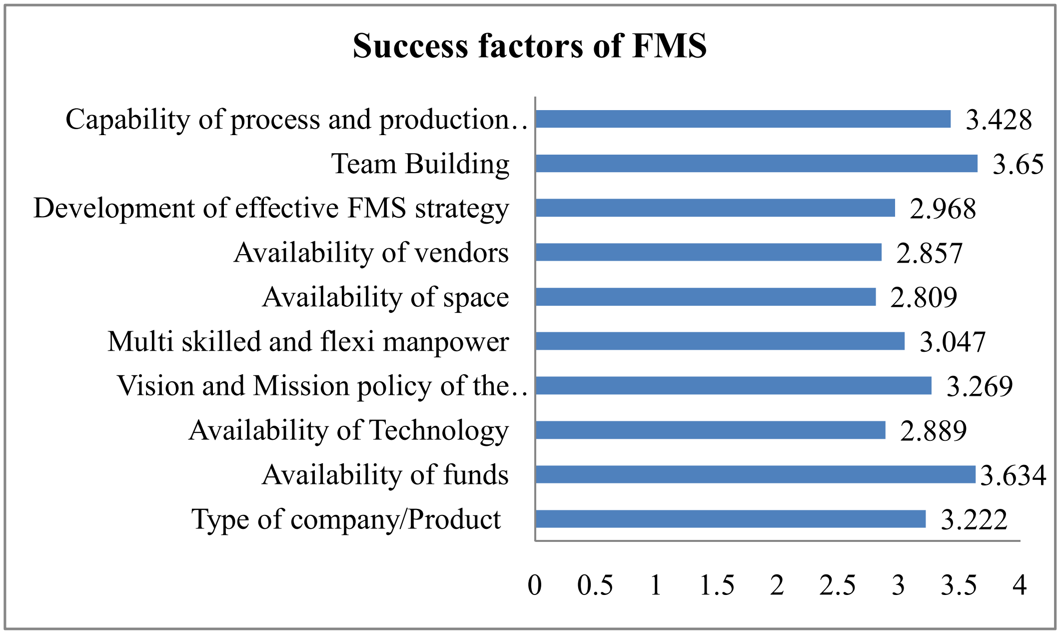

Figure 3.4: Data for the critical success factors of FMS

3.3.5 Problems Anticipated in Adoption of FMS

Table 3.6 and Figure 3.5 shows the survey results of the major obstacles or the problems anticipated/ encountered for the adoption of FMS. Non availability of government support (mean = 3.206), high cost of maintenance (mean = 2.907), non availability of the trained personnel (mean = 2.809) and lack of clear vision and knowledge (mean = 2.698) are the major barriers for the adoption of FMS.

Table 3.6: Data for the problems anticipated in adoption of FMS

S.No.	Problems anticipated	Mean	Rank
1.	Lack of clear vision and knowledge	2.698	4
2.	Non availability of government support	3.206	1
3.	Complex operational and control techniques of FMS	2.269	10
4.	Fear of failure	2.523	8
5.	High cost of FMS transition	2.682	5
6.	Non-availability of trained personnel	2.809	3
7.	High cost of maintenance	2.907	2
8.	Vendor selection problems	2.677	6
9.	Demand uncertainties	2.365	9
10.	Poor rate of return	2.667	7

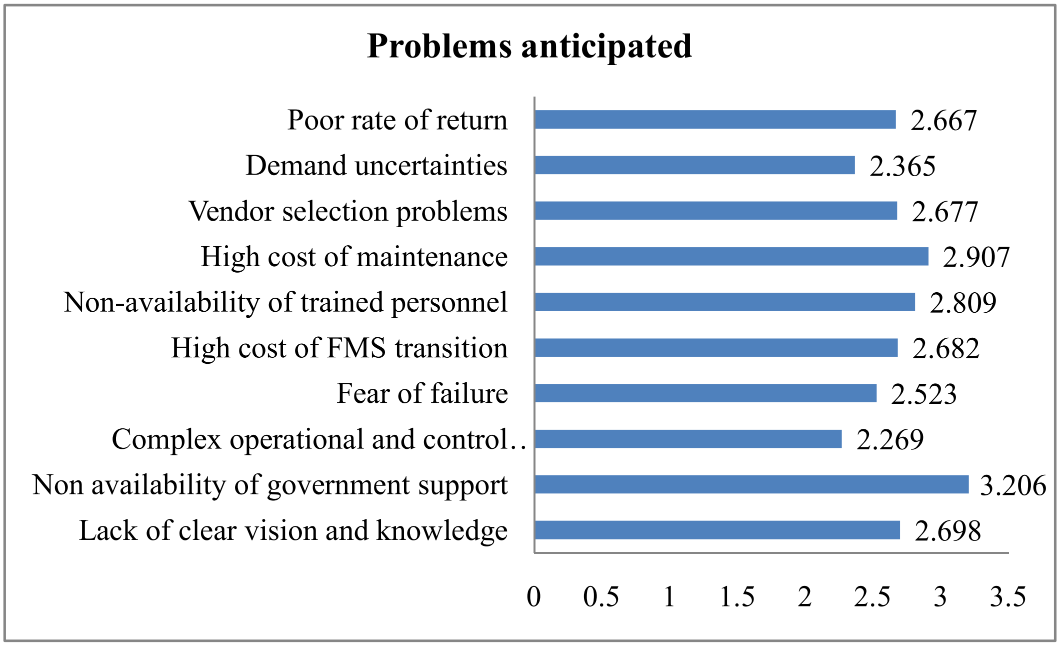

Figure 3.5: Data for the problems anticipated in adoption of FMS

3.3.6 Effect of FMS Adoption Initiatives on the Performance Measurement

The performance of any organization is measured by some defined criteria. For achieving better edge in the market and achieve the desired goals, it is necessary to improve the performance of the organization on these set measures. Advanced manufacturing techniques like FMS help to achieve these. Table 3.7 and Figure 3.6 shows the effect of FMS on some of the performance measurement criteria. The major improvements are in achieving flexibility in production (mean = 3.523), capacity utilisation (mean = 3.396), timely delivery of products (mean = 3.365) etc.

Table 3.7: Data for the effect of FMS adoption initiatives on the performance measurement

S.No.	Factors	Mean	Rank
1.	Manufacturing cost	2.920	10
2.	Level of inventory	3.253	5
3.	Timely delivery of products	3.365	3
4.	Flexibility in production	3.523	1
5.	Capacity utilisation	3.396	2
6.	Employee satisfaction	2.889	11
7.	Customer satisfaction	3.142	6
8.	Mean flow time/Process cycle time	3.111	7
9.	Market share	2.556	12
10.	Net profit	3.349	4
11.	Total cost reduction	3.079	8
12.	Easy retrieval of parts with standardized coding and classification	3.063	9

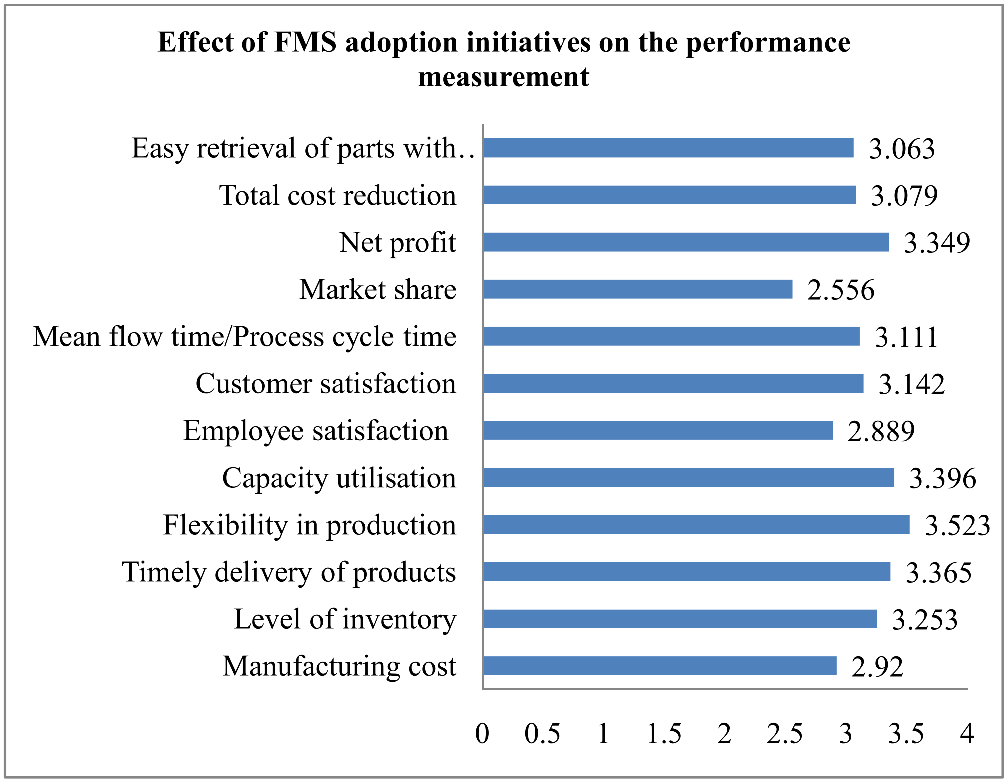

Figure 3.6: Data for the effect of FMS adoption initiatives on the performance measurement

3.3.7 Level of Productivity Improvements Achieved by FMS

Table 3.8 and Figure 3.7 shows the level of productivity improvements achieved by FMS. The top ranker factors for achieving the productivity improvement because of FMS are improved workpiece processes (mean = 3.873), plant modernization (mean = 3.778), quick response to customers (mean = 3.761) and reduced delivery times (mean = 3.714). The survey results of other factors are also shown in Table 3.8.

Table 3.8: Data for the productivity improvements achieved by FMS

S.No.	Factors	Mean	Rank
1.	Reduction in labour cost	3.481	7
2.	Reduced delivery times	3.714	4
3.	Quick response to the customers	3.761	3
4.	Reduction in floor space	3.253	11
5.	Reduction in rework and scrap	3.126	14
6.	Improved part quality	3.380	9

7.	Reduced set ups	3.634	5
8.	Increased output	3.571	6
9.	Better inventory control	3.396	8
10.	Improved workpiece processes	3.873	1
11.	Improved tool management	3.015	16
12.	Reduced manual inspection	3.031	15
13.	Reduced material handling	3.333	10
14.	Improved layout of machinery	3.158	12
15.	Plant modernization	3.778	2
16.	Reduced machine downtime	2.968	17
17.	Better control and documentation	3.142	13

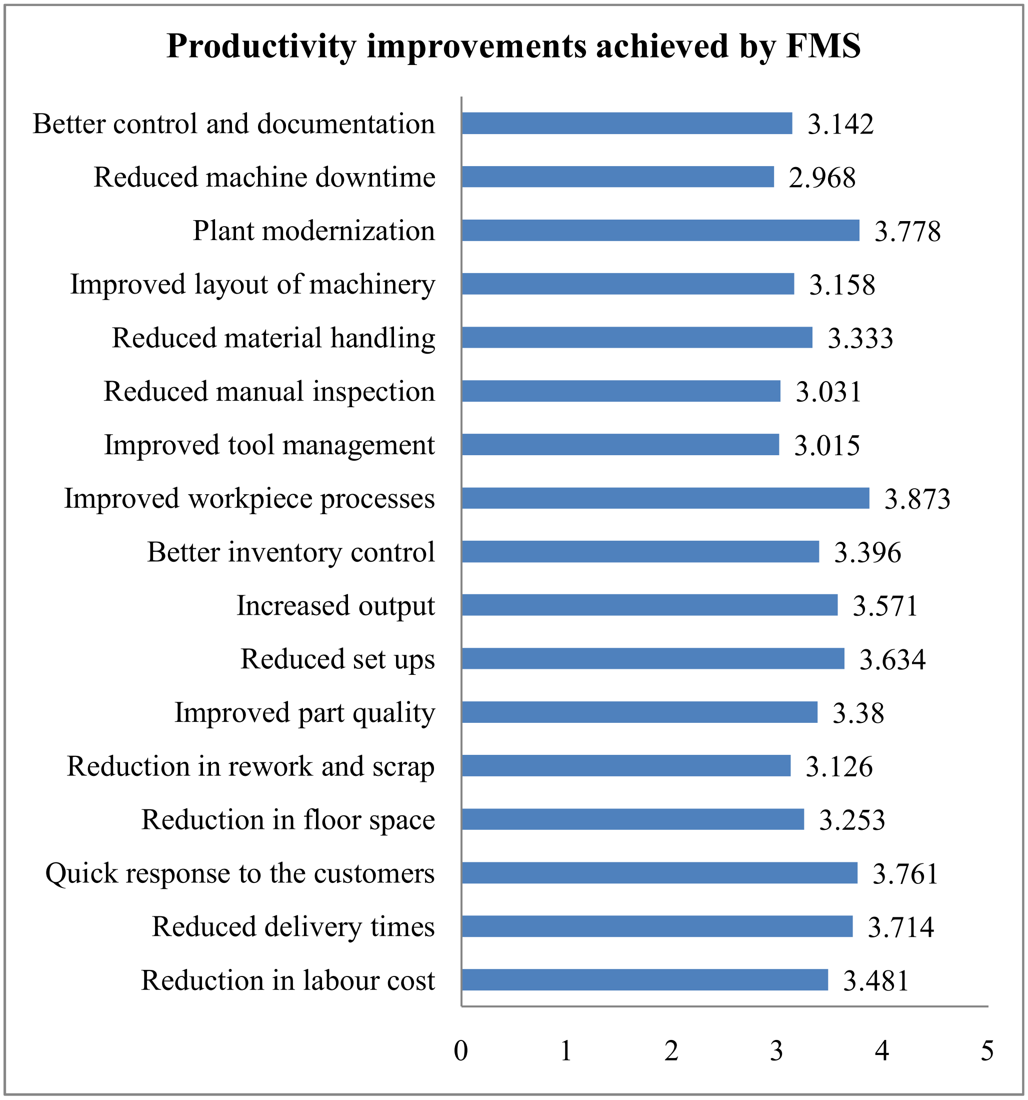

Figure 3.7: Data for the productivity improvements achieved by FMS

3.3.8 Planning and Design Issues of FMS

The planning and design of FMS is very complicated task and various factors affect it. The survey obtained the response of the organizations on various planning and design issues of FMS. As per the survey, layout and space (mean = 3.476) is the major planning and design issue, followed by material handling systems (AGVs, AS/RS) (mean = 3.238) and production volume (mean = 3.190), respectively. The mean scores of the responses for the other planning and design issues are also shown in Table 3.9 and Figure 3.8.

Table 3.9: Data for the planning and design issues of FMS

S.No.	Planning and design issues	Mean	Rank
1.	Well defined part families	2.984	9
2.	Production volume	3.190	3
3.	Processing requirements	3.031	7
4.	Physical characteristics of the workpart	2.539	13
5.	Types of workstations	2.988	8
6.	Possibility of variations in process routings	3.079	6
7.	Layout and space	3.476	1
8.	Material handling systems (AGVs, AS/RS)	3.238	2
9.	Work-in-process inventories	2.936	10
10.	Cutting tools	3.158	5
11.	Pallet fixtures	2.444	14
12.	Control systems (DNC, Host computers etc.,)	2.841	11
13.	Availability of robots	2.809	12
14.	Storage capacity	3.158	4

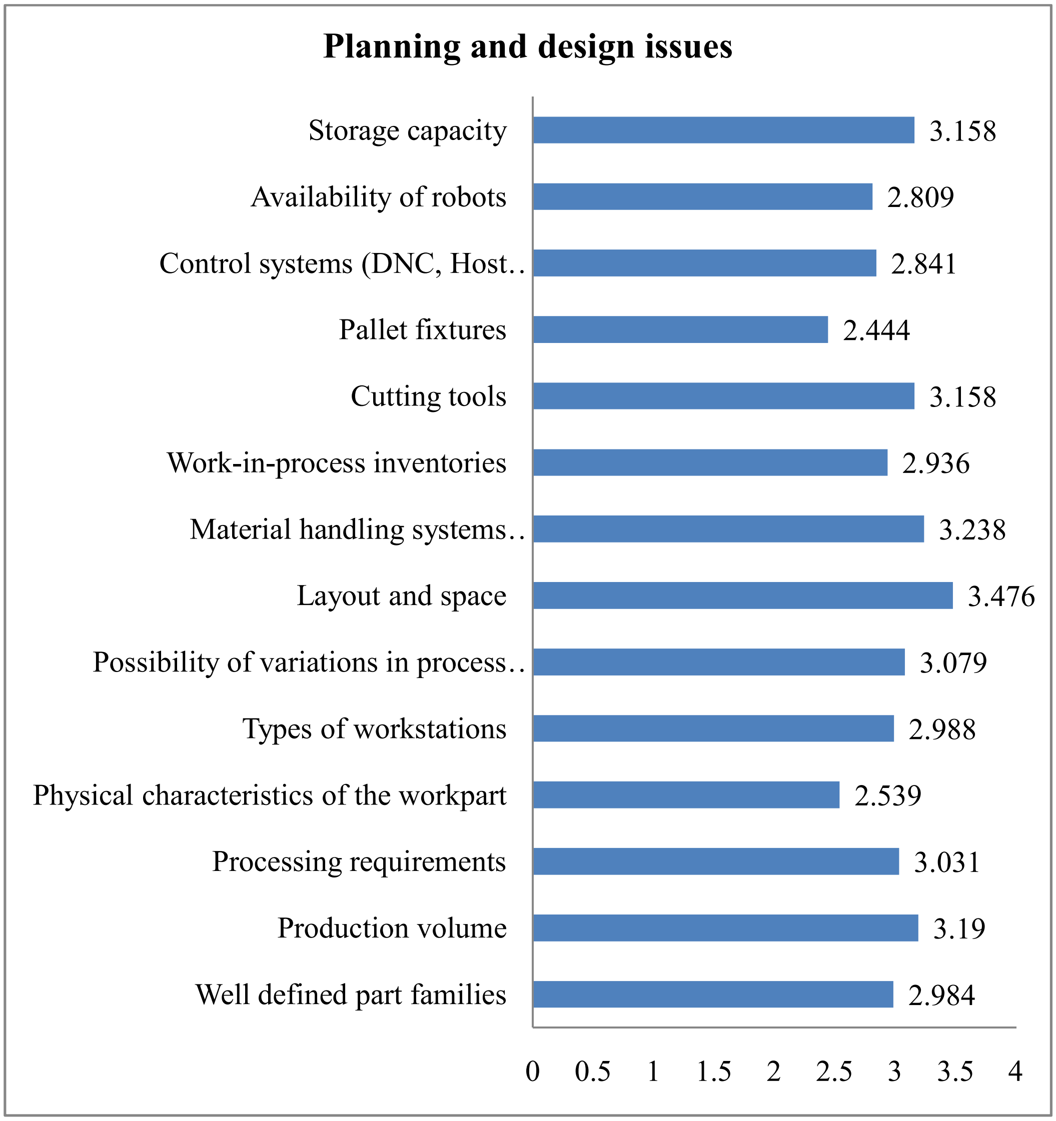

Figure 3.8: Data for the planning and design issues of FMS

3.3.9 Operational Issues of FMS

The working of FMS is far more complicated than a simple conventional manufacturing system because of many operational issues. The survey responses on these various operational issues of FMS are shown in Table 3.10. Maintenance policy (mean = 3.396), dispatching criteria (mean = 3.174) and pallet and fixture allocation (3.126) are the major operational issues. The other issues with their mean score of responses and the ranks are also shown in Table 3.10 and Figure 3.9

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Table 3.10: Data for the operational issues of FMS

S.No.	Operational issues	Mean	Rank
1.	Scheduling criteria/policy	2.682	8
2.	Dispatching criteria/policy	3.174	2
3.	Machine loading	3.079	5
4.	Part routing	2.809	7
5.	Part grouping	2.523	9
6.	Tool management	2.936	6
7.	Pallet and fixture allocation	3.126	3
8.	Maintenance policy (Preventive/Breakdown) (frequency)	3.396	1
9.	Inspection Policy (in process/finished goods) (frequency)	3.111	4

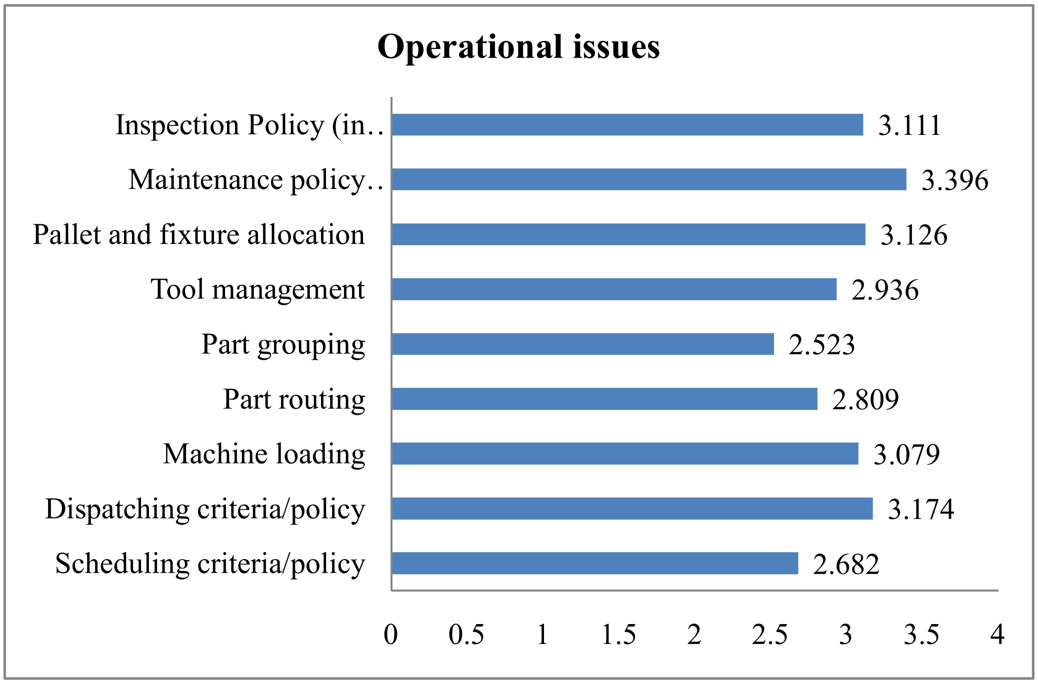


Figure 3.9: Data for the operational issues of FMS

3.3.10 Implementation and Integration Issues of FMS

Implementation of FMS is a very complicated task because of lack of any set standard procedure for implementation. There is also a problem of integration of the different components of FMS in the absence of any standard protocol. So, the survey included the various implementation and integration issues of the FMS and the ranking of these issues as per the survey results is shown in Table 3.11 and Figure 3.10. The organizations feel that the system maintenance (mean = 3.222), availability of trained manpower (mean = 3.190) and availability of the training facilities (mean = 2.904) are the major issues.

Table 3.11: Data for the implementation and integration issues of FMS

S.No.	Implementation and integration issues	Mean	Rank
1.	Availability of compatible technologies for different components of FMS	2.296	10
2.	Availability of standard industrial networks and protocols	2.678	7
3.	Availability of softwares, sensors and other mechatronics components for system integration	2.380	9
4.	Availability of trained manpower for handling these	3.190	2
5.	Availability of training/upgrading facilities for personnel	2.904	3
6.	System maintenance	3.222	1
7.	Integration of FMS with other systems operating in your company	2.873	5
8.	Integration of new sensors in existing control architecture	2.634	8
9.	Vendor quality	2.889	4
10.	Alternate technologies	2.857	6

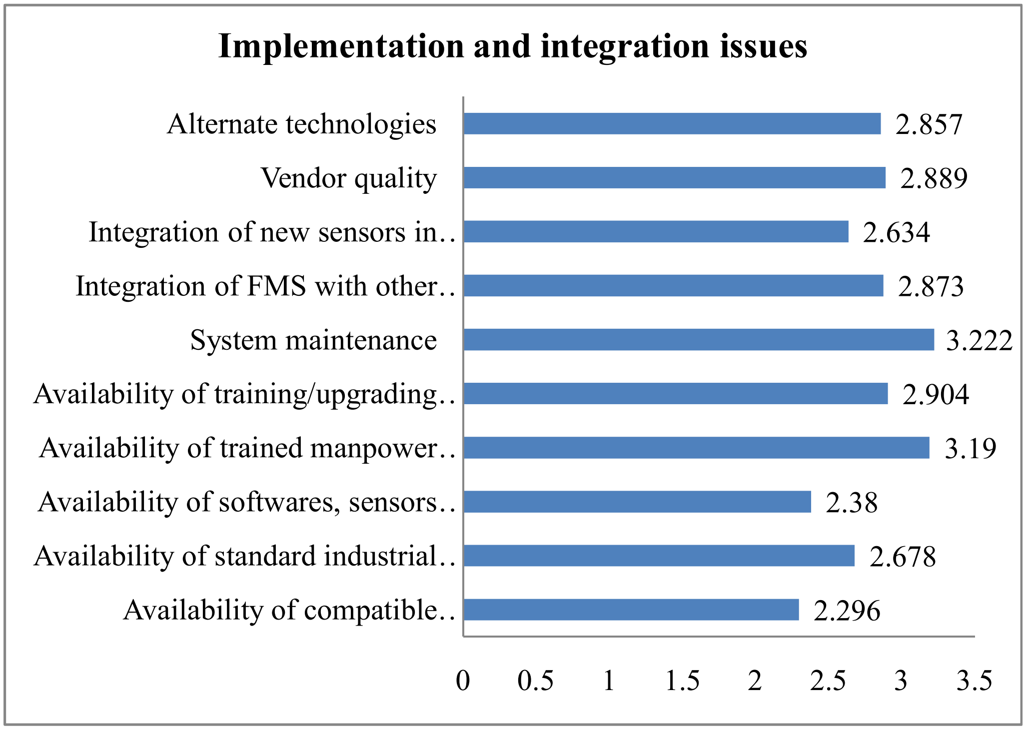


Figure 3.10: Data for the implementation and integration issues of FMS

3.3.11 Flexibility Issues of FMS

Flexibility is one of the major requirements to increase the competitiveness of the organizations. Flexibility in the manufacturing systems enables them to cope with the sudden changes in the market. So, the survey of various flexibility issues of FMS was done and it was found that the level of tool buffer (mean = 3.682), level of the automation of the machine tools (3.619), scope for the combination of operations (mean = 3.556) are the major issues to increase the flexibility of the system. The other issues along with their mean score of responses and the ranks are also given in Table 3.12 and Figure 3.11.

Table 3.12: Data for the flexibility issues of FMS

S.No.	Flexibility issues	Mean	Rank
1.	Ability to manufacture a variety of products	2.634	12
2.	Flexible fixturing	3.111	9
3.	Scope for combination of operations	3.556	3
4.	Level of automation of machine tools	3.619	2
5.	Use of automated material handling devices	2.952	10
6.	Use of reconfigurable machine tools	2.889	11
7.	Ability to quickly address machine failure	3.253	7
8.	Ability to route the workpieces differently	3.190	8
9.	Tool turret capacity	3.269	6
10.	Level of tool buffer	3.682	1
11.	Ability to manufacture the same product on different machine tools	3.380	4
12.	Flexibility of the job holding devices	3.333	5

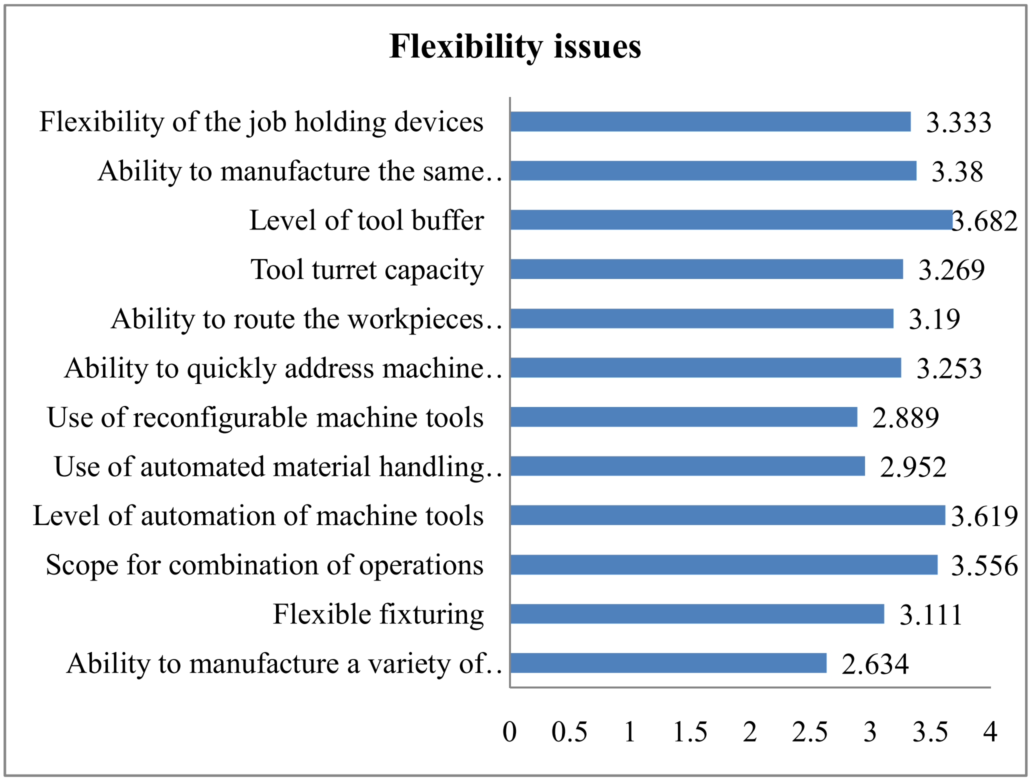


Figure 3.11: Data for the flexibility issues of FMS

3.3.12 Material Handling Issues of FMS

Material is handled in an industry right from the entry gate upto the exit. The material handling cost constitute approximately to 30-40% of the manufacturing cost. So the material handling issues are important in the design and operation of FMS. The survey results of the various material handling issues of FMS is given in Table 3.13 Figure 3.12. The major issues in this are the compatibility of different MH equipments with processing stations/machine tools/ AS/RS and other handling devices (mean = 3.714), the equipments already present (mean = 3.667) and traffic management (3.460) etc.

Table 3.13: Data for the material handling issues of FMS

S.No.	Material handling issues	Mean	Rank
1.	Purchasing/Initial cost of MH equipments	2.571	18
2.	Load carrying capacity	2.825	13
3.	Programming flexibility of MH equipments	2.809	15
4.	Operational cost	3.174	8
5.	Throughput rate	2.746	17

6.	Capacity to handle different shapes and volumes (Variety of parts)	3.396	4
7.	Storage/Retrieval MH equipments	3.349	5
8.	Operational Control	2.968	11
9.	Automation	3.142	9
10.	Floor space	3.269	6
11.	AGVs/ Robots and other advanced MH equipments already present	3.667	2
12.	Number of AGVs required	2.811	14
13.	Layout of AGV tracks	2.889	12
14.	Vehicle dispatching rules	3.253	7
15.	Traffic management	3.460	3
16.	Positioning of idle vehicles	2.778	16
17.	Failure management	2.365	19
18.	Compatibility of different MH equipments with processing stations/machine tools / AS/RS and other handling devices	3.714	1
19.	Comparison with cheap human labour	3.063	10

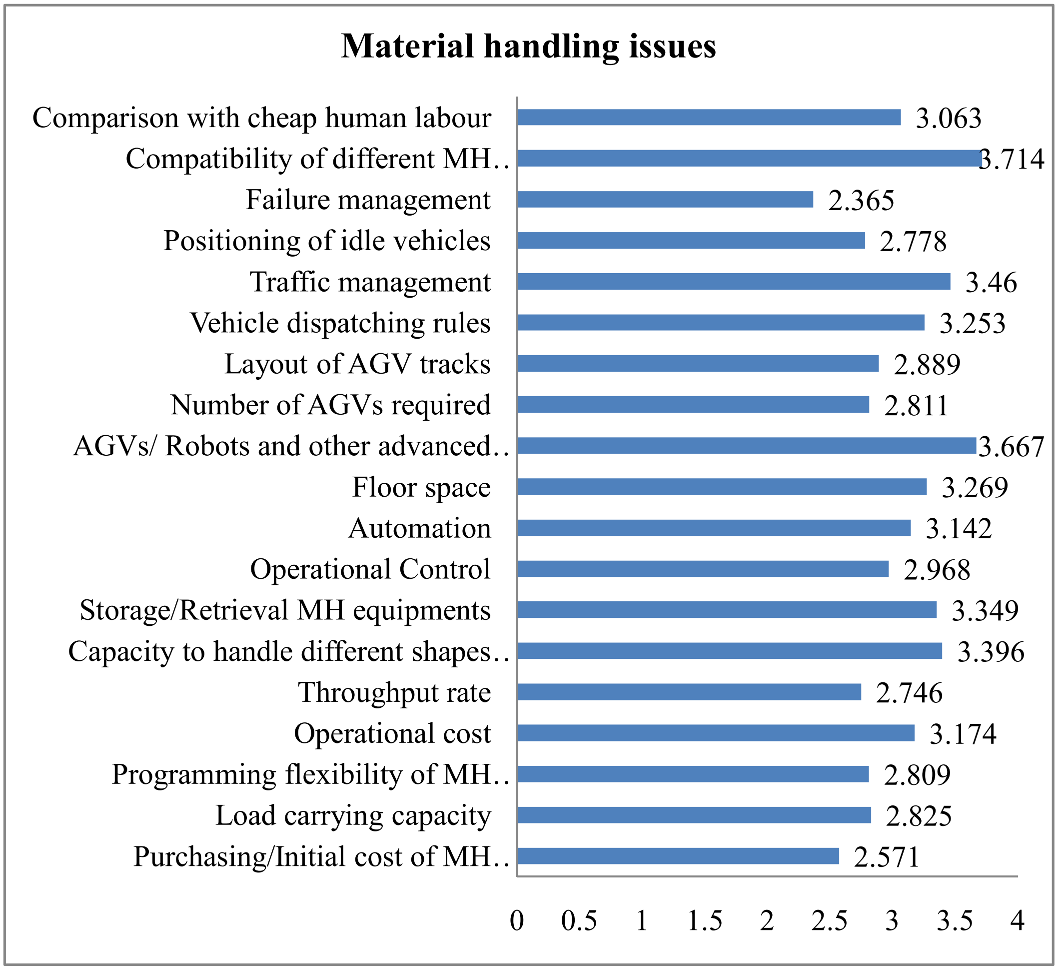


Figure 3.12: Data for the material handling issues of FMS

3.3.13 Loading and Scheduling Issues of FMS

Loading and scheduling decisions for an FMS are very difficult because of the number of alternatives available. There are various mathematical and simulation models available to assist in loading and scheduling decisions but still, it is one of the major issues with the production manager. The survey collected the responses of the practising managers on the various loading and scheduling issues of FMS and these are given in Table 3.14and Figure 3.13. Number of machine tools (mean = 3.793), material handling time (mean = 3.730) and machining speed (mean = 3.714) are the major loading and scheduling issues in FMS.

Table 3.14: Data for the loading and scheduling issues of FMS

S.No.	Loading and scheduling issues	Mean	Rank
1.	Variety of part types	3.142	18
2.	Types of machine tools	3.556	10
3.	Number of machine tools	3.793	1
4.	Control system of FMS	3.153	17
5.	Cutting tools and their handling	3.496	12
6.	Storage systems (finite-in-process buffers)	2.892	26
7.	Tool magazine capacity	3.476	13
8.	Maintenance schedules	3.158	16
9.	Tool life	3.609	7
10.	Pallet and fixture allocation	3.000	24
11.	Operation completion time	3.603	8
12.	Machining speed	3.714	3
13.	Machine workload and the equipment utilization	3.619	6
14.	Set up time/cost	3.667	4
15.	Machining time/cost	3.174	15
16.	Movement of parts between machines	3.079	20
17.	Number of shifts	3.507	11
18.	Frequency of new parts arrival	3.071	21
19.	Alternate routing of parts	2.778	28
20.	Type of FMS	3.095	19
21.	Variations in part demand	3.047	23
22.	Material handling time	3.730	2
23.	Flexibility in processing sequence	3.376	14
24.	Workstation/ transportation system breakdown	3.634	5
25.	Rush orders	3.063	22
26.	Tool sharing	3.593	9

27.	Tool regrinding	2.873	27
28.	Partitioning of the production order into number of batches	2.952	25

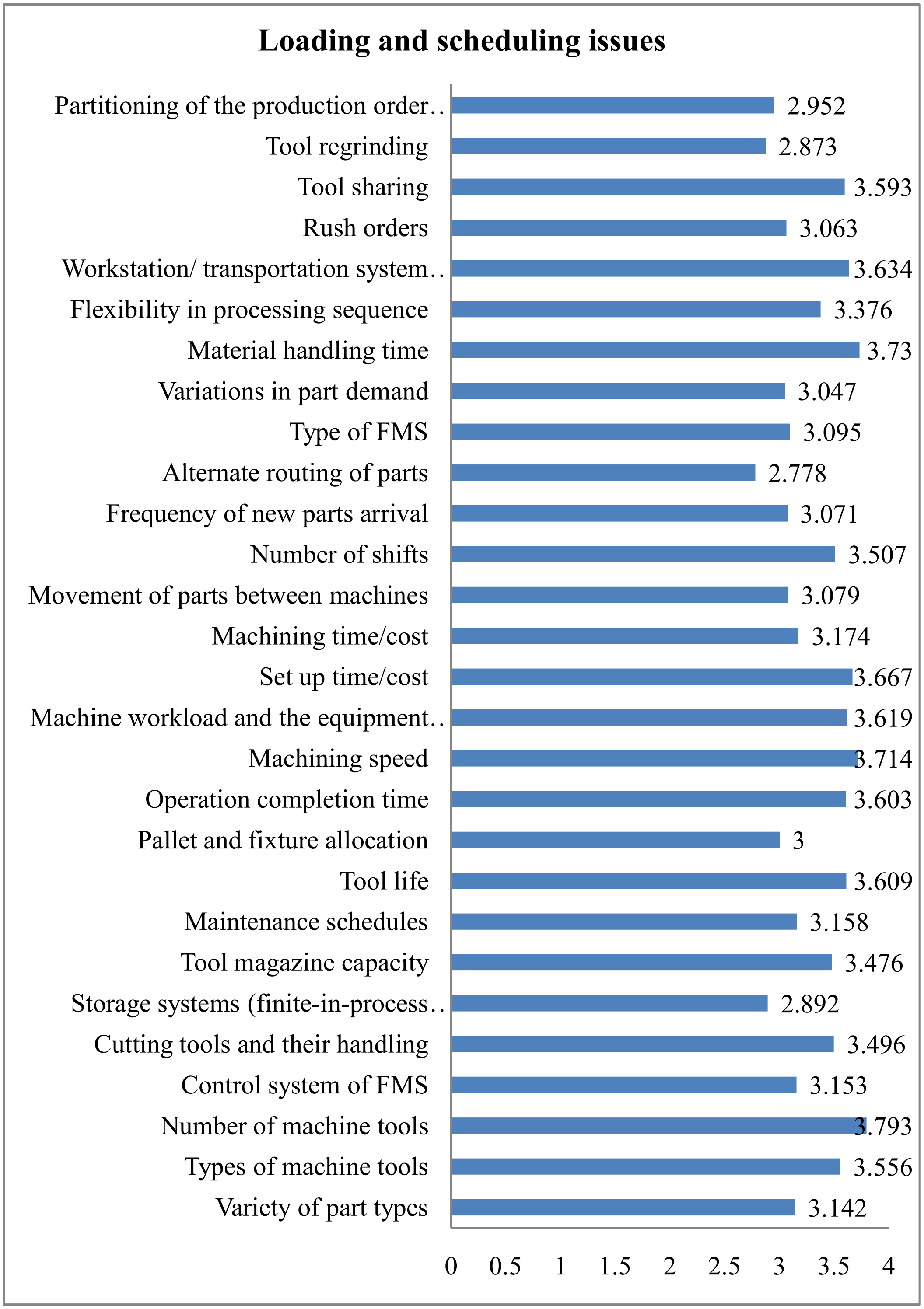


Figure 3.13: Data for the loading and scheduling issues of FMS

3.3.14 Issues Regarding Feasibility of Conversion to FMS

Conversion to FMS is both strategic and tactical issue. FMS as a manufacturing strategy can help an organization to improve its processes and align it to the requirements of its customers. There are some issues which increase the feasibility of conversion to FMS. The survey questionnaire included these issues and the responses of the organizations were obtained on these issues. Table 3.15 and Figure 3.14 shows these responses and the ranking of the issues. Effective planning and vision (mean = 3.730), availability of technology (mean = 3.721) and the effective use of tools like CAD/CAM, MRP etc. (mean = 3.667) are the top issues for feasibility of conversion to FMS.

