To analyze Material Handling, Tooling and Social Issues of Flexible Manufacturing System

THESIS

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by

SURINDER KUMAR

(Registration No. - YMCAUST/Ph/32/2010)

Under the supervision of

Dr. Tilak Raj

PROFFESOR

Department of Mechanical Engineering

YMCA University of Science & Technology, Faridabad

Department of Mechanical Engineering

Faculty of Engineering and Technology

YMCA University of Science & Technology

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

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CANDIDATE'S DECLARATION

I, hereby, declare that this thesis entitled **TO ANALYZE MATERIAL HANDLING, TOOLING AND SOCIAL ISSUES OF FLEXIBLE MANUFACTURING SYSTEM** by me, being submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy in **DEPARTMENT OF MECHANICAL ENGINEERING** under Faculty of Engineering & Technology of YMCA University of Science & Technology Faridabad, during the academic year 2017-2018, is a bonafide record of my original work carried out under guidance and supervision of **Dr. TILAK RAJ, PROFESSOR, DEPARTMENT OF MECHANICAL ENGINEERING, YMCAUST, FARIDABAD** 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.

SURINDER KUMAR

Registration No: YMCAUST/Ph32/2010

CERTIFICATE OF THE SUPERVISOR

This is to certify that this thesis entitled **TO ANALYZE MATERIAL HANDLING, TOOLING AND SOCIAL ISSUES OF FLEXIBLE MANUFACTURING SYSTEM** by **Surinder Kumar** submitted in fulfillment of the requirement for the Degree of Doctor of Philosophy in **DEPARTMENT MECHANICAL ENGINEERING** under Faculty of Engineering & Technology of YMCA University of Science & Technology Faridabad, during the academic year 2017-2018, 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.

(Tilak Raj, Ph.D.)

PROFESSOR

Department of Mechanical Engineering

Faculty of Engineering & Technology

YMCA University of Science & Technology

Faridabad

Dated:

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SURINDER KUMAR

Registration No.: YMCAUST/Ph32/2010

ABSTRACT

In current scenario, manufacturing concerns are facing the market competition at global level due to the certain reasons like high quality products demanded by the customers at lowest price, shortened life cycle of the products and cut throat competition in technology and these issues have forced the manufacturing concerns to adopt advanced technology in production systems. Use of advance and automated technologies such as computer integrated manufacturing (CIM), advance manufacturing systems (AMS), reconfigurable manufacturing systems (RMS), flexible manufacturing systems (FMS) and advance robotic systems have forced and realized the manufacturing concerns to adopt these systems for enhancing their productivity and flexibility. FMS is one of such technologies to cope up with the high global competition. But a proper understanding is desirable in every respect before investing and implementing the FMS. Adoption of such newer and costly technology does not guarantee the profit and may lead to big loss in term of finance. Hence a profound understanding of such modern technology is must for its successful implementation to acquire maximum benefit at minimal cost.

The use of FMS in developing countries like India is comparatively low due to adoption of traditional systems since long time. Availability of human labour in abundance and other related social implications and lack of suitable strategies are the main hurdles in adoption of FMS.

In this research work, material handling, tooling and social issues of flexible manufacturing system have been analyzed for Indian industries for adopting FMS. For this purpose, an extensive literature review has been conducted to understand the importance of FMS issues in Indian industries context. Interpretive structural modeling (ISM) technique has been used to identify the relationship and dependence among material handling, tooling and social issues, Fuzzy Analytical hierarchy process (FAHP) and modified grey relational analysis (M-GRA) techniques has been utilized to find out the best material handling equipment out of the given alternatives. Graph theoretic approach (GTA) has also been used to analysis of material handling equipment effectiveness in FMS by using GTA approach. A case study of a piston manufacturing shop has been conducted for enhancing the productivity and flexibility in FMS environment. A L.P model has been developed for maximization of profit

with proper tool management. PSO technique has been utilized for determining the path layout of AGV in FMS.

The major contributions made through this research are as follows:

- This current research provides a comprehensive review of literature and survey reports in Indian modern industries and identified some existing issues related to material handling, tooling and social implications of flexible manufacturing system.
- Various problems and issues in material handling, tooling and social implications have been identified.
- The current trends and complication in material handling, tooling and social implications have been reviewed.
- Trend of Indian manufacturing industries towards the importance of material handling, tooling and social implications have been found out.
- The issues related to social implications in FMS are identified and their drive and dependence power have been found out and most significant factors have been extracted by using ISM approach.
- Material handling variables have been identified which are helpful in design and selection of material handling equipment and their drive and dependence power have also been analyzed and most important variables for material handling equipment have been analyzed through ISM approach.
- A frame work for the comparison of material handling equipments for a FMS environment has been carried out by using FAHP technique and appropriate equipment (AGV) has been identified which is the best one for FMS.
- Multi Attribute Selection of a Mobile Robot (AGV) for flexible manufacturing system is identified and a frame work has been developed by using combined AHP and M-GRA technique.
- Effective index of material handling (EIMH) equipment variables have been calculated which helps in evaluating the feasibility of material handling equipment selection for FMS by using GTA base framework.

- A case study for piston manufacturing shop has been developed and main issues of productivity and flexibilities have also been explored for enhancing the productivity.
- A linear programming model has been developed based on case study for maximization of profit of a product with proper utilization of tool management.
- A model has also been developed for optimization of path layout by using a particle swarm optimization (PSO) technique.

Keywords: Flexible Manufacturing Systems, Interpretive structural modeling, Fuzzy Analytic Hierarchy Process, Modified Grey Relational Analysis, Graph Theoretic Approach, linear programming, Productivity, Flexibility, Particle Swarm Optimization

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LIST OF ABBREVIATIONS

S. No.	Title	Abbreviations
1.	Flexible manufacturing System	FMS
2.	Numerically controlled (NC) machine	NC
3.	Computer numerical control	CNC
4.	Direct numerical control	DNC
5.	Single machine cell	SMC
6.	Flexible machine cell	FMC
7.	Automated Guided Vehicle	AGV
8.	Automatic Storage and Retrieval System	AS/RS
9.	Special purpose machine	SPM
10.	Material Handling System	MHS
11.	Interpretive structural modeling	ISM
12.	Weighted Interpretive structural modeling	W-ISM
13.	Total Interpretive structural modeling	T-ISM
14.	Analytic Hierarchy Process	AHP
15.	Fuzzy Analytic Hierarchy Process	FAHP
16.	Modified Grey Relational Analysis	MGRA
17.	Graph Theoretic Approach	GTA
18.	Linear Programming	LP
19.	Particle Swarm Optimization	PSO
20.	Reach ability matrix	RM
21.	Structural Self-Interaction Matrix	SSIM
22.	Cross-Impact Matrix Multiplication Applied to Classification	MICMAC
23.	Proximity Laser Scanner	PLS
24.	Laser Scanner interface	LSI
25.	Computer integrated manufacturing	CIM
26.	Reconfigurable Manufacturing Systems	RMS

27.	Advance manufacturing systems	AMS
28.	Design support and expert system	DS&ES
29.	Computer Control Device	CCD
30.	Genetic Algorithms	GA
31.	Programmable Logic controller	PLC
32.	Advance Manufacturing techniques	AMT
33.	Total Productive Maintenance	TPM
34.	Research and Development	R&D
35.	Multi Attribute Decision Making	MADM
36.	Multi Criterion Decision Making	MCDM
37.	Grey Relational Analysis	GRA
38.	Material Handling Devices	MHD
39.	Pick and Delivery	P&D
40.	Alternative Current	Ac
41.	Consistency Ratio	CR
42.	Random Index	RI
43.	Geometric Mean	GM
44.	Effectiveness Index of Variables	EIV
45.	Effectiveness Index	EI
46.	Java Virtual Machine	JVM
47.	Simulated Annealing	SA
48.	Simple Additive Weighting	SAW
49.	Weighted Product Method	WPM
50.	Sensitivity analysis	SA
51.	Automated Material Handling	AMH
52.	Material Handling Equipment	MHE
53.	Material Handling	MH
54.	Intensity of Risk	IOR
55.	Humanized Flexible Manufacturing System	HFMS
56.	Radio Frequency	RF
57.	Critical Path Method	CPM

58.	Effectiveness Index Variable	EIV
59.	Effective Index of Material Handling	EIMH
60.	Permanent function	Per K*
61.	Special purpose Machine	SPM
62.	Vertical Machine Center	VMC
63.	High speed Steel	HSS
64.	Structural Equation Modelling	SEM
65.	Technique Ordered Preference by Similarity to the Ideal Solution	TOPSIS

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

Flexible manufacturing system (FMS) may be defined as an integrating computer controlled system of automated material handling equipments (MHEs) and numerically controlled (NC) machine tools which can simultaneously process medium sized volumes of a variety of parts with quick tooling, instruction changeovers and executing the operations according to the required order (Strecke,1983). Today's dynamic and global competition in the market, advancement in technology and ever changing customer's demand due to higher product range at reasonable prices and reduction in goods life have become big issues for national and international level manufacturing concerns (Raj et al., 2009). It has strained the companies to understand the significance of FMS. To fulfil the dynamic demands of customers, the modern industries require inconsistent, flexible, adaptive and receptive to alterations in different technologies and being able to manufacture diversity of goods in a short period at minimal cost for their survival. For this purpose, adoption of automation and advanced material handling Equipments may also be one of the solutions. Organization

According to the Bellasi and Fadlalla (1998) FMSs propose various advantages over conventional manufacturing systems and its implementation is not easy as presented in hypothetical study. To run FMS as a precise and progressive technology is not easy. The features of FMS promise many returns like better machine utilization and reduction in number of machine tools, reduction in process inventory, enhancement in productivity, reduction in labour costs, consistent product quality, minimum space and setup costs reduction (Palframann, 1987; Green, 1986). FMS consists of various unified components of hardware and software. It not only increases the efficiency of processes in term of quality and economy but also improves the overall utilization of all the elements used in industry. The smooth and economical activity of any FMS depends on the success of strategies for designing, controlling and organizing of all components of FMS; however, these can be explained with three main perspectives: Automated Material Handling (AMH), Tooling and Social Implications of FMS.

- **Automated Material Handling (AMH)**: Automated material handling is a process in which movement of materials takes place automatically from one workstation to another for completing the operations along with the required sequence. Material handling equipments (MHEs) have proved most important phase of the manufacturing system with time. Tompkins et. al (2003) stated that about 50% of the functioning cost can be credited easily by adopting the activity of automated material handling. The choice base integration of MHEs with facilities has a vital role in moving, loading-unloading and storage of material within the facility. Presently, advanced MHEs such as robots, automated guided vehicles (AGVs), and automatic storage and retrieval (AS/RS) system are considered as the secure and accurate media for material handling. These MHEs are interlinked by a computer network system in FMS environment for their proper control. AGVSs are also utilized in FMSs to offer flexibility in routing parts through different essentials available in the system. These latest technology equipments are highly intricate and expensive due to the dynamic ambience of FMS. Furthermore, if these AGVS are not capable in achieving the objective, the whole performance of machines in the system may be affected. Therefore a careful design and effective planning are necessary for the selection of material handling equipments.

- **Tool Management:** Tool management means proper and adequate arrangement of tooling for required operations. Tool management is an extremely multifaceted task and is often stressed by FMS clients and researchers. Even though having such difficulties FMSs working are successful and performance also has been considerably improved with competent tool management (Stecke and James, 1981; Shanker and Virat, 1999; Vis, 2006; Qiu et al., 2002; Egbelu and Tanchoco, 1984).Tool management also considers its profitable impact, while tooling includes 25-30 per cent of the fixed costs of production in computerized machining environment (Egbelu and Tanchoco, 1984; Topkins and White, 1984). Various industries have recently developed combined tool management systems with tremendously promising results (Egbelu and Tanchoco, 1984). Recently, an integrated tool management system has also launched the fifth generation of FMS. The tool management also act as an important subsystem and influences the entire arrangement and operations of the system (Tomek 1986). The latest literature indicates that still numerous tool management problems have to be resolved (Buyurgan et al., 2004). This is mightily due to the lack of complete understanding regarding the tool management and becomes necessary before trying any new tooling activity, like tool governing policy, optimized algorithms for tools, design of a tool delivery system and expansion of control software's (Kusiak, 1986).

- **Social Implication:** Now a day's flexible manufacturing system has become the essential requirement of the modern manufacturing system. Use of such latest technology is only a way to increase capacity, productivity and quality as per competitive market demand (Yazen and Valerity, 2010). A perfect planning is required for its implementation so that its benefits can be reap in term of profit. Long term benefit can be achieved by producing a range of products and fully utilization of machines, labour, shop floor flexibility and premium goods with minimization of processing lead time. A large-volume production can be easily achieved by the replacement of conventional manufacturing systems with fixed automation and transfer lines (Raj et al., 2010). Still there are some positive and negative implications of this technology which influence the social life of people working in industries in many ways like economy related, time related, technology related and society related (Pant and Ruff, 1995).

  Economy related implications includes lower cost of mass production, lower inventory levels, reduced scrap and rework, information tracking costs, cost reduction in variety of jigs and fixtures, reduction in loading /unloading time, tooling maintenance cost, reduction in labour cost, initial cost of installing the FMS and general maintenance cost.

  For the adoption of such advance and beneficial technology the management of the manufacturing concerns should think in a positive way for the development of advance technologies which can be acquired in an effective way and can be proved fruitful to the society.

1.2 TYPES OF FMS

Flexible Manufacturing System can be classified and designed as per specific applications subject to the nature like specific family of parts and processes. FMS can also be differentiated according to the type of manufacturing operations they perform.