Table 3.15: Data for the issues regarding feasibility of conversion to FMS

S.No.	Conversion factors	Mean	Rank
1.	Does the production volume suit adoption of FMS?	3.396	5
2.	Does the product type suit adoption of FMS?	2.587	20
3.	Availability of finances for conversion	2.984	12
4.	Top management involvement/commitment	3.650	4
5.	Effective planning and vision	3.730	1
6.	Availability of technology	3.721	2
7.	Availability of vendors/their selection	3.174	10
8.	Work culture/ team spirit and motivation	2.825	16
9.	Availability of adequate space	3.349	6
10.	Effective use of tools like CAD/CAM, MRP etc.,	3.667	3
11.	Overcoming fear of failure	2.936	13
12.	Possibility of training and relocation of the workers	2.793	17
13.	Support from the workforce for transition to FMS	2.841	15
14.	Additional skills required of FMS personnel	3.269	7
15.	Possibility of learning/knowhow of complex operational and control techniques of FMS	3.222	8
16.	Availability of precise performance measurement techniques (measures like flexibility, productivity, quality etc.,)	3.079	11
17.	Availability and use of advanced MH equipments like robots/ AGVs etc.,	2.889	14
18.	Possibility of changing the current layout of machines	2.778	18
19.	Support from government and other funding agencies	3.206	9
20.	Ability/readiness to face loss of market share during transition period	2.333	21
21.	Willingness to bear temporary losses	2.634	19

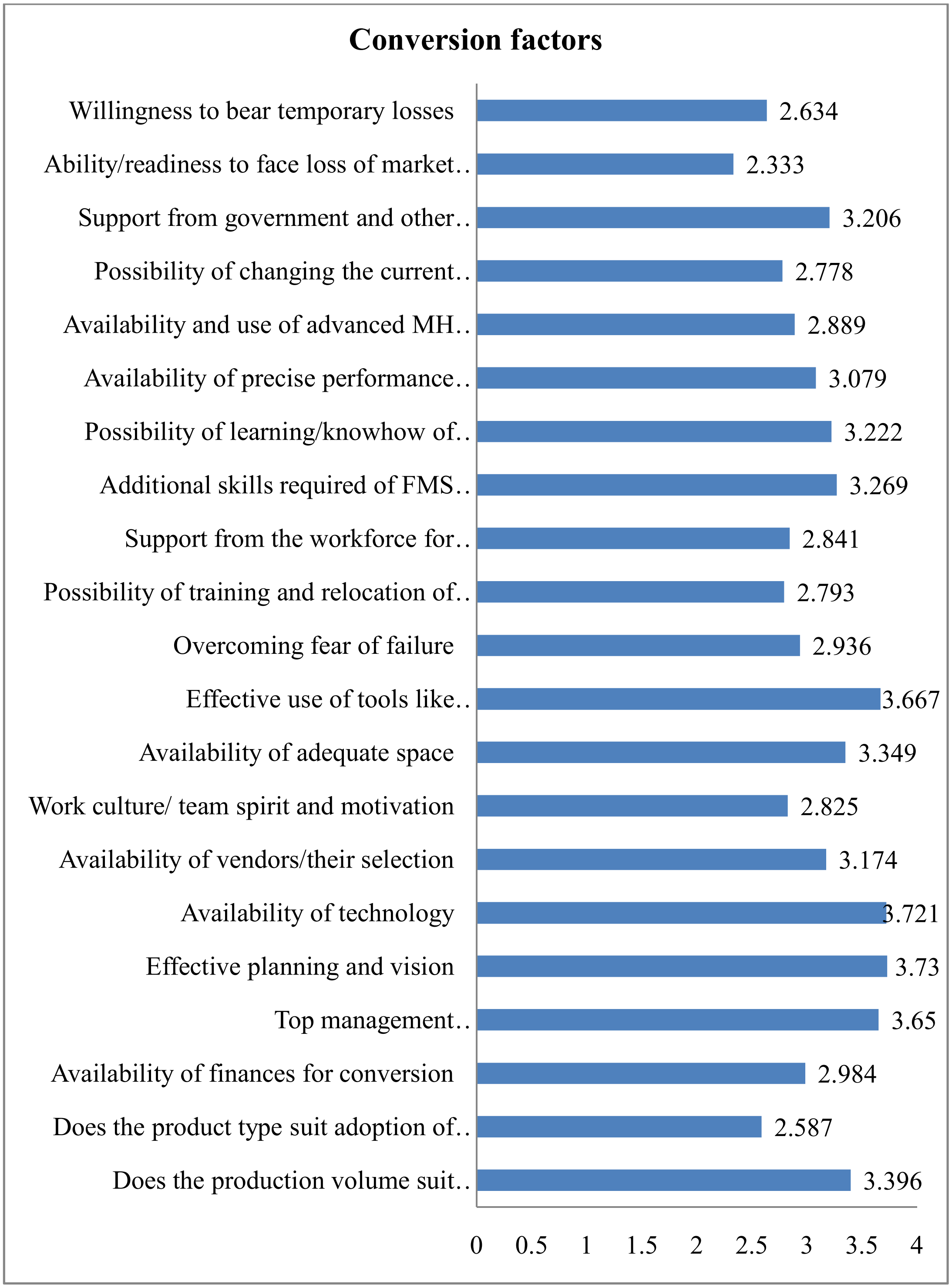


Figure 3.14: Data for the issues regarding feasibility of conversion to FMS

3.4 CONCLUSION

The main objective of the survey was to know about present scenario and the inclination of the Indian manufacturing industries towards different issues related to the advanced manufacturing systems like FMS. Different factors/ issues were identified and the response of the industries was collected. These responses highlight the fears and uncertainties of the practising managers towards these issues. These responses can be further used for the analysis and modelling these various issues.

CHAPTER IV

IDENTIFICATION AND MODELLING OF THE VARIOUS FACTORS AFFECTING THE PRODUCTIVITY OF FMS

4.1 INTRODUCTION

The rapidly changing market environment introduces uncertainty into production planning, and flexible manufacturing systems are one possibility of coping with this uncertainty as they allow the manufacturing of a large variety of products in variable quantities. FMS could be an option for industries which want to boost productivity as well as respond quickly to an increasingly changing marketplace. FMS produces in mid variety, mid volume range and can meet the changing market demands very quickly.

FMS requires huge capital investment and is a complex system. FMS involves integration of different components like the machining centres, material handling devices like robots, AGVs, AS/RS, Computer control etc. These sub systems are manufactured by different companies and no standard protocols are available for their integration and use. Further, in the Indian context, although the CNCs are manufactured here, rest of the components are to be imported which further complicates the FMS installation. So, although FMS provides a lot of strategic and tactical benefits, yet all of these may not be possible with all installations. A manufacturing manager should know what are the specific benefits he is expecting from the FMS installation and what is the time span within which these benefits start coming in.

In this chapter, an effort has been made to enlist the factors affecting the productivity of FMS installation and further an attempt has been made to model these different factors using the Interpretive Structural Modelling (ISM) technique. Therefore, in this chapter 15 factors have been identified through literature survey and expert opinion. These various factors are analysed using ISM approach which shows their inter-relationships. This model is further strengthened using MICMAC analysis by defining the driving power and dependencies of these factors.

4.2 PRODUCTIVITY AND FMS

Enhancing productivity and reacting swiftly to an ever changing market seem to be mutually opposite objectives. Yet these could overlie in the domain of the flexible manufacturing system. By using the concept of mid- variety and mid- volume manufacturing system, both the productivity as well as the flexibility can be achieved. FMS allows the advantageous levels of both the aims to be achieved.

Basically, *"Productivity is a concept relating the conversion of inputs to outputs."*

This concept can be more specifically defined as outputs relative to the four major resource inputs of any firm:

Productivity = Outputs / Inputs (Labour + Capital + Material + Energy)

This definition of productivity is called total factor productivity. Outputs with respect to any or less than four of these inputs are called the partial measures of productivity.

With FMS very large benefits like decreased costs, increased utilization of capital equipments and reduction of work in progress has been realized, all leading to overall increased productivity.

4.3 IDENTIFICATION OF VARIOUS FACTORS AFFECTING THE PRODUCTIVITY OF FMS

15 factors were identified on the basis of the literature review and discussions with the industry and the academia experts, which affect the productivity of FMS installations. These factors are presented with their reference sources in Table 4.1.

Table 4.1: Various factors affecting the productivity of FMS

S.No.	Factor	Reference Source
1.	Reduced direct labour cost	Saloman and Biegel [36]; Koren and Shpiitalni [208]
2.	Reduced delivery times	Keong et al. [126]; Singholi et al. [19]
3.	Increased output	Chan [46]; Wadhwa et al. [181], Gola and Swic [3]
4.	Better inventory control	Groover [112]

5.	Quick response to customers	Groover [112]
6.	Improved part quality	Adam et al. [40]; Bayazit [124]
7.	Improved workpiece processes	Groover [112]; Koren [207]
8.	Reduced number of set-ups	Kaighobadi et al. [103]; Chan and Chan [49]; Bayazit [124]
9.	Improved tool Management	Gandhi and Thompson [114]; Hoffman [67], Thomas and Leon [203]; Raj et al. [187]
10.	Reduced manual inspection	Sanchez [13]; Chan and Chan [49]; Gola and Swic [3]
11.	Reduced material handling	Mahadevan and Narendran [23]
12.	Improved layout of machinery	Kouvelis and Kiran [133]; Chen and Adam [44]
13.	Plant modernization	Groover [112]
14.	Reduced machine downtime	Groover [112], Shnits et al. [26]; Sridharan and Kumar [122]
15.	Better control and documentation	Groover [112]

4.4 ISM APPROACH FOR MODELLING OF FACTORS

The stepwise development of model for analyzing the factors affecting the productivity of FMS by ISM is given below:

4.4.1 Establishing the Contextual Relationship between the Factors

After identifying and enlisting the factors affecting productivity of FMS through literature review and expert opinion, the next step is to analyse these factors. For this purpose, a pair wise comparison of the factors is carried out and a contextual relationship is established between the factors [129]. The contextual relationship among the various factors is developed by consulting some experts, both from academia and the industry. The existence of a relation between any two factors (*i* and *j*) is based on the contextual relationship for each factor. The associated direction of this relationship is also decided. The direction of the relationship between any two factors (*i* and *j*) is represented by the following four symbols

i. If the factor *i* influences factor *j* then the symbol V is used.
ii. If the factor *j* influences factor *i* then the symbol A is used.
iii. If the factors *i* and *j* both influence each other, then the symbol X is used.
iv. And, if the factors *i* and *j* both are unrelated, then the symbol O is used.

4.4.2 Development of Structural Self-Interaction Matrix (SSIM)

The SSIM is developed for 15 factors which are identified, based on the contextual relationship between the factors. The SSIM is presented in Table 4.2. The following statements show some examples of the usage of symbols in SSIM, where (*i,j*) representing (row factor, column factor):

(i) As factor 2 influences or reaches to factor 5 so the symbol V is assigned to cell (2, 5).
(ii) As factor 14 influences the factor 1, so the symbol A is assigned to cell (1,14).
(iii) As factors 2 and 15 influence each other, symbol X is assigned to cell (2, 15).
(iv) As factors 1 and 15 are unrelated, so symbol O is assigned to cell (1, 15)

Table 4.2: Structural self – interaction matrix (SSIM)

Factor	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**
1	O	A	A	O	O	A	A	A	A	O	O	O	O	A
2	X	A	A	A	A	A	A	A	A	O	V	V	V	
3	A	A	A	A	A	A	A	A	A	A	V	O		
4	V	A	A	A	V	V	A	A	A	O	A			
5	A	A	A	A	A	A	A	A	A	A				

6	A	O	A	O	A	A	A	A	A
7	V	V	X	V	V	V	X	V	
8	V	V	A	X	V	V	A		
9	V	V	X	X	V	V			
10	V	V	A	O	V				
11	V	A	A	A					
12	V	V	X						
13	V	V							
14	V								

4.4.3 Development of the Reachability Matrix

The reachability matrix indicates the relationship between factors in the binary form. This matrix is obtained in two sub-steps. In the first sub-step, the SSIM format is converted into initial reachability matrix by transforming the information of each cell of SSIM into binary digits. The symbols V, A, X, O of SSIM are replaced by 1s or 0s to get initial reachability (IR) matrix:

(i) In the SSIM, if the cell *(i, j)* has the symbol V, then in IR matrix this cell entry becomes 1 and the cell (*j*, *i*) entry becomes 0.

(ii) In the SSIM, if the cell (*i, j*) has the symbol A, then in IR matrix this cell entry becomes 0 and the cell (*j*, *i*) entry becomes 1.

(iii) In the SSIM, if the cell (*i, j*) has the symbol X, then in IR matrix this cell entry becomes 1 and the cell (*j*, *i*) entry also becomes 1.

(iv) In the SSIM, if the cell (*i, j*) has the symbol O, then in IR matrix this cell entry becomes 0 and the cell (*j*, *i*) entry also becomes 0.

Following the above rules, the initial reachability matrix is prepared and is shown in Table 4.3.

Table 4.3: Initial reachability matrix

Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1
3	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
4	0	0	0	1	0	0	0	0	0	1	1	0	0	0	1
5	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
6	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	0	1	0	1	1	1	0	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	0	1	1	0	0	0	1	1	0	0	1	1
11	0	1	1	0	1	1	0	0	0	0	1	0	0	0	1
12	0	1	1	1	1	0	0	1	1	0	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	0	0	0	0	0	1	0	0	1	1
15	0	1	1	0	1	1	0	0	0	0	0	0	0	0	1

In the second sub-step, the final reachability matrix is obtained by incorporating the concept of transitivity. Transitivity is a relation between three elements such that if relationship holds between the first and second and relationship also holds between the second and third, then relationship must necessarily hold between the first and third (i.e. i! j, j! k then i!k). So the final reachability matrix consists of some entries from pair-wise comparisons and some inferred entries. Final reachability matrix is shown in Table 4.4 where in transitivity is marked as 1*.

Table 4.4: Final reachability matrix

Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	1	1	1*	0	0	0	1*	1*	0	0	0	1

3	0	0	1	1*	1	0	0	0	0	0	0	0	0	0	0
4	1*	1*	1*	1	1*	1*	0	0	0	1	1	0	0	1*	1
5	0	0	0	1	1	0	0	0	0	1*	1*	0	0	0	1*
6	0	0	1	1*	1	1	0	0	0	0	0	0	0	0	0
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	0	1	1*	1	1	1	1*	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1*	1	1	0	0	0	1	1	0	0	1	1
11	1*	1	1	1*	1	1	0	0	0	0	1	0	0	0	1
12	1*	1	1	1	1	1*	1*	1	1	1*	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1*	0	0	0	1*	1	0	0	1	1
15	1*	1	1	1*	1	1	0	0	0	0	0	0	0	0	1

Note: 1 entries are included to incorporate transitivity.*

4.4.4 Partitioning the Reachability Matrix

From the reachability matrix a structural digraph is developed for this the reachability set and antecedent set for each factor are found. On the different sets and subsets of the elements partition levels may be induced from the reachability matrix as expressed by Warfield [82]. From these partitions, the different levels of the structural model can be formed [37].

By partitioning the reachability set and antecedent set for each factor is found and further the intersection for these sets is derived for all the factors and levels of different factors are determined.

The top level factors are those which will not reach the other factors above their own level in the hierarchy. The antecedent set for a factor (*i*) is that factor (*i*) itself and all other factors which may reach it from lower levels. So, we get the intersection set of the reachability set and the antecedent set as same as the reachability set [37]. To identify different levels of structure, the top level factors, once identified are removed one by one and the same procedure is carried out to find the next level of top factors. With the help of these levels of factors the digraph and the final ISM model is developed. In the model and the digraph the top level factor is placed at the top most hierarchy followed by other level factors.

The following tables show the partitioning of the 15 factors identified. Level identification process of these factors is completed in eight iterations as shown in Tables 4.5–4.12.

Table 4.5: Iteration 1

Factor	Reachability Set	Antecedent Set	Intersection Set	Level
1	1	1,2,4,7,8,9,10,11,12,13,14,15	1	**I**
2	1,2,3,4,5,6,10,11,15	2,4,7,8,9,10,11,12,13,14,15	2,4,10,11,15	
3	3,4,5	2,3,4,6,7,8,9,10,11,12,13,14,15	3,4	
4	1,2,3,4,5,6,10,11,14,15	2,3,4,5,6,7,8,9,10,11,12,13,14,15	2,3,4,5,6,10,11, 14,15	
5	4,5,10,11,15	2,3,4,5,6,7,8,9,10,11,12,13,14,15	4,5,10,11,15	**I**
6	3,4,5,6	2,4,6,7,8,9,10,11,12,13,14,15	4,5,6,12,13,14,15	
7	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	7,9,12,13	7,9,12,13	
8	1,2,3,4,5,6,8,9,10,11,12,13,14,15	7,8,9,12,13	8,9,12,13	
9	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	7,8,9,12,13	7,8,9,12,13	
10	1,2,3,4,5,6,10,11,14,15	2,4,5,7,8,9,10,12,13,14	2,4,5,10,14	
11	1,2,3,4,5,6,11,15	2,4,5,7,8,9,10,11,12,13,14	2,4,5,11	
12	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	7,8,9,12,13	7,8,9,12,13	
13	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	7,8,9,12,13	7,8,9,12,13	

14	1,2,3,4,5,6,10,11,14,15	4,7,8,9,10,12,13,14	4,10,14	
15	1,2,3,4,5,6,15	2,4,5,7,8,9,10,11,12,13, 14,15	2,4,5,15	

Table 4.6: Iteration 2

Factor	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
2	2,3,4,6,10,11,15	2,4,7,8,9,10,11,12,13, 14,15	2,4,10,11,15	
3	3,4	2,3,4,6,7,8,9,10,11,12, 13,14,15	3,4	**II**
4	2,3,4,6,10,11,14,15	2,3,4,6,7,8,9,10,11,12, 13,14,15	2,3,4,6,10,11,14,15	**II**
6	3,4,6	2,4,6,7,8,9,10,11,12, 13, 14,15	4,6	
7	2,3,4,6,7,8,9,10,11,12,13, 14,15	7,9,12,13	7,9,12,13	
8	2,3,4,6,8,9,10,11,12,13,14,15	7,8,9,12,13	8,9,12,13	
9	2,3,4,6,7,8,9,10,11,12,13, 14,15	7,8,9,12,13	7,8,9,12,13	
10	2,3,4,6,10,11,14,15	2,4,7,8,9,10,12,13,14	2,4,10,14	
11	2,3,4,6,11,15	2,4,7,8,9,10,11,12,13,14	2,4,11	
12	2,3,4,6,7,8,9,10,11,12,13, 14,15	7,8,9,12,13	7,8,9,12,13	
13	2,3,4,6,7,8,9,10,11,12,13, 14,15	7,8,9,12,13	7,8,9,12,13	
14	2,3,4,6,10,11,14,15	4,7,8,9,10,12,13,14	4,10,14	
15	2,3,4,6,15	2,4,7,8,9,10,11,12,13, 14,15	2,4,15	

Table 4.7: Iteration 3

Factor	Reachability Set	Antecedent Set	Intersection Set	Level
2	2,6,10,11,15	2,7,8,9,10,11,12,13,14,15	2,10,11,15	
6	6	2,6,7,8,9,10,11,12,13, 14,15	6	**III**
7	2,6,7,8,9,10,11,12,13,14,15	7,9,12,13	7,9,12,13	
8	2,6,8,9,10,11,12,13,14,15	7,8,9,12,13	8,9,12,13	
9	2,6,7,8,9,10,11,12,13,14,15	7,8,9,12,13	7,8,9,12,13	
10	2,6,10,11,14,15	2,7,8,9,10,12,13,14	2,10,14	
11	2,6,11,15	2,7,8,9,10,11,12,13,14	2,11	
12	2,6,7,8,9,10,11,12,13,14,15	7,8,9,12,13	7,8,9,12,13	
13	2,6,7,8,9,10,11,12,13,14,15	7,8,9,12,13	7,8,9,12,13	
14	2,6,10,11,14,15	7,8,9,10,12,13,14	10,14	
15	2,6,15	2,7,8,9,10,11,12,13,14,15	2,15	

Table 4.8: Iteration 4

Factor	Reachability Set	Antecedent Set	Intersection Set	Level
2	2,10,11,15	2,7,8,9,10,11,12,13,14,15	2,10,11,15	**IV**
7	2,7,8,9,10,11,12,13,14,15	7,9,12,13	7,9,12,13	
8	2,8,9,10,11,12,13,14,15	7,8,9,12,13	8,9,12,13	

9	2,7,8,9,10,11,12,13,14,15	7,8,9,12,13	7,8,9,12,13	
10	2,10,11,14,15	2,7,8,9,10,12,13,14	2,10,14	
11	2,11,15	2,7,8,9,10,11,12,13,14	2,11	
12	2,7,8,9,10,11,12,13,14,15	7,8,9,12,13	7,8,9,12,13	
13	2,7,8,9,10,11,12,13,14,15	7,8,9,12,13	7,8,9,12,13	
14	2,10,11,14,15	7,8,9,10,12,13,14	10,14	
15	2,15	2,7,8,9,10,11,12,13,14,15	2,15	**IV**

Table 4.9: Iteration 5

Factor	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
7	7,8,9,10,11,12,13,14	7,9,12,13	7,9,12,13	
8	8,9,10,11,12,13,14	7,8,9,12,13	8,9,12,13	
9	7,8,9,10,11,12,13,14	7,8,9,12,13	7,8,9,12,13	
10	10,11,14	7,8,9,10,12,13,14	10,14	
11	11	7,8,9,10,11,12,13,14	11	**V**
12	7,8,9,10,11,12,13,14	7,8,9,12,13	7,8,9,12,13	
13	7,8,9,10,11,12,13,14	7,8,9,12,13	7,8,9,12,13	
14	10,11,14	7,8,9,10,12,13,14	10,14	

Table 4.10: Iteration 6

Factor	Reachability Set	Antecedent Set	Intersection Set	Level
7	7,8,9,10,12,13,14	7,9,12,13	7,9,12,13	
8	8,9,10,12,13,14	7,8,9,12,13	8,9,12,13	
9	7,8,9,10,12,13,14	7,8,9,12,13	7,8,9,12,13	
10	10,14	7,8,9,10,12,13,14	10,14	**VI**
12	7,8,9,10,12,13,14	7,8,9,12,13	7,8,9,12,13	
13	7,8,9,10,12,13,14	7,8,9,12,13	7,8,9,12,13	
14	10,14	7,8,9,10,12,13,14	10,14	**VI**

Table 4.11: Iteration7

Factor	Reachability Set	Antecedent Set	Intersection Set	Level
7	7,8,9,12,13	7,9,12,13	7,9,12,13	
8	8,9,12,13	7,8,9,12,13	8,9,12,13	**VII**
9	7,8,9,12,13	7,8,9,12,13	7,8,9,12,13	**VII**
12	7,8,9,12,13	7,8,9,12,13	7,8,9,12,13	**VII**
13	7,8,9,12,13	7,8,9,12,13	7,8,9,12,13	**VII**

Table 4.12: Iteration 8

Factor	Reachability Set	Antecedent Set	Intersection Set	Level
7	7	7	7	**VIII**

4.4.5 Development of Conical Matrix

In the next step, by placing together the factors at the same level from the rows and columns of the FRM a conical matrix is developed, as shown in Table 4.13. From this conical matrix the drive power and the dependence power of each factor is computed. The drive power of a factor is the total of the number of ones in the rows and the dependence power is the total of number of ones in the columns. Next, drive power and dependence power ranks are calculated by giving highest ranks to the factors that have the maximum number of ones in the rows and columns respectively [189, 185]

Table 4.13: Conical matrix

Factors	1	5	3	4	6	2	15	11	10	14	8	9	12	13	7	Drive Power
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
5	0	1	0	1	0	0	1	1	1	0	0	0	0	0	0	5
3	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	3
4	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	10
6	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	4
2	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	9
15	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	7
11	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	8
10	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	10
14	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	10
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	14
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15

7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
Dependence Power	12	14	13	14	12	11	12	11	10	8	5	5	5	5	4	

4.4.6 Development of Digraph

An initial digraph along with the transitivity links is developed from the data of the conical matrix. This digraph contains as many nodes as the number of factors connected by edges. From this the indirect links are removed to reach at the final digraph. In this final digraph, the top level factors are placed at the top and the successive level factors are placed in the next level, so on, until the lowest level factors are placed at the bottom of the digraph [189, 185]. The digraph developed based on the portioning of the 15 factors is shown in Figure 4.1.

4.4.7 ISM Model Development

Finally, the factor statements are added instead of nodes of the digraph to convert it into ISM model. The developed ISM model is shown in Figure 4.2.

4.4.8 Check for Conceptual Inconsistency

The model is finally checked for any conceptual inconsistencies. This is done by the identification and removal of any intransitivity from the final model.

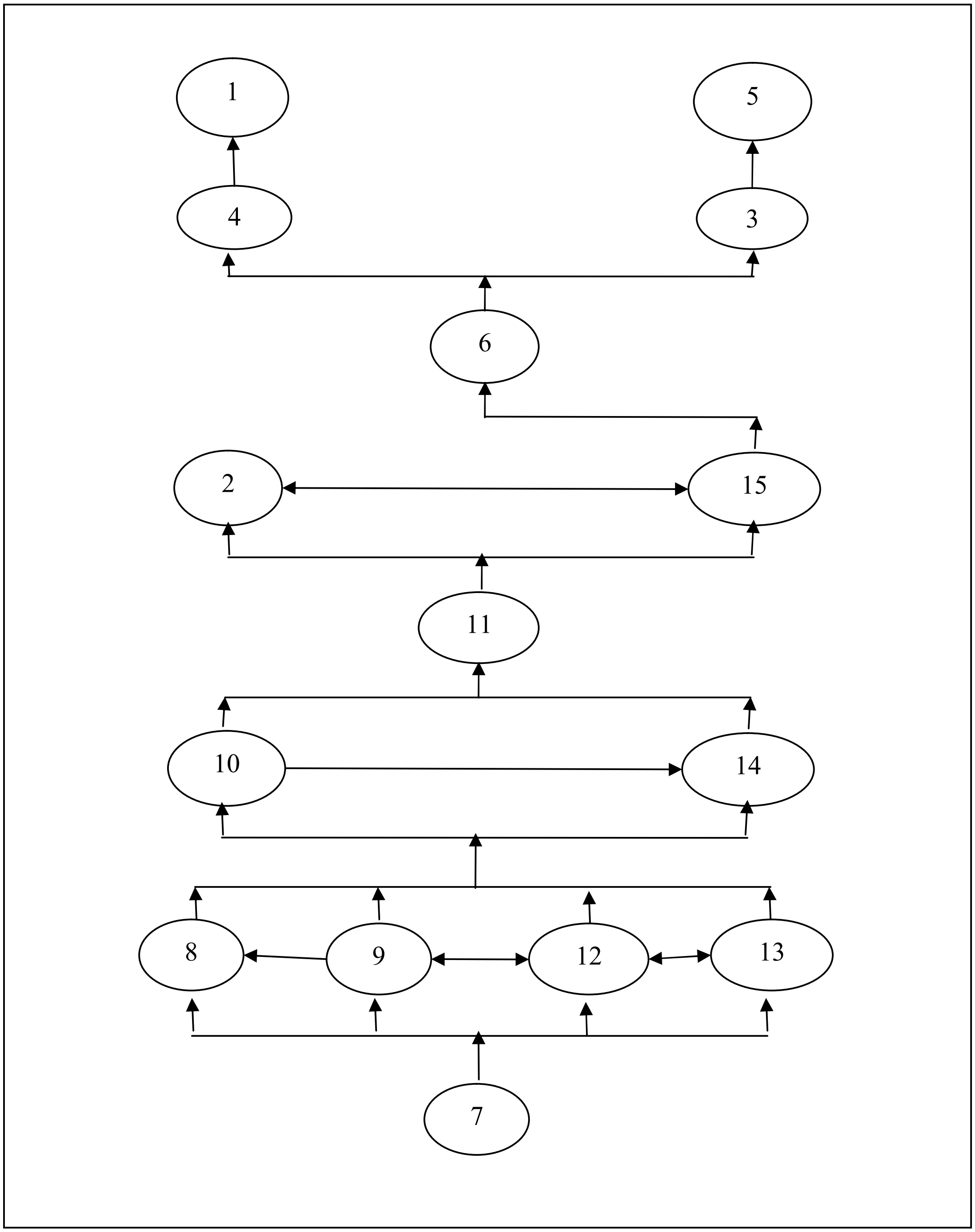


Figure 4.1: Digraph depicting the hierarchy of factors affecting the productivity in FMS

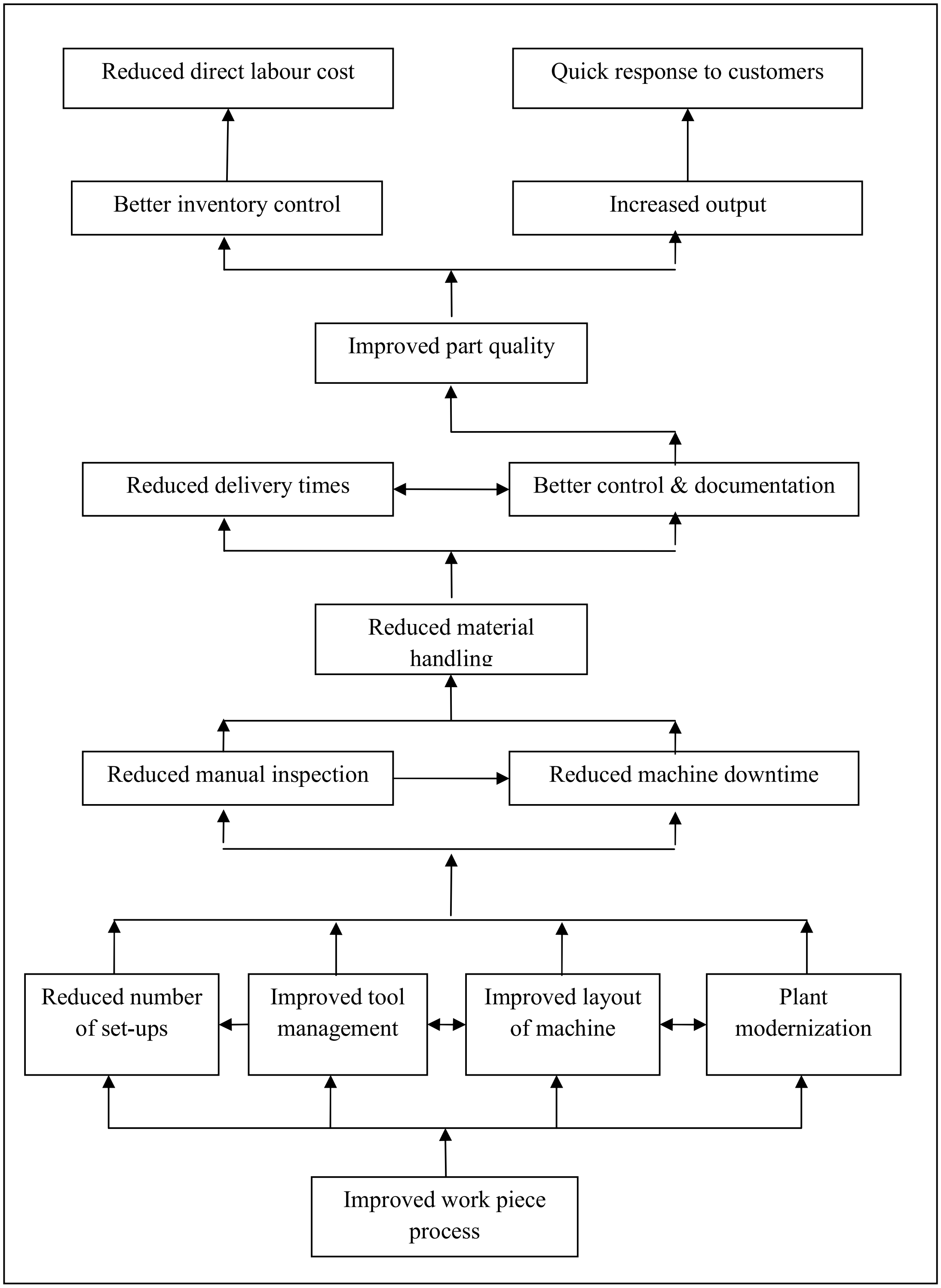


Figure 4.2: Interpretive structural model showing the hierarchy and the interrelation between factors affecting the productivity in FMS

4.5 MICMAC ANALYSIS

MICMAC stands for “Matrice d’Impacts croises-multipication applique´ an classment (cross-impact matrix multiplication applied to classification)”. The multiplication properties of matrices are used for the MICMAC analysis [64]. The analysis of the drive and dependence power of the different factors is done with the help of MICMAC. It identifies and categorizes the key factors that drive the system. In the present case, the different factors have been divided into four categories on the basis of their drive power and dependence power. These different categories are as follows:

(i) *Autonomous factors:* The factors having low drive power and the dependence power are categorized as the autonomous factors. They are comparatively disjointed from the system and have very few links with other factors.

(ii) *Dependent factors:* This category includes those factors which have weak drive power but strong dependence power.

(iii) *Linkage factors:* These have high drive power in addition to a high dependence power. They are the factors on which any action taken will not only effect them but also the other factors of the system.

(iv) *Independent factors:* Theses are also called the key factors as all other factors depend on these. Any improvements/ changes in these factors effects the whole system as they have very high drive power but low dependence power. So, these themselves are relatively independent from others.

This classification is similar to that by Mandal and Deshmukh [9].The drive power and dependence power of factors is shown in Table 4.13. Thereafter, the drive power-dependence power is drawn as shown in Figure 4.3.

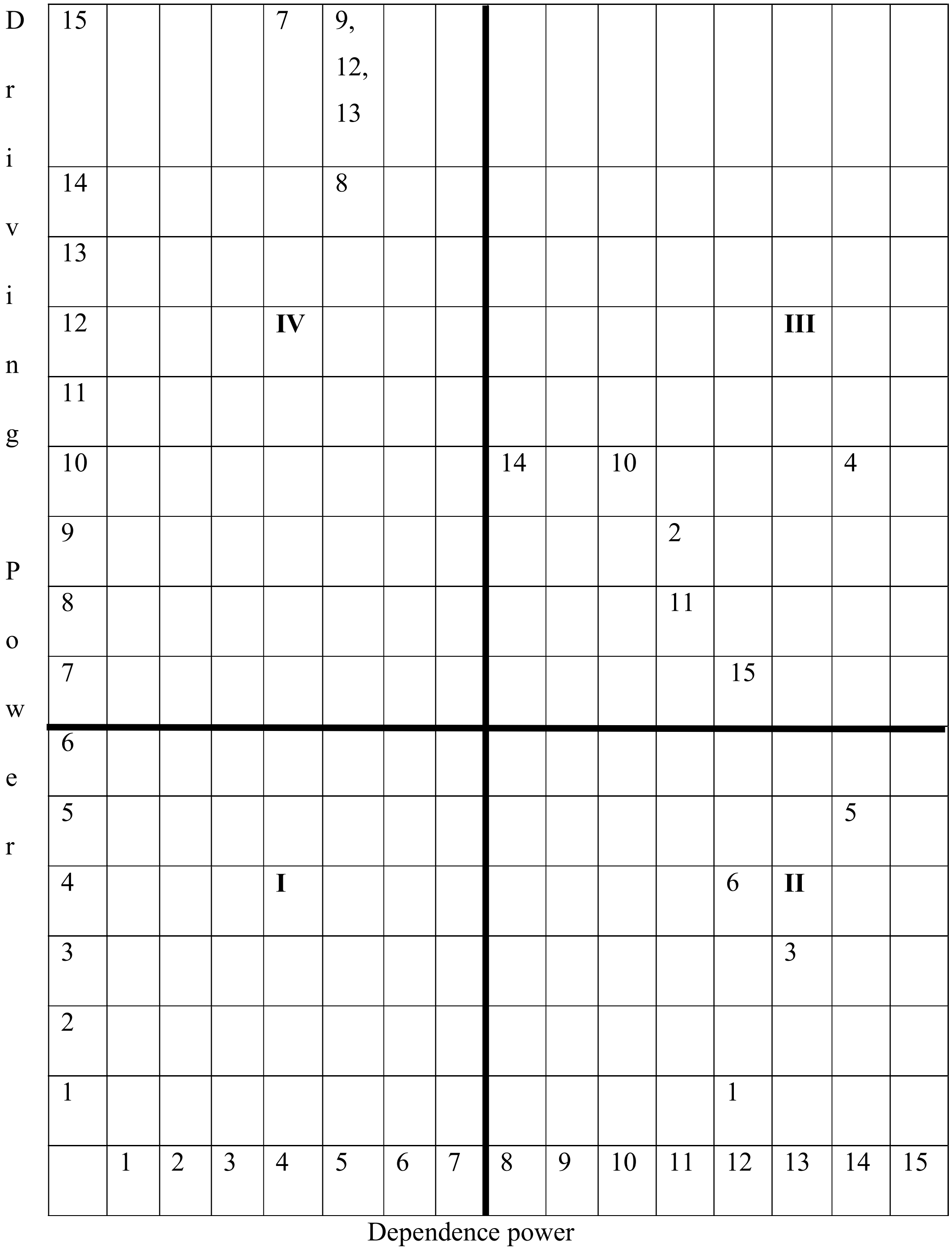


Figure 4.3: Clusters of factors affecting the productivity of FMS

This figure has been divided into four clusters. First cluster includes ‘autonomous factors’, second cluster includes ‘dependent factors’, third cluster includes ‘linkage factors’ and fourth cluster contains ‘independent factors’. In the further interpretation of this Figure 4.3, it is observed from Table 4.13 that factor 1 has drive power of 1 and dependence power of 12, hence in Figure 4.3, it is positioned in the second cluster. Its placement in the second cluster shows that it is a dependent factor. Similarly, all the factors are positioned at places corresponding to their driving power and dependence power.

4.6 DISCUSSION

The main aim of this chapter is to identify the factors that extensively affect the productivity of FMS in any manufacturing organization so that management may successfully handle these factors. An ISM-based model has been developed to analyze the interrelationships between different FMS factors. The managers can get an insight of these factors and understand their relative importance and interdependencies. The driver power-dependence matrix (Figure 4.3) gives some valuable insights about the relative importance and inter-dependence among the FMS factors. The research indicates that Reduced labour cost, Quick response to customers, Increased output, Inventory control and Improved part quality, are among the top-level factors. Reduced delivery times, Better control and documentation, Reduced material handling, Reduced manual inspection and Reduced machine downtime are the middle level factors. These results are reflected in the model. Reduced number of set-ups, Improved tool management, improved layout of machinery, plant modernization and Improved work piece processes are the lowest level factors. However, ISM model suggests that these have a very high driving power.

This research has some other implications for the practicing managers. The driver power dependence diagram gives some valuable insights about the relative importance and interdependencies of the factors. The managerial implications as emerging from this study are:

(i) Figure 4.3, the driver power dependence indicates that there is no autonomous factor. Autonomous factors are weak drivers and weak dependents and do not have much influence on the system. The absence of autonomous factors in this study indicates that all the considered factors have much influence on the productivity of FMS and management should pay attention to all the factors for achieving higher productivity.

(ii) Dependent factors are Reduced Direct Labour Cost (factor 1), Increased output (factor 3), Improved part quality (factor 6), Quick response to the customers (factor 5) and Better control and documentation (factor 15). These factors strongly depend on others are but are relatively weak drivers. The administration should hence take much care of these factors.

(iii) Factors Reduced material handling (factor 11), Reduced delivery times (factor 2), Reduced machine downtime (factor 14), Reduced manual inspection (factor 10), Better inventory control (factor 4) are linkage factors. They influence as well as are influenced by other factors appreciably. These factors can create positive environment regarding the productivity improvement in FMS but are again dependent on the independent factors.

(iv) It is further observed from figure 6 that factors Reduced number of set-ups (factor 8), Improved tool management (factor 9), Improved layout of machinery (factor 12), Plant modernization (factor 13) and Improved work piece processes (factor 7) are independent factors. These are strong drivers and can be considered as the core foundation of all the factors. These are the ‘key factors’ which affect the productivity of FMS.

4.7 CONCLUSION

In this chapter, the various factors which affect the productivity in FMS installation are identified. Sometimes manufacturing companies take quick decisions regarding the adaption of new technologies just by following the production system reports of the competitors without taking into account their own capabilities or limitations. In such cases new technologies like FMS prove suicidal. It is essential that the interested companies must do some introspection before adopting the FMS atmosphere. They must know what they are heading for. What is the effect of adopting FMS on the productivity of their firm, what are the factors which cause productivity increase.

Through ISM, a relationship model among the factors affecting the productivity of FMS has been developed. It is further intensified using MICMAC analysis where the driving power and the dependence power of all the factors is calculated. The purpose of identification of these factors and their analysis is to allow researchers and practicing managers to pay proper attention to these factors and see what factors are available with their installation and where there is still scope for the productivity improvement.

CHAPTER V

A TISM MODEL FOR STRUCTURING THE PRODUCTIVITY ELEMENTS OF FLEXIBLE MANUFACTURING SYSTEM

5.1 INTRODUCTION

Adoption of FMS in any industry is a tough decision and although much literature is available on the benefits offered by an FMS, this technique needs much consideration before its large scale adoption because of its capital intensive nature. FMS is seen as an option for those industries which want to boost productivity as well as respond quickly to an increasingly fickle marketplace. Until recently, these two goals were seen as conflicting but with the introduction of FMS, which produces in mid variety mid volume range, the conflict between productivity and flexibility can be resolved.