- **ACCORDING TO THE OPERATIONS**

a. Processing operations

It carry outs some operation activities on a particular job to alter its shape, physical properties or appearance to add value to the material or goods. Usually more than one operation required to transform the starting material in to final product form (Groover, 2012).

b. Assembly operations

It is a process in which two or more than two parts are combined together to form a new combination of parts is called subassembly and assembly**.** The subassemblies are generally joined permanently by using the processes such as power press fitting, riveting, soldering, brazing, welding and adhesive bonding etc. In that situation it is called flexible assembly system (FAS) (Grover, 2012).

- **ACCORDING TO NUMBER OF MACHINES**

FMS can be further classified according to the number of machines in the system.

a. Single machine cell (SMC)

Single machine cell means fully automated machines which are able in completing operations without human assistance within a specified time. It is also skilful capable for processing various parts mix, responding to variations in manufacturing plan with the introduction of new component. This system is also called as sequence dependent production system (Grover, 2012).

b. Flexible manufacturing cell (FMC)

It entails two or three workstations (CNC machining) with an automated part handling system. The part handling system is linked with pickup and delivery system for loading/unloading purpose. It is also called as synchronized/ simultaneous production system (Slobodan, 2015).

c. Flexible Manufacturing System (FMS)

A flexible manufacturing system consist of four or more processing stations attached with automated material handling devices and distributed computer system for processing variety of parts as per the required sequence. It also comprise of certain equipments (e.g. co-ordinate measuring machines, part, washing stations and pallet etc.) that does not contribute to production but assists it. Moreover, it is also considered as large and sophisticated system as compared to FMC (Slobodan, 2015).

- **ACCORDING TO LEVEL OF FLEXIBILITY**

FMS can be classified on the basis of flexibility level as given below:

a. Dedicated FMS

It is mainly used for making limited range of part styles, at any one time. The product design is considered as fixed and it is also known as the process specialization or advance system to make the operation more efficient (Koelsch, 1994).

b. Random order FMS

It is capable in handling the extensive variations in part formations. To deal with these modifications, it is best suited for manufacturing the component with higher level of complexity and flexibility. This type of FMS system has less production as compared to dedicated FMS. Thus, a sophisticated computer control system is required to manage this variety of parts complexity (Groover, 2008).

1.3 NEED OF FMS

Abruptly and unpredictable market condition and changing customer demands for quality products of new varieties at the nominal price have forced the industries to adopt the latest technologies like FMS to cope up these market demands. These systems should be more flexible, easily reconfigurable, highly productive and multitasking (Mehrabi et al., 2000). The main aim of this technology is to compete with the present scenario in term of increased productivity and flexibility with the variety of products, reduction in productive time, cost and continuous improvement in quality.

1.4 BENEFITS OF FMS

The major benefits of FMS are as under (Groover, 2010):

- Reduced lead time
- Improved machine utilization
- Direct labor reduction
- Indirect labour reduction
- Flexibility
- Reduced unit cost
- Work in process inventory reduction
- Reduction of scrap
- Reduction of set up time
- Optimum balance of production
- Increased profit
- Better quality
- Reduction in rework, repairs and rejection
- Integrated manufacturing

1.5 ISSUES RELATED TO FMS IN INDIAN CONTEXT

The organisations throughout the world especially in developing countries like India want to change from conventional manufacturing system to FMS to improve their performance and economic condition. Implementation of such newer technology (FMS) is not an easy task due to complexity of issues. There are many issues of FMS which are still associated with successful implementation of this technology. Some issue related to FMS in Indian context are as follows:

- Material handling
- Tooling
- Social issues

1.5.1 Issues Related to Material Handling in FMS

Material handling system is a most important activity for enhancing the productivity in FMS environment. Material handling technology is becoming the most important criteria to all type of the productive and non productive businesses. According to the Asfahl (1992) about 87% of the total production time is utilize in Material handling, 55% of all company space, 15-75% of total cost of product and 25% time of total employees. Therefore, material handling is considered as a first and active element of the advance manufacturing system (Sujono and Lashkari, 2007). Proper design and choice of suitable MHE has become a primary consideration for modern manufacturing industries (Tompkins, 2010). The use of these effective material handling equipments makes effective utilization of workforce, energy, space, facility, human safety and reduction in production lead time, improvement in effectiveness of material flow, increased output and reduction in total cost of product and error rates (Tompkins et al., 2003). Hence design becomes the important parameter for modern systems such as FMS. A number of factors such as operational cost, safety, material flow path, space required, speed of delivery and flexibility assists in the design of MHEs.

The developing country like India who wants to compete in the manufacturing sector at global level should adopt advance technologies like FMS and for its proper implementation manufacturers are advised to adopt advance material handling systems such as automated conveyors, robots and AGVs in their industries along with the automated machines like CNC, DNC etc. Without use of such advance material handling systems proper results are impossible.

1.5.2 Issues Related to Tooling Systems in FMS

Tool management means proper and adequate arrangement of tooling required for operations. According to Tomek (1986) tool management is a coordination of functions of tooling with the machine tools and material handling devices for receiving the correct tool, in the true position at the right moment. Proper tool selection, better tool allocation, better tool monitoring and implementation of new tooling is one of the most cumbersome and difficult issue in addition to tool cost, it also contributes about 25%-30% of on-going operation cost of production in automated machining environment (Egbelu and Tanchoco, 1984). Selection and allocation of the tools in FMS is done by the computer to the machine according to the process sequence through tool management system. It not only tells about the exact quantity of tools required to fulfil the production schedule but also provide the plan for optimize cutting tools for new operations (Shayan et al., 1995). Manufacturing time for the novel component may be more because of different restrictions associated with the machine tools, cutting tools and material handling devices in flexible manufacturing system (Buyurgan et al., 2004). According to the Keung et al. (2003) FMS can also produce a variety of parts which are small in batches. However, with the addition of part variety and increase in the number of tools, the cost of tooling will increase. To overcome these issues alternatives like new designing of combined tools (Drill and reamer) may also be an option for minimizing the machining operation time and tooling cost associated with manufacturing.

1.5.3 Issues Related to Social Implications of FMS

In this modern era of competition, market and short product life has created significant pressure for the improvement in manufacturing system that may effectively deal flexibility, effectiveness and economy (Saul, 1985). In recent years it has been realize that the operations like maintenance, planning and controlling of computers are not possible without human assistance hence pep lacing a usual manufacturing method with FMS changes the human work environment (Davis, 1996). Flexible manufacturing systems tender numerous returns over conventional manufacturing systems and assist the organizations to accept the challenge of global markets.

Authors Nagar and Raj (2012b) suggested that the social relations can be improved through positive thinking and perfect planning of the management and government for the implementation of FMS. According to Groover and Zimmer (1987) flexible manufacturing systems improve work environment, but, there are some social issues (i.e. labour issues), which are treated as the hurdles in the functioning of FMS. No doubt implementation of the newer technology may be sensitive for social reasons like reduction in incentives, perks and unemployment etc. (Salahedin, 2007; Lefebvre et al., 1992). In addition to these difficulties, still there are some issues due to which people are not interested in such advanced technology, reason being mass consumption of manpower in service sector, initially high costs of implementation, inconvenience in finding spare parts, vendors, higher charge for repairs and opposition by worker unions. For this purpose proceed development policies can be fruitful in social-technological forms for the latest technology like FMS.

1.6 MOTIVATION OF THE RESEARCH

The prime concern of current research is to investigate the issues related to material handling, tooling and social issues which are forcing the manufacturing industries to adopt and implement the flexible manufacturing system. The use of FMS in today's volatile environment has becomes necessary for the industries due to fulfil rapidly changing demand of customers for new variety of products at competitive prices. But adoption of such costly technology does not guarantee the benefit and success. So, before implementing the FMS, study of its pros and cones becomes necessary for effective adoption. Material handling is an important part of a manufacturing system because most of the time spends in moving the material from initial stage to final finish product in fulfilling the customer's orders. In manufacturing concerns proper tooling management is also an important issue for minimizing the processing time and cost and to maximize the profit. Before implementing the newer technology like FMS its positive and negative social implications must also be studied so that management can take care of negative impacts of such technology in advance by developing proper strategies. These strategies may be useful in implementing modern technologies. It not only improves the overall competence but also inspire the workers to upgrade their knowledge and performance. In this way, a big issue of unemployment can also be managed. No doubt adoption of FMS as compare to conventional manufacturing system will be more beneficial and suitable in term of varied customer's demand at competitive quality and prices. The facts stated above have motivated the organizations towards performing this research. There are some real facts that focus towards FMS and motivated the researchers to undertake this research. The motives of the research are as under:

- Technological and financial competition at global level market has inspired to follow FMS in to their organisations to gain the benefit by using this technology.
- Failures of FMS adoption in Indian industries because of their unsuitable environment in manufacturing concerns have motivated to find out FMS suitability.
- Selection of material handling equipment for supply of material in a safe and effective way is a big issue in manufacturing industries. This also has motivated for implementation of FMS environment in industries.

- The current research lacks in providing information regarding maximization of profit in competitive industrial environment which is only possible by using FMS environment.
- In developing countries like India there may be the resistance in adoption of FMS due to availability of abundance of labour at cheaper rates. But implementation of FMS can tackle such problems through proper strategies like skill and persona development of labour etc.
- Adoption and implementation of FMS may lead various problems which can be solved by analyzing the various issues of FMS and other alternatives of manufacturing technologies which may be useful for industries.

1.7 GAPS IN LITERATURE

A review of literature brings out the following gaps in the context of flexible manufacturing system. The major factors affecting the design and operation of material handling devices of AGVs of FMS have not been analysed.

- Social implications of flexible manufacturing system have not been analysed.
- Productivity and flexibility issues related to the FMS are rarely explored.
- Selection of optimum number of tools for maximum profit is difficult.
- The driving and dependence power of social implications of FMS has not been analyzed by using ISM method.
- The performance of AGVs has not been compared with alternative material handling devices by using AHP Approach.
- There is a strong need to develop a model for optimization of path layout.

1.8 RESEARCH OBJECTIVES

The main purpose of current research work is as follows:

- To identify the major factors affecting the design and operation of material handling devices specially AGVs of FMS.

- To conduct a survey of Indian industries for identifying the social implications of FMS.
- To develop case study for exploring the issues of productivity and flexibilities with introduction of new tools in FMS.
- To develop a linear programming (L.P) model for maximum of profit with proper tool management in FMS.
- To develop an interpretive structural model to analyze the driving and dependence power of social implications of FMS.
- To develop an analytical hierarchal Process (A.H.P) model for the comparison of performance of AGVs with alternative material handling devices to be used in FMS.
- To prepare a model for the optimization of path layout of AGVs in FMS.

1.9 RESEARCH METHODOLOGIES

A questionnaire has been developed and a nationwide survey has been conducted in large and medium sized Indian industries on adaption and implementation of FMS. A five point scale has been used for this questionnaire and some techniques like:

- Interpretive structural modelling (ISM) approach
- Graph Theoretic Approach (GTA)
- Fuzzy Analytic Hierarchy Process (FAHP)
- Modified Grey Relational Analysis (M-GRA)
- Linear Programming (L.P)
- Particle swarm optimization (PSO)
- An industrial case study has been conducted for enhancing the productivity of pistons manufacturing shop for FMS environment

1.10 ORGANIZATION OF THE THESIS

The present research work has been arranged in 12 chapters. The chapter wise organization of the research has been illustrated in Figure 1.1. Summary of each chapter have been discussed as below:

Chapter I: In this chapter, the proper understanding of flexible manufacturing system their need and benefits, issues related to flexible manufacturing system, motivation of the research, gaps in literature, research objectives and methodologies in the present research have been discussed.

Chapter II: In this chapter, literature was reviewed related to flexible manufacturing systems and its associated issues as an advance manufacturing technology system which is being used at national and international level. On this topic a detailed study has been done and stated in the form of research papers and different leading global journals. Therefore for the best possible contribution in the present research work a lot of research papers related to flexible manufacturing system were studied. Through the literature review general introduction of flexible manufacturing system, their types and different issues of flexible manufacturing system, types of material handling devices, tooling used in FMS, variables affecting material handling systems, factors affecting social implications and variables affecting productivity and flexibility were identified and presented. Some important research methods such as ISM, GTA, FAHP, MGRA, PSO and analytical case study etc. are used in current research work for extracting different frameworks and models are also reported in stated chapter.

Chapter III: This chapter covers the development of questionnaire for conducting a national wide survey. The survey was conducted in different small- medium- large- scale industries. Questionnaire consists of the questions related to the variables in improving the manufacturing system, reasons for adopting material handling systems like AGV, Robot, Conveyor etc and tooling in FMS, future automated material handling, tooling used in manufacturing system, use of material handling devices in a company, functions and variables used in selection of material handling equipment, variables for achieving high productivity through material handling and tooling in FMS, factors related to the tool management in FMS and social implications of FMS. Responses of this survey from the industries were collected, analyzed and presented after discussion for different issues.

Chapter IV: In this chapter, social implication factors have been identified and analyzed by using ISM technique by developing the ISM model and MICMAC analysis.

Chapter V: In this chapter, design and operation of material handling system in FMS has been explained.

Chapter VI: In this chapter, variables influencing the selection of MHE, productivity and flexibility of FMS have been identified and analyzed by using ISM technique by developing the ISM models and MICMAC analysis.

Chapter VII: In this chapter, frameworks for MHE selection have been framed by the utilization of FAHP, AHP and MGRA techniques for flexible manufacturing system to select the best alternative out of given alternatives.

Chapter VIII: In this chapter, GTA technique has been used for quantification and development of framework for evaluation of MHEs effectiveness in flexible manufacturing system.

Chapter IX: In this chapter, a case study of a piston manufacturing shop for enhancing productivity and flexibility with the introduction of new tool and a linear programming (L.P) technique has been used for developing a (L.P) model for maximization of profit with proper tool management in FMS.

Chapter X: In this chapter, PSO approach has been used for path optimization model of AGV in FMS.

Chapter XI: In this chapter, the synthesis of research work as mentioned in the previous chapter has been presented. This chapter presents the overall picture of this research work.

Chapter XII In this chapter summary, implications and limitations of this research work have been discussed. Final conclusions of the present research and its scope for future work have also been presented.

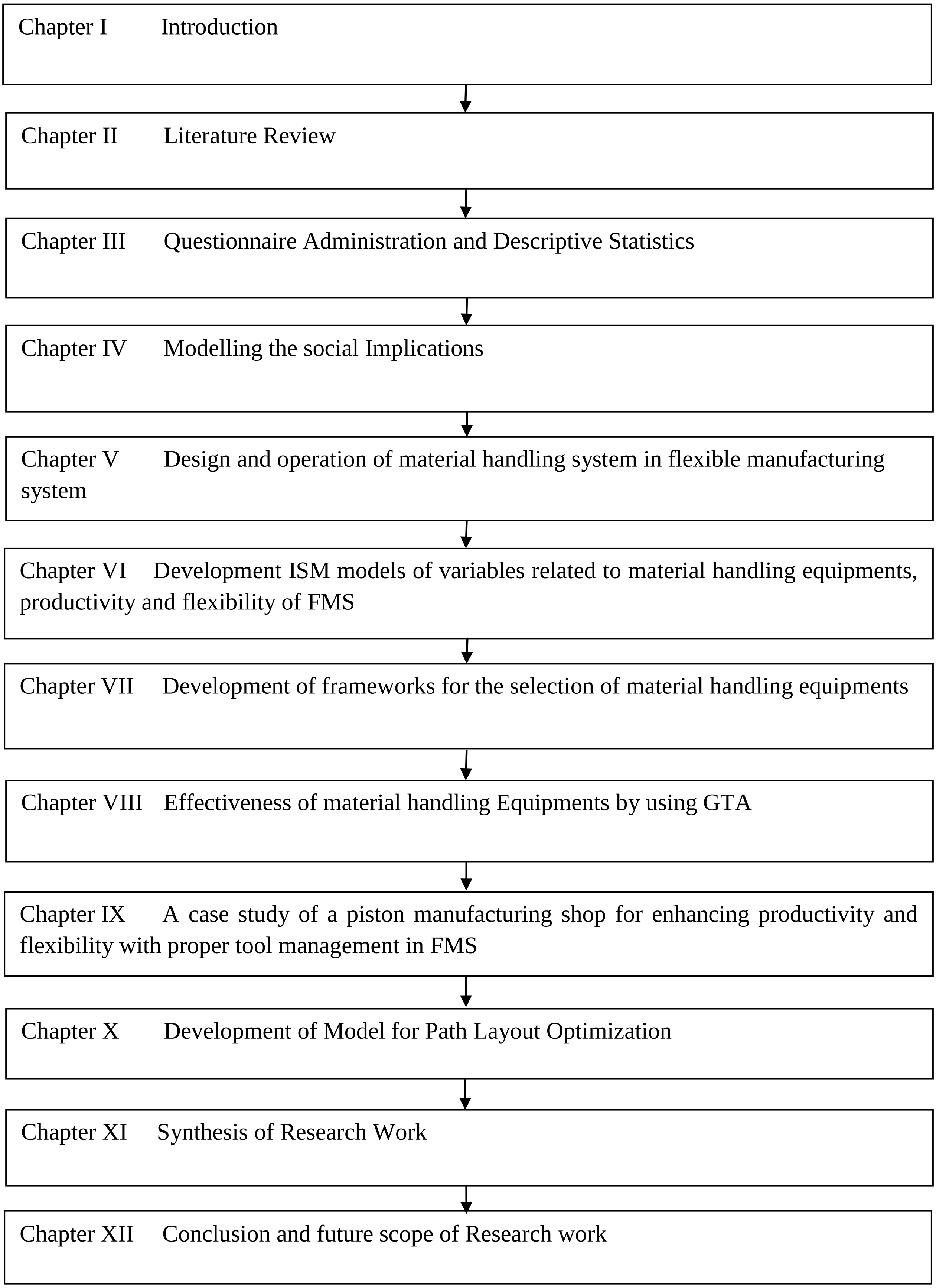


Figure 1.1 Organization of research work

1.11 SUMMARY AND CONCLUSION

In modern manufacturing scenario rapidly changing in technologies and the introduction of computers, automation and modern machines and technological competition at global level have created a need of better understanding the concept and risks of newer technology (i.e. Flexible manufacturing system). In this present research there is a need to develop the hierarchy for material handling, tooling and social issues to mitigating the risk of newer technologies**.** In this chapter, introduction, needs and benefits of FMS, issues related to FMS regarding material handling, tooling and social implications have been discussed**.** After identifying the gaps in literature regarding material handling, tooling and social issues, a comprehensive research work was prepared and executed. Different research objectives, methodologies used in the present research work and organization of whole research work has been presented in different chapters.

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

It has been reported in the literature that decision regarding material handling and tooling of FMS must be decided with respect to various performance measures (Kturk et al., 1996). In FMS parts are automatically transported under computer control through AGVs from one workstation to another for processing without human intervention (Mahadevan and Narendran, 1990). These vehicles move on a guide-paths network and transport materials among storages and machines in the industries. This is possible only by developments AGVS technology and computer control of material handlings.

Many authors have also studied the extensive literature on AGV-based MH systems and emphasised on AGV system design: (i) guide path network design, (Egbelu and Tanchoco, 1986; Huang, 1997; Kim and Tanchoco, 1991), (ii) vehicle routing (Broadbent et al., 1985; Tanchoco and Sinriech, 1992), (iii) traffic control (Koff, 1987), (iv) vehicle dispatching (Egbelu and Tanchoco, 1984), (v) optimal number of AGVs (Maxwell and Muckstadt, 1982; Egbelu, 1987; Tanchoco et al., 1987)

The AGVs not only cooperate in manufacturing but also act as a major component in the design and operation of FMS (Vinod and Solberg, l985). As well these also provide a lot of benefits including labour costs reduction, reduction in WIP, flexible material management, useful inventory modelling, automated guided vehicle systems used for better material flow, better quality promise, improved production, flexible routing and better utilization of space. But, there are several issues regarding design of AGVs which have not been solved satisfactorily by the researchers for easy and fool-proof implementation of FMSs. These issues include the path layout in the shop, number and capacity of AGVs, vehicle flexibility, position of idle vehicle and traffic management as well optimization of vehicle path and vehicle scheduling (Gotzl and Egblu, 1990). Now days in FMS system AGV is most popular choice due to its salient features such as driverless vehicle, battery power steered vehicle travelling along a directed path layout.

Cutting tool management is a critical issue in many automated manufacturing systems. The way tools are managed largely affects the productivity of a facility, as tooling has become one of the hindrances to efficient FMS performance (Kiran and Krason, 1988).

For an automated system to perform well, a better integration is also necessary between tooling facilities and other essential production functions, as well as part programming, part scheduling and process designing. In addition to critical issue in term of factory integration, tool management has direct cost implications and as per the industrial data report tooling cost account for 25-30% of total manufacturing cost in an automatic machining environment (Ayres et al., 1998). So the tooling decision largely effect the variable costs of production and the flexibility of a system, both in term of part mix and routing. Cutting tools are made of different materials which perform in different ways and have also diverse tool life (Sarin and Chen, 1987). Because tool wear is a complicated process involving phenomena such as crate information, shank wear, chipping and tempering (Cook, 1973).

Cemented carbide tools can perform better at high cutting speed as compared to high speed steel tools. Moreover, ceramic and CBN tools perform well on higher cutting speeds in comparison to cemented carbide tools. Cutting tool life varies with the type of material to be used. Resharpening of these cutting tools is done in a grinding section after wearing out their cutting edges. Shortage of tooling's contemplation may result in poor performance of an automated manufacturing system (DeWerra and Widmer, 1991).

2.2 COMPONENTS OF FMS

A group of manufacturing work stations associated with an AMH equipments and managed by integrated computer control system called FMS.

- **Primary components:** Primary components are most essential components of FMS system which consists of work centres used for machining, assembly, checking and washing etc.

  a. Workstations or Machine Tool: Workstations or Machine tools in this system are called as computer numerical control (CNC) machine tools which execute operations on part families. Now FMSs are also used for automated inspection, assembly workings and for sheet metal related work. A variety of workstations are as under:

    - Processing and machining centres;
    - Automatic load and unload stations;

- Assembly stations;
- Automated inspection stations;
- Sheet metal working stations

b. Automated Material Handling and Storage System: Different kind of automated material handling systems are utilized for the movement of work parts and subassemblies among the processing stations and storage purposes. AGVs are the most popular and useful media for material handling in automated and flexible manufacturing system (Vinod and solberg, l985). In a similar manner robots are also used for light and precision work in FMS environment for automated production lines in material handling. According to the researchers these material handling devices are very supportive and prime requirement for easy and fool-proof implementation of FMS.

The key areas of automated material handling and storage system are as follows:

- Handling of variety of work parts
- Easy Integration with computer control and other systems.
- Independent and random movement of parts among workstations
- Provisional storage
- Easy access for loading and unloading of work parts

c. A Supervisory Computer Control Network: A computer based network is used for managing the workstation activities and material handling system in FMS. The main purpose of such system is as follows:

- Production control
- Shuttle control
- Traffic management control
- Control of workstations
- Work management and monitoring system
- Distribution of control instruction to work station
- System performance monitoring and reporting

- **Secondary Components:** Secondary components are generally utilized for supporting the primary equipment in achieving the objective. These also having accommodating stations such as load-unload stations, fixtures, tools and pallet etc in combination with equipments like AGVs, robots and transport system for tooling etc.

  a. **Numerical Control (NC) Process Technology:** Numerical control (NC) systems play an important role in processing of modern production systems. Their application also attains substantial effects on flexibility and productivity. NC processes are often subjected to a great number of technological influences and require special and adapted systems for control. Programmable automation is a coded language that contains alphanumeric data for processing and maintaining relative positions between a cutting tool and a work part.

  b. **Spindle Tooling:** Spindle tooling is an automated tooling used in flexible manufacturing systems for improving the efficiency by unattended machining. In this system generally machining centres are equipped with high-capacity tool magazines and tool transport equipment. These are also automatically operated by NC handling units. Computer are used to manage machine tools and number of cutting tools according to machining setup and provide the benefits of time reduction, cost of production and less space due to proper tool management. Automated spindle tooling is also used to control the processing of parts and enhancing the flexibility for manufacturing the variety of parts. It also includes tooling strategies such as tool identification, tool setup, tool routing and tool replacement to complete the process.

  - **Work holding Fixtures:** Fixtures are used to locate and hold the component in a proper location and ensures that each component has been manufactured in the particular limits during the manufacturing process. Fixtures may vary in design as per their use. Fixtures can be utilized for non-uniform quality eliminations, frequent checking, positioning, individual marking and manufacturing processes. According to Mengawade et al., (2013) fixtures are used to increase the productivity and reduce operation time. These are also widely used in industries because of their features and advantages. These are more effective when used along with a set of locators and clamps. The locators determine the location and reference of a work piece, whereas clamps provide proper clamping forces on the fixture. Fixtures used in flexible manufacturing system like 4 and 5 axis for work holding, dual station, axis fixture, manual, pneumatic clamping and indexer with quick change and generally used for mass production machined parts in a time-efficient and cost-effective manner.

c. **Operations Management:** Operations management is a process of activities involved in converting inputs into outputs in a productive system. In company management people are also engaged in product and services like quality improvement, process design and selection, location planning, facilities planning and design of work systems in the organization. It also includes many interconnected activities, for example capacity planning, scheduling, forecasting, managing inventories, promising quality, motivation of employees and decisions regarding the facilities (Slack et al., 2010). This lead to the expansion of application of operations management for improving the productivity in service organizations.

2.3 ISSUES RELATED TO FMS

Various research papers in context to FMS have been studied and analyzed to understand the FMS scenario. Literature has many issues of FMS. Some of the important issues are as follows:

2.3.1 Material Handling Issues

In FMS material handling systems like automated guided vehicles (AGVs) are interconnected by a computers controlled system to interface with them. Various MHEs are in use for material handling in FMS and out of which AGVs have become the most accepted choice due to its effectiveness, accuracy and efficiency for material handling as compared to other type of material handling devices (Berman and Edan 2002). These automated guided vehicles are free from human intervention and battery powered operated stirring on a guided path layout. According to the Stecke and Soleberg (1981) an off board controller is utilized to transmit the signals in the forms of demands for load recognition, load position and other associated directives linked with the reception and delivery of load. AGVs are much more flexible in its operations due to its easy integration with FMS systems like NC machine tools, slave robots and computerized machine vision inspection stations. Various authors (Vis, 2006; Shankar and Vrat 1999; Mahadevan and

Narendran 1990) have discussed the following issues associated with material handling system design.

- Quantity of vehicle required
- Type of layout required in the shop
- Dispatching rules of vehicles present on shop floor
- Travel administration
- Collisions/ deadlocks avoidance prediction
- Position of idle Vehicle
- Routing flexibility
- Path optimization

Basically linear programming (L.P) and integer programming are optimization techniques used for network design. These techniques are easy and its path networks algorithms are limited to a precise topology like single loop, multi loops and meshes etc (Qiu et al., 2002). Egbelu and Tanchoco (1984) have advocated that the AGVs is a research topic for future concerning its guided track, idle position, pick and placing location and dispatching rules are being setup in a improved form for advance systems.

Numerous methods have proposed and executed for improvement in design and operational control of AVGs in various conditions by different research fellows. Literature analysis has revealed that academic institutions or research laboratories have proposed most of these methodologies but their real possibility in an industrial scenario is quite restricted. The above arguments definitely boost for a reasonable research work in the area of material handling specially AGVs. According to Tompkins and white (1984), about 13-30% of manufacturing cost can be saved by proper choice of material handling systems.