In this chapter, an attempt has been made to list some of the factors affecting the productivity of FMS through literature survey and expert opinion. These factors are structured using TISM technique. A TISM model is an up-gradation of Interpretive Structural Model (ISM). In chapter 4 the various productivity factors are modelled using ISM and now in this chapter an attempt has been made to further extend the same using TISM. The interpretation of links in terms of how it operates is comparatively weak in ISM. To upgrade ISM to TISM, the interpretation of the nodes and links is added in the structural model, which may have higher applicability in real life situations [180].

5.2 TISM APPROACH FOR MODELING THE PRODUCTIVITY FACTORS

The various steps leading to the TISM model are:

Step 1. Identify and the define factors: The various factors are identified are identified by literature survey and discussion with experts. The Various important factors affecting the productivity of FMS selected for TISM modelling are given in Table 5.1.

Table 5.1: Various factors affecting the productivity of FMS selected for TISM modelling

S.No.	Factor	Reference Source
1.	Reduced labour cost	Saloman and Biegel [36], Koren and Shpiitalni [208], Dixit and Raj [165]
2.	Increased output	Chan. [46], Wadhwa et al. [181], Gola and Swic [3]
3.	Reduced set-ups	Kaighobadi and Venkatesh [103], Chan and Chan [49], Bayazit [124]
4.	Fast response to customers	Groover [112], El-Tamini et al., [11], Singholi et al. [20]
5.	Reduced lead time	Keong et al. [126], Wadhwa et al. [181], Chan et al. [51], Singholi et al. [19]
6.	Effective inventory control	Groover [112]
7.	Better workpiece processes	Wadhwa et al. [181], Groover [112], Koren [207]
8.	Minimum material handling	Mahadevan and Narendran [23], Singh et al. [177]

Step 2. Defining the contextual relationship between these factors: After exhaustive discussions with both experts from industry and academia a contextual relationship is developed between these factors.

Step 3. Giving interpretation of contextual relationships: The interpretations are added to the SSIM and it is converted into interpretive logic.

Step 4. Interpretive logic of pair-wise comparison: In order to develop the knowledge base of interpretive logic the relationship between the factors affecting the productivity are compared pair wise by writing ‘Y’ for Yes and ‘N’ for No. Also the reasons are cited for each ‘Yes’ as given in Table 5.2.

Table 5.2: Interpretive logic-knowledge base

S.No	Factor Number	Paired comparison of Factors	Y/ N	In what way one factor will influence/enhance the other? With reason if 'Yes'
F1- Reduced labour cost				
1.	F1-F2	Reduced labour cost will influence or enhance output	N	
2.	F2-F1	Increased output will influence or enhance reduced labour cost	N	
3.	F1-F3	Reduced labour cost will influence or enhance reduced set ups	N	
4.	**F3-F1**	**Reduced set ups will influence or enhance reduced labour cost**	**Y**	**Less manpower required**
5.	F1-F4	Reduced labour cost will influence or enhance fast response to customers	N	
6.	F4-F1	Fast response to customers will influence or enhance reduced labour cost	N	
7.	F1-F5	Reduced labour cost will influence or enhance reduced lead time	N	
8.	F5-F1	Reduced lead time will influence or enhance reduced labour cost	N	
9.	F1-F6	Reduced labour cost will influence or enhance effective inventory control	N	
10.	F6-F1	Effective inventory control will influence or enhance reduced labour cost	N	
11.	F1-F7	Reduced labour cost will influence or enhance better workpiece processes	N	
12.	**F7-F1**	**Better workpiece processes will influence or enhance reduced labour cost**	**Y**	**Number of separate workstations reduces**
13.	F1-F8	Reduced labour cost will influence or enhance minimum material handling	N	
14.	**F8-F1**	**Minimum material handling will influence or enhance reduced labour cost**	**Y**	**Automated material handling devices reduces labour cost**
F2 – Increased Output				
15.	F2-F3	Increased Output will influence or enhance reduced set ups	N	
16.	**F3-F2**	**Reduced set ups will influence or enhance increased output**	**Y**	**Less unproductive time**
17.	**F2-F4**	**Increased Output will influence or enhance fast response to customers**	**Y**	**More production to meet more demands**
18.	F4-F2	Fast response to customers will influence or enhance increased output	N	
19.	F2-F5	Increased Output will influence or enhance reduced lead time	N	
20.	**F5-F2**	**Reduced lead time will influence or enhance increased output**	**Y**	**Per unit time reduction hence more output**
21.	F2-F6	Increased Output will influence or enhance effective inventory control	N	
22.	F6-F2	Effective inventory control will influence or enhance increased output	N	
23.	F2-F7	Increased Output will influence or enhance better workpiece processes	N	
24.	**F7-F2**	**Better workpiece processes will influence or enhance increased out put**	**Y**	**Reduces wastages hence more productivity**
25.	F2-F8	Increased Output will influence or enhance minimum material handling	N	
26.	F8-F2	Minimum material handling will influence or enhance increased output	Y	Transitive
F3- Reduced set ups				
27.	**F3-F4**	**Reduced set ups will influence or enhance fast response to customers**	**Y**	**Saves time and hence fast response**
28.	F4-F3	Fast response to customers will influence or enhance reduced set ups	N	
29.	**F3-F5**	**Reduced set ups will influence or enhance reduced lead time**	**Y**	**Unproductive time reduces**
30.	F5-F3	Reduced lead time will influence or enhance reduced set ups	N	
31.	**F3-F6**	**Reduced set ups will influence or enhance effective inventory control**	**Y**	**Less WIP inventory**
32.	F6-F3	Effective inventory control will influence or enhance reduced set ups time	N	
33.	F3-F7	Reduced set ups will influence or enhance better workpiece processes	N	
34.	**F7-F3**	**Better workpiece processes will influence or enhance reduced set ups**	**Y**	**More operations on a single workstation**
35.	**F3-F8**	**Reduced set ups will influence or enhance minimum material handling**	**Y**	**Movement between workstations reduces**
36.	F8-F3	Minimum material handling will influence or enhance reduced set ups	N	
F4 – Fast response to the customers				
37.	F4-F5	Fast response to the customers will influence or enhance reduced lead time	N	
38.	**F5-F4**	**Reduced lead time will influence or enhance fast response to the customers**	**Y**	**Less time means fast delivery to customers**
39.	F4-F6	Fast response to the customers will influence or enhance effective	N	

		inventory control		
40.	F6-F4	Effective inventory control will influence or enhance fast response to the customers	N	
41.	F4-F7	Fast response to the customers will influence or enhance better workpiece processes	N	
42.	**F7-F4**	**Better workpiece processes will influence or enhance fast response to the customers**	**Y**	**Better productivity**
43.	F4-F8	Fast response to the customers will influence or enhance minimum material handling	N	
44.	F8-F4	Minimum material handling will influence or enhance fast response to the customers	Y	Transitive
F5 – Reduced lead time				
45.	F5-F6	Reduced lead time will influence or enhance effective inventory control	N	
46.	F6-F5	Effective inventory control will influence or enhance reduced lead time	N	
47.	F5-F7	Reduced lead time will influence or enhance better workpiece processes	N	
48.	**F7-F5**	**Better workpiece processes will influence or enhance reduced lead time**	**Y**	**Less unproductive time**
49.	F5-F8	Reduced lead time will influence or enhance minimum material handling	N	
50.	**F8-F5**	**Minimum material handling will influence or enhance reduced lead time**	**Y**	**Less unproductive time**
F6 – Effective inventory control				
51.	F6-F7	Effective inventory control will influence or enhance better workpiece processes	N	
52.	F7-F6	Better workpiece processes will influence or enhance effective inventory control	Y	Transitive
53.	F6-F8	Effective inventory control will influence or enhance minimum material handling	N	
54.	F8-F6	Minimum material handling will influence or enhance effective inventory control	N	
F7- Better workpiece processes				
55.	**F7-F8**	**Better workpiece processes will influence or enhance minimum material handling**	**Y**	**Combining of operations**
56.	F8-F7	Minimum material handling will influence or enhance better workpiece processes	N	

Step 5. Reachability matrix and transitivity check: A reachability matrix is obtained from the interpretive logic – knowledge base by converting the paired comparisons into binary form. The reachability matrix is tested for the transitivity rule and updated iteratively. The final reachability matrix satisfying the transitivity rule is shown in Table 5.3.

Table 5.3: Reachability matrix

	F1	F2	F3	F4	F5	F6	F7	F8
F1	1	0	0	0	0	0	0	0
F2	0	1	0	1	0	0	0	0
F3	1	1	1	1	1	1	0	1
F4	0	0	0	1	0	0	0	0
F5	0	1	0	1	1	0	0	0
F6	0	0	0	0	0	1	0	0
F7	1	1	1	1	1	1*	1	1
F8	1	1*	0	1*	1	0	0	1

Step 6. Partioning the reachability matrix into different levels: To get the different levels partition is done on the reachability matrix. The partitioning is shown in Table 5.4. The different iterations are given in Table 5.4 a,b,c,d,e and f respectively for the six levels of partitioning. The various factors with their levels in TISM are given in Table 5.5.

Table 5.4: Partitioning the reachability matrix into different levels

Factors	Reachability set	Antecedent set	Intersection set	Level
		(a) Iteration 1		
F1	**1**	**1,3,7,8**	**1**	**I**
F2	2,4	2,3,5,7,8	2	
F3	1,2,3,4,5,6,8	3,7	3	
F4	**4**	**2,3,4,5,7,8**	**4**	**I**
F5	2,4,5	3,5,7,8	5	
F6	**6**	**3,6,7**	**6**	**I**
F7	1,2,3,4,5,6,7,8	7	7	
F8	1,2,4,5,8	3,7,8	8	
		(b) Iteration 2		
F2	**2**	**2,3,5,7,8**	**2**	**II**
F3	2,3,5,8	3,7	3	
F5	2,5	3,5,7,8	5	
F7	2,3,5,7,8	7	7	
F8	2,5,8	3,7,8	8	
		(c) Iteration 3		
F3	3,5,8	3,7	3	
F5	**5**	**3,5,7,8**	**5**	**III**
F7	3,5,7,8	7	7	
F8	5,8	3,7,8	8	

(d) Iteration 4				
F3	3,8	3,7	3	
F7	3,7,8	7	7	
F8	**8**	**3,7,8**	**8**	**IV**
(e) Iteration 5				
F3	**3**	**3,7**	**3**	**V**
F7	3,7	7	7	
(f) Iteration 6				
F7	**7**	**7**	**7**	**VI**

Table 5.5: List of factors and their levels in TISM

S.No.	Factor Code	Factor	Level in TISM
1.	F I	Reduced labour cost	I
2.	F4	Fast response to customers	I
3.	F6	Effective inventory control	I
4.	F2	Increased output	II
5.	F5	Reduced lead time	III
6.	F8	Minimum material handling	IV
7.	F3	Reduced set-ups	V
8.	F7	Better workpiece processes	VI

Step 7. Developing the digraph: A digraph is obtained by arranging the factors as per the levels and the links are mapped from the reachability matrix. Only significant transitive links are included and other are removed as shown in Figure 5.1.

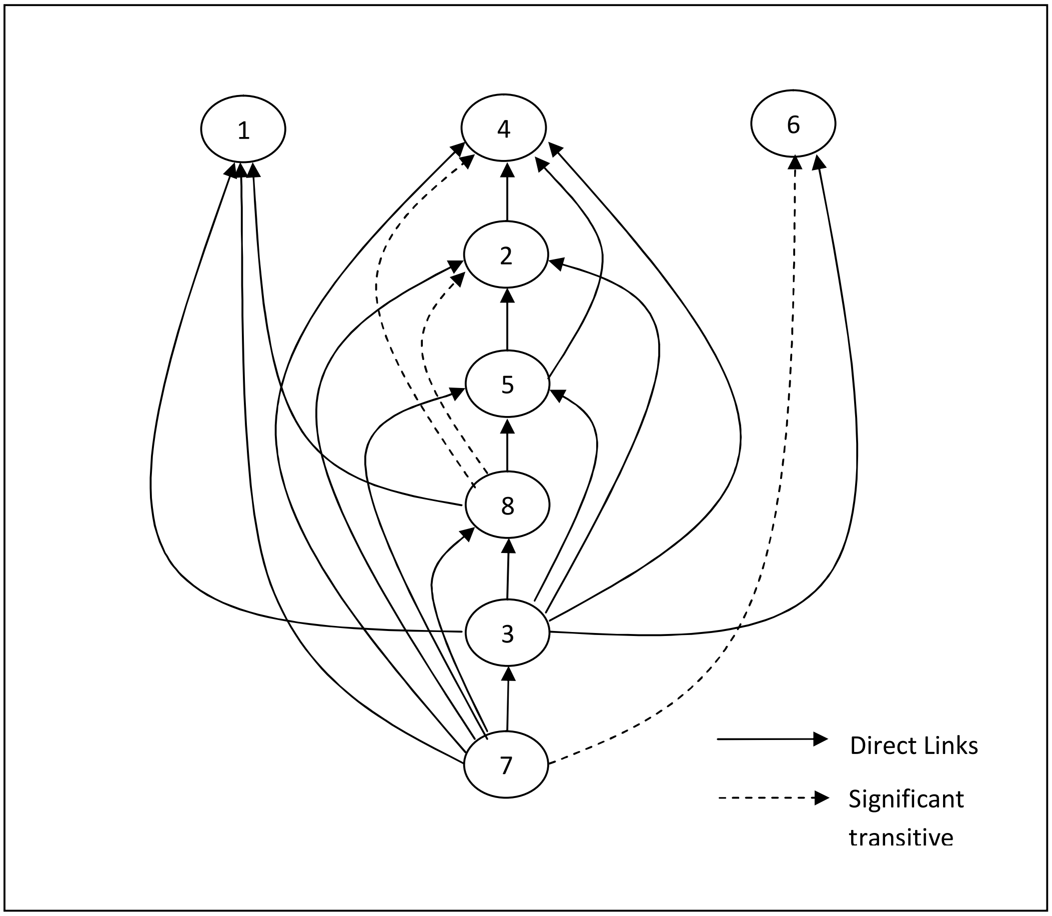


Figure 5.1: Digraph with significant transitive links

Step 8: Developing interaction matrix and converting to interpretive matrix: A binary interaction matrix is obtained from the final digraph by translating it and interpretations are added to it from the knowledge base of interpretive matrix as shown in Table 5.6.

Table 5.6: Interaction matrix

	F1	F2	F3	F4	F5	F6	F7	F8
				(a) Binary matrix				
F1	-	0	0	0	0	0	0	0
F2	0	-	0	**1**	0	0	0	0
F3	**1**	**1**	-	**1**	**1**	**1**	0	**1**
F4	0	0	0	-	0	0	0	0

F5	0	**1**	0	**1**	-	0	0	0
F6	0	0	0	0	0	-	0	0
F7	**1**	**1**	**1**	**1**	**1**	*1*	-	**1**
F8	**1**	*1*	0	*1*	**1**	0	0	-
(b) Interpretive matrix								
F1	-	-	-	-	-	-	-	-
F2	-	-	-	More production to meet more demands	-	-	-	-
F3	Less manpower required	Less unproductive time	-	Saves time and hence fast response	Unproductive time reduces	Less WIP inventory	-	Movement between workstations reduces
F4	-	-	-	-	-	-	-	-
F5	-	Per unit time reduction hence more output	-	Less time means fast delivery to customers	-	-	-	-
F6	-	-	-	-	-	-	-	-
F7	Number of separate workstations reduces	Reduces wastages hence more productivity	More operations on a single workstation	Better productivity	Less unproductive time	Better processes reduces inventory	-	Combining of operations
F8	Automated material handling devices reduces labour cost	With less material handling the output increases	-	Less material handling saves time	Less unproductive time	-	-	-

Step 9. Prepare TISM: The interpretation of the factors is added instead of nodes in the diagraph. The cause statements which are extracted from cells of interpretive direct interaction matrix are depicted along the side of the links to reach at the final structural model. This gives the TISM for productivity factors of FMS as shown in Figure 5.2.

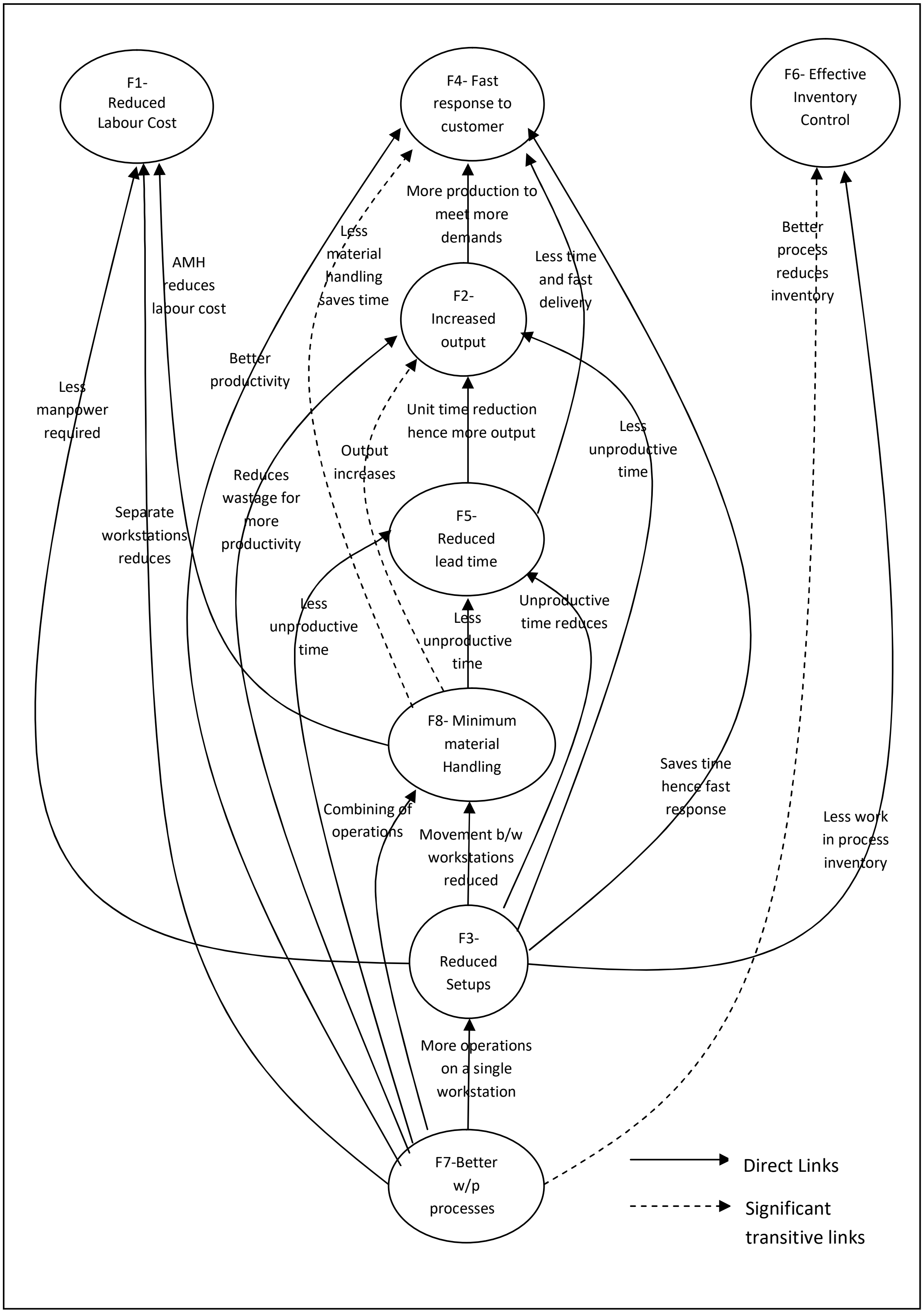


Figure 5.2: TISM for productivity factors of FMS

5.3 DISCUSSION

Main objective of this chapter is to analyse the various factors affecting the productivity of FMS. A structure is developed among these various factors by establishing their relative importance and influence on each other. The TISM model developed shows that better workpiece process is the basic factor which influences all the other factors for achieving better productivity. With improved workpiece processes, the set ups are reduced and as such more and more operations are either combined or are done at a single workstation thus leading to minimum material handling. This leads to lead time reduction and more outputs. Finally the factors like reduced labour cost, fast response to the customers and the effective inventory control are dependent factors which are influenced by the others.

5.4 CONCLUSION

The results of this study can help in the strategic and tactical decisions for a firm wanting to boost its productivity. By using TISM the interpretation of each relation is also incorporated. So a practicing engineer or the manager has a clear picture as to how each factor is related to the other factors influencing the productivity of the firm. The factors which influence the other factors more such as the workpiece processes, set ups and material handling, are of strategic orientation. On the other hand, the dependent factors, which are affected by the others like labour cost, response to customers, inventory control, are of operation and performance orientation. Therefore, better performance of FMS can be attained by continuously improving the strategic factors.

CHAPTER VI

QUANTIFYING THE INFLUENCE OF FMS ON THE PRODUCTIVITY OF A FIRM

6.1 INTRODUCTION

To compete in the marketing globalization, manufacturing industries need to produce their goods with high quality while maintaining low cost [105]. The developments in the technology front are opening many options to the industries to achieve the same. So, the adoption of flexible production technology is luring manufacturing managers worldwide. Most manufacturing organisations want to adapt to this highly attractive technology in a hurry to gain a competitive edge without caring for the suicidal repercussions of something acclaimed as the ultimate weapon of production technology [191]. FMS requires huge capital investment and is a complex system. Though FMS provides a lot of strategic and tactical benefits, yet all of these may not be possible with all installations. A manufacturing manager should know what are the specific benefits he is expecting from the FMS installation and what is the time span within which these benefits start coming in [165]. FMS is seen as an option for those industries which want to boost productivity as well as respond quickly to an increasingly fickle marketplace. Until recently, these two goals were seen as conflicting but with the introduction of FMS, which produces in mid variety mid volume range, the conflict between productivity and flexibility can be resolved.

So, it becomes necessary to enlist the factors affecting productivity of FMS installation and to further categorize them to quantify their inhibiting strengths. Therefore, an attempt has been made in this chapter to identify and categorize various productivity factors influenced by the implementation of FMS in a firm by literature survey and further these factors are quantitatively analysed to find their inhibiting strength using Graph Theoretic Approach (GTA).

6.2 IDENTIFICATION AND CATEGORISATION OF THE VARIOUS FACTORS

Based on the literature review and consultations with experienced personnel from industries and academia, it has been found that a number of productivity factors are affected by the FMS installation in any firm, these are broadly grouped into the following categories:

Table 6.1: Productivity factors with their reference sources

S.No.	Factors	Sub factors	Reference Source
1.	Strategic Factors (P_1)	Lead time reduction	Mehrabi et al., [102]; Chan and Chan, [49]; Chan et al., [51]; Ozturk et al., [15]; Raj et al., [187]; Groover, [112]; Nayak and Ray, [117]; Nayak and Ray, [118].
		Improved part quality	
		Quick response to customers	
		Plant modernization	
		Better control and documentation	
2.	Operational Factors (P_2)	Reduced set-ups	Huang and Sakurai, [137]; Mahadevan and Narenderan, [23]; Kouvelis,[132]; Das, [176]; Kashyap and Khator, [18]; Li et al.,[205]; Beamon, [22]; Buyurgan et al., [116]; Sujono and Lashkari, [178]; Groover, [112]; Um et al., [72]; Shingoli et al., [20]; Hermaste et al.,[5]; Choe et al., [130]; Jain and Raj,[197]; Kumar and Raj,[173].
		Automated material handling	
		Minimize manual inspection	
		Reduced machine down time	
		Increased spindle utilisation	
		Improved tool management	
		Flexible fixturing	
3.	Technical Factors (P_3)	Improved workpiece processes	Shantikumar and Stecke, [78]; Bengtsson and Olhager, [76]; Ali and Wadhwa, [98]; Sharma et al., [143]; Groover, [112]; Kumar and Sharma, [172]; Gothwal and Raj, [166].
		Accomodate design changes	
		Reduced floor space	
		Reduced rework and scrap	
		Reduced maintenance	
		Inventory reduction	
		Increased operator efficiency	

4.	Financial Factors (P_4)	Reduced direct labour cost Piece/ part cost reduction Improved throughput Reduced machining Cost	Gupta and Somers, [210]; D'Souza and Williams, [32]; Ozbayrak and Bell, [110]; Narain et al., [148]; Oke, [14]; Groover [112].

The main objective of this chapter is to co-relate these four categories of factors, their quantification based on their sub factors and their mutual interdependencies through graph theoretic approach

6.3 GRAPH THEORETIC APPROACH (GTA) FOR MODELLING THE PRODUCTIVITY FACTORS

GTA is a powerful tool that synthesizes the inter-relationship among different variables or subsystems and provides a synthetic score for the entire system. In this chapter, an attempt has been made to quantify the influence of FMS on the productivity of a firm.

The productivity of a firm depends on the inheritance of the various factors influenced by the FMS and on the amount of interactions among them. This is modelled by a network showing these factors and their interactions and is called a digraph i.e. a directed graph. The four categories of factors and their sub factors identified in the previous section have been utilised here to evaluate the influence of FMS on the productivity of a firm by finding an index known as 'PRO' simply meaning that to how much is the productivity of a firm is influenced by FMS installation. Hence:

$$\text{PRO for FMS} = p\ (\text{factors})$$

This approach consists of the following components:

- Digraph depiction
- Matrix depiction
- Permanent function calculation

The digraph gives the visual depiction of the factors/variables and their interdependence. The matrix is the mathematical form of the digraph and the permanent function is a mathematical model which helps to determine the 'PRO' value.

6.3.1 Digraph of FMS Productivity Factors

A digraph is the depiction of the factors and their interdependencies through nodes and edges. A digraph consists of a set of nodes P = $\{P_i\}$, with i = 1,2,3,.......M and a set of directed edges p = $\{p_{ij}\}$. A node Pi represents the i^{th} factor and edges represent the interdependence between the factors. The number of nodes P considered is equal to the number of factors considered. If a node i has a relative importance over another node j, then a directed edge or arrow is drawn from node i to node j (i.e. p_{ij}). If a node j has a relative importance over i then a directed edge is drawn from node j to i (i.e. p_{ji}).

To develop the FMS productivity factors digraph, four major categories of factors as mentioned in section 6.2 are selected and are represented by four nodes as shown in Figure 6.1.

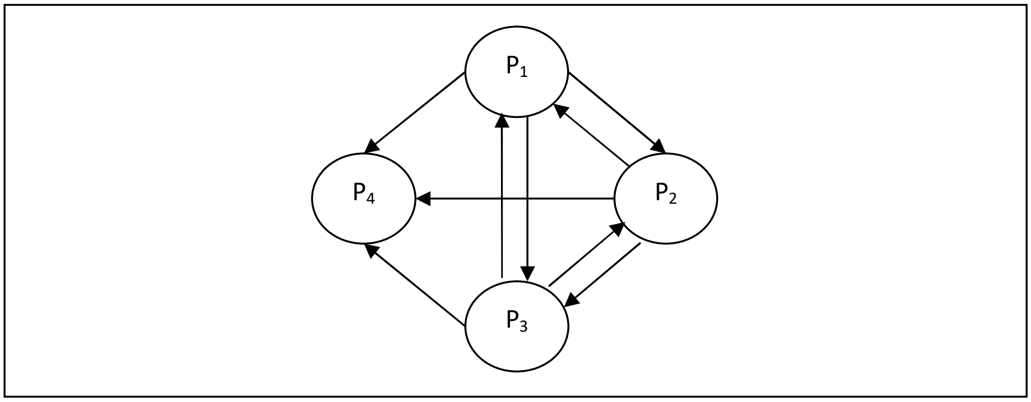


Figure 6.1: FMS productivity factors digraph

The directed edges are drawn according to interdependence of these factors for example, the strategic factors affect all other factors and so from P_1 to P_2, P_3 and P_4, directed edges are drawn. In the same fashion all the other directed edges are drawn and digraph is developed. The digraph developed in the present case is shown in Figure 6.1. This developed digraph helps the experts to visualize and analyze the given FMS situation, but as the number of factors and their interrelationships increase, the digraph becomes complex. In such cases the digraph is represented in matrix form.

6.3.2 Matrix Representation of FMS Productivity Factors

A matrix is a convenient and useful way of representing a digraph for computer processing. Mathematical manipulations can be easily done with the matrices. One to one depiction of the FMS productivity digraph is obtained from the matrix representation. A digraph can be represented by a binary matrix (p_{ij}), where p_{ij} shows the relative importance amongst the factors i and j such that, $p_{ij} = 1$, if the i^{th} factor is more important than the j^{th} factor and $p_{ij} = 0$, for vice versa [155].

In general, if there are M number of contributing categories of factors and interdependencies exist among all of these categories and there are no self loops, i.e. $p_{ii} = 0$, then the FMS productivity matrix, P is written as:

$$
P = \begin{array}{c} \text{Factors} \\ P_1 \\ P_2 \\ P_3 \\ \cdots \\ \cdots \\ P_m \end{array}
\begin{array}{c} \begin{array}{ccccccc} P_1 & P_2 & P_3 & \cdots & \cdots & P_m \end{array} \\
\begin{pmatrix}
P_1 & p_{12} & p_{13} & \cdots & \cdots & p_{1m} \\
p_{21} & P_2 & p_{23} & \cdots & \cdots & p_{2m} \\
p_{31} & p_{32} & P_3 & \cdots & \cdots & p_{3m} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
p_{m1} & p_{m2} & p_{m3} & \cdots & \cdots & P_m
\end{pmatrix} \end{array} \quad ....(6.1)
$$

The FMS productivity matrix for the FMS productivity digraph with four categories of influencing factors shown in Figure 6.1 is written as:

$$
P^* = \begin{array}{c|cccc}
\text{Factors} & P_1 & P_2 & P_3 & P_4 \\
\hline
P_1 & P_1 & p_{12} & p_{13} & p_{14} \\
P_2 & p_{21} & P_2 & p_{23} & p_{24} \\
P_3 & p_{31} & p_{32} & P_3 & p_{34} \\
P_4 & 0 & 0 & 0 & P_4
\end{array} \quad ....(6.2)
$$

In this matrix P*, the diagonal elements P_1, P_2, P_3 and P_4 represent the effect of FMS on the four categories of productivity factors and p_{ij} represent the interdependency of elements *i* and *j*, represented by the edge p_{ij} from *i* to *j* in the digraph.

6.3.3 Permanent Representation of Productivity Factors Matrix

To have a unique representation of the above digraph and matrix (Figure 6.1 and Equation 6.2), a permanent function of the productivity factors is calculated. As given by Jukat and Ryser [201] the permanent function is widely used in the combinatorial mathematics as a standard matrix function. Quantitative value of the effect of FMS on the productivity of any firm is obtained by this permanent function by substituting the values of P_i and p_{ij} in matrix P*. This multinomial representation does not contain any negative sign and only includes all the information regarding critical factors so no information is lost. The expression for permanent function corresponding to four element digraph as shown in Figure 6.1 is written as:

$$\begin{aligned} Per\ P^* = {} & \sum_{i=1}^{4} P_i + \sum_{i,j,k,l} (p_{ij}p_{ji})P_kP_l \\ & + \sum_{i,j,k,l} (p_{ij}p_{jk}p_{ki} + p_{ik}p_{kj}p_{ji})P_l \\ & + \sum_{i,j,k,l} (p_{ij}p_{ji})(p_{kl}p_{lk}) \\ & + \sum_{i,j,k,l} \{(p_{ij}p_{jk}p_{kl}p_{li}) + (p_{il}p_{lk}p_{kj}p_{ji})\} \qquad \ldots (6.3) \end{aligned}$$

Equation (6.3) contains 4! terms and which are arranged in n+1 groupings, where n is the number of factors. The value of n equals to four in the present case. The physical significance of the various groupings appearing in Equation (6.3) is explained as:

- The first grouping represents the interactions of four major productivity factors (P_1, P_2, P_3 and P_4).
- In the absence of any self loops in the digraph , the second grouping is absent.
- Two- element interdependence loop (i.e. p_{ij} and p_{ji}) is represented by the terms of the third grouping. It expresses the productivity measure of the remaining two unconnected factor.
- A set of three elements interdependence loops (i.e. $p_{ij}p_{jk}p_{ki}$ or $p_{ik}p_{kj}p_{ji}$) is represented by each term of the fourth grouping. It expresses the productivity measure of the remaining one unconnected factor.

- The fifth grouping contains terms arranged in two subgroups. The terms of the first subgroup consist of two element interdependence loops (i.e. $p_{ij}p_{ji}$ and $p_{kl}p_{lk}$). The second subgroup terms are a product of four element interdependence loops (i.e. $p_{ij}p_{jk}p_{kl}p_{li}$ or $p_{il}p_{lk}p_{kj}p_{ji}$).

If the values of productivity matrix i.e. Equation (6.2) are substituted in Equation (6.3), then some of the terms in various groupings are nullified and the resultant permanent representation is as follows:

$$\text{Per P}^* = P_1P_2P_3P_4 + (p_{12}p_{21})\, P_3P_4 + (p_{13}p_{31})\, P_2P_4 + (p_{23}p_{32})\, P_1P_4 + (p_{12}p_{23}p_{31} + p_{13}p_{32}p_{21})\, P_4 \qquad ....(6.4)$$

6.4 METHODOLOGY

The term 'PRO' defined in section 6.3 is the index to show the effect of FMS on the productivity of any firm. The permanent function, Equation (6.4) is proposed for the evaluation of it. 'PRO' index contains all the possible components of FMS productivity factors and their interdependence. The numerical value of FMS influence of productivity is named as PRO i.e.

PRO = Per P* = Permanent function of productivity factors matrix ....(6.5)

This PRO value can be calculated for any organisation and will show the effect of FMS on their productivity. As the multinomial Equation (6.3) contains only positive terms therefore, higher values of P_i and P_{ij} will result in an increased value of PRO. Higher value of PRO for any industry means that higher is the gain in productivity because of FMS for the industry. To calculate this index, the values of P_i and p_{ij} are required. The value of each factor (P_i) is determined by considering them as sub system and GTA is applied to each. Depending on the number of factors and their interdependence, digraph is made for each sub group and a permanent matrix is written for each sub group and the permanent function is calculated. The value of these factors and their interdependence is found on the basis of manufacturing system data available in the organisation and the experience of manufacturing personnel. A ranked value on a scale can be used in the absence of any quantitative value. In this case we have taken a scale of 1-9, as shown in Table 6.2. The ranked value of a factor will depend on the influence of FMS on that factor. If the influence is more in a particular organisation, then a high rank such as 8 or 9 is assigned, otherwise a lower rank 1 or 2 is assigned. For assigning the numerical values to interdependence of factors p_{ij}, again the opinion of experts is taken as these cannot be measured directly. These qualitative values of interdependence of factors are also assigned on a scale, 1-5 in the present case as shown in Table 6.3.

Table 6.2: Inheritance of productivity factors

S.No.	Quantitative measure of productivity factors	Assigned value of productivity factors
1.	Extremely insignificant	1
2.	Very insignificant	2
3.	Moderately insignificant	3
4.	Slightly insignificant	4
5.	Medium value	5
6.	Slightly significant	6
7.	Moderately significant	7
8.	Very significant	8
9.	Extremely significant	9

Table 6.3: Interdependence of productivity factors

S.No.	Qualitative measure of interdependence of productivity factors	Assigned value
1.	Very weak	1
2.	Weak	2
3.	Medium	3
4.	Strong	4
5.	Very Strong	5

On the basis of this discussion, using GTA, a methodology for the estimation of PRO for a firm is proposed. The main steps of this methodology are as follows:

1. Identify the various factors which effect productivity of any industry and which are influenced by the FMS adoption in the industry. For this purpose, a questionnaire is floated in the industry and responses are collected. The questionnaire consists of major categories of productivity factors (four in the present case) and each category is further listed with its sub factors.
2. Based on the response from the data collected, develop the FMS productivity factors digraph considering the above factors and their interdependence. The number of nodes in the digraph should be equal to the number of major factor categories and the magnitude and direction of the edges should correspond to their interdependence (p_{ij}), as shown in Figure 6.1.
3. For each category of factors, logically develop a digraph among the sub factors based on the interactions among them. These are the digraphs at the sub factor levels.
4. Based on the above mentioned digraphs among the sub factors, develop sub factor matrix. This will be of size M x M, with diagonal elements representing sub factors and the off-diagonal elements representing interactions among them.
5. Calculate the permanent function at each sub factor level. Use the numerical values for the inheritance and the interdependence as given in Table 6.2 and 6.3.
6. Develop the FMS productivity matrix from productivity digraph. The values of the permanent function at each sub factor level provide inheritance (diagonal elements P_i) for each factor. The value of interaction among these factors (i.e. off-diagonal elements p_{ij}) is to be decided by the discussions with the experts on the basis of Table 6.3.
7. Calculate the permanent function of FMS productivity factors using Equation 6.4 at the organisation level. This is the value of PRO which quantifies the influence of FMS on the productivity.
8. Record and document these results for future analysis.

Based on the methodology discussed above, the organisation can evaluate the extent of influence of FMS on the productivity.

6.5 CASE EXAMPLE

The case of an industry is considered with the proposed methodology. The considered industry is an Indian motorcycle and scooter manufacturer based in NCR, India. The company is the largest two- wheeler manufacturer in the world, with a market share of about 46%. In year 2015, the market capitalisation of the company was US$4.3 billion.

In this case, the PRO value of this organisation is determined by substituting the values of inheritance (P_i) and interdependence (p_{ij}) of the productivity factors in Equation (6.1). After discussion and consultation with the persons from the industry, a numerical value is assigned to different categories of factors (i.e. P_1, P_2, P_3 and P_4). For determining the quantitative measure of each category of factors, it is considered as a sub system and GTA is applied to it.

6.5.1 Determination of PRO Value

The stepwise implementation of the approach is as follows:

1. The various productivity factors affected by the FMS installation are identified and presented in Table 6.1.
2. Sub factors for these major factors are also identified and presented as in Table 6.2.
3. A digraph is developed as shown in Figure 6.1, for these four major categories of factors.
4. Digraphs are also developed for other category of factors (Figure 6.2 to 6.5) by considering the mutual interdependencies of sub factors which affect the any category of factors. The sub factors are represented by the nodes in these digraphs and their interrelationships are represented by different edges.
5. Numerical values of inheritance of sub factors and their interdependencies are assigned as per the two proposed scales (Table 6.2 and 6.3).
6. The productivity factors digraph and the matrix for each category of factors are written as:

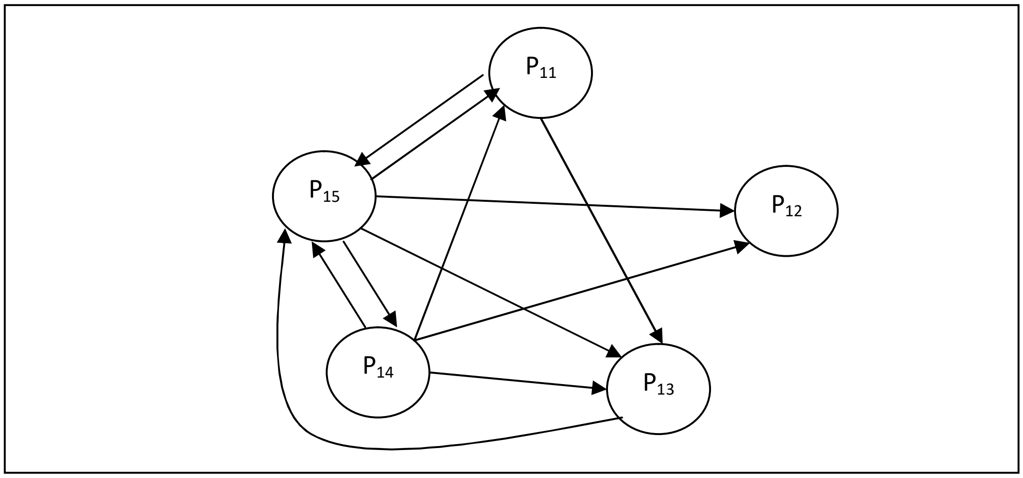


Figure 6.2: Digraph for strategic factors

Matrix for Strategic Factors:

$$P_1^* = \begin{array}{c} \\ P_{11} \\ P_{12} \\ P_{13} \\ P_{14} \\ P_{15} \end{array} \begin{array}{c} \begin{array}{ccccc} P_{11} & P_{12} & P_{13} & P_{14} & P_{15} \end{array} \\ \begin{pmatrix} 8 & 0 & 5 & 0 & 2 \\ 0 & 7 & 0 & 0 & 0 \\ 0 & 0 & 9 & 0 & 2 \\ 4 & 3 & 3 & 7 & 2 \\ 4 & 2 & 3 & 3 & 6 \end{pmatrix} \end{array} \quad ....(6.6)$$

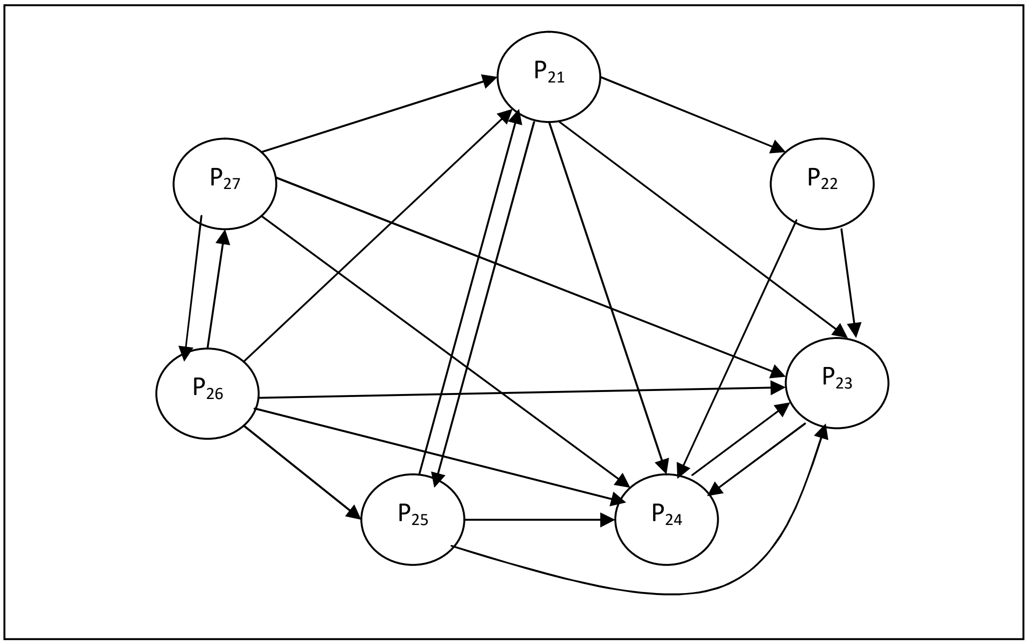


Figure 6.3: Digraph for operational factors

Matrix for Operational Factors:

$$P_2^*= \begin{array}{cc} & \begin{array}{ccccccc} P_{21} & P_{22} & P_{23} & P_{24} & P_{25} & P_{26} & P_{27} \end{array} \\ \begin{array}{c} P_{21} \\ P_{22} \\ P_{23} \\ P_{24} \\ P_{25} \\ P_{26} \\ P_{27} \end{array} & \begin{pmatrix} 8 & 3 & 4 & 5 & 4 & 0 & 0 \\ 0 & 8 & 4 & 3 & 0 & 0 & 0 \\ 0 & 0 & 6 & 3 & 0 & 0 & 0 \\ 0 & 0 & 2 & 8 & 0 & 0 & 0 \\ 5 & 0 & 4 & 5 & 7 & 0 & 0 \\ 4 & 0 & 4 & 4 & 4 & 7 & 4 \\ 3 & 0 & 3 & 4 & 0 & 3 & 6 \end{pmatrix} \end{array} \qquad \text{..........(6.7)}$$

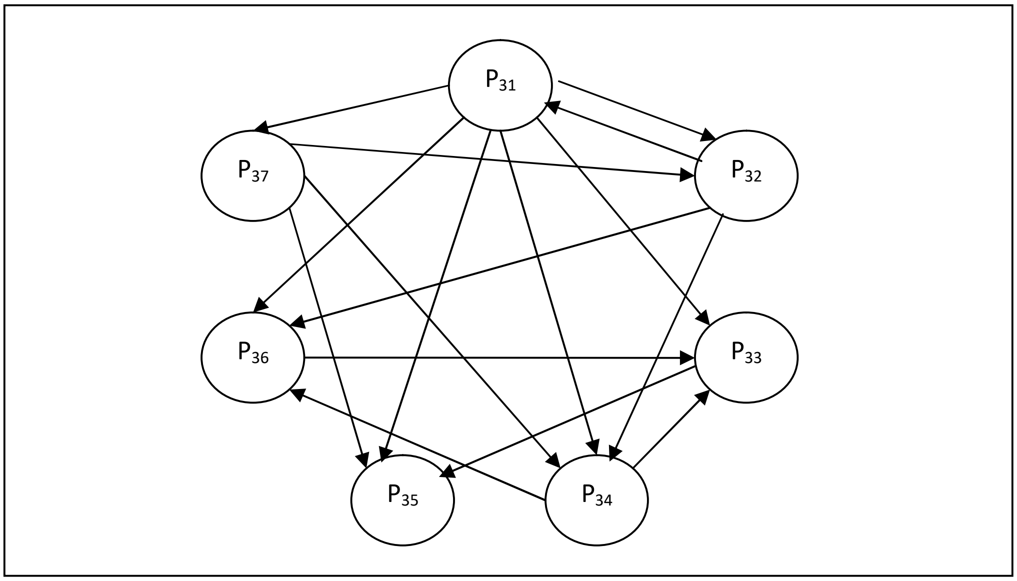


Figure 6.4: Digraph for technical factors

Matrix for Technical Factors:

$$
{}_{3}{*}= \begin{array}{c|ccccccc}
 & P_{31} & P_{32} & P_{33} & P_{34} & P_{35} & P_{36} & P_{37} \\
\hline
P_{31} & 8 & 5 & 4 & 4 & 3 & 4 & 4 \\
P_{32} & 4 & 9 & 0 & 4 & 0 & 2 & 0 \\
P_{33} & 0 & 0 & 6 & 0 & 3 & 0 & 0 \\
P_{34} & 0 & 0 & 3 & 6 & 0 & 3 & 0 \\
P_{35} & 0 & 0 & 0 & 0 & 6 & 0 & 0 \\
P_{36} & 0 & 0 & 4 & 0 & 0 & 7 & 0 \\
P_{37} & 0 & 4 & 0 & 4 & 3 & 0 & 7
\end{array} \qquad \text{.........(6.8)}
$$

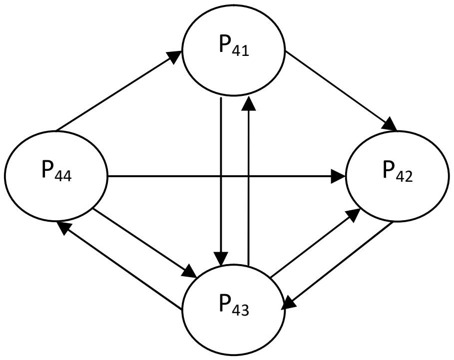


Figure 6.5: Digraph for financial factors

Matrix for Financial Factors:

$$
P_4{*}= \begin{array}{c|cccc}
 & P_{41} & P_{42} & P_{43} & P_{44} \\
\hline
P_{41} & 8 & 5 & 3 & 0 \\
P_{42} & 0 & 6 & 3 & 0 \\
P_{43} & 3 & 4 & 8 & 3 \\
P_{44} & 4 & 3 & 3 & 7
\end{array} \qquad \text{........(6.9)}
$$

7. The value of permanent function for each category of factors is calculated e.g. the value of permanent function for strategic factors category is:

$Per\ P_1^* = (P_{11}P_{12}P_{13}P_{14}P_{15}) + [(p_{115}\,p_{151})\ P_{12}P_{13}P_{14} + (p_{135}\,p_{153})\ P_{11}P_{12}P_{14} + (p_{145}\,p_{154})\ P_{11}P_{12}P_{13}] + [(p_{113}\,p_{135}\,p_{151})\ P_{12}P_{14} + (p_{115}\,p_{154}\,p_{141})\ P_2P_3 + (p_{135}\,p_{154}\,p_{143})\ P_1P_2] + [(p_{113}\,p_{135}\,p_{154}\,p_{141})\ P_{12}]$

Putting the values from the matrix of Strategic Factors:

$Per\ P_1^* = 8 \times 7 \times 9 \times 7 \times 6 + [(2 \times 4)\ 7 \times 9 \times 7 + (2 \times 3)\ 8 \times 7 \times 7 + (2 \times 3) \times 8 \times 7 \times 9] + [(5 \times 2 \times 4)\ 7 \times 7 + (2 \times 3 \times 4)\ 7 \times 9 + (2 \times 3 \times 3)\ 8 \times 7] + [(5 \times 2 \times 3 \times 4)\ 7]$

$Per\ P_1^* = 21168 + (3528 + 2352 + 3024) + (1960 + 1512 + 1008) + (840)$

$Per\ P_1^* = 35392$

Similarly, the value of permanent function for each category of factors is calculated and the calculated values come out to be:

$Per\ P_2^* = 1772928$, $Per\ P_3^* = 1070496$ and $Per\ P_4^* = 5097$

8. The values of permanent function at sub factor level are taken as the diagonal elements of productivity matrix at the system level in Equation (6.1), and assigning the values of interdependence we have,

$$P^* = \begin{array}{c|cccc} & P_1 & P_2 & P_3 & P_4 \\ \hline P_1 & 35392 & 3 & 2 & 3 \\ P_2 & 5 & 1772928 & 5 & 4 \\ P_3 & 5 & 4 & 1070496 & 5 \\ P_4 & 0 & 0 & 0 & 5097 \end{array} \quad .....(6.10)$$

9. The value of permanent function at the system level is evaluated by putting the values from this matrix in Equation (6.4), as:

$Per\ P^* = (35392 \times 1772928 \times 1070496 \times 5097) + [(3 \times 5)\ 1070496 \times 5097] + [(2 \times 5)\ 1772928 \times 5097] + [(5 \times 4)(35392 \times 5097)] + [(3 \times 5 \times 5 + 2 \times 4 \times 5)\ 5097]$

$$\boldsymbol{Per\ P^* = 3.4237 \times 10^{20}} \quad ....(6.11)$$

10. This value of *Per P** = 3.4237 x 10^{20} indicates the 'PRO' of any firm and is the quantification or the mathematical value showing how much is the productivity of any firm is influenced by the FMS installation.

6.5.2 Range of PRO Values

Further the hypothetical extreme values of the PRO are calculated. These are the maximum and minimum values of PRO and indicate the scope of improvement at overall and subsystem level. The productivity index is maximum or minimum when the inheritance of all the factors is maximum or minimum respectively. For example, the value of Per P_1* for the first category i.e. strategic factors is maximum when the inheritance of all its sub factors is maximum, i.e. 9, as per Table 6.2. Hence the productivity factors matrix for this category may be rewritten as:

$$P_1^* = \begin{array}{c c} & \begin{array}{ccccc} P_{11} & P_{12} & P_{13} & P_{14} & P_{15} \end{array} \\ \begin{array}{c} P_{11} \\ P_{12} \\ P_{13} \\ P_{14} \\ P_{15} \end{array} & \begin{pmatrix} 9 & 0 & 5 & 0 & 2 \\ 0 & 9 & 0 & 0 & 0 \\ 0 & 0 & 9 & 0 & 2 \\ 4 & 3 & 3 & 9 & 2 \\ 4 & 2 & 3 & 3 & 9 \end{pmatrix} \end{array} \qquad \text{........(6.12)}$$

The maximum value of Per P_1* for the first category is 81351.

The value of Per P_1* of strategic factors is minimum when the inheritance of all its sub factors is minimum, i.e. 1 as per Table 6.2. Hence the FMS productivity matrix for this category may be rewritten as:

$$P_1^* = \begin{array}{c} \\ P_{11} \\ P_{12} \\ P_{13} \\ P_{14} \\ P_{15} \end{array} \begin{array}{c} \begin{array}{ccccc} P_{11} & P_{12} & P_{13} & P_{14} & P_{15} \end{array} \\ \begin{pmatrix} 1 & 0 & 5 & 0 & 2 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 2 \\ 4 & 3 & 3 & 1 & 2 \\ 4 & 2 & 3 & 3 & 1 \end{pmatrix} \end{array} \qquad \text{........(6.13)}$$

The minimum value of Per P_1* for the first category is 223.

In the same way, the maximum and minimum values for each factor are computed as presented in Table 6.4. The extreme limits of PRO indicates its range, which can be utilised in finding the influence of FMS installation on the productivity of the firm. There is maximum scope for the improvement in productivity when the PRO value is near its minimum value and the scope is minimum or maximum utilization has been made when the PRO is near its maximum value.

Table 6.4: Maximum and minimum values of productivity index

Factor/ Sub factor level	Maximum Value	Current Value	Minimum Value
P_1	81351	35392	223
P_2	7354719	1772928	1911
P_3	6383853	1070496	85
P_4	10143	5097	319
P	387.41×10^{20}	3.4237×10^{20}	1.156×10^{10}

6.6 DISCUSSION

FMSs are capital investment-intensive and complex systems. To get the most benefits out of this advanced manufacturing system, the design and implementation of FMSs should be carefully planned and decided. The ultimate aim of any production system is to improve the productivity to gain advantage over the competitors. Successful implementation of FMS in any organisation boosts its productivity by reducing the lead time, improving the part quality, reducing the inventory, automating the material handling, accommodating the design changes and increasing the operator efficiency. Therefore, it becomes necessary to understand the impact of FMS implementation on the productivity of the firm.

The methodology presented in this chapter, aids in the estimation of impact of FMS on various productivity factors. By knowing about the intensity of different factors, some measures and precautions can be taken by the managers about these factors. It was seen in the considered case, that, operational factors have the maximum intensity. At the sub factor level, reduced set-ups, automated material handling, minimum manual inspection, reduced machine downtime, increased spindle utilisation, improved tool management and flexible fixturing play a significant role in boosting the productivity of FMS installation. So emphasis must be made more on handling these factors to increase productivity.

Table 6.4 also reveals an important observation, i.e. the scope for improvement at this factor level for the present organisation. The computed value of performance index of this factor is 1772928, which is still nowhere near the maximum value of 7354719. This shows how much the productivity can still be improved.

The next major category of factors is technical factors. At the technical level, improved workpiece processes and ability to accommodate design changes increases the productivity of the firm. With FMS, the requirement of the floor space, maintenance, rework and inventory level also reduces which goes onto increase the overall productivity. Again by comparing the current index of these factors with the hypothetical best, the scope for improvement can be judged and major and bold steps can be taken to gain advantage.

The next main category is the strategic factors with performance index value of 35392. These factors are related with the ultimate advantages offered by the FMS. The very aim of adopting this advanced manufacturing technique is to respond to the changing customer demands quickly with quality products by reducing the lead time. In this category also the current value is compared with the maximum value.

The next category is the financial factors. The productivity is improved by FMS installation by reduction in direct labour cost, machining cost, per unit cost reduction and improved throughput. But FMS is a capital intensive system so these financial benefits do not start coming into picture directly at the early stages. So the top management and the practising managers have to be patient and with reasonable rate of return should go for FMS.

The results shown in Table 6.4 may further be evaluated to provide a clear index of the scope for performance improvement. For this purpose we calculate productivity opportunity gain and productivity opportunity loss as shown in Table 6.5. Productivity opportunity gain shows the percentage gained with respect to minimum value and the productivity opportunity loss shows the percentage by which we lag to reach the maximum value of opportunity presented to us.

$$Productivity\ Opportunity\ Gain = \frac{(Current\ value - Minimum\ Value)}{(Maximum\ Value - Minimum\ Value)} * 100$$

$$Productivity\ Opportunity\ Loss = \frac{(Maximum\ Value - Current\ Value)}{(Maximum\ Value - Minimum\ Value)} * 100$$

Table 6.5: Values of productivity opportunity gain and loss

Factor/Subfactor	Performance Opportunity Gain	Performance Opportunity Loss
P_1	43.35	56.65
P_2	24.09	75.91
P_3	16.77	83.33
P_4	48.63	51.36
P	0.88	99.12

The maximum value for performance opportunity gain is 48.63 for P_4 (Financial Factors). This maximum value actually depicts the percentage by which it has already achieved the advantage and need less attention. On the other hand, system or subsystem having low value of performance opportunity gain needs more attention to the amount of percentage shown in the performance opportunity loss column. The overall value of performance opportunity loss for firm’s productivity index stands at 99.12 which being very low, requires urgent attention towards improvement through proper implementation of FMS.

6.7 CONCLUSION

The present work is considered highly significant for industries in developing countries like India. Indian industries have made use of CNC machines in their production lines to increase their productivity and improve the quality of their products. Some of them have even introduced robots, AGVs, CAD/CAM systems in their industries but they are reluctant to adopt the next phase of manufacturing, i.e., FMSs. This reluctance is due to the lack of precise data regarding the implementation effects of FMS.

The unique contribution of the present work is to quantify the impact of FMS implementation on the productivity of any organisation. A value of *Per P* calculated in this work is* $3.4237\text{x}10^{20}$ which indicates the ‘PRO’ of any firm and is the quantification or the mathematical value, showing how much is the productivity of any firm is influenced by the FMS installation. The mathematical model presented in this chapter can be used to develop a policy for the performance of FMS based on the intensity of different categories of factors. The chapter presents a numerical index for each of the productivity factors category as such it can be used by the managers to focus more on the critical factors and a maximum and minimum values for the same has also been calculated to further highlight the scope for improvement.

As a conclusion, an attempt has been made in this chapter to identify the various productivity factors affected by the FMS implementation, they are grouped into sub factors. A logical procedure based on GTA methodology is used to help focus on the productivity in a FMS environment. A numerical index is proposed to evaluate these productivity factors which ranks them so that the practising managers can have better focus. Further the productivity opportunity gain and productivity opportunity loss is calculated from this numerical index which gives the practising managers a clear picture of the present status of utilisation of this technology and quantifies the scope of improvement.

CHAPTER VII

FEASIBILITY ANALYSIS OF FMS IN SMALL AND MEDIUM SCALE INDIAN INDUSTRIES WITH A HYBRID APPROACH USING ISM AND TOPSIS

7.1 INTRODUCTION

In Indian economy small and medium scale industries occupy an important place, because of their employment potential and their contribution to total industrial output and exports. Indian manufacturing industry has witnessed irrepressible competition in the recent times in terms of low costs, improved quality and diverse products with superior performance [94]. In the last few years, strategic thinking has overtaken single minded cost reduction and cost minimisation in manufacturing [155]. During the past two decades, both the large scale industries and small and medium enterprises (SMEs) are experiencing dramatic changes in business environment including increasing consumer awareness of quality, rapid technology advancement, cost competition and globalisation of business [193].

The major challenges faced by the manufacturing industries today is quick adaptation to the changing customer demands, quality improvement in addition to cost reduction and in-time delivery. A large number of manufacturing small and medium enterprises in India are working as the supplier of the large industries [83]. So, they are becoming the part of bigger supply chains and the quality and timely delivery of their products becomes significantly important [144]. For achieving increased competitiveness, the manufacturing SMEs also need to replace or supplement their previous methods of production with more flexible and dynamic production systems.

The mass production is being replaced by low volume high variety production [95]. In this context, the manufacturing organisations adopt flexible manufacturing systems (FMSs) to meet the challenges imposed by today’s volatile market standards [191]. Manufacturing flexibility is widely recognised as a critical component to achieve competitive advantage in the market and improve an organisation’s capability to respond to customer demands without incurring excessive time and cost penalties [85]. FMS is vital for the present day manufacturing organizations to increase productivity in high and ever changing product proliferation [75], and is being adopted by both large as well as small scale industries to enhance their productivity.

FMS consists of general purpose manufacturing machines integrated with automated material handling systems which renders to perform different types of operations. There is a central computer system control over these machines and material handling systems [7]. Adoption of FMS in any industry is a tough decision and although much literature is available on the benefits offered by an FMS, still this technique being capital intensive, needs much consideration before being adopted blindly. This is especially so in case of small and medium scale industries. FMS is seen as an option for those industries which want to boost productivity as well as respond quickly to an increasingly fickle marketplace. Until recently, these two goals were seen as conflicting but with the introduction of FMS, which produces in mid variety mid volume range, the conflict between productivity and flexibility can be resolved.

Therefore, an attempt has been made in the present chapter to identify the various attributes of feasibility of FMS in small and medium scale Indian industries and further these attributes are modelled using Interpretive Structural Modelling (ISM) technique. In order to validate the ISM model, the same attributes are evaluated using TOPSIS technique and the two results are compared and discussed.

7.2 SMALL AND MEDIUM ENTERPRISES

After attaining independence in 1947, India adopted mixed economic planning as a method to achieve economic development. Along with the large scale sector the thrust was on small and medium scale industries because of its decentralised, small size, employment intensity with limited capital resources and enormous potential to use technology based products. With time, moving from the traditional khadi and cottage industries the scope of modern SMEs have shifted to manufacturing, ancillary, construction, service and feeder industries.

The definition of SME in India was ratified in 2006 vide ‘The Micro, Small and Medium Enterprises Bill, 2006’. The Ministry of Small Scale Industries, Govt. of India, vide its notification number S.O. 1722(E), dated October 5, 2006, has defined MSME based only on the criteria of their ‘Investment in Plant and Machinery’ in INR (Rs.), as indicated below:

1. Micro enterprise: not exceeding Rs.25 lakh for manufacturing industries and not exceeding Rs.10 lakh for service industries.

2. Small enterprise: more than Rs.25 lakh but not exceeding Rs.5 crore for manufacturing industries and more than Rs.10 lakh but not exceeding Rs.2 crore for service industries.

3. Medium enterprise: more than Rs. 5 crore but not exceeding Rs.10 crore for manufacturing industries and more than Rs. 2 crore but not exceeding Rs. 5 crore for service industries.

(source: http://www.eisbc.org/Definition_of_Indian_SMEs.aspx).

The role of SMEs is vital for the economic growth of the country [83]. Research shows that the success of SMEs has a direct impact on the economic development of the country [99]. As per the ‘MSME at a Glance’ Report of the Ministry of MSMEs, the sector consists of 36 million units and provides employment to over 80 million persons. The Sector produces more than 6,000 products contributing to about 8% of GDP. The total manufacturing output of about 45% and 40% to the exports from the country are from this sector. The sector is growing at a rate of about 8% per year in India and the government is taking different measures to further boost their growth.

The small and medium scale industries in India generate employment to the large and growing population with limited capital resources, have enormous potential to use technology based products and are highly flexible to meet the needs and expectations of the customers. SMEs carry on business on a small scale and as such the element of risk is also less. They are generally based on local resources and as such there is no problem regarding their availability and exert little burden on imports. These industries usually meet the demands of the local market and make use of the industrial waste. They mostly work as feeder industries for the large scale industries. SMEs can be located anywhere and help in the development of backward areas of the country and help in reducing the rural-urban regional disparity. They help in building achievement motivation amongst entrepreneurs.

7.2.1 Major Problems Regarding Small and Medium Scale Industries in India for Successful Implementation of FMS

Although small and medium scale industries in India have lots of potential but still their growth is restrained because of some constraints like:

- The implementation of FMS needs capital investment and SMEs generally have fund constraint. Adopting new technologies and improvement in equipment, tools, materials etc all need considerable funds which may be difficult for most of SMEs to afford.
- Small and medium scale industries usually lack the required awareness for the ways to implement and the impact on the organisational performance for the FMS. There is mostly lack of knowhow of complex operational and control techniques of FMS. Effective use of tools like CAD/CAM, MRP and other information management tools is also missing.
- Lack of managerial skills and business experience of the top management/ owners. The ownership of small and medium scale industries is usually with one individual in sole- proprietorship or it can be with a few individuals in partnership. Even with multiple partners it is usually a one man show with other partners being sleeping partners. These units are managed in a personalised fashion and the owner is actively involved in all the decisions regarding business. The lack of owners'/ managers' ability to form effective business strategies results in reluctance in adopting FMS. They usually are interested in short term gain rather than the long term goals.
- One of the major hurdles of SMEs in adopting FMS is the human resource constraint which includes lack of manpower, lack of education and skills, technical expertise and shorter average length of employment of the employees in that organisation. Singh et al. [145] pointed out that skill and technical knowledge is limited among the employees of Indian SMEs than large scale firms this is because most of the SMEs employ the local unskilled youth and train them as per the job requirements only. Further these firms usually do not have extra/ enough manpower to substitute the employees who undergo training programs to learn about the complex operational and control techniques of FMS. This is further inflated by the shorter length of

employment of the employees. As the employees/ operators become skilled and experienced, they switch over to some other large scale or more lucrative employment.

- Lack of supportive attitude and the work culture in the organisation. The benefits of FMS are usually realised gradually and after a long period. Many times it becomes difficult for the organisations to survive this long gestation period hence there is lack of commitment to successfully implement FMS. The inherent resistance of employees of Indian SMEs to any change of existing methods, systems and processes in the organisation also act as a major hurdle in the path of adopting FMS.

7.2.2 Strengths of SMEs for Adopting FMS

Inspite of some constraints, there are some strengths which give relative advantage to SMEs for the adoption of FMS, like,

- Capability of taking decisions quickly. SMEs usually have a flat organisational structure with lack of bureaucracy with the decision making power lying directly in the hands of owners/ managers. This has a positive impact on the organisations adaptability and response to the changing environment. It is easier to adopt newer technologies with the proper vision and commitment of the top personnel.
- It is usually easier to implement these technologies with some modifications like ‘Humanised FMS’, as suggested by Nagar and Raj [24], on small scale in developing countries like India than on large scale. The element of risk and loss involved is also small with SMEs.
- Strong government support and funding. To have a uniform growth of the whole country the government of India is taking different measures to increase the competitiveness of SMEs, both in national and international markets.

  Institutional Support Structure for MSMEs in India

  At Federal Level:

  1. Ministry of MSMEs
  2. Small Industries Development Organisation (SIDO)
  3. National Small Industries Corporation (NSIC)
  4. Entrepreneurship Development Institutions (EDIs)

At State Level:

1. Directorate of Industries
2. District Industries Centre

Others:

1. Industries Associations
2. NGOs
3. Banks and Financial Institutions

The main initiatives taken by the government of India to support the growth of SMEs include:

- i. A Small Scale Industries Board (SSIB) was constituted in year 1954 under the chairmanship of the Industrial minister of the government. It is an apex non- statutory body to render advice on all issues pertaining to SSI sector.
- ii. The Small Industries Development Bank of India (SIDBI) was established as the principal financial institution for the promotion, financing and development of industries in the small scale sector.
- iii. Separate wing of IDBI for SSI to provide effective financial support to this sector.
- iv. Setting up of Technology Development Cell and Export Development Cell in the SIDO.
- v. Market promotion of the SSIs products through common brand names, cooperatives etc.
- vi. Giving priority in government purchase programmes/ allocation of raw materials etc.
- vii. Simplification of statutes, regulations and procedures, excise exemptions etc.
- viii. Loans for technology upgradation.
- ix. Development of testing laboratories.

- Better employee’s involvement and participation. The limited strength of employees can prove to be a positive gain also. Because of less strength of employees it is easier to actively involve them and motivate them for a team work. The trust and empowerment on employees is also better with small number of employees having close and direct relationship with the top management. With less number of employees, it is generally much easier and less time and money consuming to train and educate them about the newer technologies.

Based on the above discussions, 17 attributes were identified which contribute to the possibility of installing FMS in a small and medium scale industry. These attributes are presented in Table 7.1.

Table 7.1: Major attributes for the feasibility of FMS in a small and medium scale industry

S.No.	**Attribute**
1.	Volume and Type of Production
2.	Availability of Funds
3.	Vision and Mission Policy of the Industry
4.	Pattern of Demand Uncertainties and Rush Orders
5.	Availability of Technology
6.	Availability of Vendors
7.	Support from Government and other Funding Agencies
8.	Work Culture and Team Building
9.	Multi skilled and Flexi-manpower
10	Availability of Adequate Space
11.	Capability of Process and Production Changes
12.	Possibility of Changing the Current Layout
13.	Knowhow of Complex Operational and Control Techniques of FMS
14.	Availability of Training and Upgrading Facilities for the Manpower
15.	Integration of FMS with the other Systems Operating in the Industry
16.	Effective use of Tools like CAD/CAM, MRP, MAP etc.
17.	Capacity to Bear Loss of Market Share Temporarily

7.3 ISM MODEL FOR FEASIBILITY OF FMS IN SMALL AND MEDIUM SCALE INDUSTRIES

In this section the development of a model of feasibility of FMS in small scale industries in India using ISM is described.

7.3.1 Development of SSIM

ISM model is developed by using the results of an industrial survey carried out in various industries in India. The opinion of various experts from these industries is used to form the initial conceptual relationship among the 17 attributes identified in section 7.2. The experts from academia were also consulted to remove any conceptual inconsistency. The following four symbols are used to describe the direction of relationship between any two attributes, *i* and *j*:

- If the attribute *i* influences attribute *j,* use symbol V.
- If attribute *j* influences attribute *I,* use symbol A.
- If attributes *i* and *j* influences each other, use symbol X.
- If attributes *i* and *j* are unrelated, use symbol O.

On the basis of the contextual relationship between the attributes a Structural Self – Interaction Matrix is developed for the various attributes as shown in Table 7.2.

Table 7.2: Structural self-interaction matrix

Attribute	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**
1	O	V	V	O	O	V	V	O	A	O	A	O	O	A	A	A
2	V	V	O	V	O	V	O	O	O	O	A	V	V	O	X	
3	V	V	V	V	V	V	V	O	O	V	A	V	V	V		
4	O	A	O	O	O	V	X	O	A	O	A	O	O			
5	O	X	V	X	A	O	V	O	X	O	A	X				
6	O	V	V	O	O	O	O	O	O	O	A					
7	V	V	V	V	O	V	V	O	O	O						
8	V	X	O	A	O	O	V	O	X							
9	O	X	V	A	V	V	V	O								
10	O	V	V	O	O	V	V									
11	V	X	A	A	X	X										
12	O	V	V	O	A											
13	O	V	V	A												
14	O	V	O													
15	O	X														
16	O															

7.3.2 Development of the Reachability Matrix

To develop the reachability matrix from the SSIM, binary digits 0 and 1 are used instead of the symbols of SSIM. This is done by substituting V, A, X, O of SSIM by 1s or 0s to get initial reachability (IR) matrix as described below:

(i) In the SSIM, if the cell *(i, j)* has the symbol V, then in IR matrix this cell entry becomes 1 and the cell (*j*, *i*) entry becomes 0.

(ii) In the SSIM, if the cell (*i, j*) has the symbol A, then in IR matrix this cell entry becomes 0 and the cell (*j*, *i*) entry becomes 1.

(iii) In the SSIM, if the cell (*i, j*) has the symbol X, then in IR matrix this cell entry becomes 1 and the cell (*j*, *i*) entry also becomes 1.

(iv) In the SSIM, if the cell (*i, j*) has the symbol O, then in IR matrix this cell entry becomes 0 and the cell (*j*, *i*) entry also becomes 0.

Following the above rules, the initial reachability matrix is prepared and is shown in Table 7.3.

Table 7.3: Initial reachability matrix

Attribute	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0
2	1	1	1	0	1	1	0	0	0	0	0	1	0	1	0	1	1
3	1	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	1
4	1	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0
5	0	0	0	0	1	1	0	0	1	0	1	0	0	1	1	1	0
6	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0
7	1	1	1	1	1	1	1	0	0	0	1	1	0	1	1	1	1
8	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	1	1
9	1	0	0	1	1	0	0	1	1	0	1	1	1	0	1	1	0
10	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0
11	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	1	1
12	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0
13	0	0	0	0	1	0	0	0	0	0	1	1	1	0	1	1	0

14	0	0	0	0	1	0	0	1	1	0	1	0	1	1	0	1	0
15	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0
16	0	0	0	1	1	0	0	1	1	0	1	0	0	0	1	1	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

The reachability matrix obtained in Table 7.3 is known as initial reachability matrix. The final reachability matrix is obtained from the initial matrix by incorporating transitivity i.e. if an attribute *a* influences attribute *b* and attribute *b* further influences attribute *c* the attribute *a* automatically influences attribute *c.* The final reachability matrix obtained by incorporating transitivity is shown in Table 7.4 wherein transitive influences are shown as 1*.

Table 7.4: Final reachability matrix

Attributes	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1	1	0	0	1*	1*	0	0	1*	1*	0	1	1	1*	0	1	1	1*
2	1	1	1	1*	1	1	0	1*	1*	0	1*	1	1*	1	1*	1	1
3	1	1	1	1	1	1	0	1	1*	0	1	1	1	1	1	1	1
4	1	0	0	1	0	0	0	0	0	0	1	1	1*	0	1*	1*	1*
5	1*	0	0	1*	1	1	0	1*	1	0	1	1*	1*	1	1	1	1*
6	0	0	0	1*	1	1	0	1*	1*	0	1*	0	0	1*	1	1	0
7	1	1	1	1	1	1	1	1*	1*	0	1	1	1*	1	1	1	1
8	1*	0	0	1*	1*	0	0	1	1	0	1	1*	1*	0	1*	1	1
9	1	0	0	1	1	1*	0	1	1	0	1	1	1	1*	1	1	1*
10	0	0	0	1*	1*	0	0	1*	1*	1	1	1	1*	0	1	1	1*
11	1*	0	0	1	1*	0	0	1*	1*	0	1	1	1	0	1*	1	1
12	0	0	0	1*	1*	0	0	1*	1*	0	1	1	1*	0	1	1	1*
13	0	0	0	1*	1	1*	0	1*	1*	0	1	1	1	1*	1	1	1*
14	1*	0	0	1*	1	1*	0	1	1	0	1	1*	1	1	1*	1	1*
15	0	0	0	1*	1*	0	0	1*	1*	0	1	1*	1*	0	1	1	1*
16	1*	0	0	1	1	1*	0	1	1	0	1	1*	1*	1*	1	1	1*
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

7.3.3 Partitioning the Reachability Matrix

The final reachability matrix is partitioned by finding the reachability and the antecedent sets for each attribute [82]. The process is completed in nine iterations giving nine different levels for the ISM model. In the present case, the 17 factors, along with their reachability set, antecedent set, intersection set and levels are presented in Tables 7.5 - 7.13.

Table 7.5: Iteration 1

Attribute	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,4,5,8,9,11,12,13,15,16,17	1,2,3,4,5,7,8,9,11,14,16	1,4,5,8,9,11,16	
2	1,2,3,4,5,6,8,9,11,12,13,14,15,16,17	2,3,7	2,3	
3	1,2,3,4,5,6,8,9,11,12,13,14,15,16,17	2,3,7	2,3	
4	1,4,11,12,13,15,16,17	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	1,4,11,12,13,15,16	
5	1,4,5,6,8,9,11,12,13,14,15,16,17	1,2,3,5,6,7,8,9,10,11,12,13,14,15,16	1,5,6,8,9,11,12,13,15,16	
6	4,5,6,8,9,11,14,15,16	2,3,5,6,7,9,13,14,16	5,6,9,14,16	
7	1,2,3,4,5,6,7,8,9,11,12,13,14,15,16,17	7	7	
8	1,4,5,8,9,11,12,13,15,16,17	1,2,3,5,6,7,8,9,10,11,12,13,14,15,16	1,5,8,9,11,12,13,15,16	
9	1,4,5,6,8,9,11,12,13,14,15,16,17	1,2,3,5,6,7,8,9,10,11,12,13,14,15,16	1,5,6,8,9,11,12,13,14,15,16	
10	4,5,8,9,10,11,12,13,15,16,17	10	10	
11	1,4,5,8,9,11,12,13,15,16,17	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	1,4,5,8,9,11,12,13,15,16	
12	4,5,8,9,11,12,13,15,16,17	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16	4,5,8,9,11,12,13,15,16	
13	4,5,6,8,9,11,12,13,14,	1,2,3,4,5,7,8,9,10,11,12	4,5,8,9,11,12,13,	

	15,16,17	,13,14,15,16	14,15,16	
14	1,4,5,6,8,9,11,12,13,14,15,16,17	2,3,5,6,7,9,13,14,16	5,6,9,13,14,16	
15	4,5,8,9,11,12,13,15,16,17	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	4,5,8,9,11,12,13,15,16	
16	1,4,5,6,8,9,11,12,13,14,15,16,17	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	1,4,5,6,8,9,11,12,13,14,15,16	
17	17	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,17	17	**I**

Table 7.6: Iteration 2

Attribute	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,4,5,8,9,11,12,13,15,16	1,2,3,4,5,7,8,9,11,14,16	1,4,5,8,9,11,16	
2	1,2,3,4,5,6,8,9,11,12,13,14,15,16	2,3,7	2,3	
3	1,2,3,4,5,6,8,9,11,12,13,14,15,16	2,3,7	2,3	
4	1,4,11,12,13,15,16	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	1,4,11,12,13,15,16	**II**
5	1,4,5,6,8,9,11,12,13,14,15,16	1,2,3,5,6,7,8,9,10,11,12,13,14,15,16	1,5,6,8,9,11,12,13,15,16	
6	4,5,6,8,9,11,14,15,16	2,3,5,6,7,9,13,14,16	5,6,9,14,16	
7	1,2,3,4,5,6,7,8,9,11,12,13,14,15,16	7	7	
8	1,4,5,8,9,11,12,13,15,16	1,2,3,5,6,7,8,9,10,11,12,13,14,15,16	1,5,8,9,11,12,13,15,16	
9	1,4,5,6,8,9,11,12,13,14,15,16	1,2,3,5,6,7,8,9,10,11,12,13,14,15,16	1,5,6,8,9,11,12,13,14,15,16	
10	4,5,8,9,10,11,12,13,15,16	10	10	
11	1,4,5,8,9,11,12,13,	1,2,3,4,5,6,7,8,9,10,11,12	1,4,5,8,9,11,12,13	**II**

	15,16	,13,14,15,16	,15,16	
12	4,5,8,9,11,12,13,15,16	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16	4,5,8,9,11,12,13,15,16	**II**
13	4,5,6,8,9,11,12,13,14,15,16	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16	4,5,8,9,11,12,13,14,15,16	
14	1,4,5,6,8,9,11,12,13,14,15,16	2,3,5,6,7,9,13,14,16	5,6,9,13,14,16	
15	4,5,8,9,11,12,13,15,16	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	4,5,8,9,11,12,13,15,16	**II**
16	1,4,5,6,8,9,11,12,13,14,15,16	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	1,4,5,6,8,9,11,12,13,14,15,16	**II**

Table 7.7: Iteration 3

Attribute	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,5,8,9,13	1,2,3,5,7,8,9,14	1,5,8,9	
2	1,2,3,5,6,8,9,13,14	2,3,7	2,3	
3	1,2,3,5,6,8,9,13,14	2,3,7	2,3	
5	1,5,6,8,9,13,14	1,2,3,5,6,7,8,9,10,13,14	1,5,6,8,9,13,14	**III**
6	5,6,8,9,14	2,3,5,6,7,9,13,14	5,6,9,14	
7	1,2,3,5,6,7,8,9,13,14	7	7	
8	1,5,8,9,13	1,2,3,5,6,7,8,9,10,13,14	1,5,8,9,13	**III**
9	1,5,6,8,9,13,14	1,2,3,5,6,7,8,9,10,13,14	1,5,6,8,9,13,14	**III**
10	5,8,9,10,13	10	10	
13	5,6,8,9,13,14	1,2,3,5,7,8,9,10,13,14,	5,8,9,13,14	
14	1,5,6,8,9,13,14	2,3,5,6,7,9,13,14	5,6,9,13,14	

Table 7.8: Iteration 4

Attribute	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,13	1,2,3,7,14	1	
2	1,2,3,6,13,14	2,3,7	2,3	
3	1,2,3,6,13,14	2,3,7	2,3	
6	6,14	2,3,6,7,13,14	6,14	**IV**

7	1,2,3,6,7,13,14	7	7	
10	10,13	10	10	
13	6,13,14	1,2,3,7,10,13,14,	13,14	
14	1,6,13,14	2,3,6,7,13,14	6,13,14	

Table 7.9: Iteration 5

Attribute	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,13	1,2,3,7,14	1	
2	1,2,3,13,14	2,3,7	2,3	
3	1,2,3,13,14	2,3,7	2,3	
7	1,2,3,7,13,14	7	7	
10	10,13	10	10	
13	13,14	1,2,3,7,10,13,14,	13,14	**V**
14	1,13,14	2,3,7,13,14	13,14	

Table 7.10: Iteration 6

Attribute	Reachability Set	Antecedent Set	Intersection Set	Level
1	1	1,2,3,7,14	1	**VI**
2	1,2,3,14	2,3,7	2,3	
3	1,2,3,14	2,3,7	2,3	
7	1,2,3,7,14	7	7	
10	10	10	10	**VI**
14	1,14	2,3,7,14	14	

Table 7.11: Iteration 7

Attribute	Reachability Set	Antecedent Set	Intersection Set	Level
2	2,3,14	2,3,7	2,3	
3	2,3,14	2,3,7	2,3	
7	2,3,7,14	7	7	
14	14	2,3,7,14	14	**VII**

Table 7.12: Iteration 8

Attribute	Reachability Set	Antecedent Set	Intersection Set	Level
2	2,3	2,3,7	2,3	**VIII**
3	2,3	2,3,7	2,3	**VIII**
7	2,3,7	7	7	

Table 7.13: Iteration 9

Attribute	Reachability Set	Antecedent Set	Intersection Set	Level
7	2,3,7	7	7	**IX**

7.3.4 Development of the Conical Matrix

In the next step, a conical matrix is developed from the final reachability matrix, as shown in Table 7.14. The drive power of a factor is derived by summing up the number of ones in the rows and its dependence power by summing up the number of ones in the columns. Next, drive power and dependence power ranks are calculated by giving highest ranks to the factors that have the maximum number of ones in the rows and columns respectively [189, 138].