2.3.2 Tooling Issues

Tool management can be defined as a systematic arrangement of tooling for appropriate functioning with the machine tools and material handling devices. Selection of tooling in FMS is one of the most cumbersome and difficult issue (Tomek, 1986). Generally allocation of the tools in FMS is done by the computer to the machine according to the process sequence through tool management system (Shayan et al., 1995). It also improves in rationalization of tooling with the monitoring sensors. Machine set up time for the original product may be more due to lot of constraints related to the material handling devices, machine and cutting tools in FMS (Buyurgan et al, 2004).

According to the Keung et al. (2003) Flexible manufacturing system is used to produce variety of parts which are small in batches. Due to which the number of tool types, tool cost and about 25%-30% of on-going operation cost will also increase. By adopting the tool management system an accurate selection of tooling is possible (Buyargan et al., 2004). There are some critical tool issues which are treated as a hurdle in smooth production for any manufacturing industry. The various issues related to the tooling aspects of FMS are as follows:

- Better tool life
- Selection of proper tooling
- Better tool allocation
- Better tool monitoring
- Selection of proper tooling
- Multi-tasking tool

2.3.3 Social Issues

In flexible manufacturing technology increasing benefits are offered as the system integrates more elements of the plant operations. If FMS system is not managed properly then high investment itself may degrade the plant performance. The operations like maintenance, planning and controlling of computers are not possible without human assistance (Davis, l996). No doubt FMSs improve work environment, but, there are some social issues (i.e. labour issues), which are treated as the barricades in the implementation of flexible manufacturing system (Groover and Zimmer, 1984).These are as follows:

- Technology change
- Huge investment at initial level
- Employees’ resistance in transition to FMS
- Cut off in labour force
- Improvement in societal importance of employees

- Inclination of workforce towards service sector
- Unemployment

2.4 TYPES OF MATERIAL HANDLING DEVICES

Material handling devices are used for loading/picking and unloading/placing the raw material from one workstation to the other. Robots, AGVs and automated conveyors are the main components of the material handling system. Generally two types of material handling equipments are used to serve the purpose. Major types of material handling devices are as follows:

2.4.1 Conventional Material Handling Devices

- **Cranes:** A crane is a type of weight lifting machine which is used to transfer the material from one workstation to the other or to carry the material from one place to the other to move the loads in variable paths within a restricted area (Apple, 1972). These also provide more flexibility as compare to other type of material handling devices. Usually these cranes are equipped with a winch rope, wire ropes and chains etc. These cranes are used for various purposes in industries like automobile industry, paper industry, construction industry and many more.
- **All mechanical equipments operated by human labour:** Material handling involves the mechanical equipments and human labour to transfer the material between workstations, loading and unloading in port and a storage area like warehouses etc. The main sub-categories of mechanical equipments are as cranes, industrial trucks and non powered conveyors etc. which are operated by human being (Frazelle, 2002).
- **Monorail-guided trolleys:** Overhead monorails guided trolleys are generally used to lift large or heavy load horizontally. These may be manual or powered driven. Power-operated overhead monorails systems are used with single or multiple girders and may be top-running or bottom-running. These are low cost systems used to enhance productivity. According to Anjikar and Handa, (2013) overhead monorail guided material handling equipments are more suitable for the industry due to economical, maintenance and space availability point of view.

- **Hoist:** Hoist is a mechanism used for vertical lifting and lowering the load as per Institute of Industrial Engineers 2000. These are often put together with cranes and monorails for providing vertical translation capability. Generally these use chains or wire rope as its lifting medium.
- **Forklift trucks:** Fork lift truck is a motorized industrial truck which is used to lift and shift materials for short distances. According to Sisko (2003), fork lift truck could be useful for logistics service for moving the finished product in warehousing and for dispatching activities.

2.4.2 Non Conventional Material Handling Devices/Automated Material Handling Devices

The aim of using automated material handling systems is to move the material in the correct amount to the required position at exact time in the minimal cost without human intervention. Some of the automated materials handling equipments are as follows:

- **Automated guided vehicles:** Automated Guided Vehicles (AGVs) are the advanced material handling systems. These are generally used for moving the material from one workstation to the other without human intervention. These are the battery powered operated systems and have a capability to interface with various systems of production, material handling and storage equipments and with workstation for coordinating (Mahadevan and Narendran, 1990). The material movement is a most significant part of the productive and non productive environment which also contributes to a significant portion of the final products cost. The handling of materials must be performed safely, effectively and accurately. These are the better systems used to supply the right kind of materials at right position within the required time. These vehicles (AGVS) have become just like hot cake for the present and future industries.
- **Robotics:** A robot is a multifunctional and reprogrammable manipulator or a machine invented for performing a variety of tasks such as parts movement, materials movement and tools selection etc. Today’s modern robots are equipped with multiple capabilities to attain the predetermined quality at constant speed for repetitive tasks (Yuste et al., 2010). These devices are also capable in performing complex and tedious work. Industrial robots can easily improve the production as compare to human labour. The choice of robot is a difficult task for real industrial

situation. To overcome the difficulties multifaceted features and facilities have been included in robots like mobile robots with thinking and decision making capabilities. A decision on robot selection depends on various parameters such as cost, load carrying capacity, degree of automation, flexibility and working efficiency with safety.

- **Automated conveyor system:** Automated conveyor system is a highly sophisticated material handling equipment that used to transfer materials from one place to other via belt chain or rollers. These are especially useful for moving of heavy or bulky materials. These automated conveyor systems quickly follow the commands of computer for effective and efficient movement for a wide variety of materials. Utilization of such automated conveyors can enhance the productivity. According to Aruna and Beena (2015) for future automation, automated conveying systems are also easily available to fulfil the variety of needs of different industries.
- **Remote controlled equipment:** Remote control equipments are those equipments which are used to follow the newer technology based on automation at every step in every process. Under the remote control technology the equipments are used to follow the commands in the form of networking signals. Generally remote-controlled automation is used for manufacturing settings and maintenance applications. Super-robots without human assistance are the examples of remote control and networking intelligence. Sensors and programmable logic controller (PLC) are the main components of a remote control system to follow the instructions of a remote. Remote control equipments are the future equipments which will totally eliminate the need of human labour in future industries and problems in equipments can also diagnosis automatically. Hence use of such equipments will be beneficial for material handling and its control.

2.5 TOOLING USED IN FMS

2.5.1 Cutting Tools

In modern machining centres cutting tools plays an important role and has a significant effect on the performance of production systems. So, role of cutting tools management in modern manufacturing cannot be ignored. Due to advancement in manufacturing hardware and software technologies tools are automatically transported from tool magazine/crib to machine and between machines in shop floor. In modern flexible manufacturing machining systems correct cutting tools are available for a machine at correct time. FMS reduces the cutting tool inventories, cost and production delays. The machining centres are designed with automated tool-changers for allotting the cutters to the machine from an automatic tool magazine. Tooling capacity of these tool magazines may be in a range from16 to 80 cutting tools. In machining systems cutting tool related information is an integral part of decision making and shop floor controller ensures availability of cutting tools i.e. types, number of tools and tool life. To increase the efficiency of cutting tool use, tool database and related information necessary for enhancing the tool life cycle in cutting process (Svinjarevic et al., 2007).

2.5.2 Pallet and Fixtures

In FMS machining centres are equipped with two or more than two pallet shuttles to transfer the work part automatically to the spindle of the machining centre for performing the machining operation on it**.** In this system loading /unloading of the finish parts is done by the operator while the machine tool is engaged in machining the current part. This process reduces non-productive time on the machine. These are allowed for integration with machines, material handling and in process storage. Basically this palletized part is a steel disk having slots on surface. These slots are used to fasten the fixture to the pallet.

A fixture is a work-holding device used for holding the work part on machine table. According to Henriksen (1973) fixtures are the devices used for holding and maintaining the accuracy. Fixtures are the support devices that are widely used in manufacturing industries. These fixtures are categorized into various models like turning and machining fixtures, custom work holding fixtures, tombstone fixtures, indexing fixtures and fixtures for CNC machines. These fixtures are known for their easy operations, durability and optimum quality. These are also known as low production cost elements of machine shops and CNC shops.

2.6 FACTORS AFFECTING DESIGN AND OPERATION OF MATERIAL HANDLING SYSTEMS

The major factors which are affecting the material handling systems are as follows:

- **Speed of Delivery:** Speed of delivery means rate of material transfer between one work station to another through MHEs like AGVs, robots, conveyors, lifts, hoists and belts etc. Material transfer rate depends on various aspects such as size, shape, quantity of parts, distance between processing stations, location and type layout of different workstations, obstructions in between the path of movement, load delivery capacity and speed of the material handling equipment etc (Koste and Malhotra, 1998). The distribution and transportation network also an important parameter of material handling in reducing the cost and maximizing the delivery speed (Pramod and Banwet, 2010). Material transfer speed can also be boosted by engaging automated material handling systems that improve efficiency of material movement. Computers are also used to direct and actuate the process of materials in manufacturing through automatic loaders for pick and place items in storage and retrieval system.
- **Flexibility:** Flexibility of material handling may be defined as :
    - Ability to handle variety of parts of different shapes and sizes.
    - Ability to move materials through different paths.
    - Ability to be configured to different workstations.

  Material handling equipments such as AGVs, robots and conveyors are generally used for increasing the productivity by moving parts by different paths to various workstations for proper processing (Greenwood, 1988). Equipments utilized for such work must be capable to handle a variety of parts of different shapes and sizes for achieving flexibility in material handling. Flexibility not only decreases the labour cost, lead time but also guarantees better quality (Eade, 1989).

  Reveliotis (1999) suggested that flexibility act as an excellence for modern manufacturing system which is necessitated by the time based competition for the current manufacturing strategy.
- **Space requirement:** The requirement of space plays an important role in choice and utilization of MHEs in FMS. It is governed by various factors such as equipment to be used, workpart shape and quantity to be handled and integration with the different devices present in workstation. The requirement of space depends upon the material handling device to be used in work-station. For

example, robot and automated guided vehicle systems have different space requirement.

- **Safety:** Safety refers to the protection from the situations which may lead to the harm to the devices, injury and loss of persons working in the system. Poor management of material handling results into injuries along with increase in production cost. Sezen, (2003) illustrated conventional material handling accounts twenty five percent operational injuries. These injuries may be avoided by effective utilisation of automated material handling devices, advanced safety measures system. This will result into proper utilisation of man and machine in an industrial system.
- **Material flow path:** It basically refers to the flow of material from one location to another location through the defined path in minimum time and with greater precision. Si et al., (2009) stated that equipments such as forklift trucks, automated guided vehicle systems and conveyor system can be effectively utilized for effective material flow. Now a days software's are available for defining the material flow path and accordingly required modification may be carried out. Authors such as Bartholdi and Platzman, (1989); Bozer and Srinivasan, (1991); Tanchoco and Sinriech, (1992) specified that single loop guiding path and tandem path may be utilized for smooth material flow with decentralized control. The material flow path should be designed in such a way that it consists of inconsistency free route so that occurrence of production delays are minimum (Lee et al., 1993). The main objective of effective material flow path is to decrease the quantity of vehicles along with minimum travel time of all vehicles in the system (Akturk and Yilmaz, 1996).
- **Coordination with plant facilities:** It is a way of interaction of the manufacturing facilities with the MHEs. It plays a significant role in control of cost and production rate in an manufacturing system. Material handling equipments such as cranes, pallet trucks, forklift trucks, AGVS, AS/RS, conveyor systems and robots are widely used for movement of material from one location to other location in the plant (Sarkar et al., 2011). Sometimes, it becomes very difficult to coordinate the all MHEs with the other machine in the system due to their design parameters constraints and interfacing software's. In the present scenario, new automated

equipments are available which are extremely responsive, flexible and self-directed consisting of latest compatible communication modules.

- **Throughput rate:** It is considered as organized and valuable outcome of a system. Automated material handling equipments such as AGVs, conveyors, manipulators or robots are effectively utilized for smooth material flow with less material flow time. Smooth flow of material results into increased productivity as well as throughput production rate. Vander Meer (2000) stated that enhancement of capacity of such equipments result into output time reduction with increased production.
- **Automation:** It is a self actuating mechanism used to enhance productivity and quality which are beyond the reach of human labour. It is considered as a step beyond mechanization which is used to increase speed, load capacity and repeatability automatically. It can be effectively utilized for increasing the economy by enhancement in productivity, improvement in quality, work flow, consistency of process/product and reduction in material handling time. MHEs play an important role in fulfilling the requirements and potential for performance, reliability and safety at a reasonable cost.
- **Plant layout:** Plant layout refers to systematic arrangement of machine to work with material and man inside the plant and preparation of operation sequence for equipment layout for all feasible system solutions in which all required systems can be easily integrate successfully and economically within the required time. Malakooti and D'Souza (1987) stated that the design of plant layout should be done in such a way that it can be utilized to minimize the time and materials handling cost, maximize the flexibility and production rate. Different type of the layouts such as single row, double row, cluster type, loop, circular, tandem, cell type, work type and machine type are widely used plan layouts as per the requirement of plant set up. The main objective of systematic plant layout is to maximise the production rate at minimum cost. So, it is considered as an important factor in the selection of MHEs.
- **Load carrying capacity:** It means a capacity of MHE by which it can shift the maximum load from one location to another location. Multiple-load carriers are also available for transferring the material. Ozden (1988) suggested many

strategies for the cutback in manufacturing cycle time and scheduling of operations related to multiple-load carriers.