Table 7.14: Conical matrix

Attribute	**17**	**4**	**11**	**12**	**15**	**16**	**5**	**8**	**9**	**6**	**13**	**1**	**10**	**14**	**2**	**3**	**7**	**Driving Power**
17	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4	1	1	1	1	1	1	0	0	0	0	1	1	0	0	0	0	0	8
11	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	0	0	11
12	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	10
15	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	10
16	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	13
5	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	13
8	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	0	0	11
9	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	13
6	0	1	1	0	1	1	1	1	1	1	0	0	0	1	0	0	0	9
13	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	0	12
1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	0	0	11
10	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0	0	0	11
14	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	13
2	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	15
3	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	15
7	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	16
Dependence Power	16	16	16	15	16	16	15	15	15	9	15	11	1	9	3	3	1	

7.3.5 Development of the Digraph and the ISM Model

On the basis of the conical matrix, an initial digraph having nodes and the links is developed which also includes transitivity links. From this a final digraph is obtained by deleting the transitivity liks. This digraph is shown in Figure 7.1. In this, the issues are placed in a hierarchy, to give different levels to the attributes [189, 138]. The ISM model for the feasibility of FMS in SMEs is shown in Figure 7.2.

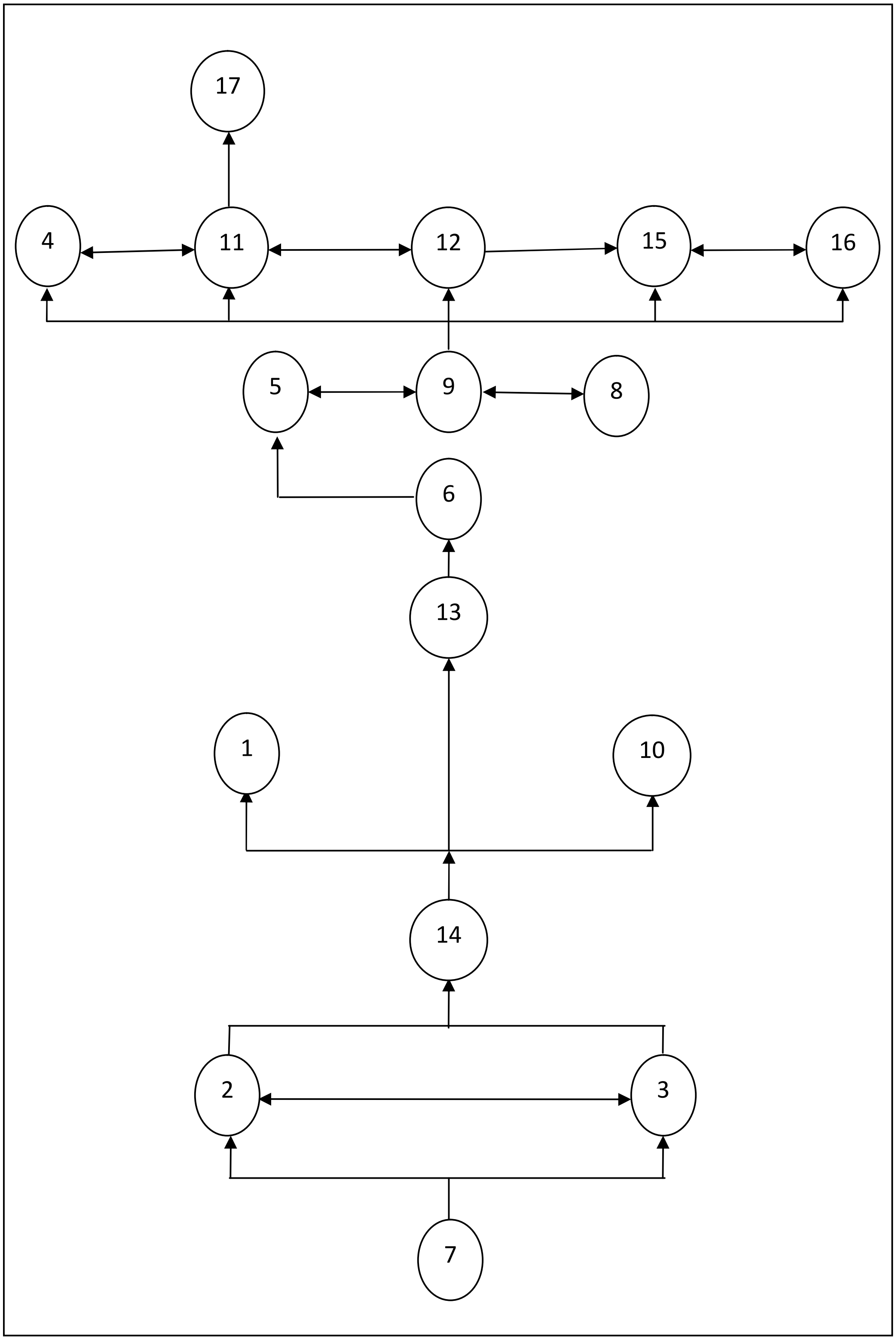


Figure 7.1: Digraph showing the interrelationship between the different attributes of feasibility of FMS in SMEs

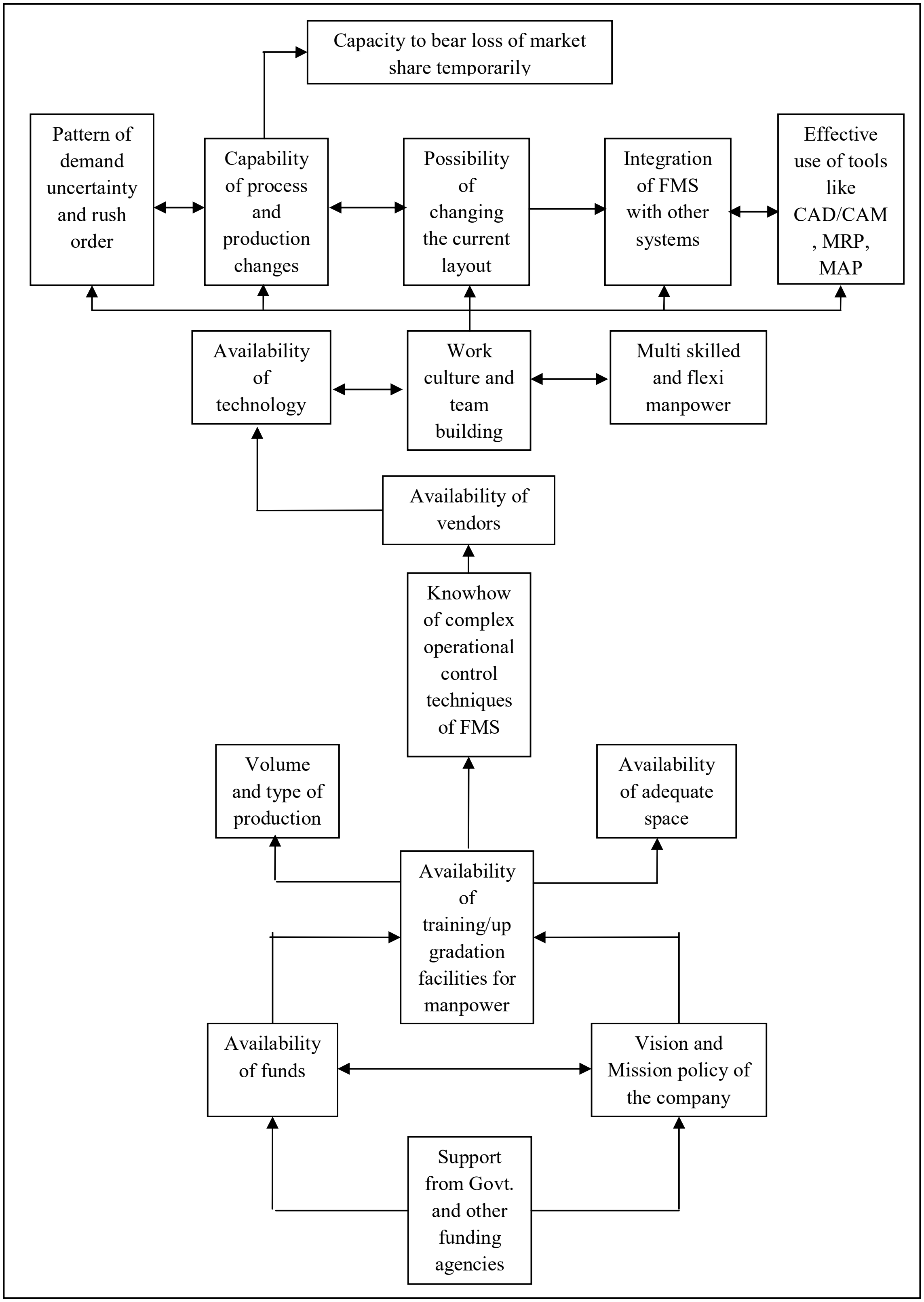


Figure 7.2: An interpretive structural model showing the levels of the attributes affecting the feasibility of FMS in SMEs

7.3.6 MICMAC Analysis

Further these attributes are analysed using MICMAC based on the multiplication properties of the matrices as suggested by Sharma et al. [64]. All the attributes are partitioned into four categories based on their driving power and the dependence power as:

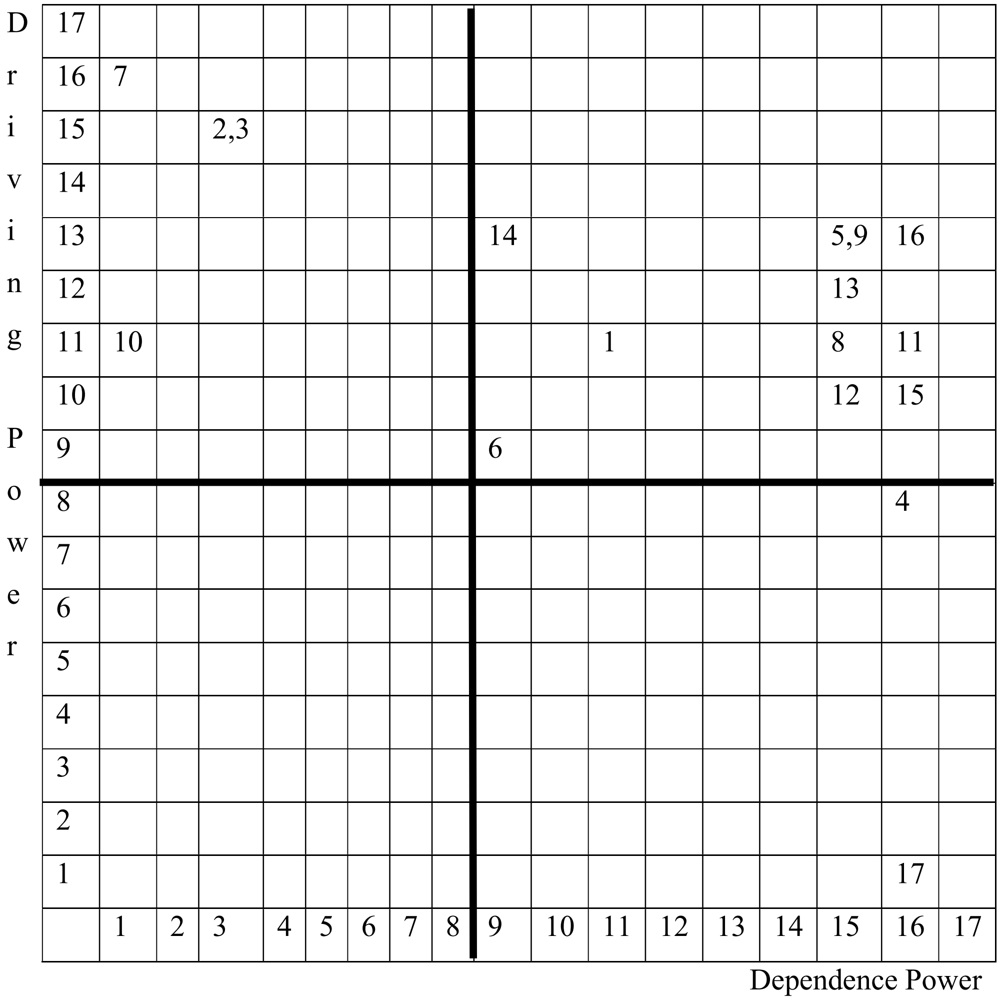
(i) *Autonomous factors:* The factors having low drive power and the dependence power are categorized as the autonomous factors. They are comparatively disjointed from the system and have very few links with other factors.

(ii) *Dependent factors:* This category includes those factors which have weak drive power but strong dependence power.

(iii) *Linkage factors:* These have high drive power in addition to a high dependence power. They are the factors on which any action taken will not only effect them but also the other factors of the system.

(iv) *Independent factors:* Theses are also called the key factors as all other factors depend on these. Any improvements/ changes in these factors effects the whole system as they have very high drive power but low dependence power. So, they themselves are relatively independent from others.

This classification is similar to that by Mandal and Deshmukh [9] and is shown in Table 7.14. Based on the drive power and the dependence power as calculated in Table 7.14 all the attributes are clustered as shown in Figure 7.3.



17																	
16	7																
15			2,3														
14																	
13									14						5,9	16	
12															13		
11	10										1				8	11	
10															12	15	
9									6								
8																4	
7																	
6																	
5																	
4																	
3																	
2																	
1																17	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

Figure 7.3: MICMAC analysis

7.4 FEASIBILITY MODEL BY TOPSIS

In this section the feasibility model for FMS in small and medium scale industries is made using TOPSIS. The various steps for which are described as under:

Step 1: Objective is to find the feasibility of FMS in a small scale Indian industry. For this 17 attributes were identified as given in Table 7.1.

Step 2: The next step, a decision matrix is developed containing all the data about the attributes. The data for these attributes over different criteria is taken from the survey conducted on various issues related to FMS in different industries spread over India (Chapter 3). In our survey 17 attributes of feasibility of FMS in small and medium scale industries were rated on a scale of 5 in which responses from 63 respondents were collected. Thus, number of attributes is, n=17 and criteria, k=5. This raw data has been converted into frequency table showing the number of instances of a given rating for a particular alternative, for example, instances of rating of 5 (most important), 4 (above average), 3 (average), 2 (below average) and 1 (least important) for attribute 1-'Volume and Type of Production' was 12, 9, 34, 8 and 0 respectively. The data thus collected from survey is shown in Table 7.15 and the normalised data is shown on Table 7.16.

Table 7.15: Data collected through survey

Rating	**5**	**4**	**3**	**2**	**1**
Attribute	**Most Important**	**Above Average**	**Average**	**Below Average**	**Least important**
1	12	9	34	8	0
2	0	5	52	6	0
3	6	34	23	0	0
4	5	3	30	19	6
5	12	24	25	2	0
6	0	23	28	12	0
7	3	8	52	0	0
8	0	11	30	22	0
9	8	13	30	12	0
10	6	18	34	2	3
11	3	4	24	28	4
12	2	18	13	24	6
13	2	28	15	18	0
14	0	9	34	18	2
15	6	8	22	27	0
16	18	18	16	10	1
17	5	0	18	28	12

Now the decision matrix is changed into standardized form using the Equation (7.1), where, X_{ij} is the raw data from Table 7.15.

$$S_{ij} = X_{ij} / \left(\left(\sum_{i=1,j=1}^{n,k} \left({X_{ij}}^2 \right) \right)^{1/2} \right) \qquad \text{...........} \; (7.1)$$

Table 7.16: Data in normalised form

Rating	5	4	3	2	1
Attribute	**Most Important**	**Above Average**	**Average**	**Below Average**	**Least important**
1	4.9104	1.1882	9.2709	0.9179	0.0000
2	0.0000	0.3667	21.6855	0.5163	0.0000
3	1.2276	16.9579	4.2425	0.0000	0.0000
4	0.8525	0.1320	7.2178	5.1773	2.2953
5	4.9104	8.4496	5.0124	0.0574	0.0000
6	0.0000	7.7601	6.2875	2.0652	0.0000
7	0.3069	0.9388	21.6855	0.0000	0.0000
8	0.0000	1.7750	7.2178	6.9413	0.0000
9	2.1824	2.4791	7.2178	2.0652	0.0000
10	1.2276	4.7529	9.2709	0.0574	0.5738
11	0.3069	0.2347	4.6194	11.2437	1.0201
12	0.1364	4.7529	1.3553	8.2607	2.2953
13	0.1364	11.5008	1.8045	4.6466	0.0000
14	0.0000	1.1882	9.2709	4.6466	0.2550
15	1.2276	0.9388	3.8816	10.4549	0.0000
16	11.0483	4.7529	2.0531	1.4341	0.0638
17	0.8525	0.0000	2.5984	11.2437	9.1811

Step 3: A set of importance weights w_k is developed for each of the criteria using Equation (7.2). Table 7.17 shows these criteria weights.

$$Normalised\ weight\ of\ each\ importance = \frac{Total\ of\ each\ importance}{Grand\ total\ of\ all\ importance} \quad \ldots \quad 7.2$$

Table 7.17: Weightage of rating

Rating	Most Important	Above Average	Average	Below Average	Least important
Instance of each importance	88	233	480	236	34
Total of each importance	440	932	1440	472	34
Normalized weight of each importance	0.1326	0.2809	0.4340	0.1423	0.0102

Step 4: With these weights, weighted matrix is calculated by multiplying each value of a rating column by its respective weight. The elements W_{ij} , of the weighted normalized matrix are computed as:

$$W_{ij} = w_k S_{ij} \qquad \text{.............(7.3)}$$

The weighted matrix is shown in Table 7.18.

Table 7.18: Weighted matrix of normalized data

Rating	**5**	**4**	**3**	**2**	**1**
Attribute	**Most Important**	**Above Average**	**Average**	**Below Average**	**Least important**
1	0.6511	0.3338	4.0236	0.1306	0.0000
2	0.0000	0.1030	9.4115	0.0735	0.0000
3	0.1628	4.7635	1.8412	0.0000	0.0000
4	0.1130	0.0371	3.1325	0.7367	0.0234
5	0.6511	2.3735	2.1754	0.0082	0.0000
6	0.0000	2.1798	2.7288	0.2939	0.0000
7	0.0407	0.2637	9.4115	0.0000	0.0000
8	0.0000	0.4986	3.1325	0.9877	0.0000
9	0.2894	0.6964	3.1325	0.2939	0.0000
10	0.1628	1.3351	4.0236	0.0082	0.0059
11	0.0407	0.0659	2.0048	1.6000	0.0104
12	0.0181	1.3351	0.5882	1.1755	0.0234
13	0.0181	3.2306	0.7831	0.6612	0.0000
14	0.0000	0.3338	4.0236	0.6612	0.0026
15	0.1628	0.2637	1.6846	1.4877	0.0000
16	1.4650	1.3351	0.8910	0.2041	0.0007
17	0.1130	0.0000	1.1277	1.6000	0.0936

Step 5: Identify the ideal attribute i.e. the most desirable issue on each criterion, S+. The ideal attribute is the maximum value of each rating column of the weighted matrix. Table 7.19 displays the ideal alternative chosen using said criteria from Table 7.14.

Table 7.19: Table of ideal attribute

	max W_{i1}	max W_{i2}	max W_{i3}	max W_{i4}	max W_{i5}
S+	1.4650	4.7635	9.4115	1.6000	0.0936

Step 6: Identify the nadir attribute i.e. reverse extreme desirable attribute on each criterion, S-. The nadir attribute is the minimum value of each rating column of the weighted matrix. Table 7.20 displays the nadir alternative chosen using said criteria from Table 7.15.

Table 7.20: Table of nadir attribute

	min W_{i1}	min W_{i2}	min W_{i3}	min W_{i4}	min W_{i5}
S-	0.0000	0.0000	0.5882	0.0000	0.0000

Step 7: Develop a distance measure over each criterion to both ideal (D+) and nadir (D-).The distance from ideal is calculated using Equation (7.4).

$$D_t^{+} = \left\{\sum_{j=1}^{k}(W_{ij}^{-}\ S_j^{+})^2\right\}^{1/2} \qquad i = 1,2,3 \dots\dots n \qquad \text{................ (7.4)}$$

and the distance from nadir can be calculated using Equation (7.5).

$$D_t^{-} = \left\{\sum_{j=1}^{k}(W_{ij}^{-}\ S_j^{-})^2\right\}^{1/2} \qquad i = 1,2,3 \dots\dots n \qquad \text{................ (7.5)}$$

Table 7.21: Distance of ideal and nadir attribute from weighted data

Attribute	**D_i+**	**D_i-**
Volume and Type of Production	9.9483	4.0871
Availability of Funds	10.0869	9.4078
Vision and Mission Policy of the Industry	8.9314	5.1079
Pattern of Demand Uncertainties and Rush Orders	10.3337	3.2158
Availability of Technology	9.5461	3.2817
Availability of Vendors	9.4289	3.5013
Support from Government and other Funding Agencies	9.9987	9.4107
Work Culture and Team Building	9.9379	3.3179

Multiskilled and Flexi-manpower	10.0482	3.2309
Availability of Adequate Space	9.5048	4.2381
Capability of Process and production Changes	10.4780	2.5626
Possibility of Changing the Current Layout	10.6480	1.8724
Knowhow of Complex Operational and Control Techniques of FMS	9.8258	3.3883
Availability of Training and Upgrading Facilities for the Manpower	9.8820	4.0866
Integration of FMS with the other Systems Operating in the Industry	10.5112	2.2653
Effective use of Tools like CAD/CAM, MRP, MAP etc.	10.5316	2.1809
Capacity to Bear Loss of Market Share Temporarily	10.9507	1.9603

Step 8: A ratio R is used to show **t**he relative closeness of a any attribute to the ideal solution So, R_i, can be expressed as a ratio R equal to the distance to the nadir divided by the sum of the distance to the nadir and the distance to the ideal, as shown in Equation (7.6).

$$R_i = \frac{D_i^-}{D_i^- + D_i^+} \qquad i = 1,2,3 \ldots..n \qquad \text{...........(7.6)}$$

For each attribute, determine a ratio R equal to the distance to the nadir divided by the sum of the distance to the nadir and the distance to the ideal, as shown in Equation (7.6) and calculated in Table 7.22.

Table 7.22: Ratio of distance to nadir from total

Attribute	$\mathbf{R_i}$
Volume and Type of Production	0.2912
Availability of Funds	0.4826
Vision and Mission Policy of the Industry	0.3638
Pattern of Demand Uncertainties and Rush Orders	0.2373
Availability of Technology	0.2558
Availability of Vendors	0.2708
Support from Government and other Funding Agencies	0.4849

Work Culture and Team Building	0.2503
Multiskilled and Flexi-manpower	0.2433
Availability of Adequate Space	0.3084
Capability of Process and production Changes	0.1965
Possibility of Changing the Current Layout	0.1495
Knowhow of Complex Operational and Control Techniques of FMS	0.2564
Availability of Training and Upgrading Facilities for the Manpower	0.2926
Integration of FMS with the other Systems Operating in the Industry	0.1773
Effective use of Tools like CAD/CAM, MRP, MAP etc.	0.1716
Capacity to Bear Loss of Market Share Temporarily	0.1518

Step 9: Rank order attributes by maximizing the ratio in Step 8 as shown in Table 7.23.

Table 7.23: Ranking the attributes from largest to smallest value

Attributes	**R_i**
Support from Government and other Funding Agencies	0.4849
Availability of Funds	0.4826
Vision and Mission Policy of the Industry	0.3638
Availability of Adequate Space	0.3084
Availability of Training and Upgrading Facilities for the Manpower	0.2926
Volume and Type of Production	0.2912
Availability of Vendors	0.2708
Knowhow of Complex Operational and Control Techniques of FMS	0.2564
Availability of Technology	0.2558
Work Culture and Team Building	0.2503
Multiskilled and Flexi-manpower	0.2433
Pattern of Demand Uncertainties and Rush Orders	0.2373
Capability of Process and production Changes	0.1965
Integration of FMS with the other Systems Operating in the Industry	0.1773
Effective use of Tools like CAD/CAM, MRP, MAP etc.	0.1716
Capacity to Bear Loss of Market Share Temporarily	0.1518
Possibility of Changing the Current Layout	0.1495

7.5 DISCUSSION

The aim of this chapter is to find the feasibility of FMS in small and medium scale Indian industries. For this 17 attributes have been identified which influence the adoption of FMS in SMEs. Further these are modelled using two distinct, well established modelling approaches, ISM and TOPSIS. In ISM based model a hierarchy of different attributes for the adoption of FMS in small and medium scale industries is established. The practising managers of these industries can understand about the relative importance and interdependencies of these attributes. The drive power-dependence power matrix (Figure 7.2) shows some valuable findings in relation to these attributes. Research indicates that capacity to bear loss of market share temporarily, pattern of demand uncertainty and rush orders, capability of process and production changes, possibility of changing the current layout, integration with other systems operating in the industry and effective use of tools like CAD/CAM, MRP, MAP etc are the top level attributes. Availability of technology, work culture, multi-skilled manpower, availability of vendors, knowhow of complex techniques of FMS, production volume and type and the availability of space form the middle level attributes. The availability of training facilities, funds, vision and mission of company and the government support from the lowest level attributes. The ISM model suggests the lowest level attributes have a very high driving power and as such influence all other attributes. This implies for the adoption of FMS in small and medium scale industries the support from government is very important. Further with a positive vision and mission of the company the commitment of top management is achieved, which along with the availability of some funds can lead to the adoption of FMS. The other middle level and top level attributes although very important for the success of FMS can be achieved with the availability of lower level attributes.

The ISM model is validated using TOPSIS methodology on the same attributes. The hierarchy model given by TOPSIS is similar to that of ISM to a large extent. The TOPSIS also evaluated that the government support is most necessary for the growth and development of SMEs followed by the availability of funds, proper vision and availability of space. So these attributes can be treated as the key attributes for making the adoption of FMS feasible.

7.6 CONCLUSION

Small industry sector has performed exceedingly well and enabled our country to achieve a wide measure of industrial growth and diversification. By its less capital intensive and high labour absorption nature, SSI sector has made significant contributions to employment generation and also to rural industrialisation. Competitive market is forcing big organizations to utilize the untapped potential of these small and medium scale industries. In the era of outsourcing, SMEs are an important link in the supply chain, making it more effective and efficient. This is the opportune time to set up projects in the small-scale sector. The promotional and protective policies of the Govt. have ensured the presence of this sector in an astonishing range of products, particularly in consumer goods. However, the bugbear of the sector has been the inadequacies in capital, technology and marketing. The process of liberalisation coupled with Government support will therefore, attract the infusion of just these things in the sector. The new competition is in terms of reduced cost, improved quality products with higher performance, a wider range of products and better services, all delivered simultaneously to enhance value to the customer. FMS has a set of tools and techniques which can help these industries to boost their competitiveness. With small alterations in their style of working SMEs can have the required structure for adopting flexible manufacturing system.

CHAPTER VIII

A LAPTOP METHODOLOGY FOR CONVERSION OF A CONVENTIONAL MANUFACTURING SYSTEM INTO FMS

8.1 INTRODUCTION

Traditional factories derived their competitive advantage from a combination of size, volume and standardisation [207]. But today's industries relay more on flexibility than on standardisation. Advanced technologies have fundamentally changed the nature of manufacturing and opened up opportunities for new styles of competition in many industries. Today, variety and innovation will no longer have to be traded off against productivity.

To achieve the goals of productivity as well as flexibility, the industries are moving towards advanced manufacturing techniques and especially adopting flexible Manufacturing system (FMS). Many researchers have advocated the use of Flexible Manufacturing Systems to meet the challenges of global competition. Evans et al., [62] have noted that the main feature of an FMS is its flexibility, i.e. the ability to produce a variety of parts with low set up times. FMSs are supposed to help regain competitiveness through improvements in productivity and quality [93]. Developed countries worldwide have adopted FMS and have started reaping its benefits, but the developing countries are still far behind. Despite the potential benefits offered by FMS, their adoption rates are relatively slow, especially in developing countries like India. Indian manufacturing industries are using conventional manufacturing systems for quite a long time [25]. The main reason for this may be attributed to the fact that although a lot of literature is available to support the adoption of FMS by highlighting its potential benefits but still there is not enough literature showing its implementation and stepwise adoption process.

The main objective of this chapter is to propose a methodology for conversion of a conventional manufacturing system into FMS and to justify the same by highlighting the characteristics of FMS through a decision making process. Adoption of FMS is a strategic issue and requires lots of planning and decision making. Multi-criteria analytic decision making tools are an aid in strategic decision making. This chapter is an attempt to select the best alternative of manufacturing based on FMS by means of Analytical Hierarchical Process (AHP) approach.

So, the main aims of this chapter are:

- To propose a new methodology for conversion of a conventional manufacturing system into FMS.
- To identify the various alternatives and their sub attributes to implement the proposed methodology.
- To select the best alternative using Analytical Hierarchical Process and its justification.

8.2 PROPOSED METHODOLOGY

In this chapter, a new methodology named as **"LAPTOP"** is suggested to change the conventional manufacturing system into flexible manufacturing system. The flexible manufacturing systems are designed for different objectives which may be bounded by certain specific constraints and requirements and vary from application to application. But the proposed methodology is helpful in organizing the team effort for systematic approach to accomplish the conversion process. The proposed methodology includes the following steps:

- L- List
- A-Alternatives
- P- Propose
- T- Try
- O- Organize
- P- Proceed

8.2.1 List

Once the management has set its objective as per company policies for the conversion to FMS and have defined the operating parameters that will meet these objectives, which work as the design drivers and will become the benchmark to determine the conversion success, the first step is to list all the related details of the products being manufactured. This listing creates a product database and includes information from every functional group of the organization. The database should not only include the current requirements but also give scope for the future activities. This listing includes:

- List the products and their models which are being manufactured in the plant. It includes all the details regarding product structure and design like dimensions, shape, size etc. for both the current and future products.

- List the materials of these products.
- List the various operations of these products
- List the routing sheets with overall product and part flow.
- List the current machine tools i.e. key equipments utilized along with their current processing times and the process and equipment capabilities possible.
- List the current cutting tools along with their cutting conditions like speed, feed rate, depth of cut etc.
- List the various change over procedures like setups, fixtures etc.
- List the current inspection points, methods, frequency and related equipments.
- List the material handling equipments- both primary and secondary types.
- List the current layout of machines.
- Note the area and overhead space etc, available, required.
- List the physically linked work steps or processes.
- List the part family groupings, if any.
- List the other requirements like clean rooms, special ventilation or special access etc., if needed.
- Identify and list central manufacturing facilities like washers, fastening, heat treatment etc.
- List the scheduled, periodic and preventive maintenance policies.
- Identify and record the sales volume for current output, future forecasts and seasonality.

8.2.2 Alternatives

In this step, present processes and techniques are challenged for unnecessary or redundant costs and possible changes are thought of and various alternatives are suggested regarding the following:

- Materials: alternate materials which can be standardized and provide better service life.
- Operations:
    i. the operations which can changed or omitted or combined.
    ii. the operations which are performed on a very small percentage of the total parts.
    iii. Non value adding operations of any kind.
    iv. Operations which can be standardized.

v. Operations that take place outside the present shop as these operations usually increase WIP, throughput time and reduces part quality.

- Machines: list the alternate advance machine tools which can provide better productivity.
- Cutting Tools: list the alternate cutting tools specially that of combinational type in which multiple operations can be done in one go.
- Fixtures: list the alternate fixtures especially reconfigurable types which can be reconfigured for new products in least possible time.
- Inspection: list the alternate advance inspection methods and equipments.
- Routing sheet: list alternate routes and prepare the new route sheets.
- Material handling: list alternate material handling techniques and related equipments.
- Layout: list the alternate layouts of machines.

Analyze the listed alternatives and conclude the best ones in different categories i.e. for materials, operations and machines etc. This can be done with the help of MADM techniques like AHP or ANP. For taking the decisions regarding the best alternatives the help of experts' views or of simulation software can also be taken.

8.2.3 Propose

Prepare the proposal for the selected alternative. This proposal should include the total investment in new materials, machines and equipments and tools, space utilization, future planning and flexibility to be achieved.

Specify what types of different flexibilities are required or desired. Browne et al., [77] defined eight types of flexibilities and Buzzacott, [73] has quantified them. We have to define of all these, what different flexibilities are more importantly required in our system. As we must always keep in mind that all the setups can never have all types of flexibilities and the more flexible a system is, it is more expensive and difficult to manage. The proposals should state clearly the range of part types or components to be produced i.e. their product mix and volumes.

8.2.4 Try

After preparing the proposal of selected alternatives, run proposed FMS practically and note down the real (practical) hurdles in achieving the proposed objectives.

8.2.5 Organize

Remove the practical hurdles observed during trial (above) stage and organize the different components of FMS in such a way that no such hurdles appear again and said objectives are achieved without much difficulty.

8.2.6 Proceed

Finally, proceed with the above model of FMS and get the desired results

8.3 VALIDATION OF THE PROPOSED METHODOLOGY THROUGH A CASE STUDY

In this section, a case study is presented to validate the proposed methodology for conversion of a conventional manufacturing system into FMS. A conventional manufacturing system of an Indian company is selected and different alterations are made to the same to make it a flexible manufacturing system. For this, the work of researchers Raj et al. [188] is selected as the conventional system and is further extended to convert it into FMS. It is a multi- national company in the northern India which manufactures compressors for air- conditioning, refrigeration and other cooling applications. This multi- national company is a US$2.4 billion cooling giant with global presence. It produces 150 million units per year and has more than 15% of global market share. Now, this company visualizes achieving increasing share of market with increased productivity and up dation of its manufacturing system. The stepwise methodology is implemented as follows:

8.3.1 Step: List

The first step in the proposed methodology is listing of all the present practices and prepare a product database, which can be critically analyzed in the next step. For the selected case, the present layout of the machine shop, which manufactures 5000 units per day, comprises of seven different production lines, which manufacture different components of the product to be assembled later (Figure 8.1). The different machine tools and other workstations are depicted by numbers in squares in Figure 8.1 at their respective positions. The analysis of the present layout shows that the machine utilization of present setup is very low and there is also duplicacy of machines in different lines. The total space occupied by the machines in the present setup is about 1150 m^2 and the power load is 1190 HP. The labor productivity measured in units per man per day (UMD) is about 19 to 21.

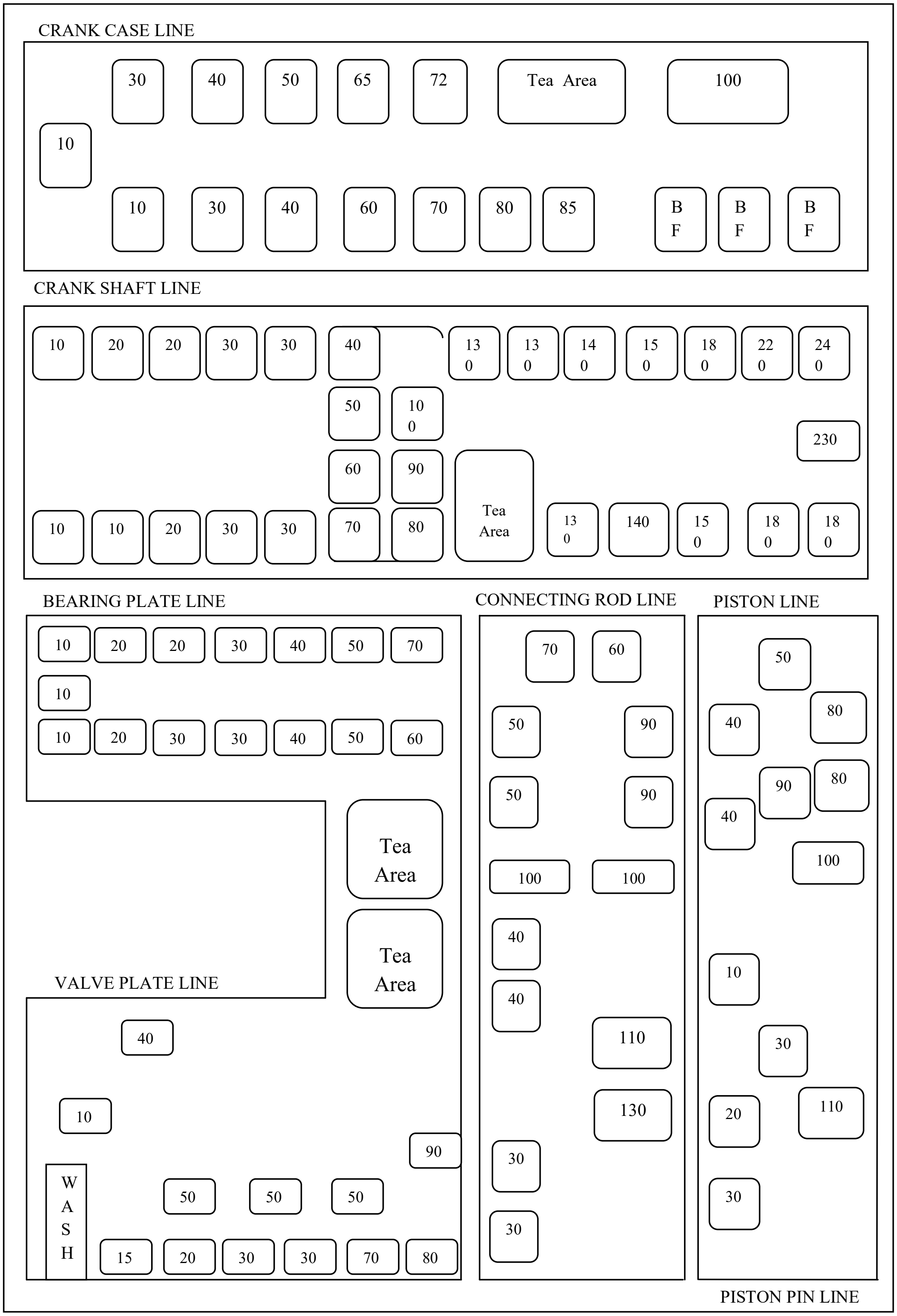


Figure 8.1: Existing layout of machine shop (Alternative ‘A_1’)

The production lines consist of conventional dedicated machine tools and special purpose machines (SPMs), so the changeover time for the 15 different models of the product, which are at present being manufactured is very high, resulting in large batch size and high inventory. This makes the flexibility of the present setup to be almost negligible.

In the present case, the company is having enough funds to change its production system with the changing technological advancements. It wants to meet the challenges of globalization and changing market scenario by adopting better manufacturing techniques. Its vision is to emerge as a global giant in the present product sector. For this, it wants to:

- increase the productivity through implementation of advanced manufacturing systems like, FMS and CIM.
- increase the flexibility of the present manufacturing system to cope up with the changes in volume and design.
- improve customer relations by providing better quality and reliability of products in shorter time.

8.3.2 Step: Alternatives

In this step the planning of alternate configurations for the machine shop is done to make it more flexible. Further, all the proposed alternatives are analyzed by AHP technique to select the best alternative. In this case study, the company wants to increase its flexibility along with productivity. It wants to reduce space utilization, power consumption, have better material handling and manpower utilization. It wants to boost its productivity by reducing the machine downtime and the idle time by reducing the setup and changeover times. In this way, it expects to reduce the lead time and have better customer relations by more prompt and reliable deliveries. It further wants to reduce the inventories. For all this, it is prepared to adopt more advanced technologies like CAD/CAM, CNC machining centers, advanced material handling equipments etc.

With this aim in mind, two alternative configurations are proposed for the machine shop to convert it into flexible manufacturing system. FMS involves the use of programmable machining centers, which are capable of rapid adjustments to design changes, automatic guided vehicles, robots and conveyors for better material handling and automatic storage and retrieval systems (AS/RS), automatic inspection systems etc., all controlled by central computer systems. So, in the alternate proposals the present production lines are critically analyzed and the current equipments are replaced with these components of FMS. But since FMS involves heavy investments in equipments, therefore, two alternatives for conversion are proposed which represent gradual shift to FMS.

8.3.2.1 Alternative 'A_2'

In the current machine shop configuration, there is a problem of poor space utilization, low utilization of machines, high power consumption, low flexibility and low productivity. To overcome these problems, some changes are proposed, like, machine load is calculated and some machines, which are found to be surplus, are removed from the machining area. Some machines are replaced with programmable CNC machining centers, which are capable of being reprogrammed according to part changes. Relocation of some machines is also proposed to remove bottlenecks and to increase density ratio for proper space utilization. To improve the labor productivity conventional machine tools are replaced with automatic CNC turning and CNC milling machines.

8.3.2.2 Alternative 'A_3'

Alternative A_2 is further improved by making some changes in the material handling techniques. To have better material handling and further reduce the requirement of manpower, the AGV tracks are laid between the different production cells for the transfer of material. Use of conveyors is also made within one cell for the transfer of unfinished component from one workstation to another. It is proposed to change the layout of bearing plate line and make it unmanned automatic production cell by making use of robot and using robot centric configuration by arranging all the workstations around it.

Taking into consideration the above discussed changes, alternate configurations are made as shown in Figure 8.2 and 8.3 respectively. These configurations are discussed with a group of manufacturing experts. Based on their view points, different costs and other calculations are done. In these proposed alternatives since, expensive and sophisticated equipments and components are used so the cost of implementation has increased, but there is a reduction in space utilization, power consumption and number of operators, which increases the productivity. These calculations are shown in Table 8.1 and Table 8.2.

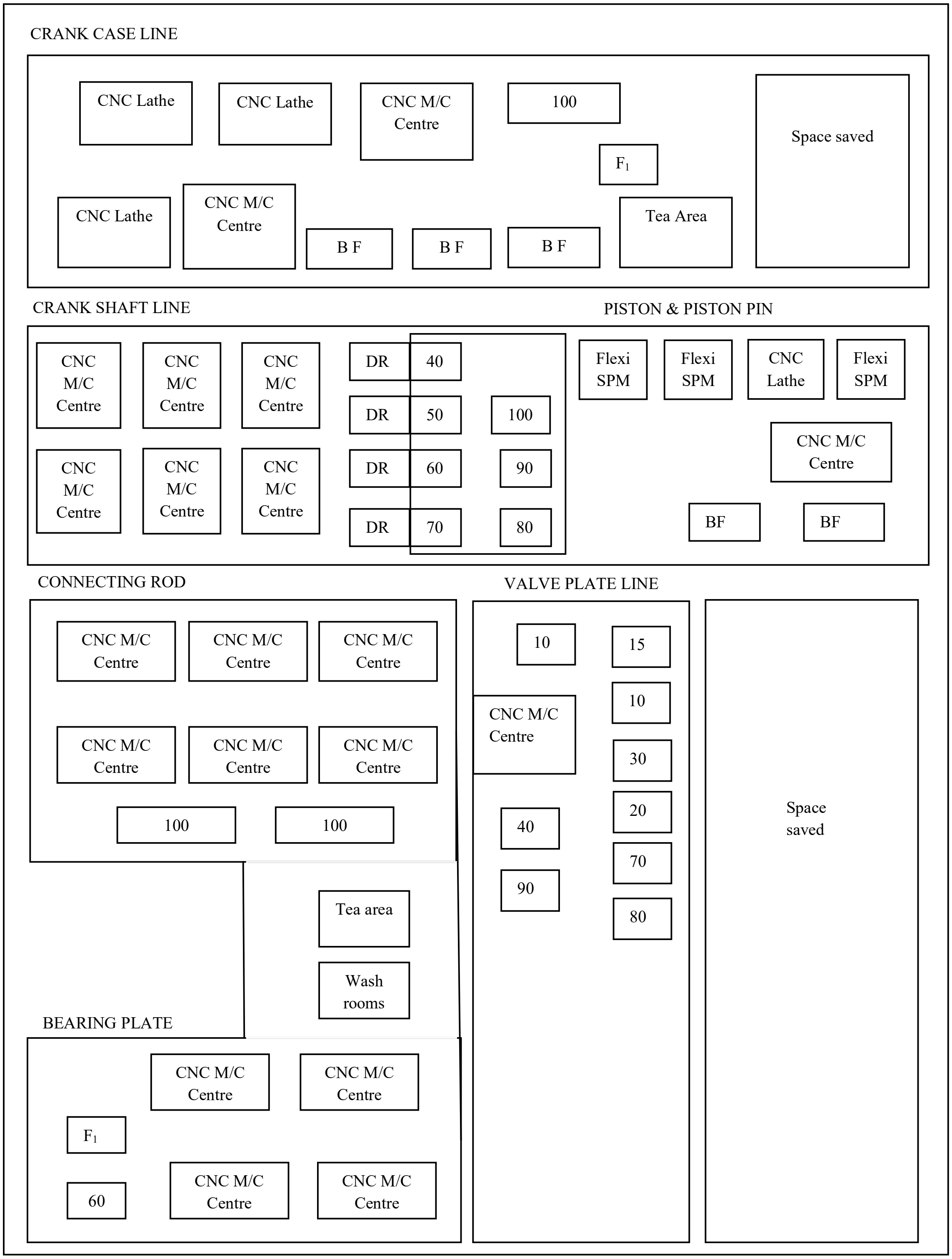


Figure 8.2: Semi-flexible manufacturing system (Alternative ‘A_2’)

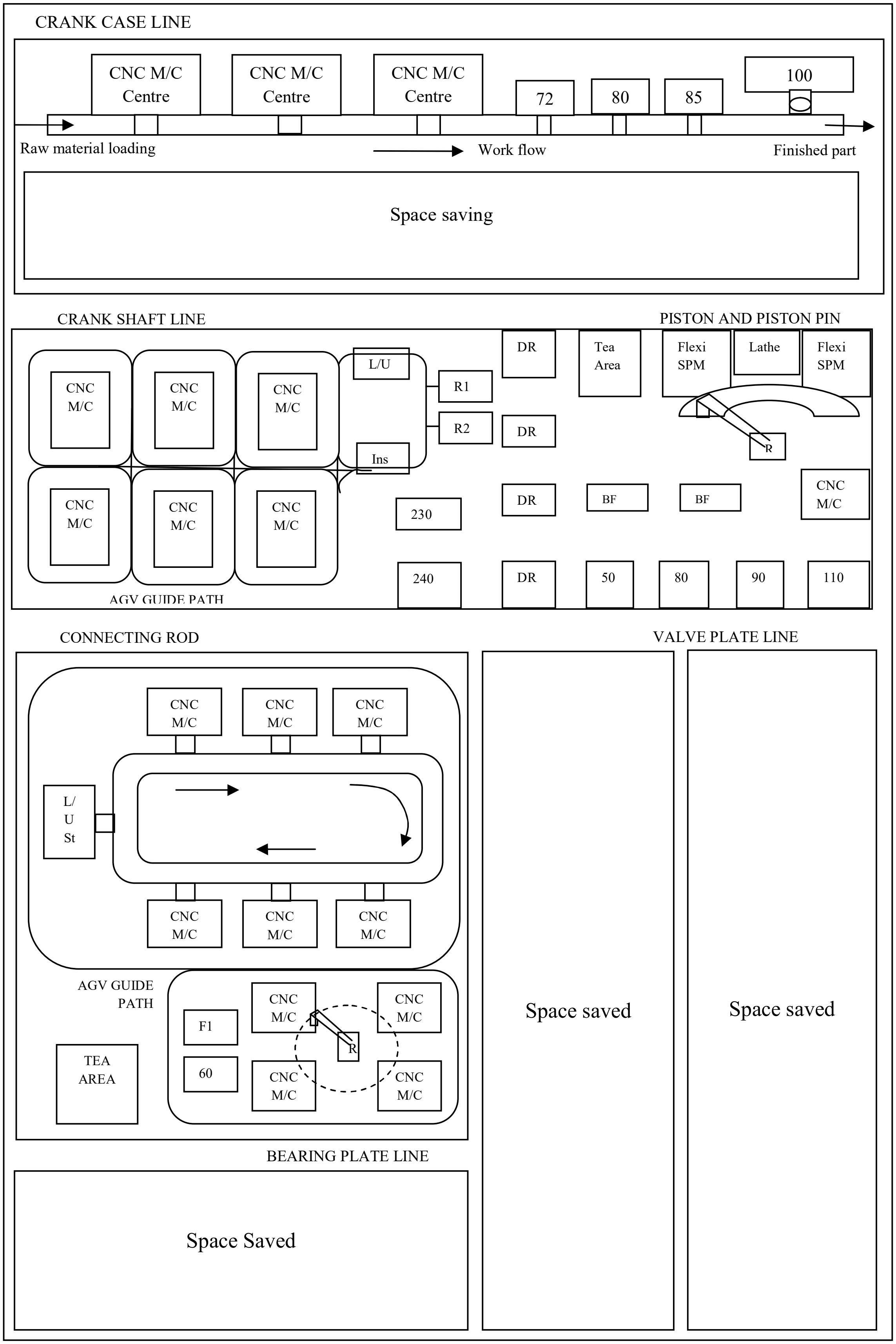


Figure 8.3: Flexible manufacturing system (Alternative ‘A$_3$’)

Table 8.1: Cost of equipments in different alternatives

	Cost of equipments in alternative ‘A_1’ (millions of US dollars)					Cost of equipments in alternative ‘A_2’ (millions of US dollars)					Cost of equipments in alternative ‘A_3’ (millions of US dollars)				
	New				Old *					Old*					Old*
Production lines	Conventional Machines	CNC	SPM	Total		Conventional Machines	CNC	SPM and other stations	Total		Conventional Machines	CNC	SPM	Total	
Crank case	0.0468	-	-	0.0468	-	0.0062	0.2500	-	0.2562	0.0101	0.0140	0.2343	0.0937	0.3420	0.0086
Crankshaft	0.0937	-	-	0.0937	-	0.0312	0.4687	-	0.4999	0.0148	0.0156	0.4687	0.1562	0.6405	0.0187
Bearing plate	0.0468	-	-	0.0468	-	0.0046	0.3125	-	0.3171	0.010	0.0046	0.3125	0.1562	0.4733	0.0101
Valve plate	0.0375	-	-	0.0375	-	0.0281	0.0781	-	0.1062	0.0023	0.0125	0.0781	-	0.0906	0.0067
Connecting rod	0.0468	-	-	0.0468	-	0.0093	0.4687	-	0.478	0.0093	-	0.4687	0.2500	0.7187	0.0118
Piston and piston pin	0.0390	-	-	0.0390	-	-	0.1093	0.3125	0.4218	0.0098	-	0.0312	0.4687	0.4999	0.0098
Total				0.3106					2.0792	0.0564				2.765	0.0657

*Salvage value of old equipment in millions of US dollars

Table 8.2: Cost of implementation of different alternatives

						Cost in millions of US dollars			
Alternatives	Space required (m^2)	Power required (HP)	Total number of machinists required per day	Labour productivity (UMD)	Space saving	Cost of new equipments (a)	Cost of making alterations/ installation (b)	Salvage value of old equipments (c)	Net cost of implementation (a)+(b)-(c)
A_1	1150	1190	258	(5000/258) = 19.4	-	-	-	-	-
A_2	875	650	115	(5000/115) = 43.47	23.9%	2.0792	0.030	0.0564	2.0528
A_3	720	690	65	(5000/65) = 76.9	37.4%	2.765	0.045	0.0657	2.7443

Although there is increase in the cost of the alternative A_2 and A_3 but still, since the primary aim was to implement FMS for achieving better flexibility and productivity, and this has been achieved as shown by the calculations in Table 8.1 and Table 8.2. So, one of the alternatives from A_2 or A_3 is selected for the final implementation. This decision can be further supported by using MADM techniques like AHP, by giving priority weights for different criteria. The calculations for the AHP model are given in the next sub-section.

8.3.2.3 The AHP model

In the present case the main objective is to select the best alternative for the conversion of conventional manufacturing system into FMS. For this, following the LAPTOP methodology all the database of the existing manufacturing system is prepared in detail, as stated in section 8.3.1. Then, the present systems are critically analyzed for alternatives. Then the alternatives are evaluated following the AHP technique. For this AHP model, the goal is placed at the top level of hierarchy. The various attributes which contribute towards the performance of manufacturing systems are identified and form the second level of hierarchy. In this work, seven strategic factors namely productivity, cost and investment, flexibility, speed and responsiveness, quality and reliability, technical feasibility and human factor, have been identified to achieve this goal.

The third level of the model is formed by the sub-attributes which affect the second level attributes. The fourth or the lowest level of the hierarchy is formed by the different alternatives, namely alternative A_1, A_2 and A_3 respectively. In this case, alternative A_1 represents the present layout of a conventional manufacturing system and alternative A_2 and A_3 are the proposed FMSs, and a comparison between the three is done using the AHP technique. The following section gives a brief about the attributes and the sub-attributes selected for the present study.

8.3.2.4 Attributes and sub- attributes of the AHP model

Following are the various attributes considered in AHP modeling for the validation of the proposed methodology.

8.3.2.4.1 Productivity

The concept of productivity is analogous to the efficiency of the system. Productivity means how much and how well we produce from the resources used [71]. Productivity is of vital importance to a company's ability to compete and make profits over time. It is argued that productivity is one of the most important attribute guiding any economic production [69]. Grossman, [59] for example, discusses productivity improvement as representing one of the key competitive advantages of an enterprise. 'Do more with less' to optimise productivity gain is vital for companies in today's increasing competitive world [111]. So, productivity gain is selected as an attribute for the decision making regarding the best alternative. The various sub-attributes for the productivity considered in this work are:

- Space requirement (P_1)
- Material handling (P_2)
- Power consumption (P_3), and
- Manpower requirement (P_4)

The best alternative should occupy less space for accommodating more machinery by having the system layout which allows decrease in in-process inventory, smooth and minimum material handling and consume less power and improve labour productivity. The best alternative should have the best capacity utilization with minimum idle time.

8.3.2.4.2 Cost and investment

The cost and investments involved directly influences the performance of any manufacturing system. It has to be decided whether the company is in a position to make the required investment and is it in accordance with the company's corporate policy? As the aim of any enterprise is to make profits, so the costs justification for adopting FMS is very necessary. The following sub-attributes are considered for cost and investment:

- Initial cost of equipments (C_1)
- Operating cost (C_2)
- Maintenance cost (C_3), and
- Scrap cost (C_4)

Initial cost of equipments includes the initial investment in setting up the FMS. Purchasing and installing cost of workstations, tools, handling systems etc., all come under this. Cost of equipments is comparatively lower in conventional manufacturing systems (involving simple machine tools) in comparison with the FMSs which have automatic and programmable equipments. The operating cost is the general cost required to run the plant efficiently [188]. The maintenance cost is the capital investment for the maintenance of different tools and equipment. It includes the production loss due to maintenance, breakdowns, cost of spare parts and cost of maintenance personnel. Again this cost increases with the increasing complexity of the system. The scrap cost represents the cost of raw materials wasted as scrap and also the cost of machine tools becoming obsolete.

8.3.2.4.3 Flexibility

The main aim of the present work is to increase the flexibility of the manufacturing systems, so that they are better able to compete with the ever changing market scenario. So, flexibility of the different alternatives is one of the major attributes for selecting the best alternative. In a manufacturing system, flexibility is the ability of the system to respond to changes in the production parameters [103]. The more flexible a system is, the better it is equipped to handle the changes in part sizes and geometry, variations in batch size and product types. For flexibility the following sub-attributes are considered in this work:

- Volume flexibility (F_1)
- Design flexibility (F_2)
- Routing flexibility (F_3), and
- Machine flexibility (F_4)

Volume flexibility refers to the ease with which the system accommodates the variations in batch size. Design flexibility refers to the handling of size and geometry changes of the products easily. The routing flexibility is defined as the ability of the manufacturing system to manufacture a product by alternate routes through the system. And the machine flexibility refers to the various types of operations that a particular type of machine can perform without requiring a prohibitive effort in switching from one operation to another. In the present work, the use of CNC machines and flexi-SPMs has been suggested to increase the flexibility. These machines increase the flexibility of the system by allowing more number of operations to be performed on the same machine, more variety of parts to be made by changing the part programs, allowing alternate routing as each CNC machine is capable of handling a variety of part types. The flexibility of different systems is measured with respect to the time needed to develop new products, range of products, machine changeover time, increase in multipurpose equipment, decrease in bottleneck stations etc.

8.3.2.4.4 Speed and Responsiveness

Manufacturing speed and responsiveness is related to the ability of a manufacturing system to utilize its existing resources to make a rapid and balanced response to predictable and unpredictable changes [33]. It basically represents the ability of the plant to change its capacity and functionality with maximum reusability against demand fluctuations. The following sub-attributes are considered under this umbrella:

- Capacity to handle new products (S_1)
- Manufacturing Lead time (S_2)
- Frequency of delivery (S_3)

The sub-attribute S_1 represents the capability of the system to manufacture new products easily. The more quickly a system can reset its tools for the next mix of product, lesser will be the manufacturing lead time. This is more significant in case of batch production as the system has to change its tooling [25]. The indicators for the measurement of these criteria can be percentage reduction in material travel time between workcenters, percentage increase in annual number of new product introduction, difference between the actual and the theoretical throughput time etc.

8.3.2.4.5 Quality and reliability

This is an indicator of the quality of the product whether it conforms to the required specifications and tolerances. An indicator of the mean time to failure and average downtime i.e. how often the system breaks down, to what extent the breakdown effects the whole system and how long it takes to restore back. The following sub-criteria are considered for this:

- Number of defects per unit (Q_1)

- Meantime between failures (Q_2)
- Schedule adherence (Q_3), and
- Level of customer complaints (Q_4)

The number of defects per unit is directly related to the quality of the system. The quality and reliability of the different alternatives is influenced by the mean time between failures with better adherence to the schedule and low level of customer complaints. The measuring criteria for these attributes can be percentage reduction in number of defects, scrap value reduction, unscheduled downtime reduction, percentage of inspection operations eliminated, percentage of orders delivered, percentage reduction in lead time per product line etc.

8.3.2.4.6 Technical feasibility

This is an indication of the company's policy towards modernization, integration and innovation. Is the system such that it facilitates such policies? Can the system adapt to changes in the technological front easily? The sub-attributes in this front are:

- Integrability (T_1)
- Scalability (T_2)

Whenever there is any change in the product to be manufactured, the system has to reconfigure its hardware and software as per the required changes. Integrability is the ability to integrate the hardware and software modules rapidly and precisely by a set of mechanical, informational and control interfaces that enables integration and communication. Scalability is the ability to easily change the production capacity. Scalability may require at the machine level adding spindles to a machine to increase its productivity and at the system level changing the part routing to increase the system capacity as the market for the product grows.

8.3.2.4.7 Human Factor

It involves the comparison of the attributes in terms of the efficiency and convenience to the workers. The sub- attributes for this are:

- Safety (H_1)
- Ergonomics (H_2)

The hierarchical model with all the levels is shown in Figure 8.4.

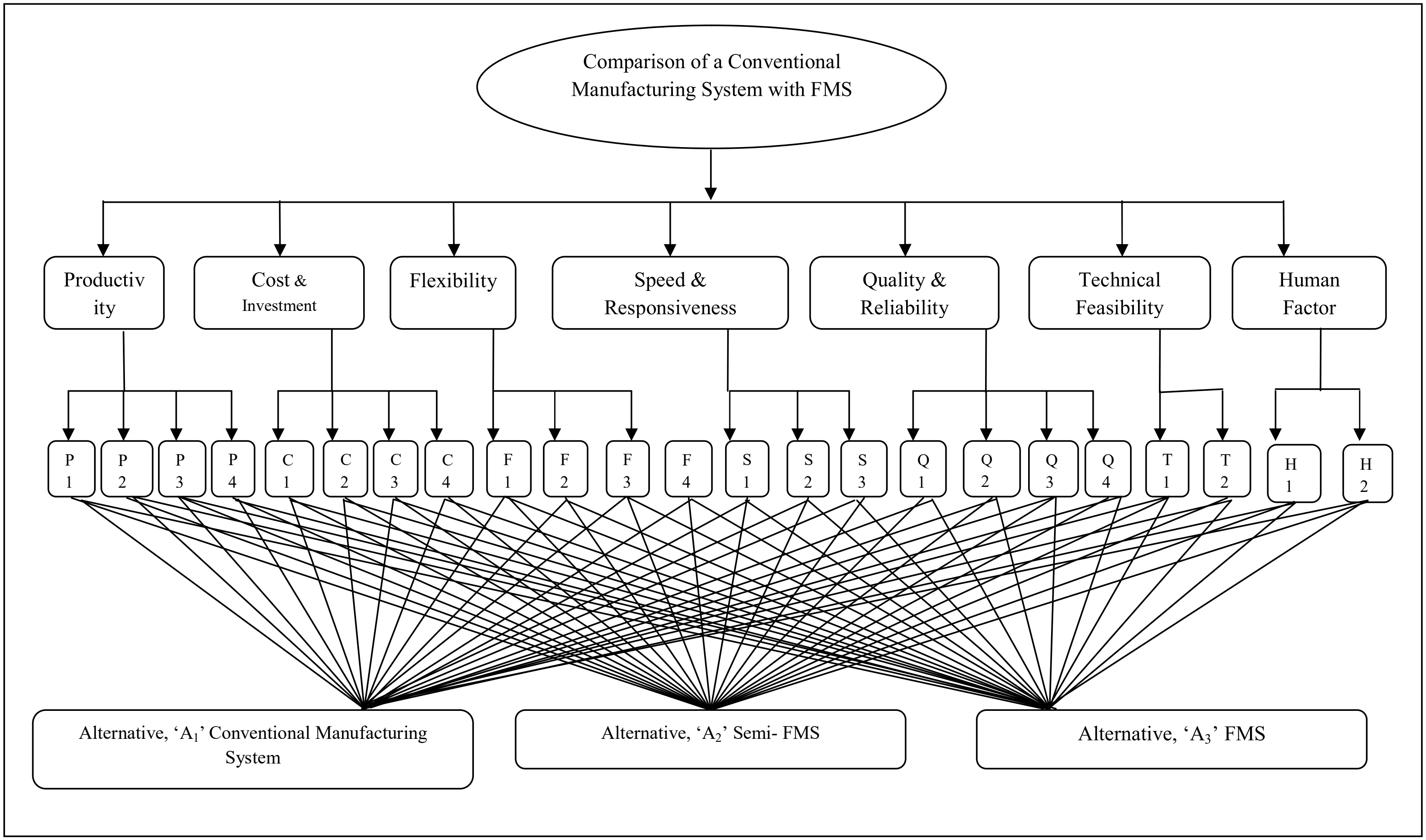


Figure 8.4: Different levels of the AHP model

8.3.2.5 Priority weights for different levels

In this section, priority weights based on the pair-wise comparison of all the attributes, sub-attributes and alternatives with respect to their higher levels are determined. Saaty's [184], 9 point scale was used to do the pair wise comparisons (as shown in Table 8.3).

Table 8.3: Saaty's nine point scale

Comparative Importance	**Definition**	**Explanation**
1	Equally important	Two decision elements equally influence the parent decision element
3	Moderately more important	One decision element is moderately more influential than the other
5	Strongly more important	One decision element has stronger influence than the other
7	Very strongly more important	One decision element has significantly more influence than the other
9	Extremely more important	The difference between influences of the decision elements is extremely significant
2,4,6,8	Intermediate importance values between two adjacent judgments	Judgment values between equally, moderately, strongly, very strongly and extremely
Reciprocals		If v is the judgment value when i is compared to j, then $1/v$ is the judgment value when j is compared to i

Based on this scale, the pair-wise comparison of different attributes is shown as a matrix in Table 8.4.

Since productivity is considered as more important than cost, quality, technical feasibility and human factors, so its value is decided as 5, 3, 2 and 2 times more respectively. Whereas, flexibility and speed and responsiveness are considered 3 and 2 times more important than productivity respectively. So entries are made in the matrix accordingly. The pair-wise comparison matrix is normalized by dividing each value by the sum of the corresponding column. The consistency ratio for this matrix comes out to be 0.09, which shows that the entries are consistent as the value is less than 0.10 [184].

The next step is to examine the effect of level III attributes on the respective attributes of level II. For this, same procedure is adopted as discussed above. Table 8.5 shows the analysis of different sub-attributes on attributes at level II and the weights are calculated. All these weights are represented in the first column (M) of Table 8.7. Next, the analysis of pair-wise comparison matrix of different alternatives (A_1, A_2 and A_3) with respect to different sub-attributes is shown in Table 8.6.

Table 8.7 shows the data from all the pair-wise matrices. From this data, the suitability index is calculated and the alternative with the highest suitability index is selected.

Table 8.4: Analysis of different attributes w.r.t. the required goal

	Pair-wise comparison							**Normalised matrix**							
	P	**C**	**F**	**S**	**Q**	**T**	**H**	**P**	**C**	**F**	**S**	**Q**	**T**	**H**	**Weights**
P	1	5	1/3	½	3	2	2	0.132	0.263	0.129	0.069	0.3025	0.121	0.125	0.167
C	1/5	1	1/5	¼	1/3	2	2	0.026	0.0138	0.0779	0.034	0.0336	0.121	0.125	0.062
F	3	5	1	4	3	5	4	0.398	0.263	0.389	0.551	0.3025	0.303	0.25	0.356
S	2	4	¼	1	2	2	2	0.256	0.531	0.097	0.138	0.2016	0.121	0.125	0.017
Q	1/3	3	1/3	½	1	4	3	0.0442	0.158	0.129	0.069	0.1008	0.242	0.1875	0.126
T	1/2	½	1/5	½	¼	1	2	0.0663	0.0263	0.0779	0.069	0.0252	0.060	0.125	0.061
H	1/2	½	¼	½	1/3	1/2	1	0.0663	0.0263	0.097	0.069	0.0336	0.030	0.0625	0.053

Max. eigen value = 7.73; Consistency ratio = 0.09

Table 8.5: Analysis of different sub-attributes w.r.t. attributes

		Pair-wise comparison				Normalised matrix				
		P_1	P_2	P_3	P_4	P_1	P_2	P_3	P_4	Weights
Productivity	P_1	1	2	7	2	0.466	0.566	0.437	0.315	0.449
	P_2	½	1	5	3	0.233	0.283	0.312	0.473	0.326
	P_3	1/7	1/5	1	1/3	0.066	0.056	0.062	0.052	0.059
	P_4	1/2	1/3	3	1	0.233	0.094	0.187	0.157	0.164
	Max. eigen value = 4.108; Consistency ratio = 0.039									
Cost and investment		C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	
	C_1	1	1/3	3	7	0.223	0.206	0.290	0.350	0.264
	C_1	3	1	6	9	0.670	0.620	0.580	0.450	0.587
	C_1	1/3	1/6	1	3	0.074	0.103	0.096	0.150	0.103
	C_1	1/7	1/9	1/3	1	0.032	0.069	0.032	0.050	0.044
	Max. eigen value = 4.09; Consistency ratio = 0.033									
Flexibility		F_1	F_2	F_3	F_4	F_1	F_2	F_3	F_4	
	F_1	1	1	1	1/5	0.125	0.166	0.125	0.115	0.131
	F_2	1	1	1	1/3	0.125	0.166	0.125	0.192	0.151
	F_3	1	1	1	1/5	0.125	0.166	0.125	0.115	0.131
	F_4	5	3	5	1	0.625	0.500	0.625	0.577	0.584
	Max. eigen value = 4.03; Consistency ratio = 0.012									
Speed and responsiveness		S_1	S_2	S_3		S_1	S_2	S_3		
	S_1	1	2	7		0.608	0.600	0.636		0.615
	S_2	1/2	1	3		0.304	0.300	0.272		0.292
	S_3	1/7	1/3	1		0.087	0.100	0.091		0.092
	Max. eigen value = 3.002; Consistency ratio = 0.002									
Quality and reliability		Q_1	Q_2	Q_3	Q_4	Q_1	Q_2	Q_3	Q_4	
	Q_1	1	2	5	5	0.526	0.521	0.588	0.454	0.525
	Q_2	1/2	1	2	3	0.263	0.260	0.235	0.272	0.257

	Q_3	1/5	½	1	2	0.105	0.130	0.117	0.181	0.132
	Q_4	1/5	1/3	1/2	1	0.105	0.087	0.058	0.091	0.084
	Max. eigen value = 4.04; Consistency ratio = 0.015									
Technical feasibility		*T_1*	*T_2*			*T_1*	*T_2*			
	T_1	1	3			0.75	0.75			0.75
	T_2	1/3	1			0.25	0.25			0.25
	Max. eigen value = 2; Consistency ratio = 0.00									
Human factor		*H_1*	*H_2*			*H_1*	*H_2*			
	H_1	1	7			0.875	0.875			0.875
	H_2	1/7	1			0.125	0.125			0.125
	Max. eigen value = 2; Consistency ratio = 0.00									

Table 8.6: Analysis of alternatives w.r.t. sub-attributes

			Pair-wise comparison			**Normalised matrix**			
			A_1	**A_2**	**A_3**	**A_1**	**A_2**	**A_3**	**Weights**
Productivity	Space required (P_1)	A_1	1	¼	1/7	0.083	0.058	0.096	0.079
		A_2	4	1	1/3	0.333	0.235	0.225	0.264
		A_3	7	3	1	0.583	0.705	0.677	0.655
	Material handling (P_2)	A_1	1	1/3	1/5	0.111	0.077	0.130	0.106
		A_2	3	1	1/3	0.333	0.231	0.217	0.260
		A_3	5	3	1	0.555	0.692	0.362	0.536
	Power consumption (P_3)	A_1	1	1/3	1/5	0.111	0.100	0.117	0.109
		A_2	3	1	½	0.333	0.300	0.294	0.309
		A_3	5	2	1	0.555	0.600	0.588	0.581
	Manpower required (P_4)	A_1	1	1/3	1/7	0.091	0.062	0.102	0.085
		A_2	3	1	¼	0.272	0.018	0.179	0.213
		A_3	7	4	1	0.636	0.750	0.718	0.701
Cost and investment	Initial cost (C_1)	A_1	1	7	9	0.797	0.823	0.750	0.790
		A_2	1/7	1	2	0.114	0.117	0.166	0.132

		A_3	1/9	½	1	0.088	0.058	0.083	0.076
	Operating cost (C_2)	A_1	1	3	5	0.652	0.667	0.625	0.648
		A_2	1/3	1	2	0.217	0.222	0.250	0.229
		A_3	1/5	½	1	0.130	0.111	0.125	0.122
	Maintenance cost (C_3)	A_1	1	3	5	0.652	0.667	0.625	0.648
		A_2	1/3	1	2	0.217	0.222	0.250	0.229
		A_3	1/5	½	1	0.130	0.111	0.125	0.122
	Scrap cost (C_4)	A_1	1	1/5	1/7	0.077	0.062	0.087	0.075
		A_2	5	1	½	0.384	0.312	0.304	0.333
		A_3	7	2	1	0.538	0.625	0.608	0.590
Flexibility	Volume flexibility (F_1)	A_1	1	1/7	1/5	0.077	0.087	0.062	0.075
		A_2	7	1	2	0.538	0.608	0.625	0.590
		A_3	5	½	1	0.384	0.304	0.312	0.333
	Design flexibility (F_2)	A_1	1	1/5	1/8	0.071	0.047	0.085	0.067
		A_2	5	1	1/3	0.357	0.238	0.228	0.274
		A_3	8	3	1	0.571	0.714	0.685	0.656
	Routing flexibility (F_3)	A_1	1	¼	1/7	0.083	0.058	0.096	0.079
		A_2	4	1	1/3	0.333	0.235	0.225	0.264
		A_3	7	3	1	0.583	0.705	0.677	0.655
	Machine flexibility (F_4)	A_1	1	1/5	1/9	0.067	0.038	0.081	0.062
		A_2	5	1	¼	0.333	0.192	0.184	0.236
		A_3	9	4	1	0.600	0.770	0.734	0.701
Speed and responsiveness	Capacity to handle new products (S_1)	A_1	1	1/5	1/9	0.067	0.038	0.081	0.062
		A_2	5	1	¼	0.333	0.192	0.184	0.236
		A_3	9	4	1	0.600	0.770	0.734	0.701
	Manufacturing lead time (S_2)	A_1	1	1/3	1/7	0.091	0.062	0.102	0.085
		A_2	3	1	¼	0.272	0.018	0.179	0.213
		A_3	7	4	1	0.636	0.750	0.718	0.701
	Frequency of delivery (S_3)	A_1	1	1/3	1/6	0.100	0.077	0.111	0.096
		A_2	3	1	1/3	0.300	0.230	0.222	0.250
		A_3	6	3	1	0.600	0.692	0.666	0.652
Quality and reliability	Number of defects per unit (Q_1)	A_1	1	¼	1/5	0.100	0.077	0.117	0.098
		A_2	4	1	½	0.400	0.307	0.294	0.333
		A_3	5	2	1	0.500	0.615	0.588	0.567
	Meantime	A_1	1	1/5	1/3	0.111	0.117	0.100	0.110

	between failures (Q_2)	A_2	5	1	2	0.555	0.588	0.600	0.581
		A_3	3	½	1	0.333	0.294	0.300	0.309
	Schedule of adherence (Q_3)	A_1	1	1/3	1/5	0.111	0.100	0.117	0.109
		A_2	3	1	½	0.333	0.300	0.294	0.309
		A_3	5	2	1	0.555	0.600	0.588	0.581
	Level of customer satisfaction (Q_4)	A_1	1	¼	¼	0.111	0.111	0.111	0.111
		A_2	4	1	1	0.444	0.444	0.444	0.444
		A_3	4	1	1	0.444	0.444	0.444	0.444
Technical feasibility	Integrability (T_1)	A_1	1	1/7	1/5	0.077	0.087	0.062	0.075
		A_2	7	1	2	0.538	0.608	0.625	0.590
		A_3	5	½	1	0.384	0.304	0.312	0.333
	Scalability (T_2)	A_1	1	¼	1/6	0.090	0.077	0.100	0.089
		A_2	4	1	½	0.363	0.307	0.300	0.323
		A_3	6	2	1	0.545	0.615	0.600	0.588
Human factor	Safety (H_1)	A_1	1	1/5	1/7	0.077	0.062	0.087	0.075
		A_2	5	1	½	0.384	0.312	0.304	0.333
		A_3	7	2	1	0.538	0.625	0.608	0.590
	Ergonomics (H_2)	A_1	1	1/3	1/7	0.091	0.062	0.102	0.085
		A_2	3	1	¼	0.272	0.018	0.179	0.213
		A_3	7	4	1	0.636	0.750	0.718	0.701

Table 8.7: Data summary for the calculation of suitability index

Weights of sub-attributes (M)	Weights of attributes (N)	Weights of different alternatives			(M) X (N) X (weights of different alternatives)		
		A_1	A_2	A_3	A_1	A_2	A_3
0.449	0.167	0.079	0.264	0.655	0.006	0.02	0.049
0.326	0.167	0.106	0.260	0.536	0.006	0.014	0.029
0.059	0.167	0.109	0.309	0.581	0.001	0.003	0.006
0.164	0.167	0.085	0.213	0.701	0.002	0.006	0.019
0.264	0.062	0.790	0.132	0.076	0.013	0.002	0.001
0.587	0.062	0.648	0.229	0.122	0.024	0.008	0.004

0.103	0.062	0.648	0.229	0.122	0.004	0.001	0.001
0.044	0.062	0.075	0.333	0.590	0.001	0.001	0.002
0.131	0.356	0.075	0.590	0.333	0.003	0.028	0.016
0.151	0.356	0.067	0.274	0.656	0.004	0.015	0.035
0.131	0.356	0.079	0.264	0.655	0.004	0.012	0.031
0.584	0.356	0.062	0.236	0.701	0.013	0.049	0.146
0.615	0.017	0.062	0.236	0.701	0.001	0.002	0.007
0.292	0.017	0.085	0.213	0.701	0.001	0.001	0.003
0.092	0.017	0.096	0.250	0.652	0.001	0.001	0.001
0.525	0.126	0.098	0.333	0.567	0.006	0.022	0.038
0.257	0.126	0.110	0.581	0.309	0.004	0.019	0.01
0.132	0.126	0.109	0.309	0.581	0.002	0.005	0.01
0.084	0.126	0.111	0.444	0.444	0.001	0.005	0.005
0.75	0.061	0.075	0.590	0.333	0.003	0.027	0.015
0.25	0.061	0.089	0.323	0.588	0.001	0.005	0.009
0.875	0.053	0.075	0.333	0.590	0.003	0.015	0.027
0.125	0.053	0.085	0.213	0.701	0.001	0.001	0.005
Suitability indices of different alternatives					**0.103**	**0.263**	**0.468**

8.3.3 Step: Propose

In this step, a proposal is prepared for the selected alternative (Alternative 'A_3', in this case). The detailed proposal is made including all the details regarding the range of part types or components to be produced i.e. their product mix and volumes. This proposal also includes the total investment in new materials, machines and equipments and tools, space utilization, future planning and flexibility to be achieved. These calculations for the proposed alternative are shown in Table 8.1 and 8.2. At this stage, more details regarding the central and specific support groups like, maintenance, tooling support, quality assurance etc are added to the initial layout. The paperwork areas and documentation functions are also taken care of. Appropriate scheduling methods and algorithms have to be developed.

8.3.4 Remaining Steps of the Methodology

By following the LAPTOP methodology, the best alternative of production in the present case is proposed to the management. The remaining three steps of the methodology, namely, Try, Organize and Proceed are the actual implementation and post implementation steps. It is for the management to decide and adopt the new system as per the given proposal. Care has to be taken to involve the workforce and sensitize them with the functioning of this new system of manufacturing. Any hurdles or variations from the desired goal, if encountered, must be resolved and reworked and the final conversion is achieved.

8.4 CONCLUSION

From above methodology, alternative 'A_3', flexible manufacturing system is the best option with a suitability index of 0.468 as against the 0.103 and 0.263 of the other alternatives respectively. This alternative offers more gains in productivity and flexibility. This alternative offers the highest labour productivity, highest space saving, lowest power consumption as shown in Table 8.2. Although this alternative has the highest cost of implementation because of the more advanced and sophisticated equipments, still it is compensated with other benefits. More-over it is one time investment which will bear fruits in future.

CHAPTER IX

A HYBRID MADM APPROACH FOR THE EVALUATION OF DIFFERENT MATERIAL HANDLING ISSUES IN FMS

9.1 INTRODUCTION

Material handling is involved at all stages from the time the raw material enters the factory till the finished product goes out. Depending on the type, a component may be handled even fifty times or more before it changes to finished product. As material handling adds no value but increases the production cycle time, it is desirable to eliminate handling wherever possible. According to Sule [38] and Sujono & Lashkari [178], material handling accounts for 30–75% of the total cost of a product along the production chain, and efficient material handling can be responsible for reducing the manufacturing system operations cost by 15–30%. It, thus, becomes clear that the cost of production of an item can be lowered considerably by making a saving in the material handling cost.

Materials handling management is among many factors that contribute to improve a company’s performance [53]. Many researchers have stressed the importance of proper material handling in an organisation. Tuzkaya et al. [61], point outs that the use of proper material handling equipment can enhance the production process, and improves system flexibility. Proper selection of appropriate material handling equipment has become a most important parameter for modern manufacturing concerns [74]. Selecting appropriate material handling equipment can decrease manufacturing lead times, increase the efficiency of material flow, improve facility utilization and increase productivity [127]. An efficient MH system greatly improves the competitiveness of a product through the reduction of handling cost, enhances the production process, increases production and system flexibility, increases efficiency of material flow, improves facility utilization, provides effective utilization of manpower, and decreases lead time [22].

In today’s versatile and dynamic industrial scenario the importance of material handling systems is also increasing. Today, more and more industries are adopting advanced manufacturing technologies and systems to cope up with this market pressure. In this regard, manufacturing flexibility is widely recognised as a critical component to achieve competitive advantage in the market and improve an organisation's capability to respond to customer demands without incurring excessive time and cost penalties [85]. So, industries are now opting for low volume, high variety flexible manufacturing systems instead of the mass production [165]. An FMS is designed to combine the efficiency of a mass production line and the flexibility of a job shop to produce a variety of products on a group of machines [158]. FMS is crucial for modern manufacturing to enhance productivity involved with high product proliferation [75] and is being adopted by both large as well as small scale industries to enhance their productivity.

FMS can be defined as general purpose manufacturing machines, coupled with material handling systems and having the capabilities to perform different types of operations. In these systems, machines and material handling systems are controlled by a central computer system [7]. Material handling equipments form an important component of FMS and using proper material handling equipment can enhance the production process, provide effective utilization of manpower, increase production, and improve system flexibility.

Groover [112] highlights that despite its importance, materials handling is a topic that frequently is treated superficially by the companies. So, in this chapter an attempt has been made to discuss the different issues related to material handling systems especially in advanced manufacturing systems like FMS. These issues are further modelled based on their importance using Interpretive Structural Modelling (ISM) approach. In order to validate the ISM model, the same issues are evaluated using TOPSIS technique and the two results are compared and discussed.

9.2 MATERIAL HANDLING SYSTEM AND EQUIPMENTS

The Materials Handling Industry of America [MHIA] defines materials handling management as "Material Handling is the movement, storage, control and protection of material, goods, and products throughout the process of manufacturing, distribution, consumption and disposal. The focus is on the methods, mechanical equipment, systems and related controls used to achieve these functions" (mhia.org/learning/glossary).

Material handling involves the movement of materials, manually or mechanically in batches or one item at a time within the plant. The movement may be horizontal, vertical or the combination of the both, it can be on a fixed path or on variable path. There is a need of installing safe and efficient methods and equipments for handling materials. It has been found that 35 to 40% of the plant accidents are due to bad methods of material handling.

According to Karande and Chakravorty [139], the main functions performed by MH equipment can be classified into four broad categories, that is, (a) transport, (b) positioning, (c) unit formation, and (d) storage. Usually, all the MH functions are one or more combinations of these four primary functions. The transport equipments simply move materials from one point to another, and mainly include conveyors, industrial trucks, cranes, and so forth. Unlike transport equipments, positioning equipments are usually employed at workstations to aid machining operations like, robots, index tables, rotary tables, etc. Unit formation equipments are used for holding or carrying materials in standardized unit load forms for transport and storage and generally includes bins, pallets, skids, and containers. Storage equipments are used for holding or buffering materials over a period of time. Typical examples that perform this function are AS/RS, pallet racks, and shelves. Today a wide variety of equipments are available for all these functions, each having distinct characteristics and cost. Selection of the proper equipment for a designed manufacturing system is a very complicated task and is often influenced by the ongoing development of new technology, practices, and equipment.