- **System networking:** It is a way of synchronization in terms of communication with plant facilities to refine the general performance of an organization. Communication networking has an effective utility in governing and interfacing the automated MHEs with computer control (Chan et al., 2012). These equipments usually communicate and interface in two ways. In first way, communication between AGV and its interface by means of remote control, scanner and vision system when the vehicle reaches the station for picking or delivering the part. In second way, it occurs when a station complete its processing operation on the part, afterwards part is advanced to next station as per part scheduling and routing (governed by central computer control). Here, all communications are done with the help of central computer and there is no provision for direct communications between the machines. Satoshi et al. (2007); Park et al., (2009) illustrated that vehicle is controlled by different colours and patterns painted on the lane. So, it is considered as an important parameter in selection of MHE.
- **Economics:** Economics is also a most important consideration for the selection of MHEs. Economy of the plant also increases as increase in productivity, quality and enhanced work flow by the proper selection of MHE. Fundamentally, material handling is related with the flow of materials, work-in-process minimization inside and outside the plant (Sujono and Lashkari, 2007). The main objective is to transfer the material, parts and finished goods from one location to another location in required time, at accurate location, in right form and orientation with minimum total cost. Tompkins et al. (1996) illustrated that that about 20-50% of the total operating expenses accounts for material handling in a manufacturing system. MH operations account for 80% to 95% of total time spent between customer orders and shipment of final products. Processing time and processing cost can also be reduced by implementing the techniques and strategies of effective material handling. The strategies are extending product life cycle time, reducing productivity losses, fully utilization of space, equipments, safety regulations and by minimizing capital expenditures (Muller, 1983).

2.7 FACTORS AFFECTING SOCIAL ISSUES

The various factors affecting the social issues of FMS are as follows:

- **Unemployment:** Modern technologies are being improved day by day and their result will induce up a big change in the industries and society. Beginning of latest era of computerization in manufacturing will minimize the manpower demand. Latest developments in technologies can cause of panic in the courage of earthborn labour like unemployment (Aven et al., 2007). As a result of increased productiveness by automation, non-nature of new jobs for mortal labour and ontogeny population are the force causes which create an anxiety of unemployment in the choice of humanistic labour (Groover, 1987).
- **Reduction in labour force:** Adoption of latest expensive technology and curtailment of manpower is an adult amalgamation system in underdeveloped country like India where the liberal and economical workforce is easily available. Chan and Swarankar (2006) have advocated that it has become difficult to survive in market without implementing advance technology and automation in term of cost, quality and service. The use of automation technology can increase the production rate at an advanced level than the manpower efforts, hence such latest technology not only improves the productivity but it will also minimize the workforce.
- **Fear of technology change:** Utilization of FMS will prove a big revolution for the industries and the society in term of productivity and improved economy but it creates a panic in the mindset of labour due to non conversant with technical knowledge and utilization of latest machines. They may feel the inconvenience like idealness, anxiety, harassment and may be antiquated in extremity of knowledge and ability after execution of most modern technology (Hua et al., 2005).
- **Reduction of purchase power due to unemployment and high cost of product:** Industrial automation will decrease the purchase power of items because of joblessness of workers and high price of product. Adoption of newer technology means replacement of workers and creation of unemployment. They will not get the salary to purchase the high cost manufactured goods brought by automation in the market. It may result economic depression in the workers.

- **Initially high capital investment:** According to the authors (e.g. Kumar et al., 2006b; Rao and Deshmukh, 1994) a huge capital investment is required for the FMS installation and its automated system setups. Therefore, starting with a higher investment is not a choice for everyone. That's why high expenditure of FMS and its high degree of uncertainty are the main causes for its low response.
- **Retrenchment of employees:** In the current scenario labour cutback is a major concern in India (Shastri et al., 2010). As per the labour survey reports quantity of labour is increasing about 2.5% yearly in as compare to the employment rate 2.3%. Due to unskilled labour force, lack of specific knowledge of work and advancement in technologies are the major causes of labour reduction as compare to skilled labour in market. Similarly FMS may also a hurdle for new candidates to the job market (Lee, 2005).
- **Employees' resistance in transition to FMS:** Grieco et al., (2001) have advocated that FMS is a technique which deals with high level of mechanization and changes the human concert in the organization. In a country like India employees' are not ready to adopt FMS because they think adoption of such technology will bring up a lot of problems in terms of unemployment, retrenchment, harassment and loss of benefits like perks and incentives (Raj et al., 2007a). So, employees are not agree to transit to FMS.
- **Improved quality of product:** Quality has a very vital role in achieving its mission for any organisation. Use of quality standards in an industry not only advances the value of the product but also increases the workability of people and reputation of the organisation. The use of automation can improve quality and quantity both in term of accuracy in comparison to conventional methods. Thus, automation is a phase for improvement and living a better life to employees. So, production of superior quality product and provision of better services to the consumers and society quickly are the main sources for their survival (Oginni and Ogunyomi, 2012).
- **Availability of more variety of products:** FMS is a technology which can process a variety of products easily as per customers demand. This technology provides more options to select customized manufactured goods for the similar

cost and same motive. Hence, more variety of goods can be available at minimal cost to the society (Pisano, 1994).

- **Change in social status of employees:** Use of FMS not only improves the status of any organization but also improves the technical knowledge of employees and makes them more employable for the advanced technological industries. With due regard better qualification and handsome wages also enhance the social standard of workers (Dutton and Dukerich, 1991).
- **Long-term committed relationships with the vendors:** Vendors, raw material and spares are the major problem in the execution of FMS (Raj et al. 2006). Vendors are not able to make long term association with the industries due to fast revolution in technology, changes in goods, quality of raw material and setup of advance hardware and software's which needs time for being prepared . So, lack of vendors and hindrance in supply of modern machinery are the main barricade in FMS (Aven et al., 2007).
- **Improvement in salaries/incentives:** Utilization of FMS equipments will fetch the profit to the industries and the employees who are related with this atmosphere for getting high pay and monetary benefits than the others. According to Dutton and Dukerich (1991), workforce of these industries not only has the social status but also get the financial benefits. Enhancement in salaries, incentives and perks are also a reason to motivate the manual labour towards the industries (Nagar et al., 2013).
- **Trend of labour towards service sector:** Recently it has been found that shifting of labour from industries to service sector has become more common in the India. Institutions and Society are more accountable for the evolution of this inclination. The increase in regulation services, speedy development in privacy sector in India has utilized a share of indisputable labour, or else has gone into industries. As a result of high salaries offers and liberty of working peoples are changing from industrial sector to service sector. Some examples of service sector are as, banking, insurance, medical line, teaching, personal services, direct sales and marketing etc**.**
- **Improved technical skill and education of employees:** Practically trained and high knowledgeable workers are the major needs in executing the FMS for

modern industries. Use of uneducated and unskilled labour may lead to a greater financial loss to the management. Both firms and government are offering skilled training to their workers for the adornment according to their working environment. Skill development and specialize programmes are more beneficial for increasing the productivity of FMS in industries (Liorens et al., 2005). Hence, employment of technically trained and educated workers is always beneficial to those industries which are using advance machining systems.

- **Supportive policies of the government:** Higher expenditure of FMS equipments installation at initial stage and pressure of labour agitations against implementation of FMS. According to Aven et al. (2007) deficient of government decisions, mistrustful policies and interruption in funding policies are the main difficulty in FMS execution. As per the suggestions of Raj et al. (2008) the government should make clear cut regulations and separate budget policies for the industries in the form of easy taxation process, easy licence procedure for export-import of materials, industry development loans and investment in technology for boosting the manufacturing divisions. It may prove advantageous for the future industries and society for living quality life.

2.8 FACTORS AFFECTING PRODUCTIVITY AND FLEXIBILITY OF FMS

The various factors affecting the productivity and flexibility of FMS are as follows:

2.8.1 Factors Affecting Productivity of FMS

- **High production rate:** In flexible manufacturing system high production rate means to make a component according to high customized production requirements with good quality and cost effectiveness so that it can meet the customer demands within the specified time frame. Automated machines and its accessories like CNC turning, CNC milling, VMC, head indexer, head changer, along with material-handling devices, in/out shuttle, conveyers, and automated guided vehicle and machining centre are mainly the sources of producing high production.

- **Reduced lead time:** Reduced lead time means reduction in manufacturing time between the machines through transportation, setup and changeover time to complete the process and deliver it to the consumer within the minimum time frame called as reduction in lead time (Keong et al., 2005). FMS generally employs automated machines like CNC which consists of automatic tool changing system for reducing operational set-up time (Saraswat et al., 2015).

- **Flow path optimization:** The process of improvement and minimization in material flow routing within the shortest travel time called flow path optimization (Ganesharajah and Sriskandarajah, 1995). According to Bayazit (2005) an automated system like automated material handling and storage etc used to reduce material movement and also assists in improving the productive time by using routing flexibility of the system. Many researchers (Michalewicz and Schoenauer, 1996; Deb et al., 2002; Fauadi and Murata, 2010) have also used the different path optimization techniques like genetic algorithms (GA), metaheuristics and particle swarm optimization etc.
- **High machine utilization:** High machine utilization refers to the percentage of time that a machine is actually in use. Computerized loading and unloading of machines are the main sources of enhancing the productivity and machine utilization. In FMS environment fully utilization of machines is also one of the main resources for producing more variety of parts with more flexibility.
- **Reduced scrap:** Scrap rate is also a main component of a production system which reduces the overall efficiency of the production system. To get rid of this problem special purpose equipment designed for production, CNC machines and computer control systems can also be used to reduce the scrap rate with the greatest possible efficiency (Groover, 2006).
- **Efficient layout arrangement:** Efficient layout means a systematic and useful arrangement of machines, equipments, services related to manufacturing and departments’ in an industry. Utilization of optimum layouts have become a valuable tool for cost reduction and enhancement of productivity (Naik and Kallurkar, 2016). By the use of efficient layout arrangement flow of materials, space, cost and time can be optimized to a great extent and overall productivity of the plant can improve.
- **Effective material handling:** It is considered as crucial and main part of any production system. Effective material handling means supply of correct amount of

the right material, in correct condition, in true position and for right cost by by means of an accurate method. Efficient material management not only enhances the production process but also improves in plant facilities like proper material flow, reduction in manpower, reduction in lead time and increase in system flexibility etc.

- **Effective tool management:** In effective tool management all type of cutting tools plays a vital role in accomplishing productive efficiencies. Adoption of advanced tooling and intelligent machining system strategies meet the evolving needs. Proper tool management can maximizes the value of their investments by the optimize use of modern machinery.
- **Reduction in man power:** Reduction in manpower is a reason for adoption of newly developed technology. Now industries have become economical in term of expenditure, quality excellence and services. According to Chan and Swarankar (2006) advance technology with mechanised automation i.e. FMS has become essential as per demand and survival of industries. Use of automation can enhance the production by automated machines than the workforce, so implementation of modern technology will be beneficial in reducing the requirement of man power to a great extent. manage
- **High flexibility:** High flexibility is the main benefit of FMS. High flexibility means production of variety of components on machine which may lead to reduction in production. Use of high flexibility in other systems may create interaction problem between the other systems of flexible manufacturing. So, very high flexibility is not desirable in the production system.

2.8.2 Factors Affecting Flexibility of FMS

- **Utilization of automated material handling systems:** Automated material handling systems are used to perform as a combined task in a manufacturing system (Sujono and Lashkari, 2007). An effective material handling equipment used to pick and deliver materials from one workstation to the other. Kulak (2005) also advocated that use of these automated systems improves in various stages of manufactured goods in term of cost, material movement, production processes, system flexibility, manufacturing lead time and cost. Material handling equipments like, computer based automated conveyors, AGVs, industrial trucks, cranes, rotary tables, automatic part feeders and industrial robots.

- **Flexible fixturing:** Flexible fixturing are the devices used for holding a variety of product configurations. Fixtures are generally designed to hold any part design configuration in the work handling system. These are generally placed on the top part of pallet with quick- change features for a given part (Groover, 2006). Flexibility in the fixtures arrangements can be increased by introducing PLC-based components which automatically follow the instructions to hold the work part in any position within a part family to minimize the setup time and increasing the productivity (Hiremath et al., 2016).
- **Automation:** Automation is used to increase flexibility, productivity, quality, work speed and cost reduction with minimization of time by the utilization of automated machines like NC, CNC and DNCs along with the automated material handling systems like Conveyors, AGVs and robots. Use of automation may increase the flexibility up to a great extent without human intervention.
- **Combination of operation:** Combination of operations means reduction in the workstations used for part manufacturing. According to Groover (2006) it may lead high efficiency in mass production where each operation is performed continuously at each workstation by combining the two or more operations with single cutting tool.
- **Arrangement of machines:** Machines are arranged in a specific layout with the combination of part and tool handling devices so that operations can be easily perform on a same kind of part family in a specific manner to enhance the production and reduce the cost and manufacturing lead time. Thus systematic arrangement of machines can increase efficiency and flexibility of the system up to a great extent.
- **Traffic Management:** Traffic management means management of the primary and secondary material handling systems in such a manner that parts reaches the correct location at right time in exact condition for right movement of part to the workstation. Traffic management includes automated workstations, conveyors, automated guided vehicles and robots to follow the traffic rules of part routing. Better traffic management can improve the flexibility of the system.

- **Throughput Rate:** A systematic and effective output of a system which is used for maximizing the throughput in terms of production (Vander Meer, 2000). It is also an important criterion for production system in flexible manufacturing environment. By the utilization of automated MHEs like AGVs, automated conveyors, manipulators or robots, minimization of lead through time and expected throughput rate in terms of revenue, flexibility and productivity can be increased.

- **Plant Layout:** It is a systematic arrangement of man machine, material and method in the plant. It is also a most important element of production system for maximizing the production rate at minimal cost. Plant facilities like automated machines and automated material handling systems used to provide a greater flexibility to achieve the required rate of production.

- **Product variety:** It is an ability to change over from one product to the other economically and quickly. Flexible automated systems are competent in manufacturing a wide range of parts without loss of time (Groover, 2003). In flexible manufacturing system no production time is lost during reprogramming and changing the physical set-up like tooling, fixtures and machine setting. Hence flexibility of a production system associated with the types of usable to be made.