As material handling adds no value but increases the production cycle time, so it is desirable to eliminate handling wherever possible. Ideally there should not be any handling at all! So, while designing the MH system, sequence the operations in logical manner so that handling is unidirectional and smooth. Use of gravity wherever possible is also desirable. Standardize the handling equipments to the extent possible as it means interchangeable usage, better utilization of handling equipments, and lesser spares holding. In selection of handling equipments, criteria of versatility and adaptability must be the governing factor. Weight of unit load must be maximum so that each ‘handling trip’ is productive. Work study aspects, such a elimination of unnecessary movements and combination of processes should be considered while installing a material handling system. Application of OR techniques such as queuing can be very effective in optimal utilization of materials handling equipments. A very important aspect in the design of a material handling system is the safety aspect. The system designed should be simple and safe to operate.

The main engineering factors to be considered for the design of an efficient MH system are like: the existing plant layout and the handling equipments, the nature of the products to be handled, production processes and equipments, quantities involved. The economic factors to be considered are: The cost of material handling equipment, operating costs, repair and maintenance costs etc. A material handling system with the lowest prospective cost is selected. The operating costs are reduced by purchasing flexible material handling systems, increasing the amount of material to be handled at one time, minimizing the idle time for the equipment, increasing speed of handling. A material handling system is said to be economical if the cost of handling per unit weight of the material for a particular movement is minimum.

So, during the design of a materials handling system we are looking for serving equipments for a complex materials handling task and synchronizing their operations [135]. The MH equipment selection is an important proportion of manufacturing expenses and the most critical material handling decisions in this area are the arrangement and design of material flow patterns [1]. This idea is shared by Ioannou [56], which argues that an important aspect of any production system is the design of a material handling system which integrates the production operations**.**

So, the decision makers have to consider various quantitative (load capacity, energy consumption, reliability, cost, etc.) and qualitative (flexibility, performance, environmental hazard, safety, load shape, load type, etc.) criteria for the design of MH systems. Some of these selection criteria are beneficial (higher values are preferred) and some are nonbeneficial (lower values are desired). Therefore, MH system design can be viewed as a multicriteria decision-making (MCDM) problem in the presence of many conflicting criteria [139].

Based on the above discussion, 19 issues related to the material handling equipments in FMS were identified. These issues are presented in Table 9.1.

Table 9.1: Major issues related to the material handling equipments in FMS

S.No.	Issue
1.	Initial cost of the MH equipments
2.	Load carrying capacity
3.	Programming flexibility of MH equipments
4.	Operational cost
5.	Throughput rate
6.	Capacity to handle different shapes and volumes
7.	Storage/ Retrieval MH equipments
8.	Operational control
9.	Automation
10	Floor space
11.	AGVs/ Robots and other advanced MH equipments already present
12.	Number of AGVs required
13.	Layout of AGV tracks
14.	Vehicle dispatching rules
15.	Traffic management
16.	Positioning of idle vehicles
17.	Failure management
18.	Compatibility of MH equipments with other workstations
19.	Comparison with cheap human labour

9.3 ISM MODEL FOR THE EVALUATION OF MATERIAL HANDLING ISSUES

In this section the development of a model for the evaluation of material handling issues in FMS using ISM is described.

9.3.1 Development of SSIM

ISM model is developed by using the results of an industrial survey carried out in various industries in India. The opinion of various experts from these industries is used to form the initial conceptual relationship among the 19 issues identified in section 9.2. The experts from academia were also consulted to remove any conceptual inconsistency. The symbols V, A, X and O are used to represent the relationship and interdependency between any two factors *i* and *j*.

Based on the contextual relationship between the issues a Structural Self –Interactive Matrix is developed for the various issues as shown in Table 9.2.

Table 9.2: Structural self-interaction matrix

Issue	**19**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**
1	X	O	O	O	O	O	O	A	O	O	A	O	O	A	O	O	A	A
2	V	O	O	O	V	V	V	V	A	O	O	O	O	A	V	V	O	
3	O	O	O	O	V	O	O	V	O	O	V	V	O	A	V	V		
4	V	O	O	O	O	O	O	O	O	O	O	A	O	A	O			
5	O	O	O	O	V	V	A	O	O	O	O	O	O	O				
6	O	V	O	O	O	V	O	V	O	O	O	O	A					
7	A	V	O	V	O	O	V	O	O	O	V	O						
8	O	V	V	O	V	V	O	O	O	O	A							
9	A	V	V	O	O	O	O	O	O	O								
10	O	O	O	V	V	O	V	V	O									
11	O	O	V	O	O	V	V	V										
12	O	A	O	O	V	V	V											
13	O	A	O	O	V	X												
14	O	A	O	O	V													
15	O	O	O	V														
16	O	O	O															
17	O	O																
18	O																	

9.3.2 Development of the Reachability Matrix

To develop the reachability matrix from the SSIM, binary digits 0 and 1 are used to replace the symbols of SSIM. This is done by substituting V, A, X, O of SSIM by 1s or 0s to get initial reachability (IR) matrix as described below:

(i) In the SSIM, if the cell *(i, j)* has the symbol V, then in IR matrix this cell entry becomes 1 and the cell (*j*, *i*) entry becomes 0.

(ii) In the SSIM, if the cell (*i, j*) has the symbol A, then in IR matrix this cell entry becomes 0 and the cell (*j*, *i*) entry becomes 1.

(iii) In the SSIM, if the cell (*i, j*) has the symbol X, then in IR matrix this cell entry becomes 1 and the cell (*j*, *i*) entry also becomes 1.

(iv) In the SSIM, if the cell (*i, j*) has the symbol O, then in IR matrix this cell entry becomes 0 and the cell (*j*, *i*) entry also becomes 0.

Following the above rules, the initial reachability matrix is prepared and is shown in Table 9.3.

Table 9.3: Initial reachability matrix

Issue	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2	1	1	0	1	1	0	0	0	0	0	0	1	1	1	1	0	0	0	1
3	1	0	1	1	1	0	0	1	1	0	0	1	0	0	1	0	0	0	0
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
5	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0
6	1	1	1	1	0	1	0	0	0	0	0	1	0	1	0	0	0	1	0
7	0	0	0	0	0	1	1	0	1	0	0	0	1	0	0	1	0	1	0
8	0	0	0	1	0	0	0	1	0	0	0	0	0	1	1	0	1	1	0
9	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0
10	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	1	0	0	0
11	0	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	0	0
12	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
13	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
18	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	0
19	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1

The reachability matrix obtained in Table 9.3 is known as initial reachability matrix. The final reachability matrix is obtained from the initial matrix by incorporating transitivity i.e. if an issue *a* influences issue *b* and issue *b* further influences issue *c,* the issue *a* automatically influences issue *c.* The final reachability matrix obtained by incorporating transitivity is shown in Table 9.4, wherein transitive influences are shown as 1*.

Table 9.4: Final reachability matrix

Issue	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
1	1	0	0	0	0	1*	1*	1*	1*	0	0	0	1*	0	0	1*	1*	1*	1
2	1	1	0	1	1	1*	1*	1*	1*	0	0	1	1	1	1	1*	1*	1*	1
3	1	0	1	1	1	0	1*	1	1	0	0	1	1*	1*	1	1*	1*	1*	1*
4	1*	0	0	1	0	1*	1*	1*	1*	0	0	0	1*	0	0	1*	1*	1*	1
5	0	0	0	0	1	0	0	0	0	0	0	0	1*	1	1	1*	0	0	0
6	1	1	1	1	1*	1	0	1*	1*	0	0	1	1*	1	1*	0	1*	1	1*
7	1*	1*	1*	1*	1*	1	1	1*	1	0	0	1*	1	1*	1*	1	1*	1	0
8	1*	0	0	1	1*	0	1*	1	1*	0	0	1*	1*	1	1	1*	1	1	1*
9	1	0	0	1*	1*	0	1*	1	1	0	0	1*	1*	1*	1*	1*	1	1	1*
10	1*	0	0	0	1*	0	0	0	0	1	0	1	1	1*	1	1	0	0	1*
11	1*	1	0	1*	1*	0	1*	0	1*	0	1	1	1	1	1*	1*	1	0	1*
12	1	0	0	0	1*	0	1*	0	1*	0	0	1	1	1	1	1*	0	0	1*
13	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1*	0	0	0
14	0	0	0	0	1*	0	0	0	0	0	0	0	1	1	1	1*	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
18	1*	0	0	0	1*	0	0	0	0	0	0	1	1	1	1*	0	0	1	1*
19	1	1*	1*	1*	0	1*	1	1*	1	0	0	1*	1*	1*	1*	1*	1*	1*	1

9.3.3 Partitioning the Reachability Matrix

The final reachability matrix is partitioned by finding the reachability and the antecedent sets for each issue (Warfield, 1974). The process is completed in twelve iterations giving twelve different levels for the ISM model. In the present case, the 19 issues, along with their reachability set, antecedent set, intersection set and levels are presented in Tables 9.5 to 9.16.

Table 9.5: Iteration 1

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,6,7,8,9,13,16,17,18,19	1,2,3,4,6,7,8,9,10,11,12,18,19	1,6,7,8,9,18,19	
2	1,2,4,5,6,7,8,9,12,13,14,15,16,17,18,19	2,6,7,11,19	2,6,7,19	
3	1,3,4,5,7,8,9,12,13,14,15,16,17,18,19	3,6,7,19	3,7,19	
4	1,4,6,7,8,9,13,16,17,18,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	
5	5, 13,14,15,16	1,2,5,6,7,8,9,10,11,12,13,14,18	5,13,14	
6	1,2,3,4,5,6,8,9,12,13,14,15,17,18,19	1,2,4,6,7,19	1,2,4,6,19	
7	1,2,3,4,5,6,7,8,9,12,13,14,15,16,17,18	1,2,3,4,7,8,9,11,12,19	1,2,3,4,7,8,9,12	
8	1,4,5,7,8,9,12,13,14,15,16,17,18,19	1,2,3,4,6,7,8,9,19	1,4,7,8,9,19	
9	1,4,5,7,8,9,12,13,14,15,16,17,18,19	1,2,3,4,6,7,8,9,11,12,19	1,4,7,8,9,12,19	
10	1,5,10,12,13,14,15,16,19	10	10	
11	1,2,4,5,7,9,11,12,13,14,15,16,17,19	11	11	
12	1,5,7,9,12,13,14,15,16,19	2,3,6,7,8,9,10,11,12,18,19	7,9,12,19	
13	5,13,14,15,16	1,2,3,4,5,6,7,8,9,10,11,12,13,14,18,19	5,13,14	
14	5,13,14,15,16	2,3,5,6,7,8,9,10,11,12,13,14,18,19	5,13,14	
15	15,16	2,3,5,6,7,8,9,10,11,12,13,14,15,18,19	15	
16	16	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,19	16	**I**
17	17	1,2,3,4,6,7,8,9,11,17,19	17	**I**
18	1,5,12,13,14,15,18,19	1,2,3,4,6,7,8,9,18,19	1,18,19	
19	1,2,3,4,6,7,8,9,12,13,14,15,16,17,18,19	1,2,3,4,6,8,9,10,11,12,18,19	1,2,3,4,6,8,9,12,18,19	

Table 9.6: Iteration 2

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,6,7,8,9,13,18,19	1,2,3,4,6,7,8,9,10,11,12,18,19	1,6,7,8,9,18,19	
2	1,2,4,5,6,7,8,9,12,13,14,15,18,19	2,6,7,11,19	2,6,7,19	
3	1,3,4,5,7,8,9,12,13,14,15,18,19	3,6,7,19	3,7,19	
4	1,4,6,7,8,9,13,18,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	
5	5, 13,14,15	1,2,5,6,7,8,9,10,11,12,13,14,18	5,13,14	
6	1,2,3,4,5,6,8,9,12,13,14,15,18,19	1,2,4,6,7,19	1,2,4,6,19	
7	1,2,3,4,5,6,7,8,9,12,13,14,15,18	1,2,3,4,7,8,9,11,12,19	1,2,3,4,7,8,9,12	
8	1,4,5,7,8,9,12,13,14,15,18,19	1,2,3,4,6,7,8,9,19	1,4,7,8,9,19	
9	1,4,5,7,8,9,12,13,14,15,18,19	1,2,3,4,6,7,8,9,11,12,19	1,4,7,8,9,12,19	
10	1,5,10,12,13,14,15,19	10	10	
11	1,2,4,5,7,9,11,12,13,14,15,19	11	11	
12	1,5,7,9,12,13,14,15,19	2,3,6,7,8,9,10,11,12,18,19	7,9,12,19	
13	5,13,14,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,18,19	5,13,14	
14	5,13,14,15	2,3,5,6,7,8,9,10,11,12,13,14,18,19	5,13,14	
15	15	2,3,5,6,7,8,9,10,11,12,13,14,15,18,19	15	**II**
18	1,5,12,13,14,15,18,19	1,2,3,4,6,7,8,9,18,19	1,18,19	
19	1,2,3,4,6,7,8,9,12,13,14,15,18,19	1,2,3,4,6,8,9,10,11,12,18,19	1,2,3,4,6,8,9,12,18,19	

Table 9.7: Iteration 3

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,6,7,8,9,13,18,19	1,2,3,4,6,7,8,9,10,11,12,18,19	1,6,7,8,9,18,19	
2	1,2,4,5,6,7,8,9,12,13,14,18,19	2,6,7,11,19	2,6,7,19	
3	1,3,4,5,7,8,9,12,13,14,18,19	3,6,7,19	3,7,19	
4	1,4,6,7,8,9,13,18,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	
5	5, 13,14	1,2,5,6,7,8,9,10,11,12,13,14,18	5,13,14	**III**
6	1,2,3,4,5,6,8,9,12,13,14,18,19	1,2,4,6,7,19	1,2,4,6,19	
7	1,2,3,4,5,6,7,8,9,12,13,14,18	1,2,3,4,7,8,9,11,12,19	1,2,3,4,7,8,9,12	
8	1,4,5,7,8,9,12,13,14,18,19	1,2,3,4,6,7,8,9,19	1,4,7,8,9,19	
9	1,4,5,7,8,9,12,13,14,18,19	1,2,3,4,6,7,8,9,11,12,19	1,4,7,8,9,12,19	
10	1,5,10,12,13,14,19	10	10	
11	1,2,4,5,7,9,11,12,13,14,19	11	11	
12	1,5,7,9,12,13,14,19	2,3,6,7,8,9,10,11,12,18,19	7,9,12,19	
13	5,13,14	1,2,3,4,5,6,7,8,9,10,11,12,13,14,18,19	5,13,14	**III**
14	5,13,14	2,3,5,6,7,8,9,10,11,12,13,14,18,19	5,13,14	**III**
18	1,5,12,13,14,18,19	1,2,3,4,6,7,8,9,18,19	1,18,19	
19	1,2,3,4,6,7,8,9,12,13,14,18,19	1,2,3,4,6,8,9,10,11,12,18,19	1,2,3,4,6,8,9,12,18,19	

Table 9.8: Iteration 4

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,6,7,8,9,18,19	1,2,3,4,6,7,8,9,10,11,12,18,19	1,6,7,8,9,18,19	**IV**
2	1,2,4,6,7,8,9,12,18,19	2,6,7,11,19	2,6,7,19	
3	1,3,4,7,8,9,12,18,19	3,6,7,19	3,7,19	
4	1,4,6,7,8,9,18,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	

6	1,2,3,4,6,8,9,12,18,19	1,2,4,6,7,19	1,2,4,6,19	
7	1,2,3,4,6,7,8,9,12,18	1,2,3,4,7,8,9,11,12,19	1,2,3,4,7,8,9,12	
8	1,4,7,8,9,12,18,19	1,2,3,4,6,7,8,9,19	1,4,7,8,9,19	
9	1,4,7,8,9,12,18,19	1,2,3,4,6,7,8,9,11,12,19	1,4,7,8,9,12,19	
10	1,10,12,19	10	10	
11	1,2,4,7,9,11,12,19	11	11	
12	1,7,9,12,19	2,3,6,7,8,9,10,11,12,18,19	7,9,12,19	
18	1,12,18,19	1,2,3,4,6,7,8,9,18,19	1,18,19	
19	1,2,3,4,6,7,8,9,12,18,19	1,2,3,4,6,8,9,10,11,12,18,19	1,2,3,4,6,8,9,12,18,19	

Table 9.9: Iteration 5

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
2	2,4,6,7,8,9,12,18,19	2,6,7,11,19	2,6,7,19	
3	3,4,7,8,9,12,18,19	3,6,7,19	3,7,19	
4	4,6,7,8,9,18,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	
6	2,3,4,6,8,9,12,18,19	2,4,6,7,19	2,4,6,19	
7	2,3,4,6,7,8,9,12,18	2,3,4,7,8,9,11,12,19	2,3,4,7,8,9,12	
8	4,7,8,9,12,18,19	2,3,4,6,7,8,9,19	4,7,8,9,19	
9	4,7,8,9,12,18,19	2,3,4,6,7,8,9,11,12,19	4,7,8,9,12,19	
10	10,12,19	10	10	
11	2,4,7,9,11,12,19	11	11	
12	7,9,12,19	2,3,6,7,8,9,10,11,12,18,19	7,9,12,19	**V**
18	12,18,19	2,3,4,6,7,8,9,18,19	18,19	
19	2,3,4,6,7,8,9,12,18,19	2,3,4,6,8,9,10,11,12,18,19	2,3,4,6,8,9,12,18,19	

Table 9.10: Iteration 6

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
2	2,4,6,7,8,9,18,19	2,6,7,11,19	2,6,7,19	
3	3,4,7,8,9,18,19	3,6,7,19	3,7,19	
4	4,6,7,8,9,18,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	
6	2,3,4,6,8,9,18,19	2,4,6,7,19	2,4,6,19	
7	2,3,4,6,7,8,9,18	2,3,4,7,8,9,11,19	2,3,4,7,8,9	
8	4,7,8,9,18,19	2,3,4,6,7,8,9,19	4,7,8,9,19	
9	4,7,8,9,18,19	2,3,4,6,7,8,9,11,19	4,7,8,9,19	

10	10,19	10	10	
11	2,4,7,9,11,19	11	11	
18	18,19	2,3,4,6,7,8,9,18,19	18,19	**VI**
19	2,3,4,6,7,8,9,18,19	2,3,4,6,8,9,10,11,18,19	2,3,4,6,8,9,18,19	

Table 9.11: Iteration 7

Issue	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
2	2,4,6,7,8,9,19	2,6,7,11,19	2,6,7,19	
3	3,4,7,8,9,19	3,6,7,19	3,7,19	
4	4,6,7,8,9,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	**VII**
6	2,3,4,6,8,9,19	2,4,6,7,19	2,4,6,19	
7	2,3,4,6,7,8,9	2,3,4,7,8,9,11,19	2,3,4,7,8,9	
8	4,7,8,9,19	2,3,4,6,7,8,9,19	4,7,8,9,19	**VII**
9	4,7,8,9,19	2,3,4,6,7,8,9,11,19	4,7,8,9,19	**VII**
10	10,19	10	10	
11	2,4,7,9,11,19	11	11	
19	2,3,4,6,7,8,9,19	2,3,4,6,8,9,10,11,19	2,3,4,6,8,9,19	

Table 9.12: Iteration 8

Issue	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
2	2,6,7,19	2,6,7,11,19	2,6,7,19	**VIII**
3	3,7,19	3,6,7,19	3,7,19	**VIII**
6	2,3,6,19	2,6,7,19	2,6,19	
7	2,3,6,7	2,3,7,11,19	2,3,7	
10	10,19	10	10	
11	2,7,11,19	11	11	
19	2,3,6,7,19	2,3,6,10,11,19	2,3,6,19	

Table 9.13: Iteration 9

Issue	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
6	6,19	6,7,19	6,19	**IX**
7	6,7	7,11,19	7	
10	10,19	10	10	
11	7,11,19	11	11	
19	6,7,19	6,10,11,19	6,19	

Table 9.14: Iteration 10

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
7	7	7,11,19	7	**X**
10	10,19	10	10	
11	7,11,19	11	11	
19	7,19	10,11,19	19	

Table 9.15: Iteration 11

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
10	10,19	10	10	
11	11,19	11	11	
19	19	10,11,19	19	**XI**

Table 9.16: Iteration 12

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
10	10	10	10	**XII**
11	11	11	11	**XII**

9.3.4 Development of the conical matrix

The issues on the same level are clubbed from the final reachability matrix across the rows and columns to develop the conical matrix. This is shown in Table 9.17. Next, drive power and dependence power ranks are calculated by giving highest ranks to the issues that have the maximum number of ones in the rows and columns respectively [189, 138].

Table 9.17: Conical matrix

Issue	**16**	**17**	**15**	**5**	**13**	**14**	**1**	**12**	**18**	**4**	**8**	**9**	**2**	**3**	**6**	**7**	**19**	**10**	**11**	**Driving Power**
16	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
17	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
15	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
5	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5
13	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5
14	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5
1	1	1	0	0	1	0	1	0	1	0	1	1	0	0	1	1	1	0	0	10
12	1	0	1	1	1	1	1	1	0	0	0	1	0	0	0	1	1	0	0	10
18	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	8
4	1	1	0	0	1	0	1	0	1	1	1	1	0	0	1	1	1	0	0	11
8	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0	14
9	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0	14
2	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	16
3	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	15
6	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	15
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	16
19	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	16
10	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	0	9
11	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	1	1	0	1	14
Dependence Power	16	11	15	13	16	14	13	11	10	9	9	11	5	4	6	10	12	1	1	

9.3.5 Development of the Digraph and the ISM Model

On the basis of the conical matrix, an initial digraph having nodes and the links is developed which also includes transitivity links. From this a final digraph is obtained by deleting the transitivity links. This digraph is shown in Figure 9.1. In this, the issues are placed in a hierarchy, to give different levels to the attributes [189, 138].

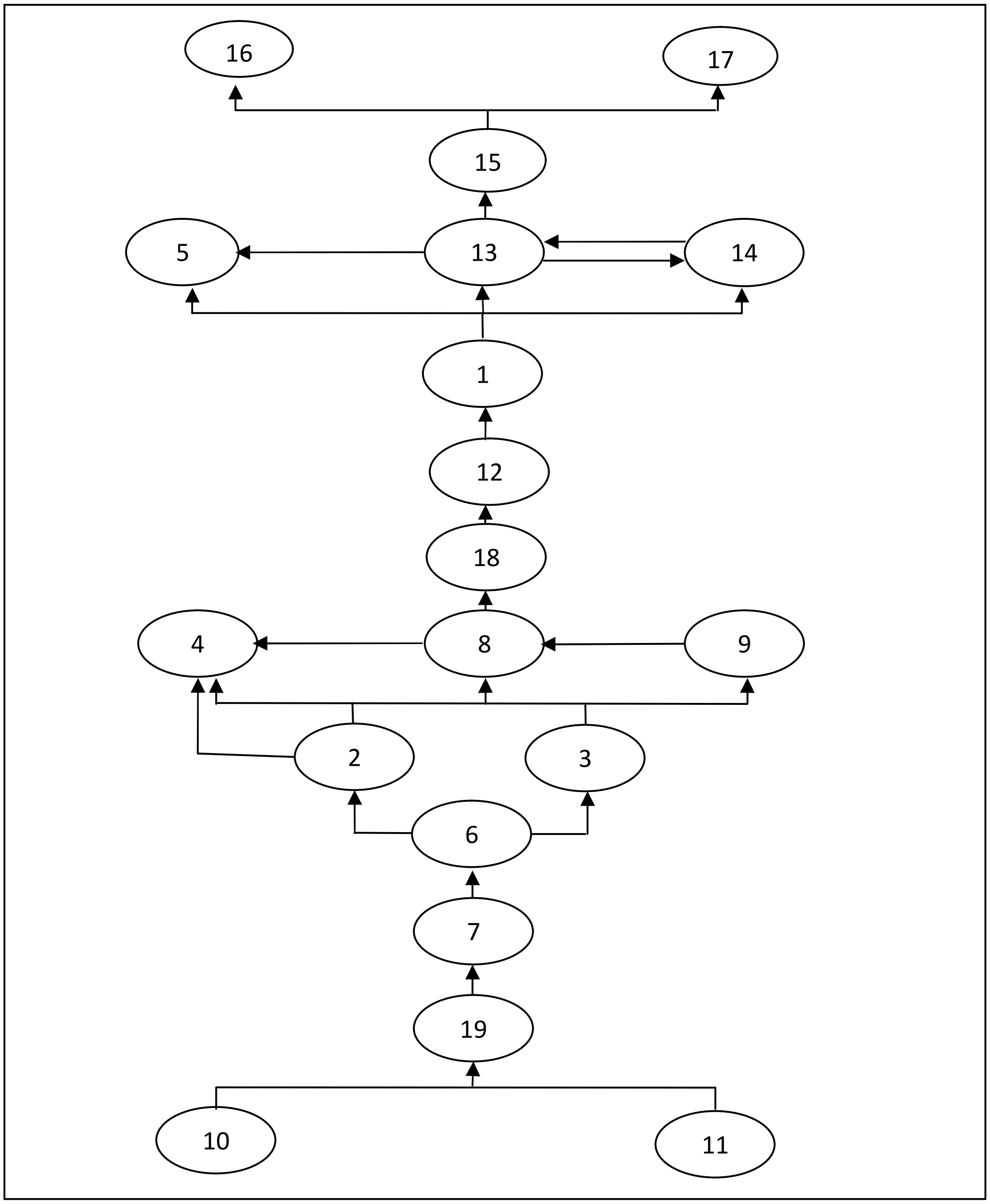


Figure 9.1: A digraph showing the relationship between different material handling issues in FMS

Now, this digraph is converted into the actual ISM model by replacing the nodes by MH issue statements as shown in Figure 9.2.

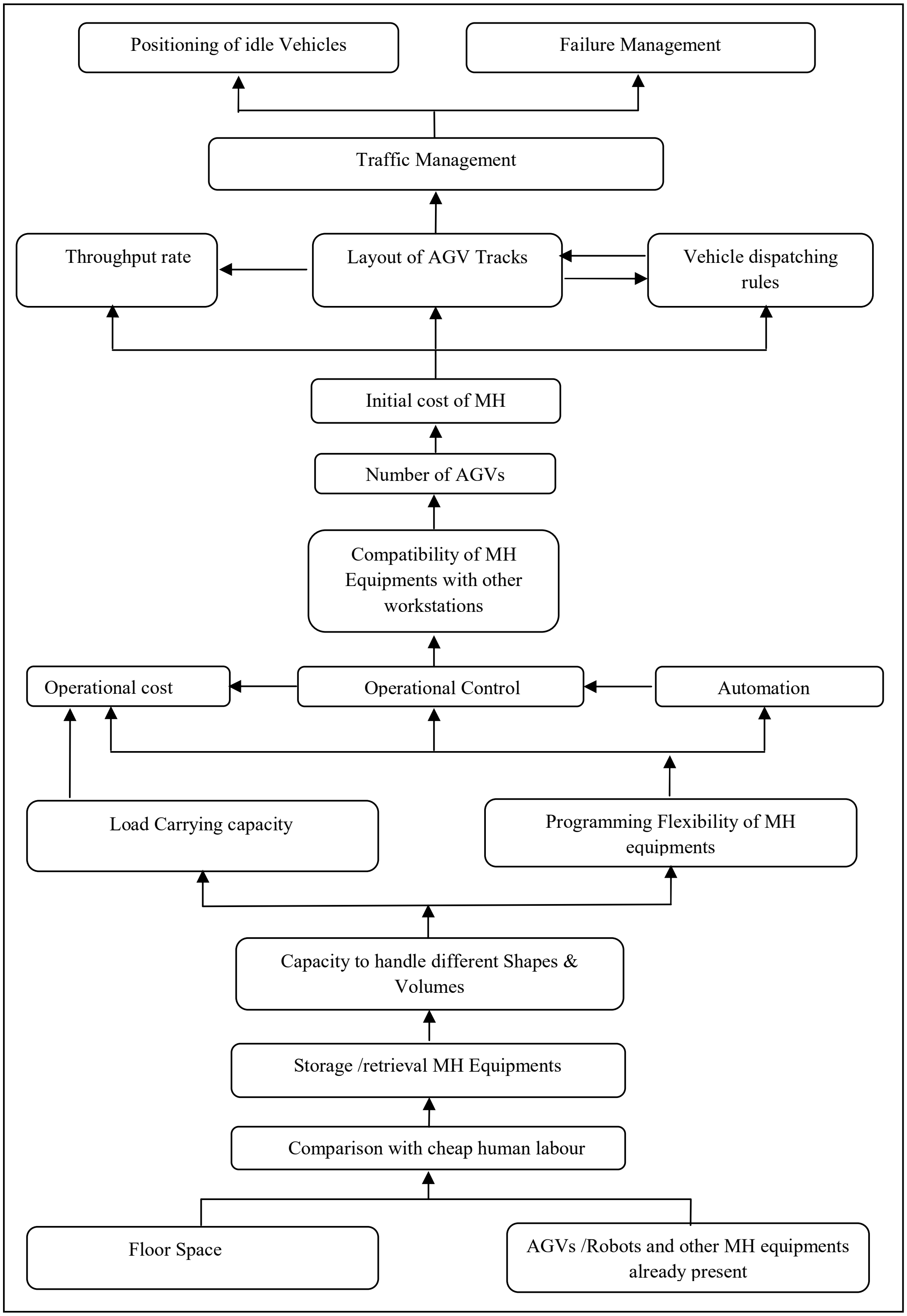


Figure 9.2: An interpretive structural model showing the levels of material handling issues

9.4 TOPSIS MODEL FOR THE EVALUATION OF MATERIAL HANDLING ISSUES

In this section the modelling of the MH issues for FMS is made using TOPSIS. The various steps which for the technique are followed as under:

Step 1: Objective is to find the significance hierarchy of different material handling issues. For this 19 issues were identified as given in Table 9.1.

Step 2: In the next step a decision matrix is developed based on all the information available on issues. The data for these issues over different criteria is taken from the survey conducted on various issues related to FMS in different industries spread over India (chapter 3). In our survey 19 issues of material handling in FMS were rated on a scale of 5 in which responses from 63 respondents were collected. Thus, number of attributes is, *n*=19 and criteria, *k*=5. This raw data has been converted into frequency table showing the number of instances of a given rating for a particular alternative, for example, instances of rating of 5 (most important), 4 (above average), 3 (average), 2 (below average) and 1 (least important) for issue 1-'Initial cost of material handling equipments' was 2, 5, 24, 28 and 4 respectively.

Table 9.18: Data collected through survey

Rating	**5**	**4**	**3**	**2**	**1**
Issue	**Most Important**	**Above Average**	**Average**	**Below Average**	**Least important**
1	2	5	24	28	4
2	1	10	33	15	4
3	0	10	34	16	3
4	0	23	28	12	0
5	5	4	29	20	5
6	12	9	34	8	0
7	6	18	34	2	3
8	2	28	15	18	0
9	0	21	30	12	0
10	4	9	50	0	0
11	5	34	22	2	0
12	0	11	30	22	0
13	6	8	22	27	0
14	7	14	30	12	0
15	17	17	18	10	1

16	2	18	13	24	6
17	4	2	18	28	11
18	11	25	25	2	0
19	3	4	50	6	0

Now the decision matrix is changed into standardized form using the Equation (9.1), where, X_{ij} is the raw data from Table 9.18.

$$S_{ij} = X_{ij}/\left((\textstyle\sum_{i=1,j=1}^{n,k}\left(X_{ij}{}^{2}\right))^{1/2}\right) \qquad \text{........ (9.1)}$$

Table 9.19: Data in normalised form

Rating	**5**	**4**	**3**	**2**	**1**
Issue	**Most Important**	**Above Average**	**Average**	**Below Average**	**Least important**
1	0.1433	0.3442	4.4057	10.8659	1.0482
2	0.0358	1.3767	8.3295	3.1184	1.0482
3	0.0000	1.3767	8.8420	3.5480	0.5896
4	0.0000	7.2829	5.9966	1.9958	0.0000
5	0.8957	0.2203	6.4326	5.5438	1.6378
6	5.1593	1.1151	8.8420	0.8870	0.0000
7	1.2898	4.4606	8.8420	0.0554	0.5896
8	0.1433	10.7935	1.7210	4.4905	0.0000
9	0.0000	6.0714	6.8839	1.9958	0.0000
10	0.5733	1.1151	19.1219	0.0000	0.0000
11	0.8957	15.9150	3.7020	0.0554	0.0000
12	0.0000	1.6658	6.8839	6.7080	0.0000
13	1.2898	0.8811	3.7020	10.1036	0.0000
14	1.7556	2.6984	6.8839	1.9958	0.0000
15	10.3545	3.9787	2.4782	1.3860	0.0655
16	0.1433	4.4606	1.2926	7.9831	2.3584
17	0.5733	0.0551	2.4782	10.8659	7.9270
18	4.3353	8.6045	4.7805	0.0554	0.0000
19	0.3225	0.2203	19.1219	0.4989	0.0000

Step 3: A set of importance weights w_k is developed for each of the criteria using Equation (9.2). Table 9.20 shows these criteria weights.

$$Normalised\ weight\ of\ each\ importamce = \frac{Total\ of\ each\ importance}{Grand\ total\ of\ all\ importances} \quad \dots\dots.9.2$$

Table 9.20: Weightage of rating

Rating	Most Important	Above Average	Average	Below Average	Least important
Instance of each importance	87	270	539	264	37
Total of each importance	435	1080	1617	528	37
Normalized weight of each importance	0.1177	0.2921	0.4374	0.1428	0.0100

Step 4: With these weights, weighted matrix is calculated. The elements of the weighted normalized matrix W_{ij} are expressed as:

$$W_{ij} = w_k S_{ij} \quad \dots\dots\dots\dots\dots(9.3)$$

The weighted matrix is shown in Table 9.21.

Table 9.21: Weighted matrix of normalized data

Rating	5	4	3	2	1
Issue	**Most Important**	**Above Average**	**Average**	**Below Average**	**Least important**
1	0.0252	0.1360	1.3506	1.1561	0.0160
2	0.0063	0.5441	2.5576	0.3318	0.0160
3	0.0000	0.5441	2.7152	0.3775	0.0090
4	0.0000	2.8782	1.8400	0.2123	0.0000
5	0.1572	0.0871	1.9741	0.5899	0.0251
6	0.9055	0.4407	2.7152	0.0944	0.0000
7	0.2264	1.7628	2.7152	0.0059	0.0090
8	0.0252	4.2656	0.5248	0.4778	0.0000
9	0.0000	2.3994	2.1129	0.2123	0.0000
10	0.1006	0.4407	5.8773	0.0000	0.0000
11	0.1572	6.2896	1.1341	0.0059	0.0000
12	0.0000	0.6583	2.1129	0.7137	0.0000
13	0.2264	0.3482	1.1341	1.0750	0.0000
14	0.3081	1.0664	2.1129	0.2123	0.0000
15	1.8172	1.5724	0.7577	0.1475	0.0010

16	0.0252	1.7628	0.3930	0.8494	0.0361
17	0.1006	0.0218	0.7577	1.1561	0.1213
18	0.7608	3.4005	1.4659	0.0059	0.0000
19	0.0566	0.0871	5.8773	0.0531	0.0000

Step 5: Identify the ideal attribute i.e. the most desirable attribute on each criterion, S+. The ideal attribute is the maximum value of each rating column of weighted matrix. Table 9.22 displays the ideal alternative chosen using said criteria from Table 9.18.

Table 9.22: Table of ideal issue

	max W_{i1}	max W_{i2}	max W_{i3}	max W_{i4}	max W_{i5}
S+	1.8172	6.2896	5.8819	1.1561	0.1213

Step 6: Identify the nadir attribute i.e. reverse extreme desirable attribute on each criterion, S-. The nadir attribute is the minimum value of each rating column of weighted matrix. Table 9.23 displays the nadir alternative chosen using said criteria from Table 9.18.

Table 9.23: Table of nadir issue

	min W_{i1}	min W_{i2}	min W_{i3}	min W_{i4}	min W_{i5}
S-	0.0000	0.0218	0.3976	0.0000	0.0000

Step 7: Develop a distance measure over each criterion to both ideal (D+) and nadir (D-). The distance from ideal can be calculated using Equation (9.4).

$$D_t^+ = \left\{\sum_{j=1}^{k}(W_{ij}^- \; S_j^+)^2\right\}^{1/2} \qquad i = 1,2,3 \ldots \ldots n \qquad \text{...............(9.4)}$$

and the distance from nadir can be calculated using Equation (9.5).

$$D_t^- = \left\{\sum_{j=1}^{k}(W_{ij}^- \; S_j^-)^2\right\}^{1/2} \qquad i = 1,2,3 \ldots \ldots n \qquad \text{...............(9.5)}$$

The calculated values are shown in Table 9.24.

Table 9.24: Distance of ideal and nadir issue from weighted data

Issue	**D_i+**	**D_i-**
Initial cost of the MH equipments	10.9437	1.7833
Load carrying capacity	10.4622	2.6358
Programming flexibility of MH equipments	10.3733	2.7948
Operational cost	9.5797	3.4227
Throughput rate	10.8597	2.0683
Capacity to handle different shapes and volumes	10.3192	2.8975
Storage/ Retrieval MH equipments	9.7465	3.2452
Operational control	9.7077	4.3243
Automation	9.6648	3.2041
Floor space	9.6956	5.8947
AGVs/ Robots and other advanced MH equipments already present	9.0706	6.3930
Number of AGVs required	10.4161	2.3253
Layout of AGV tracks	10.8966	1.6169
Vehicle dispatching rules	10.3076	2.3961
Traffic management	10.4425	2.5240
Positioning of idle vehicles	10.6712	1.9964
Failure management	11.3093	1.3914
Compatibility of MH equipments with other workstations	9.4341	3.7804
Comparison with cheap human labour	9.9357	5.8785

Step 8: A ratio R is computed which shows the relative closeness and is expressed as equal to the distance to the nadir divided by the sum of the distance to the nadir and the distance to the ideal, as shown in Equation (9.6).

$$R_i = \frac{D_i^-}{D_i^- + D_i^+} \qquad i = 1,2,3 \ldots\ldots n \qquad \ldots\ldots\ldots\ldots. (9.6)$$

So, for each issue, determine a ratio R equal to the distance to the nadir divided by the sum of the distance to the nadir and the distance to the ideal, as shown in Equation (9.4) and calculated in Table 9.25.

Table 9.25: Ratio of distance to nadir from total

Issue	R_i
Initial cost of the MH equipments	0.1401
Load carrying capacity	0.2012
Programming flexibility of MH equipments	0.2122
Operational cost	0.2632
Throughput rate	0.1600
Capacity to handle different shapes and volumes	0.2192
Storage/ Retrieval MH equipments	0.2498
Operational control	0.3082
Automation	0.2490
Floor space	0.3781
AGVs/ Robots and other advanced MH equipments already present	0.4134
Number of AGVs required	0.1825
Layout of AGV tracks	0.1292
Vehicle dispatching rules	0.1886
Traffic management	0.1947
Positioning of idle vehicles	0.1576
Failure management	0.1096
Compatibility of MH equipments with other workstations	0.2861
Comparison with cheap human labour	0.3717

Step 9: Rank order alternatives by maximizing the ratio in Step 8 as shown in Table 9.26.

Table 9.26: Ranking the attributes from largest to smallest value

Issue	R_i
AGVs/ Robots and other advanced MH equipments already present	0.4134
Floor space	0.3781
Comparison with cheap human labour	0.3717
Operational control	0.3082
Compatibility of MH equipments with other workstations	0.2861
Operational cost	0.2632
Storage/ Retrieval MH equipments	0.2498
Automation	0.2490
Capacity to handle different shapes and volumes	0.2192
Programming flexibility of MH equipments	0.2122
Load carrying capacity	0.2012
Traffic management	0.1947
Vehicle dispatching rules	0.1886
Number of AGVs required	0.1825

Throughput rate	0.1600
Positioning of idle vehicles	0.1576
Initial cost of the MH equipments	0.1401
Layout of AGV tracks	0.1292
Failure management	0.1096

9.5 DISCUSSION

The aim of this chapter is to identify the different material handling issues in an advanced manufacturing system like FMS. For this 19 issues have been identified which influence the MH system of FMS. Further these are modelled using two distinct, well established modelling approaches, ISM and TOPSIS. In ISM based model a hierarchy of different issues based on their relative importance is established. The practising managers of these industries can understand the relative importance and interdependencies of these issues. Research indicates that positioning of idle vehicles, failure management, traffic management, throughput rate, layout of AGV tracks and vehicle dispatching rules etc. are the top level issues. They have less influence and more dependence on the other MH issues. Initial cost, number of AGVs, compatibility of different MH equipments with other processing workstations and AS/RS devices, operational cost, operational control, automation, load carrying capacity and the programming flexibility form the middle level attributes. They have both the driving as well as dependence power. So they influence as well as are influenced by the other MH issues. The capacity to handle different shapes and volumes, storage and retrieval MH equipments, comparison with cheap human labour, floor space and MH equipments already present form the lowest level issues. The ISM model suggests the lowest level issues have a very high driving power and as such influence all other issues.

This implies for the proper design of a MH system in FMS the main criteria/ issue is the floor space and the existing MH system. Further, comparison with cheap human labour is also important. Especially in countries, where cheap labour is available, it may not be economically viable option to select and use the sophisticated MH equipments. So, some of the researchers have also come up with the concept of a humanised FMS where the material handling tasks in the FMS environment can be carried out by human labour [24]. The other middle level and top level issues although very important for the success of MH system design in FMS can be achieved with the availability of lower level issues.