- **Tool Interchangeable capacity:** Tool interchangability capacity means replacement of Tools. Tool management policy is adopted for right tool available in right time at right sequence. Tool magazines and automated tool changers are the devices which are generally used for processing a job. Tool magazine capacity varies from 30 -100 tools or many more in machining centres for reducing the impact of capacity constraint. This results in high spindle idle times between two different operations. Under tool management policy automatic selection of a tool set for a specified group of components, the optimization criterion being either the optimal machining cost or minimum number of machine stoppages or a combination of both (Zhang and Hinduja, 1995).

- **Multitasking tools:** Multitasking tools means machine tool which can perform the many number of operations on a single machine tool. Multitasking tools have been developed recently with having advanced functions and are capable in performing special machining operations which were previously difficult to integrate for processing. Use of these multitasking tools has high - working efficiency with the reduction of processing time with a greater flexibility. For example CNC lathe machine to 5 axis advance machining centre with improved productivity.

- **Reconfigurable Tools:** The reconfigurable manufacturing machine tool systems are those which are designed for instant adjustment in structure means changes in hardware and software component. These are designed for quickly adjustment in production facility as well in a part family to adjust the abrupt changes in regulatory requirements and rapid upgrading and quick integration of new process technology. Use of such tools can increase the flexibility of manufacturing systems (Malhotra et al., 2009).

2.9 METHODOLOGIES USED

The following methodologies have been used in this work for analysis of material handling tooling and social issues are as follows:

2.9.1 Interpretive Structural Modelling (ISM) Approach

ISM is logical approach that assists the people to structure their knowledge in form of graph (Warfield 1974; 1987). It also converts poor mental models in to graphical and hierarchical models (Sage, 1977). This methodology is used for recognizing and briefing interactions between various elements (Mandal and Deshmukh, 1994). ISM approach can be effectively used for solving the complex problems related to selection of MHEs (Pramod and Banwet, 2010; Nagar and Raj, 2012 a).

ISM approach represents the information in form of digraph or a matrix (Porter, et al., 1980; Singh et al., 2003; Faisel et al., 2006; Attri et al., 2013c). ISM technique is capable to crack the complexity in to meaningful information to deal with human mind easily. This approach has been used for analyzing the mutual relationships between material handling equipment selection variables affecting the flexibility in flexible manufacturing system (FMS).

ISM approach is considered as beneficial when a multilevel research design is necessary (Klein and Kozlowski, 2000). Raj et al. (2008) applied ISM approach in field of flexible manufacturing systems. Parmod and Banwet (2010) utilized ISM methodology in developing the model for inhibitors of telecom service supply chain. Larsen and Lewis (2007) applied this approach for analyzing the innovation barriers. Nagar and Raj (2012 a) have also applied ISM methodology for mitigation of risk in advance manufacturing technology implementation.

ISM methodology consists of following steps:

- Finding out the social implications through survey which are important for the problem solving.
- Grouping a suitable correlation among social implications regarding the pairs of social implications.
- Development of a SSIM of specified elements. It will illustrate the pair-wise relation between social implications.
- Expansion of a reachability matrix (RM) from SSIM.
- Verification of matrix by introduction of transitivity.
- Divide the RM in to different levels.
- Conversion of the RM matrix into conical form.
- Develop a directed plot based on above correlations stated in RM.
- Convert the digraph into an ISM model.
- Test out the model for conceptual inconsistency and make the necessary modifications if required.

ISM is an analysis method used in different aspects by the various researchers. Some ISM applications available in the literature have been shown in Table 2.1

Table 2.1: Brief review of ISM applications

S. No	Author(s)	Applications
1	Singh (2011)	Development of a model for the coordination in supply chain of SME's
2	Raj et al. (2012)	Modelling the factors affecting flexibility in FMS
3	Attri et al. (2013b)	Analysing the Total Productive Maintenance implementation enablers
4	Nagar and Raj (2012a)	Development of framework for risk mitigation in implementation of AMTs
5	Panahifar et al. (2014)	Analysis of Collaborative Planning, Forecasting and Replenishment (CPFR) implementation barriers
6	Trivedi et al. (2015)	Development of ISM based hierarchical model for waste management
7	Vasantha kumar et al. (2016)	analysis of factors influencing lean remanufacturing practices

2.9.2 Graph Theoretic Approach (GTA)

GTA is a very influential procedure that can be used for different fields in to assessing the inter-relationship between different variables or sub variables of material handling and give an artificial score for the whole method. In the current research, this technique is used in deciding the usefulness of variables for automated material handling. The success of material handling system variables is based on their individual nature and the relations with other variables**.** The system presenting these variables and their interactions in the form of a model called the graph representation. These connections may be direction-dependent as discussed here. If connections are not dependent on direction then automated material handling for FMS is shown by an undirected graph; if direction dependent then it is known as digraph representation. The graph theoretic illustration is consistent for visual study, it can be easily processed by a computer in the form of mathematical unit, whereas the conventional representations, such as block diagrams and flow charts. Though, these visual analysis, do not show connections between variables and are not suitable for further study and cannot be processed in mathematical form. Then digraphs are more suitable for graph theory process.

This process incorporates the following components:

- Digraph illustration
- Matrix representation
- Permanent function interpretation.

The digraph illustrates the visible show of the variables and their interdependence. Matrixes are transforming into mathematical form as a model and helps in solving the intensity of risk (IOR).

GTA can be useful in different fields. According to the various authors (i.e. Faisal et al., 2006; Grover et al., 2004; Rao and Gandhi, 2002 and Wani and Gandhi, 1999) this technique has been utilized for various applications as showing in literature for the improvement in mechanical systems. According to Rao and Gandhi (2002) GTA digraph and matrix approach can be used for failure cause analysis of machine tools. Different applications of GTA used in the literature are shown in Table 2.2.

Table 2.2: Concise review of GTA applications

S. No	Author(s)	Applications
1	Raj et al. (2010)	To evaluate the intensity of barriers in the FMS execution
2	Saha and Grover (2011)	Evaluation of critical factors of website performance
3	Attri et al. (2013d)	Multi-attribute decision making (MADM) technique
4	Dev et al. (2014)	Modeling and System analysis of a combined power plant cycle
5	Xue et al. (2015)	A review of graph theory application research in gears

The following steps engaged in GTA method are as under:

- Identify various variables that affect behaviour of material handling equipments effectiveness due to plant layout, coordination with plant facilities, system networking and their type.
- Identify the sub variables affecting different categories of step (1).

- Develop sub variables digraph considering attributes affecting each sub-variable. The quantity of nodes must be equal to the quantity of variables and edges should match to their interdependence (v_{ij}).
- A digraph has been developed among the sub-variables of material handling system equipments dependent on the relations with them.
- Development of the sub variables matrix at the subsystem level.
- Find the value of permanent function at every subsystem level and their interdependence are established on the basis of the material handling equipments effectiveness, availability of statistical data in the industry and the experience of material handling specialists.
- Develop sub-variables matrix n × n with diagonal elements of V_i for each variable and the off diagonal elements v_{ij} are indicative with them.
- Calculate Permanent function Value of the material handling variables' matrix. Basically the value of EIMH slows down the strength of various variables in any establishment due to the presence of changed variables and their interdependence.
- Listing the different material handling equipments in ascending order based on their EIMH values.
- The effectiveness of material handling equipments can be evaluated recorded and documented for further analysis as discussed above.

2.9.3 Fuzzy Analytic Hierarchy Process (FAHP) Method

The Fuzzy Analytic Hierarchy Process (FAHP) is an advanced MCDM approach and it was developed by Saaty (1994, 2000). Bevilacqua et al. (2004) suggested that AHP deals with difficult problems of qualitative and quantitative features of a problem as a useful tool. These days, there are many multi criterion decision making methods are in use. The combination of Fuzzy AHP is broadly used for solving complex decision making problems. Decision makers use a fundamental 1-5 scale of absolute numbers to make pair wise comparison in the Saaty's approach. The major gain of FAHP technique is that it provides to work at certain intervals in judgments rather than certain absolute values. In this method, fuzzy numbers are utilized for problem solution instead of crisp numbers. Chen and Hwang (1992) have proposed this method.

FAHP method is frequently used due to ability of solving the complex problems in different areas (Table 2.3) such as supplier selection and evaluation (Sun, 2010; Chamodrakas et al., 2010; Krishnendu et al., 2012; Kılınçcı and Önal, 2011); calculating performance of national R&D institutes (Jyoti and Deshmukh, 2008); optimal hospital locatin selection; marketing strategy selection (Mohaghar et.al., 2012) and personnel selection problems (Güngör et.al., 2009).

Table 2.3: Short review of FAHP applications

S. No	Author(s)	Applications
1	Klınçcı and Önal, (2011)	Supplier selection by FAHP approach for a washing machine manufacturing company
2	Chin and Liao (2011)	New product segmented under price strategy
3	Krishnendu et al (2012)	Supplier Selection
4	Vatanseverand Kazançoğlu (2014)	Machine selection problems and an application
5	Lo and Sudjatmika (2016)	Multi-Criteria technique for a supplier segmentation through modified FAHP in supply chain management

2.9.4 Modified Grey Relational Analysis (M-GRA) Method

Grey-relational analysis is a technique which is used to accomplish a relational analysis of the uncertainty of a system model and the partial information.GRA is also known as the derived evaluation method based on grey system theory. Various authors (e.g. Deng, 2005; Gnanasekaran et al., 2010; Maniya and Bhatt, 2011; Raj et al., 2012) have used this technique in various fields (Table 2.4) such as supplier selection, economics, agriculture, marketing, selection of advance manufacturing systems and material handling equipments. In this current research MGRA has been presented as MADM method.

Table 2.4: Short review of MGRA applications

S. No	Author(s)	Applications
1	Hsu and Wen (2000)	Airline network design
2	Altinel and Oncan (2005)	Design of unidirectional cyclic layouts
3	Yang and Chen (2006)	Supplier selection
4	Gnanasekaran et al. (2010)	Supplier selection an automobile industry
5	Maniya and Bhatt (2011)	Multi-attribute selection of AGV

2.9.5 Linear Programming (L.P) Approach

Linear Programming (LP) is a method used for finding the optimal solution for a known objective function. L.P is generally used for maximizing the profit or minimizing the cost of the following form (Fagoyinbo, 2008; Martin, 1983)

$Z = C1X2 + C2X2 + C3X3 + \dots\dots\dots\dots + CnXn$

This method is useful for allotment of 'scarce' of 'limited' resources, means resources are not present in unlimited quantity in the forecast period. Linear programming approach is a scientific problem-solving technique for management. This technique also has been used in other areas such as: oil refinery sector, energy planning area, agriculture sector, pollution control purposes, airlines frequency checks, transportation planning, production planning schedule, , resources and commodity prices, research and development, human health care system, education system, problem of risks and uncertainties about the behaviour of customers and many more. It is also supportive tool for the management in finding out the best decision among the alternative decision potentials (Turban, 1993).

2.9.6 Particle Swarm Optimization (PSO) Approach

This method was suggested by Dr. Eberhart and Dr. Kennedy in 1995. Generation of PSO was inspired by fish schooling and social behaviour of bird flocking. This technique is also known as stochastic optimization technique which is totally based on population. It has also many similarities with GA and other computation techniques. It is a process of revising the data generations' and initializing a population of random solutions for optima searches. Though, PSO does not have any GA type evolution operators like crossover and mutation. In this method possible solutions are called particles which fly throughout the problem space by follow the existing optimum particles.

Various authors (i.e. Eberhart and Shi 1998a; Kennedy; Eberhart and Shi, 2001) have also applied this technique for evolving weights and structure in case of neural networks. Eberhart and Hu (1999) used this to analyze human tremor register, Wachowiak et al., (2004) utilize this for 3D biomedical image work, Messerschmidt and Engelbrecht (2004) for developing play games and Yoshida et al. (2000) for control reactive power and voltage etc. PSO can be applied to resolve mainly optimization problems. Table 2.5 shows the applications of PSO.

Table 2.5: Brief review of PSO applications

S. No	Author(s)	Applications
1	Nearchou (2006)	Loop layout design problem
2	Satheesh et al. (2008)	Loop layout Design in FMS using non-traditional optimization technique
3	Fauadi and Murata (2010)	Minimization of space for machines and AGV scheduling
4	Nanvala and Awari (2011)	Scheduling of FMS
5	Shivhare and Bansal (2014)	Layout Optimization in Flexible Manufacturing

2.10 CONCLUSION

It has been concluded that manufacturing industries who wants to adopt and implement FMS should take care of different issues i.e. material handling, tooling and social issues. For successful implementation of such advance technology and cope up with high global competition there is a need of deeply understanding of various concerned issues for its implementation in industries concerned with society to fetch the maximum benefits. Various issues related to FMS have been reviewed and addressed. The important information’s regarding effective utilization of FMS has also been found. On the basis of literature, the main focused issues have been identified and analyzed as a material handling especially with AGV, utilization of combined and modified cutting tools for enhancing the productivity and flexibility with proper tool management and issues with human elements as a society regarding FMS. Finally, it is concluded that manufacturing industries should adopt the latest and suitable technology (i.e. tools and techniques) with passage of time and new strategies should also be developed to analyze the critical issues in the key areas so that the identified issues can be resolved at the earliest stage to achieve the target and maximize the profit.

CHAPTER III

QUESTIONNAIRE ADMINISTRATION AND DESCRIPTIVE STATISTICS

3.1 INTRODUCTION

In this chapter, the outcomes of a questionnaire based survey have been presented with the objective to examine some issues related to the material handling, tooling and social issues of flexible manufacturing system. Key observations received during the survey have been discussed and analyzed. Some other aspects related to questionnaire development and its administration in industry has been discussed.

3.2 QUESTIONNAIRE DEVELOPMENT

The questionnaire based survey was under taken to deal with different issues related to the material handling, tooling and social issues of flexible manufacturing system according to Indian industries. The questionnaire was designed and developed using literature review, experts' opinion of their field and academician's vision in this area. Respondents are not so enthusiastic regarding such surveys and generally reluctant to spare time to respond such questionnaires, therefore the questionnaire was designed in such a manner so that responses can be given with minimum time and effort. The questionnaire was developed by using five point (1 - 5) Likert scale. On this scale 1 represent very low, 2 represent low, 3 represent moderate, 4 stand for High and 5 represent very high i.e. very important. The questionnaire was divided into five sections. Section-1 deal with the company profile, section -2 deals with issues related with FMS, section-3 deal with issues related to material handling, section-4 deal with issues related to tooling and section-5 deals with social issues related to workforce in flexible manufacturing system.

3.3 QUESTIONNAIRE ADMINISTRATION

Several survey techniques were adopted for the administration of questionnaires such as self-contact, e-mail and postal survey etc. Survey was accomplished in medium and large scale Indian industries. The managing directors/ vice presidents/ chief-executives/ general managers/ plant heads/ senior executives and managers of various domains were contacted for their reply. Total, 300 questionnaires were floated to different type of Indian manufacturing companies for attaining their response.

3.4 QUESTIONNAIRE SURVEY RESPONSE AND RESPONDENTS PROFILE

Out of the 300 questionnaires, 74 complete questionnaires were obtained. Nine questionnaires were imperfectly filled and have leftover for further use. The conducted survey provides a response rate of 40.54 % which is not miniature for such surveys (Malhotra and Grover, 1998).

3.5 OBSERVATIONS FROM THE SURVEY

The present trends show a very important step towards adoption of Flexible manufacturing system in Indian manufacturing industries. The various important issues related to flexible manufacturing systems (FMS), material handling, tooling and social issues were emphasized in this survey. The survey results have been presented in the following sections.

3.5.1 Data Related to Variables in Improving the Manufacturing System

In this case, issues related to FMS as indicated by respondents and implementation of variables in improving the manufacturing system. From the Table 3.1 it is clear that improvement in quality (Mean= 4.58) is the most important variable for improving the manufacturing system**.**

Table 3.1 Response for variables in improving the manufacturing system

S. No	Description	Avg. score
A	Lead time reduction	4.07
B	Reduction of maintenance cost	3.74
C	Improvement in quality	4.58
D	Work-in-process inventory reduction	4.14
E	Set-up time reduction	4.16
F	Manpower reduction	4.11
G	Reduction in material handling time and distance by using AGV, Robot, Conveyor and other material handling systems	4.03
H	Reduction in tool changing time	3.84
I	Reduction in space utilization	3.89
J	Reduction in scrap through proper cutting tools.	4.03
K	Speed of response	4.08
L	Increase in machine utilization	4.26
M	Reduction in tooling cost	3.93
N	Combination of operations	3.93
O	Reconfiguration of machine tools	3.65
P	Capability to handle new products	4.22
Q	Flexibility in production	4.16
R	Automation	4.15
S	Use of flexible fixtures	3.99
T	Skilled workers	4.12

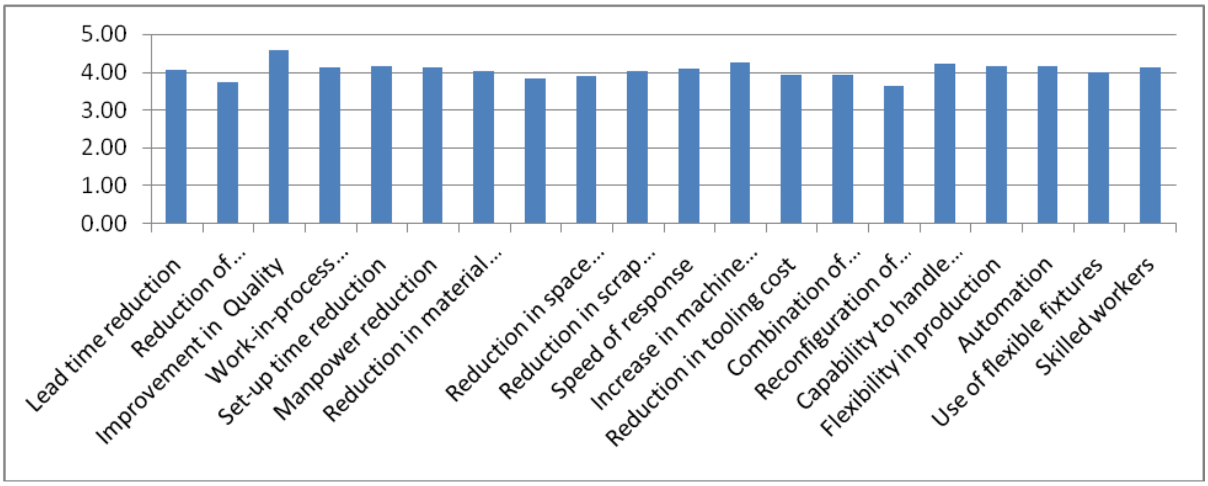


Figure 3.1: Variables in improving the manufacturing system

3.5.2 Data Related to Reasons for Adopting Material Handling Systems like AGV, Robot, Conveyor etc and Tooling in FMS

Most important type of reasons for adopting material handling systems like AGV, Robot, Conveyor etc and tooling in FMS indicated by the respondents are to improve productivity (Mean=4.20), to improve consistency (Mean= 4.08), reduction in waiting time (Mean=4.07). Similarly other variables score indicated by the respondents are presented in Table 3.2.

Table 3.2 Reasons for adopting material handling systems

S. No	Description	Avg. score
A	Smooth flow of material from one machine to another	3.91
B	To improve productivity	4.20
C	To improve consistency	4.08
D	To improve space utilization	3.84
E	To get unmanned operations	3.73
F	Forced by technology/market demand	3.50
G	To Reduce waiting time	4.07
H	Automated loading and unloading the parts on machines	3.82
I	Freedom from labour related threats	3.86
J	For improving machines integration	4.07

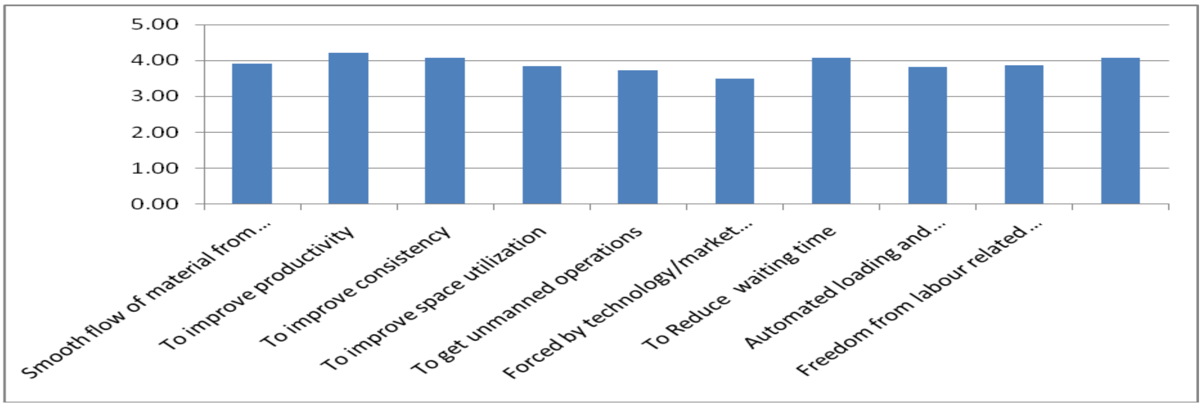


Figure 3.2: Reasons for adopting material handling systems like agv, robot, conveyor etc and tooling in FMS

3.5.3 Preference for Future Automated Material Handling, Tooling in Manufacturing System of Company

Future automated material handling, tooling in manufacturing systems indicated by the respondents are flexible manufacturing system (FMS) with material handling devices (Mean=3.89), CNC machines supported by automated material handling systems like AGVs, Conveyor, robots and other advance material handling systems (Mean= 3.76). Similarly other variables score indicated by the respondents are presented in Table 3.3.

Table 3.3 Preference for future automated material handling, tooling in manufacturing system of company

S. No	Description	Avg. score
A	CNC machines supported by conventional material handling devices	3.28
B	Flexible manufacturing system (FMS) with material handling devices	3.89
C	Total computer integrated manufacturing (CIM) system	3.50
D	Humanized flexible manufacturing system (HFMS) in which human resources are utilized as a leverage to FMS	3.53
E	CNC machines supported by automated material handling systems like AGVS, conveyor, robots and other advance material handling systems	3.76

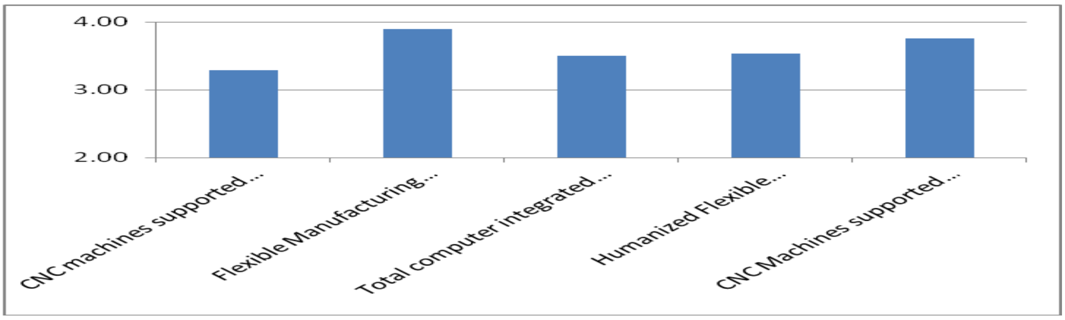


Figure 3.3: Preference for future automated material handling, tooling in manufacturing system

3.5.4 Data Related to Use of Material Handling Devices in Company

The use of MH devices in company by the respondents are forklift trucks (Mean=3.93), hoist (Mean=3.81), All mechanical equipments operated by human labor (Mean=3.81).Similarly other variables score indicated by the respondents are presented in Table 3.4.

Table 3.4 Use of material handling devices in company

S. No	Description	Avg. score
A	All mechanical equipments operated by human labor	3.69
B	Remote controlled equipments	2.84
C	Automated guided vehicles	2.64
D	Robotics	2.77
E	Automated conveyor system	3.49
F	Cranes of any type	3.69
G	Monorail-guided trolleys	3.12
H	Hoist	3.81
I	Forklift trucks	3.93
J	Wire rope ways	2.78

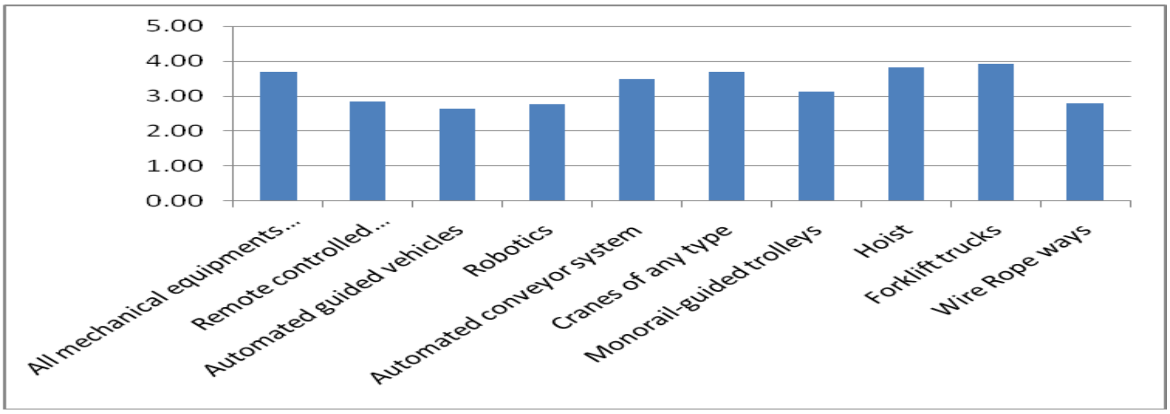


Figure 3.4: Use of material handling devices in company

3.5.5. Data Related to Functions and Variables used in Selection of Material Handling Equipment

The functions and variables used in selection of material handling equipment indicated by the respondents are speed of delivery (Mean=4.89), quality improvement (Mean= 4.86), throughput rate (Mean= 4.77). Similarly other variables score indicated by the respondents are presented in Table 3.5.