The ISM model is validated using TOPSIS methodology on the same issues. The hierarchy model given by TOPSIS is similar to that of ISM to a large extent. The TOPSIS also evaluated that the existing MH equipments and the floor space are the most necessary issues to be considered for the design of the MH system, followed by the comparison with cheap labour, operational control and compatibility of MH equipments with other workstations. So these issues can be treated as the key issues for designing and selecting the MH system for FMS.

9.6 CONCLUSION

Material handling cost is one of the major costs involved in the cost of the product. So, the proper design of the material handling system for any industry is essential to reduce cost and the lead times. This chapter identifies and models the main material handling issues in FMS. The purpose of identification of these issues and their analysis is to allow researchers and practicing managers to pay proper attention to these issues which may help them in designing the material handling systems in their organisations in a better way.

CHAPTER X

SYNTHESIS OF THE RESEARCH WORK

10.1 INTRODUCTION

Flexible Manufacturing System involves a huge investment and a high degree of uncertainty and hence requires great attention of the manufacturing firms on the various strategic as well as technical issues related to it, to reach the economic goals. For this purpose, these various issues are analysed in this research. In this chapter, the research presented in this thesis is synthesized to present an overall picture. The different studies done in previous chapters are illustrated and a link is established between all these.

10.2 SYNTHESIS OF THE RESEARCH

Research presented in this thesis covers the various issues related to the planning, design and operation of FMS. The research was carried out considering the objectives specified in chapter one. The achieved objectives of the work are as follows:

- The literature existing on design, operational, planning and other issues of FMS has been thoroughly studied.
- A questionnaire based survey has been conducted related to the various issues and factors of FMS and the perception of the manufacturing organizations towards these issues are noted and analyzed.
- Various factors affecting the productivity of FMS are identified.
- These different factors affecting productivity of FMS are modelled using ISM and TISM techniques.
- Quantification of the influence of FMS on the productivity of a firm is done using GTA technique.
- Different issues concerned with the adoption of FMS are studied.
- A new methodology is developed for the conversion of a conventional manufacturing system into FMS.
- Various alternatives and their sub attributes to implement the proposed methodology are identified.

- A case study is presented to support the proposed methodology for conversion to FMS.
- An attempt has been made to select the best alternative of manufacturing based on FMS by means of Analytical Hierarchical Process (AHP) approach.
- The strengths and limitations for adoption of advanced manufacturing systems in small and medium scale industries are identified.
- Feasibility analysis of FMS in small and medium scale industries is done.
- The different material handling issues in an FMS environment are identified.
- They are modelled in a hierarchical structure using ISM and TOPSIS.

In achieving these objectives, the different methodologies used are depicted in Table 10.1 and Figure 10.1

Table 10.1: Methodologies used in the research

Objective	Methodologies Used	Study No.
To identify the various factors/ attributes related to the select issues in the design and development of FMS.	Literature review and expert opinion	1
To note and analyze the perception of Indian manufacturing industries towards various issues related to design and development of FMS.	Questionnaire based survey	2
Modelling of various factors affecting the productivity of FMS.	Interpretive Structural Modelling and Total Interpretive Structural Modelling	3
Quantification of the influence of FMS on the productivity of a firm.	Graph Theoretic Approach	4
Feasibility analysis of FMS in small and medium scale industries.	Interpretive Structural Modelling and TOPSIS	5
A LAPTOP methodology for the conversion of a conventional manufacturing system into FMS	Analytic Hierarchy Process	6
Analysis of the different material handling issues in FMS	Interpretive Structural Modelling and TOPSIS	7

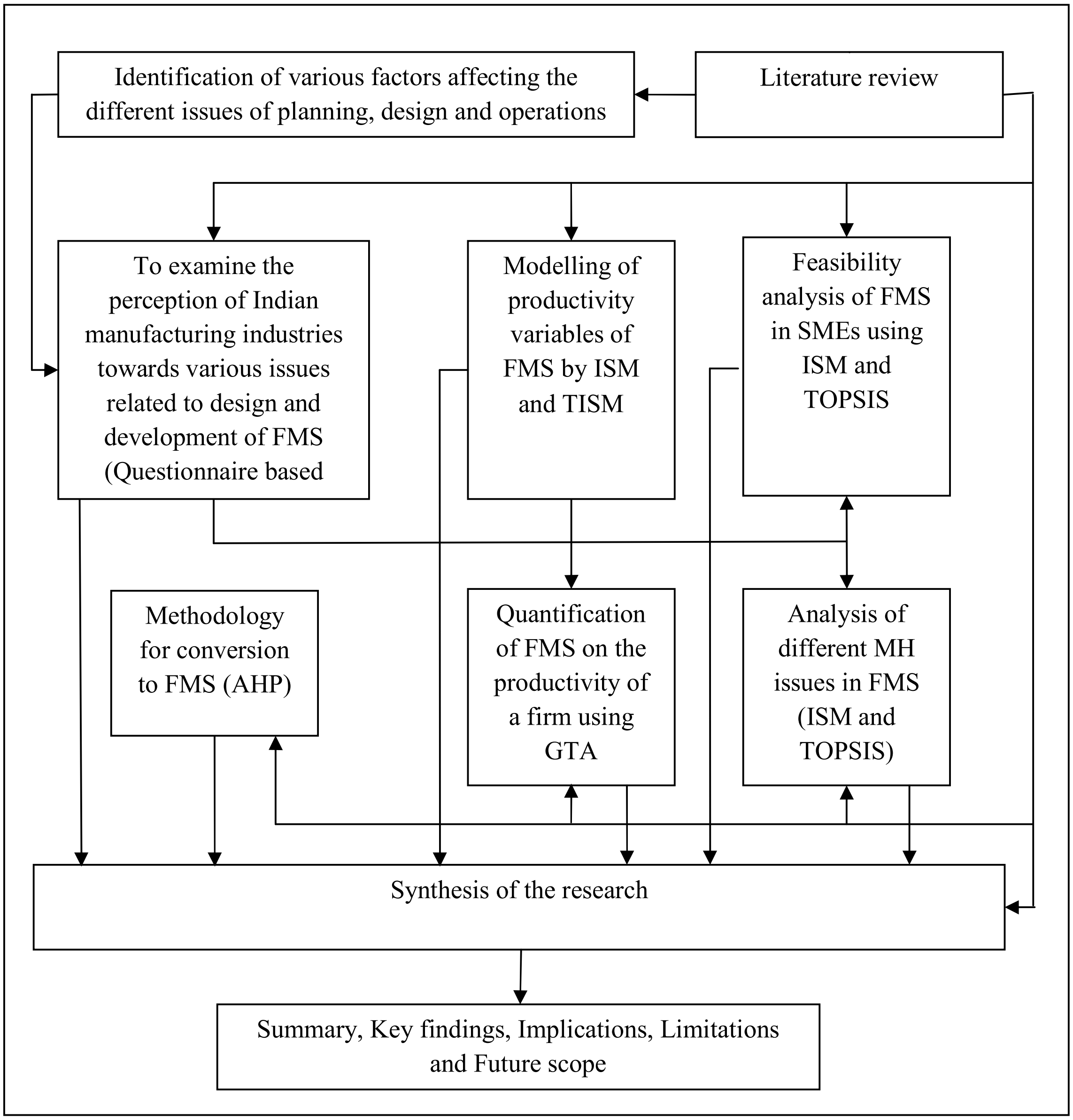


Figure 10.1: Integration of different methodologies used in the research

The studies conducted in this research are explained as under:

An exhaustive literature review has been done and the studies regarding the adoption, planning, design and operation of FMS are reported in Chapter II. The views of Indian manufacturing industries towards the various issues related to FMS are presented in Chapter III. On the basis of results of the survey, these various issues are analyzed and ranked, which provides the basis for further studies carried out in the other chapters. Chapters IV and V present the modelling of the productivity factors of FMS. For this modelling, the Interpretive Structural Modelling (ISM) and the Total

Interpretive Structural Modelling Techniques have been used. The inter-relationships and a hierarchical structure amongst the productivity factors has been developed in these modelling frameworks on the basis of the factors identified through literature review and the expert opinion through survey. The drive power and the dependence power have also been found out for these productivity factors, to identify the key factors in chapter IV. After giving a structure to the productivity factors of FMS, the influence of FMS on the productivity of a firm are quantified in Chapter VI. Graph Theoretic Approach (GTA) has been used for this quantification. In this chapter, using GTA the productivity index is calculated for a company, when FMS is installed. By finding the hypothetical best and the hypothetical worst values for this index the scope of improvement and the percentage opportunity gain and percentage opportunity loss are also presented. Chapter VII studies the feasibility of FMS in small and medium scale industries. For this, the various strengths of SMEs for adoption of FMS and various limitations of SMEs regarding adoption of FMS are thoroughly studied. Based on that, some attributes of feasibility of FMS in SMEs are identified. Further, to find the key attributes, all these attributes are modelled using ISM technique. The hierarchical framework developed by ISM is validated using TOPSIS. A new methodology called the 'LAPTOP' is developed to convert a conventional manufacturing system into FMS in Chapter VIII. This methodology presents a stepwise procedure for the conversion. The methodology presented in this chapter is validated using a case study of an Indian manufacturing industry. The attributes and the sub-attributes selected for the case study are analyzed using AHP technique. With this technique the best alternative for production based on FMS is selected. Chapter IX presents the study of different material handling issues in FMS. The various issues as identified through literature review and expert opinion are modelled using ISM and TOPSIS methodologies. This study helps to identify the key issues for designing the material handling system in an FMS.

10.3 CONCLUSION

This chapter links all the methodologies used in this research and synthesizes the whole research. An overall picture is presented for the full thesis work which has also been shown in Figure 10.1. The next chapter presents the summary, major contributions, key findings, implications, limitations and future scope of this research.

CHAPTER XI

SUMMARY, MAJOR CONTRIBUTIONS, KEY FINDINGS, IMPLICATIONS, LIMITATIONS AND SCOPE FOR FUTURE WORK

11.1 INTRODUCTION

This chapter presents a summary of the whole thesis. The major contributions and the key findings of the research are highlighted and the implications of the research for the academicians as well as for the practicing engineers and managers are also presented. The limitations of the present research are pointed out and the scope for future research is discussed.

11.2 SUMMARY

Low acceptance of FMS in developing countries like India, has provided the motivation for this research by exploring and analyzing the various issues in the design and development of FMS. This section presents the workdone towards achieving this objective. The summary of the workdone includes the following:

- An exhaustive literature review was conducted to learn about the status of present research in the field of FMS. Through this, the gaps in literature were identified and some relevant research issues in the design and development of FMS were selected.
- On the basis of literature review and discussions with experts from both industry and academia, a questionnaire was developed to conduct a survey of the Indian manufacturing industries. The questionnaire included issues like, productivity, feasibility, performance, material handling in FMS environment.
- A survey was done to know the opinions of Indian manufacturing industries towards various issues related to advanced manufacturing systems, especially the FMS.
- The survey responses were analyzed and converted to descriptive statistics which can be further used in achieving the different objectives of the research.
- The data from the descriptive statistics was used to develop an ISM based framework of the productivity factors of FMS. The interrelation between the

various productivity factors was established and key productivity factors were also identified by calculating their drive power and the dependence power through MICMAC analysis.

- The interrelation and the hierarchical structure of these productivity factors was made even more descriptive by using the TISM technique.
- Further, the graph theoretic approach (GTA) was used for the quantification of the influence of FMS on the productivity of a firm.
- The strengths and limitations of SMEs were thoroughly studied and a model of the attributes of feasibility of FMS in SMEs was developed using ISM and TOPSIS approaches.
- A new methodology named 'LAPTOP' was developed to convert a conventional manufacturing system into FMS. The various attributes and sub-attributes for this conversion methodology were analyzed using AHP approach.
- The major issues of design of material handling system in FMS were identified and modelled using MADM approaches.

11.3 MAJOR CONTRIBUTIONS OF THE RESEARCH

Although the various issues related to FMS have been extensively explored during last few decades by numerous researchers, but still the adoption and implementation of FMS is considered a difficult task. There is a gap between the theoretical research on FMS and the practical expectation and real- life complexities of manufacturing industries. This research was carried out with the aim of diminishing this gap. The major contributions of this research towards reducing this gap are:

- The present research provides a comprehensive review of literature and identifies contemporary issues related to design and development of FMS in Indian manufacturing industries.
- The inclination of Indian manufacturing industries towards different issues and factors related to FMS has been found out.
- Various measures related to productivity in FMS are identified and their interrelationships are analyzed. Their drive and dependence power have been analysed to identify the most significant key factors/measures affecting productivity.

- Quantification of the influence of FMS on the productivity of a firm is done. This gives a numerical index for showing how much is the productivity of any firm is influenced by the FMS installation. The mathematical model developed can be used to develop a policy for the performance of FMS based on the intensity of different categories of factors.
- Feasibility analysis of FMS in small and medium scale industries is done.
- Different issues concerned with the adoption of FMS are studied and a new methodology is developed for the conversion of a conventional manufacturing system into FMS.
- The different material handling issues in an FMS environment are identified and they are modelled in a hierarchical structure to highlight the key issues.

11.4 KEY FINDINGS OF THE RESEARCH

The key findings of this research work are:

- It was observed from the industrial survey that the level of adoption of FMS in India is still very poor. But most of the manufacturing industries want to adopt these advanced manufacturing systems.
- Improvement in flexibility, quality and productivity are considered as the most important reasons for adoption of FMS, followed by improvement in delivery times and market share.
- An insight into the ISM model of the productivity factors of FMS shows the different levels of these factors. The research indicates that *Reduced labour cost, Quick response to customers, Increased output, Inventory control* and *Improved part quality*, are among the top-level factors. *Reduced delivery times, Better control and documentation, Reduced material handling, Reduced manual inspection* and *Reduced machine downtime* are the middle level factors. These results are reflected in the model. *Reduced number of set-ups, Improved tool management, improved layout of machinery, plant modernization* and *Improved work piece processes* are the lowest level factors. However, ISM model suggests that these lowest level factors have a very high driving power.

- The TISM model developed shows that *better workpiece process* is the basic factor which influences all the other factors for achieving better productivity. With improved workpiece processes, the set ups are reduced leading to lead time reduction and more outputs with minimum material handling.
- The impact of FMS implementation on the productivity of the firm is quantified and a numerical index called *'PRO'* is assign to it. The *'PRO'* helps in the calculation of impact of FMS on different productivity factors. The research suggests that *operational factors* have the maximum intensity followed by the *technical factors, strategic factors* and *financial factors* respectively.
- Further by calculating the productivity opportunity gain and the productivity opportunity loss for each group of productivity factors the scope of improvement has been clearly pointed out.
- The maximum value for performance opportunity gain is 48.63 for P_4 (Financial Factors).
- The overall value of performance opportunity loss for firm's productivity index stands at 99.12 which being very low, requires urgent attention towards improvement through proper implementation of FMS.
- Feasibility analysis of FMS in SMEs shows that with small alterations in their style of working SMEs can have the required structure for adopting Flexible Manufacturing System.
- 17 attributes for feasibility of FMS in SMEs has been identified.
- Research shows that the availability of training facilities, funds, vision and mission of company and the government support form the lowest level attributes which have the most influence on all other attributes.
- The knowhow of the complex control and operational techniques of FMS, availability of space, vendors and the production volume are the middle level attributes which also needs attention.
- A stepwise methodology called 'LAPTOP' for conversion of a conventional manufacturing system into FMS is developed
- Applying the LAPTOP methodology a conventional manufacturing system has been converted into FMS and of the three alternatives proposed in the case study, the alternative 'A_3', flexible manufacturing system is the best option

with a suitability index of 0.468 as against the 0.103 and 0.263 of the other alternatives respectively.

- The alternative 'A_3' offers the highest labour productivity, highest space saving, lowest power consumption. Although this alternative has the highest cost of implementation because of the more advanced and sophisticated equipments, still it is compensated with other benefits.
- 19 issues have been identified which influence the material handling system of FMS.
- Research indicates that *positioning of idle vehicles, failure management, traffic management, throughput rate, layout of AGV tracks* and *vehicle dispatching rules* etc. are the top level issues. They have less influence and more dependence on the other MH issues.
- *Initial cost, number of AGVs, compatibility of different MH equipments with other processing workstations and AS/RS devices, operational cost, operational control, automation, load carrying capacity* and *the programming flexibility* form the middle level attributes. They have both the driving as well as dependence power. So they influence as well as are influenced by the other MH issues.
- The *capacity to handle different shapes and volumes, storage and retrieval MH equipments, comparison with cheap human labour, floor space* and *MH equipments already present* form the lowest level issues. The ISM model suggests the lowest level issues have a very high driving power and as such influence all other issues.
- For the proper design of a MH system in FMS the main criteria/ issue is the floor space and the existing MH system. Further, comparison with cheap human labour is also important. Especially in countries, where cheap labour is available, it may not be economically viable option to select and use the sophisticated MH equipments.

11.5 MAJOR IMPLICATIONS OF THE RESEARCH

Some significant contributions to the literature have been made by the findings of this research. Some important issues related to the planning, design, operation and adoption of FMS in Indian industries are dealt with in these findings. The FMSs have been discussed from practical perspective and it is found that adoption and implementation of FMS is still a far say. The major implications of this research are:

11.5.1 Implications for the Academicians and Researchers

- Identified gaps in the literature will be helpful in performing their future research.
- The questionnaire used for the identification of various issues can be used as a significant tool for performing research in those areas.
- The researchers may be encouraged to identify some more factors/attributes, which may be notable in addressing the FMS issues.
- The graph theoretic approach can be applied for comparing the productivity gains by FMS of different industries.
- The AHP model presented in the case study may be extended for other decisions in the practical case studies.

11.5.2 Implications for the Managers/ Decision Makers

- They may get valuable insight from the empirical study presented in the present research.
- The findings of the graph theoretic approach for the quantification of productivity may help them in the identification of the scope for improvements.
- The proposed methodology for the conversion is very helpful for those managers and industries which want to convert to advanced manufacturing systems but do not dare so in the lack of a justified, clear methodology.
- The managers may also find the use of ISM and other modelling techniques helpful in gaining clear perception about the various factors affecting FMS.
- The frameworks presented in this research can direct manufacturing managers to improve the performance of manufacturing operations in an FMS environment.

11.6 LIMITATIONS OF THE PRESENT RESEARCH

Though a lot of effort has been put in to the present work to develop different frame works to aid in the design and development of FMS but still, this research is not free from the limitations. Some of the limitations of this work are:

- Some particular issues related to FMS are identified and analysed in this research. All issues of FMS design and development have not been dealt with.
- Most of the variables/factors are modelled in this work based on the opinions of experts which may be biased.
- FMS productivity is expressed in terms of an index value. This index value depends on inheritance of main measures which further depends on their sub-measures and all these depend on the expert's opinion. Therefore, suitable combination of measures and their sub-measures should be selected for evaluating the FMS productivity.
- The present study applies GTA technique which gives a big numerical value of the productivity index *'PRO'*. In the present case, it is 3.4237×10^{20}, which may appear to be an odd figure for practical purposes.
- The development of an equation for the permanent function becomes difficult because of combinatorial approach, especially when there are a large number of factors. This requires computer software to solve the same.
- For GTA as well as AHP, there may be some more factors and their sub factors which can be included to make the work more accurate.
- In the case study conducted to validate the proposed methodology, LAPTOP, only some of the costs are considered.
- This research was conducted specially for Indian manufacturing industries, the outcomes of this research may differ slightly in other countries.
- The ISM based models are not statistically validated.
- The MCDM approaches like GTA or AHP can be used only by decision makers who are knowledgeable about it and are trained to interpret the data.

11.7 SCOPE FOR FUTURE WORK

The present research work can be extended in future in the following directions:

- A comprehensive global questionnaire based survey can be carried out to know the impact of identified planning, design and operational issues of FMS in manufacturing organisations world-wide.
- The ISM models developed in this research work can be validated by using structural equation modelling (SEM), also known as the linear structural relationship approach, which is used for testing the validity of such hypothetical models.
- AHP approach can be further extended to fuzzy AHP approach to get more crisp scores.
- More number of attributes may be considered in the design and development of FMS material handling model.
- The components of material handling systems in FMS environment may be selected using MADM approach.
- The permanent function value as proposed in this approach, provide a numerical value of the productivity index '*PRO*' for any industry. By knowing the *'PRO'* values of different industries, their manufacturing systems can be compared for productivity and also the scope for the improvement can be highlighted.
- In the future this work may be continued in designing other assessment frameworks which can identify performance measures suitable for different realms.
- The approach can be further extended to calculate the permanent function and hence numerical indexes at each sub factor level also.
- The proposed LAPTOP methodology can be extended to any type of variables in FMS.

11.8 CONCLUSION

This research focuses on the adoption, implementation and performance of FMS. The objective of this study is to analyze some select issues for the design and development of FMS. The issues of productivity, feasibility and conversion to FMS are addressed. A literature review is done and the gaps in literature are identified. A questionnaire has been developed and the survey of the Indian manufacturing industries has been done to understand the importance of various FMS issues based on the opinion of different respondents. The factors affecting the productivity of FMS are identified and modelled. The influence of FMS on the productivity of a firm is quantified using GTA technique. The different issues concerned with the adoption of FMS are studied and a new methodology for the conversion of a conventional manufacturing system into FMS is developed. Feasibility analysis of FMS in small and medium scale industries is carried out. The different material handling issues in an FMS environment are identified and modelled in a hierarchical structure using ISM and TOPSIS. Different case studies are conducted to validate the proposed methodologies.

It has been observed in the research that the adoption of FMS leads to benefits like, reduced number of set-ups, improved tool management, improved layout of machinery, plant modernization and improved work piece processes etc., which goes on to increase the productivity. In the framework developed through the GTA approach, for finding a clear numerical index of the productivity of a firm, the operational, technical, strategic and financial factors are considered. Amongst all these the operational factors have the most impact by having the highest numerical index value.

In the feasibility analysis of FMS in SMEs it has been observed that although FMS require huge capital investment but with slight modifications in the design of FMS, as well as the working of SMEs this manufacturing technology can be made suitable for SMEs. Strong government support, funds and availability of technology and knowledge are the main attributes for the adoption of FMS in SMEs.

A stepwise methodology called the ‘LAPTOP’ has been developed for the conversion of a conventional manufacturing system into FMS. The various steps of this methodology include ‘List, Alternatives, Propose, Try, Organize and Proceed.’ A case of Indian conventional industry which wants to convert to FMS has also been presented. Various alternatives of conversion are proposed for this industry following the LAPTOP methodology. The selection of best alternative is done using AHP technique, which shows that although FMS is capital intensive but still is suited for the industry.

The analysis of various material handling issues in an FMS environment has been done which proves to be helpful in the proper design of material handling systems in FMS. The research shows that for the proper design of a MH system in FMS the main criteria/ issue is the floor space and the existing MH system. Further, comparison with cheap human labour is also important. Especially in countries, where cheap labour is available, it may not be economically viable option to select and use the sophisticated MH equipments.

Finally, this research gives many useful insights into the design and development of FMS especially for developing countries like India. Some frameworks have been developed to enhance the productivity, feasibility and adoption of FMS using existing tools and techniques. These frameworks have both academic as well as industrial significance.

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Appendix A
QUESTIONNAIRE
Forwarding Letter

From:
Sandhya Dixit
Department of Mechanical Engineering,
YMCA University of Science and Technology, Faridabad-121006
Phone No.: 01292310108

To
____
____
____

Subject: A research project on “Analysis of Planning, Design and Operational issues of Flexible Manufacturing System”

Dear Sir/Madam,

A flexible manufacturing system is an integrated computer controlled system consisting of automated material handling devices and computer numerical controlled (CNC) machine tools that can simultaneously process medium sized volumes of a variety of part types. Keeping in view the growing importance of FMS for Indian manufacturing industries, a research work entitled “Analysis of Planning, Design and Operational issues of Flexible Manufacturing System” is being carried out for Ph.D thesis at the Mechanical Engineering Department of YMCA University of Science and Technology, Faridabad, by me under the guidance of research supervisor, Dr. Tilak Raj, Professor, YMCAUST, Faridabad.

In this regard a questionnaire covering the different issues related to flexible manufacturing system is being sent to your reputed organization. As the response given by you is of utmost importance for achieving the research objective, I earnestly request you to kindly spare some of your valuable time for giving response to the attached questionnaire as observed in your organisation and your experience as an expert in the field.

The purpose of this survey is purely academic therefore, all the responses will be kept strictly confidential and will be used only for this research work.

I will be highly obliged for your kind cooperation. Further I want to inform you that it is a time bound work, so please try to return it within seven days.

With thanks and warm regards,
Yours sincerely,

Sandhya Dixit
(Research Scholar)

Encl-
-Questionnaire
-Self addressed, stamped envelope

Questionnaire

Part 1 Company Profile

1. Name of the Company...
2. Address..

....

....

....
3. Tel: .... 4. Fax: ....
5. E-mail: ....
6. Website: ....
7. Number of Employees ....
8. Annual Turnover of your firm ....
9. Type of product/s your company is producing...
10. Sector Type: ☐ Public ☐ Private
11. Does your company have a separate and well defined FMS?
☐ Yes ☐ No
12. If No, do you want to upgrade to FMS?
☐ Yes ☐ No
13. Does your company feel any market pressure with continually changing and volatile market conditions?
☐ Yes ☐ No

Part 2 Response Sheet

1. Please indicate (use √ or any other suitable symbol) the main problems/concerns your organisation is facing at present which drives you to opt for FMS or other such advanced manufacturing systems. Rate them on a scale of 1 to 5 (1- least concerned, 2- somewhat concerned, 3- average, 4- important concern, 5- Major concern)

S. No.	Concerns	Ratings				
		1	2	3	4	5
1.	High or rising overhead costs					
2.	Producing high quality standards					
3.	Introducing new products on schedule					
4.	High or rising material cost					
5.	Availability of qualified workers					
6.	Inability to deliver on time					
7.	Poor sales forecast					
8.	Falling behind in new process technology					

9.	High or rising inventories					
10.	Yield problems and rejects					
11.	Vendor lead times					
12.	Indirect labour productivity					
13.	Poor utilization of equipments and resources					
ANY OTHER (i)						
(ii)						

2. Please rate the following competitive priorities of your firm on a scale of 1 to 5 (1- least important, 2- somewhat important, 3- average, 4- important, 5- highest priority)

S. No.	Competitive priorities (Ability to provide)	Ratings				
		1	2	3	4	5
1.	Consistent quality					
2.	High performance products					
3.	Fast and dependable deliveries					
4.	Low prices					
5.	Rapid design changes					
6.	After sales service					
7.	Rapid volume changes					
8.	Market share					
ANY OTHER (i)						
(ii)						

3. Please rate the following priorities/ important action plans of your organisation for improvement as per your organisations vision and mission policy on a scale of 1 to 5 (1- least weightage, 2- below average, 3- average, 4- above average, 5- most important)

S. No.	Action Plans	Ratings				
		1	2	3	4	5
1.	Direct labour motivation					
2.	Production and inventory control systems					
3.	Automating jobs					
4.	Integrating information systems in manufacturing					
5.	Supervisor training					
6.	Manufacturing reorganisation					
7.	Lead time reduction					

8.	Improving vendor quality					
9.	Statistical process control					
10.	Zero defects					
11.	Improving new product introduction capability					
12.	Process improvements					
13.	Flexible manufacturing systems					
14.	Quality circles					
15.	Reducing set up times					
16.	Worker Safety					
17.	Giving workers a broader range of tasks					
18.	Improvement in physical working conditions					
19.	Supplier- customer integration					
ANY OTHER (i)						
(ii)						

4. Please indicate the availability of the following critical success factors of FMS with your organisation at a rating from 1 to 5 (1- not at all, 2- somewhat, 3- average, 4- above average, 5- very much)

S. No.	Success factors of FMS	Ratings				
		1	2	3	4	5
1.	Type of company/Product (Is it suitable for FMS adoption?)					
2.	Availability of funds					
3.	Availability of Technology					
4.	Vision and Mission policy of the company					
5.	Multi skilled and flexi manpower					
6.	Availability of space					
7.	Availability of vendors					
8.	Development of effective FMS strategy					
9.	Team Building					
10.	Capability of process and production changes					
ANY OTHER (i)						
(ii)						

5. Please indicate the level of problems anticipated for adoption of the FMS in your organisation at a rating from 5 to 1 (5- not at all, 4- somewhat, 3- average, 2- above average, 1- very much)

S. No.	Problems anticipated	Ratings				
		1	2	3	4	5
1.	Lack of clear vision and knowledge					
2.	Non availability of government support					
3.	Complex operational and control techniques of FMS					
4.	Fear of failure					
5.	High cost of FMS transition					
6.	Non-availability of trained personnel					
7.	High cost of maintenance					
8.	Vendor selection problems					
9.	Demand uncertainties					
10.	Poor rate of return					
ANY OTHER (i)						
(ii)						

6. Please indicate the effect of FMS adoption initiatives taken by your organisation on the following parameters of performance measurement at a rating from 1 to 5 (1- not at all, 2- somewhat, 3- average, 4- above average, 5- very much)

S. No.	Factors	Ratings				
		1	2	3	4	5
1.	Manufacturing cost					
2.	Level of inventory					
3.	Timely delivery of products					
4.	Flexibility in production					
5.	Capacity utilisation					
6.	Employee satisfaction					
7.	Customer satisfaction					
8.	Mean flow time/Process cycle time					
9.	Market share					
10.	Net profit					
11.	Total cost reduction					
12.	Easy retrieval of parts with standardized coding and classification					
ANY OTHER (i)						
(ii)						

7. Please indicate the level of productivity improvements achieved by the FMS installation on the following productivity factors on a scale of 1 to 5 (1- not at all, 2- somewhat, 3- average, 4- above average, 5- very much)

S. No.	Factors	Ratings				
		1	2	3	4	5
1.	Reduction in labour cost					
2.	Reduced delivery times					
3.	Quick response to the customers					
4.	Reduction in floor space					
5.	Reduction in rework and scrap					
6.	Improved part quality					
7.	Reduced set ups					
8.	Increased output					
9.	Better inventory control					
10.	Improved workpiece processes					
11.	Improved tool management					
12.	Reduced manual inspection					
13.	Reduced material handling					
14.	Improved layout of machinery					
15.	Plant modernization					
16.	Reduced machine downtime					
17.	Better control and documentation					
ANY OTHER (i)						
(ii)						

8. Please indicate whether the availability of the following planning and design issues with your organisation support the FMS on a scale of 1 to 5 (1- not at all, 2- somewhat, 3- average, 4- above average, 5- very much)

S. No.	Planning and design issues	Ratings				
		1	2	3	4	5
1.	Well defined part families					
2.	Production volume					
3.	Processing requirements					
4.	Physical characteristics of the workpart					
5.	Types of workstations					
6.	Possibility of variations in process routings					
7.	Layout and space					
8.	Material handling systems (AGVs, AS/RS)					
9.	Work-in-process inventories					
10.	Cutting tools					
11.	Pallet fixtures					
12.	Control systems (DNC, Host computers etc.,)					

13.	Availability of robots					
14.	Storage capacity					
ANY OTHER (i)						
(ii)						

9. Please indicate whether the availability of the following operational issues with your organisation support the FMS on a scale of 1 to 5 (1- not at all, 2- somewhat, 3- average, 4- above average, 5- very much)

S. No.	Operational issues	Ratings				
		1	2	3	4	5
1.	Scheduling criteria/policy					
2.	Dispatching criteria/policy					
3.	Machine loading					
4.	Part routing					
5.	Part grouping					
6.	Tool management					
7.	Pallet and fixture allocation					
8.	Maintenance policy (Preventive/Breakdown)(frequency)					
9.	Inspection Policy (in process/finished goods)(frequency)					
ANY OTHER (i)						
(ii)						

10. Please indicate whether the availability of the following implementation and integration issues with your organisation support the FMS on a scale of 1 to 5 (1- not at all, 2- somewhat, 3- average, 4- above average, 5- very much)

S. No.	Implementation and integration issues	Ratings				
		1	2	3	4	5
1.	Availability of compatible technologies for different components of FMS					
2.	Availability of standard industrial networks and protocols					
3.	Availability of softwares, sensors and other mechtronic components for system integration					
4.	Availability of trained manpower for handling these					
5.	Availability of training/upgrading facilities for personnel					
6.	System maintenance					
7.	Integration of FMS with other systems operating in your company					

8.	Integration of new sensors in existing control architecture					
9.	Vendor quality					
10.	Alternate technologies					
ANY OTHER (i)						
(ii)						

11. Please indicate the level of availability of the following Flexibility issues in your esteemed organisation on a scale of 1-5 (1- not at all, 2- somewhat, 3- average, 4- above average, 5- very much)

S. No.	Flexibility issues	Ratings				
		1	2	3	4	5
1.	Ability to manufacture a variety of products					
2.	Flexible fixturing					
3.	Scope for combination of operations					
4.	Level of automation of machine tools					
5.	Use of automated material handling devices					
6.	Use of reconfigurable machine tools					
7.	Ability to quickly address machine failure					
8.	Ability to route the workpieces differently					
9.	Tool turret capacity					
10.	Level of tool buffer					
11.	Ability to manufacture the same product on different machine tools					
12.	Flexibility of the job holding devices					
ANY OTHER (i)						
(ii)						

12. Please rate the following material handling issues as per your perception of importance on a scale of 1 to 5 (1- least of all, 2- below average, 3- average, 4- above average, 5- most important)

S. No.	Material handling issues	Ratings				
		1	2	3	4	5
1.	Purchasing/Initial cost of MH equipments					
2.	Load carrying capacity					
3.	Programming flexibility of MH equipments					
4.	Operational cost					
5.	Throughput rate					
6.	Capacity to handle different shapes and volumes (Variety of parts)					
7.	Storage/Retrieval MH equipments					

8.	Operational Control					
9.	Automation					
10.	Floor space					
11.	AGVs/ Robots and other advanced MH equipments already present					
12.	Number of AGVs required					
13.	Layout of AGV tracks					
14.	Vehicle dispatching rules					
15.	Traffic management					
16.	Positioning of idle vehicles					
17.	Failure management					
18.	Compatibility of different MH equipments with processing stations/machine tools / AS/RS and other handling devices					
19.	Comparison with cheap human labour					
ANY OTHER (i)						
(ii)						

13. Please rate the following issues in the hierarchy of their importance on the loading and scheduling criteria of your organisation as per your perception on a scale of 1 to 5 (1- least important, 2- below average, 3- average, 4- above average, 5- most important)

S. No.	Loading and scheduling issues	Ratings				
		1	2	3	4	5
1.	Variety of part types					
2.	Types of machine tools					
3.	Number of machine tools					
4.	Control system of FMS					
5.	Cutting tools and their handling					
6.	Storage systems (finite-in-process buffers)					
7.	Tool magazine capacity					
8.	Maintenance schedules					
9.	Tool life					
10.	Pallet and fixture allocation					
11.	Operation completion time					
12.	Machining speed					
13.	Machine workload and the equipment utilization					
14.	Set up time/cost					
15.	Machining time/cost					
16.	Movement of parts between machines					
17.	Number of shifts					
18.	Frequency of new parts arrival					
19.	Alternate routing of parts					
20.	Type of FMS					

21.	Variations in part demand					
22.	Material handling time					
23.	Flexibility in processing sequence					
24.	Workstation/ transportation system breakdown					
25.	Rush orders					
26.	Tool sharing					
27.	Tool regrinding					
28.	Partitioning of the production order into number of batches					
ANY OTHER (i)						
(ii)						

14. Please rate the following main factors regarding the feasibility of conversion of a conventional manufacturing system into FMS in your firm on a scale of 1 to 5 (1- least important, 2- below average, 3- average, 4- above average, 5- most important)

S. No.	Conversion Factors	Ratings				
		1	2	3	4	5
1.	Does the production volume suit adoption of FMS					
2.	Does the product type suit adoption of FMS					
3.	Availability of finances for conversion					
4.	Top management involvement/commitment					
5.	Effective planning and vision					
6.	Availability of technology					
7.	Availability of vendors/their selection					
8.	Work culture/ team spirit and motivation					
9.	Availability of adequate space					
10.	Effective use of tools like CAD/CAM, MRP, MAP etc.,					
11.	Overcoming fear of failure					
12.	Possibility of training and relocation of the workers					
13.	Support from the workforce for transition to FMS					
14.	Additional skills required of FMS personnel					
15.	Possibility of learning/knowhow of complex operational and control techniques of FMS					
16.	Availability of precise performance measurement techniques (measures like flexibility, productivity, quality etc.,)					
17.	Availability and use of advanced MH equipments like robots/ AGVs etc.,					

18.	Possibility of changing the current layout of machines					
19.	Support from government and other funding agencies					
20.	Ability/readiness to face loss of market share during transition period					
21.	Willingness to bear temporary losses					
ANY OTHER (i)						
(ii)						

Part 3 Respondent's Profile

1. Name with signature (If you please):

2. Designation:
(i) CEO [] (ii) Sr. Manager [] (iii) Manager [] (iv) Supervisor [] (v) Junior Staff []

3. Your functional area:
(i) Production [] (ii) Research and Development [] (iii) Maintenance [] (iv) Quality Control [] (v) Marketing [] (vi) Any other (Please specify)

4. Your association in years with the current organisation:
(i) Less than 5 [] (ii) 5-7 [] (iii) 8-10 [] (iv) More than 10 []

5. Your total experience in years:
(i) Less than 5 [] (ii) 5-7 [] (iii) 8-10 [] (iv) More than 10 []

6. Would you like to share the findings of the survey:
(i) Yes (ii) No

Thanking you for sparing your highly valuable time.

Regards,

Sandhya Dixit
Department of Mechanical Engineering
YMCA University of Science and Technology,
Faridabad- 121006 (Haryana)
Ph. No. 09899804575
E-mail: sandhya_parinam@yahoo.co.in

Appendix B

BRIEF PROFILE OF THE RESEARCH SCHOLAR

Sandhya Dixit received her B.E. Mechanical Engineering from NIT Kurukshetra in 2001 and M.Tech in Mechanical Engineering with specialization in Manufacturing and Automation Technology from MD University Rohtak, Haryana in the year 2008. She is currently pursuing her Ph.D from YMCA University of Science & Technology Faridabad, Haryana. She is working as Assistant Professor in Mechanical Engineering Department at J. C. Bose University of Science and Technology, YMCA, Faridabad, Haryana. Her research interests include Flexible Manufacturing Systems and Advanced Manufacturing Technologies.

Appendix C

LIST OF PUBLICATIONS OUT OF THESIS

The following is the list of publications during the duration of the PhD:

List of Published Papers

S. No.	**Title of the paper along with volume, Issue No., year of publication**	**Publisher**	**Impact factor**	**Referred or Non-Referred**	**Whether you paid any money for publication**	**Remarks**
1.	Sandhya Dixit, Tilak Raj (2017), 'A TISM Model for Structuring the Productivity Elements of Flexible Manufacturing System', *World Academy of Science, Engineering and Technology, International Journal of Industrial and Manufacturing Engineering,* Vol.11, No.4, pp. 905-912.	WASET	-	Referred	No	UGC, ISI
2.	Sandhya Dixit, Tilak Raj (2016) 'Identification and modelling of the various factors affecting the productivity of FMS', *International Journal of Productivity and Quality Management*, Vol. 17, No. 3, pp.353-379.	InderScience	-	Referred	No	Scopus, UGC
3.	Sandhya Dixit, Tilak Raj (2015) 'Framework to convert a conventional manufacturing system into FMS', *YMCAUST International Journal of Research*, Vol. 3, No. 1.	YMCA UST	-	Referred	No	Google Scholar
4.	Sandhya Dixit, Tilak Raj "Quantification of the influence of FMS on the productivity of a firm", *International Journal of Process Management and Benchmarking*, **IN PRESS.**	Inderscience	-	Referred	No	Scopus, UGC

5.	Sandhya Dixit, Tilak Raj (2018), "Feasibility analysis of FMS in small and medium scale Indian industries with a hybrid approach using ISM and TOPSIS", ***International Journal** of Advanced Operations Management,* Vol. 10, No. 3, https://doi.org/10.1504/IJAOM.2018.093740	Inderscience	-	Referred	No	Scopus, UGC
6.	Sandhya Dixit; Tilak Raj (2018), "A Hybrid MADM Approach for the Evaluation of Different Material Handling Issues in Flexible Manufacturing Systems", *Adm. Sci.* 2018, Volume 8, Issue 4, 69, 1-19.	Administrative Sciences	-	Referred	No	ESCI, Scopus

List of Communicated Papers

S. No.	**Title of the paper along with volume, Issue No., year of publication**	**Publisher**	**Impact factor**	**Referred or Non-Referred**	**Whether you paid any money for publication**	**Remarks**
1.	Methodology for Conversion of a Conventional Manufacturing System into FMS' Communicated to Part B- Journal of Engineering Manufacture	SAGE Journals	-	Referred	No	SCIE, Scopus

List of Conferences/ Seminar

S.No	**Title**	**Year**
1.	'Flexible Automation in World Class Industries', Sandhya Dixit, Tilak Raj, International Conference on SDREM- Dec, 2016.	2016
2.	'The Changing Manufacturing Environment from the Mass Manufacturing to the Flexible Manufacturing', Sandhya Dixit, Tilak Raj, National Conference TAME 2017	2017