Table 3.5 Functions and variables used in selection of material handling equipment

S. No	Description	Avg. score
A	Dispatching of automated guided vehicles	4.27
B	Quality improvement	4.86
C	Integration of facilities	3.93
D	Simulation techniques	3.28
E	Managing operational techniques	4.08
F	Accommodating new models in the system	3.99
G	Speed of delivery	4.89
H	Available area/space	4.76
I	Communication system	3.76
J	Flexibility	4.74
K	Type of material handling systems	4.35
L	Overhead and miscellaneous cost	3.68
M	Operational cost	4.59
N	Space required	4.73

O	Number of machines	4.77
P	Number of operations	4.70
Q	Safety	3.93
R	Distance between machines	4.54
S	Sensors	3.47
T	Material flow path	4.59
U	Arrangement of machines	4.68
V	Capability of material handling systems	4.31
W	Traffic management	4.62
X	Coordination with plant facilities	4.28
Y	Flexibility issues	3.72
Z	Type of machines	4.46
A1	Type of facilities, work rotation and storage devices	4.09
B1	Throughput rate	4.77
C1	Type of operations	4.47
D1	Routing flexibility	4.54
E1	Maintenance cost	4.03
F1	Automation	4.73
G1	Automation cost	4.22
H1	Standardization of equipments	4.04
I1	Remote control interface	4.03
J1	Plant layout	4.69
K1	Type of path layout	4.58
L1	Types of material handling systems (MHS)	4.30
M1	Automated control of flow path	4.58
N1	Load carrying capacity	4.35
O1	Flexibility in product and process routing for future expansion	3.99
P1	Product variety	4.61
Q1	System networking	3.78
R1	Automated inspection systems	4.57
S1	Interface facility with workstation	4.19
T1	Vision system	3.70

U1	Machine flexibility	4.62
V1	Automated inspection systems	4.34
W1	Interface facility with workstation	4.11
X1	Vision system	3.69
Y1	MHS Response time of material systems	4.03
Z1	Economics	4.82
A2	Type of product size availability	4.27
B2	Use of automated workstations	4.49
C2	Type of product	4.41
D2	Machine depreciation cost	3.96
E2	Cost	4.54
F2	Load carrying capacity	4.72
G2	Efficiency	3.88

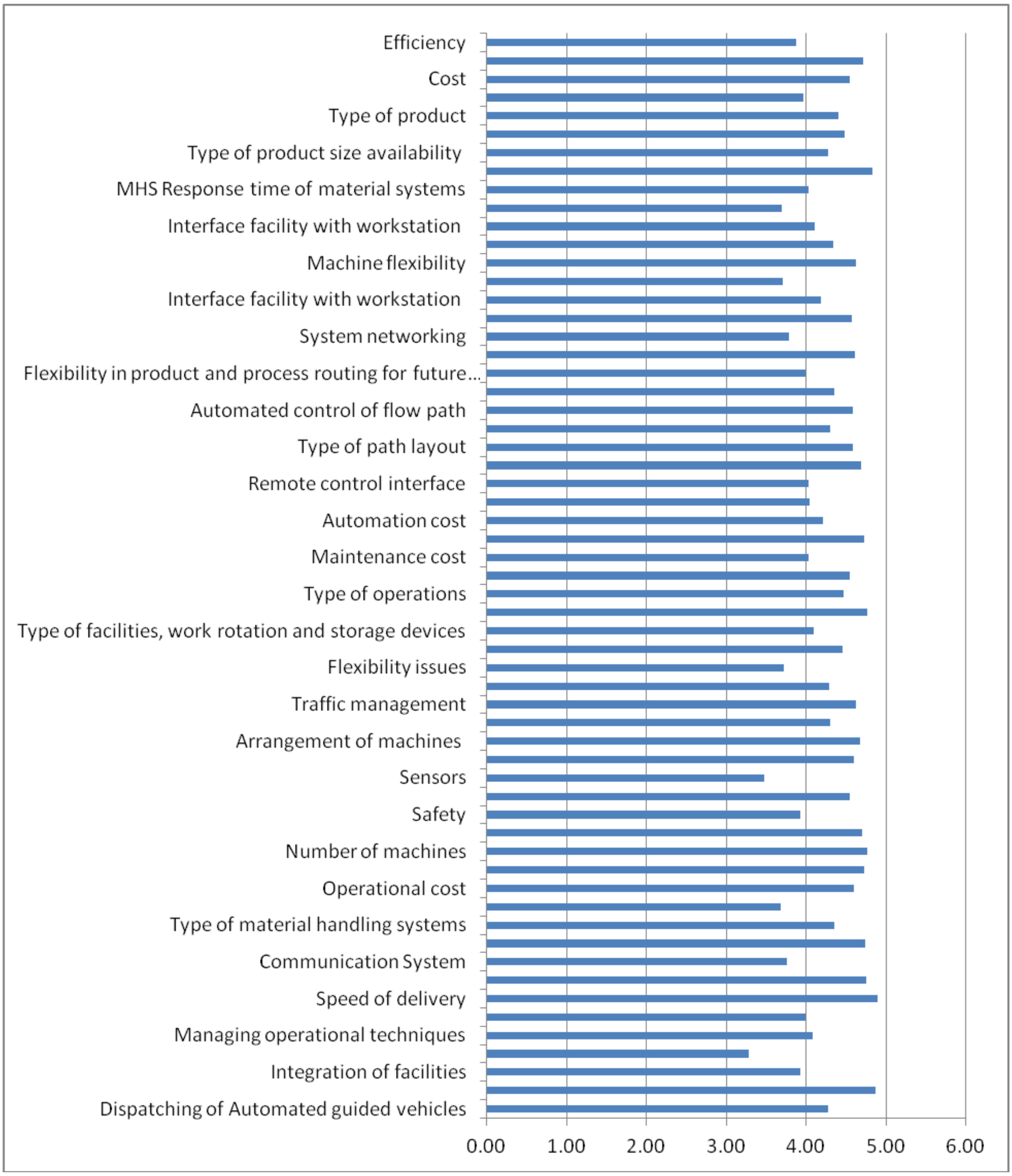


Figure 3.5: Functions and variables used in selection of material handling equipment

3.5.6. Data Related to Factors for Achieving High Productivity Through Material Handling and Tooling in FMS

The factors for achieving high productivity through material handling and tooling are indicated by the respondents are high production rate (Mean=4.99), high machine utilization (Mean= 4.93), reduced lead time (Mean= 4.86). Similarly other variables score indicated by the respondents are presented in Table 3.6.

Table 3.6 Factors for achieving high productivity through material handling and tooling in FMS

S. No	Description	Avg. score
A	High production rate	4.99
B	Reduced lead time	4.86
C	Flow path optimization	4.62
D	High machine utilization	4.93
E	Reduced scrap	4.84
F	Efficient layout arrangement	4.70
G	Effective material handling	4.80
H	Effective tool management	4.11
I	Reduction in man power	4.11
J	High flexibility	3.68

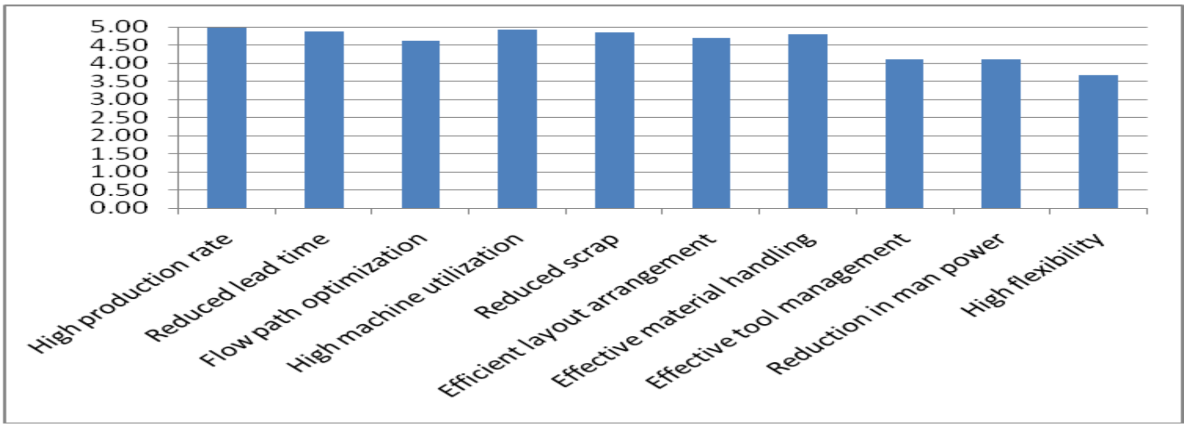


Figure 3.6: Factors for achieving high productivity through material handling and tooling in FMS

3.5.7 Data Related to Factors for the Tool Management in FMS

The important factors as indicated by the respondents regarding the tool management are tool standardization (Mean=4.18), selection of proper tooling (Mean= 4.15), effective tool management (Mean= 4.04). Similarly other factors score indicated by the respondents are presented in Table 3.7.

Table 3.7 Factors for the tool management in FMS

S. No	Description	Avg. score
A	Number and types of machine tools	3.73
B	Capacity of tool magazines of CNC machines	3.55
C	Part types and their processing requirements	3.73
D	Cutting tool material properties	3.55
E	Multi-tasking tools	3.82
F	Tool cost	3.70
G	Tool inventory	3.91
H	Tool life	3.92
I	Tool standardization	4.18
J	Tool interchangeable capacity	3.58
K	Frequency of tool movement	3.50
L	Effective tool management	4.04
M	Selection of proper tooling	4.15
N	Availability of tool copies or sister tooling	3.80
O	Varity of tooling	3.96

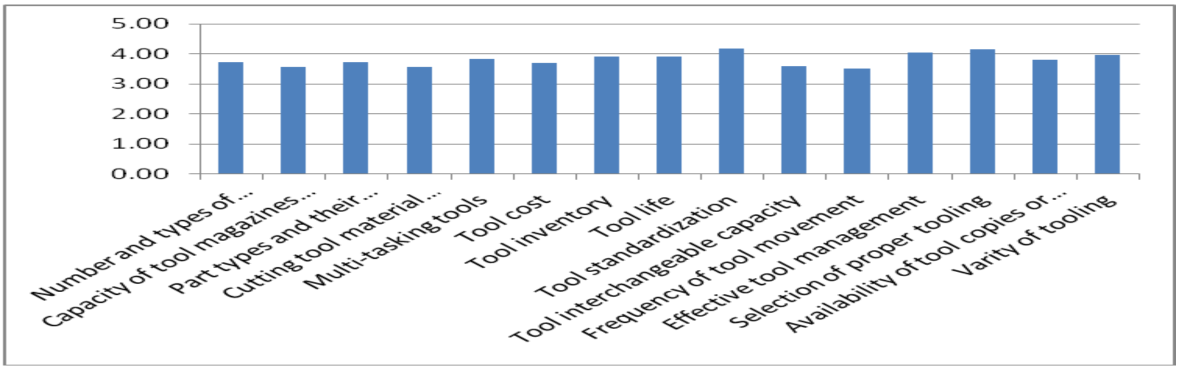


Figure 3.7: Factors for tool management in FMS

3.5.8 Data Related to Social Implications with the Use of FMS

Most important type of social implications in FMS indicated by the respondents are as improved quality of product (Mean=4.1), long-term committed relationship with vendors (Mean= 4.00), improvement in salaries/incentives (Mean= 4.00). Similarly other factors score indicated by the respondents are presented in Table 3.8.

Table 3.8 Social implications of FMS

S. No	Description	Avg. score
A	Fear of unemployment.	3.6
B	Reduction in labour force	3.8
C	Fear of technology change	3.5
D	Reduction of purchase power due to unemployment and high cost of product	3.3
E	Initially high capital investment	3.9
F	Retrenchment of employees	3.2
G	Employee’s resistance in transition to FMS	3.4
H	Improved quality of product	4.1
I	Availability of more variety of products	3.9
J	Change in social status of employees	3.7
K	Long-term committed relationship with vendors	4.0
L	Improvement in salaries/incentives	4.0
M	Trend of labour towards service sector	3.6
N	Improved technical skill and education of employees	3.9
O	Supported policies of the Government	3.4

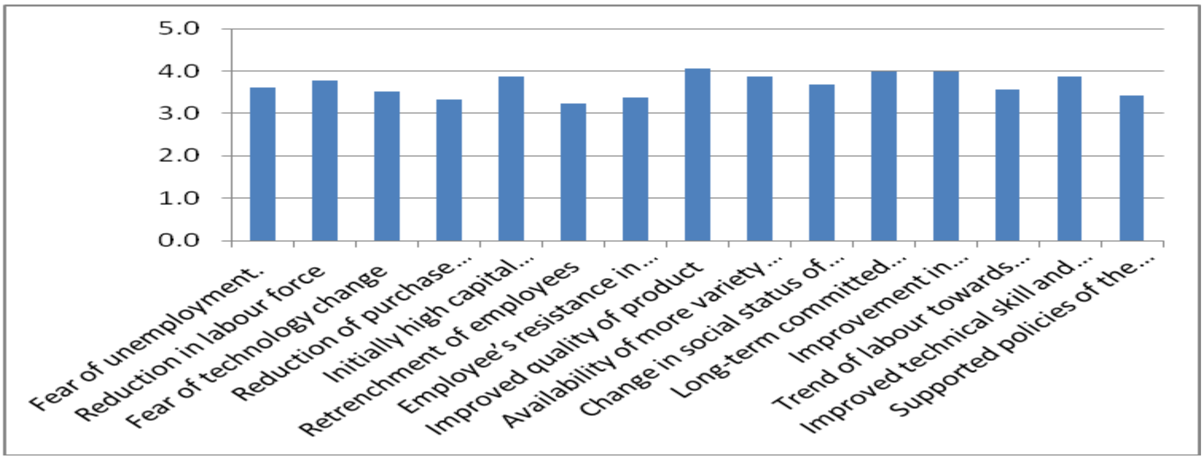


Figure 3.8: Social implications of FMS

3.6 DISCUSSION AND CONCLUSION

Different issues related to flexible manufacturing, material handling, tooling and social issues in Indian manufacturing industries have been observed through the questionnaire survey. The main idea of this investigation was to discover the present scenario of material handling, tooling and social issues in Indian manufacturing industries. On the other side factors like ever changing customers demand for improved quality of product, demand of more variety of products, improved social status, technical skill, education of employees, competitive environment at global level and trend of labour towards service sector have directed the Indian industries to adopt the FMS. Industries wants to get rid of from labour problems created by labour trade unions and requirement of quality products at optimal cost due to which adoption of FMS has become necessary. FMS system can easily replace human labour by robots and AGVS for proper and systematic material handling. Respondents believe that factors like high production rate, reduced lead time, reduction in scrap, high machine utilization and reduction in man power is only possible through FMS adoption as a latest technology. Therefore, for the successful implementation of flexible manufacturing there is a need of valuable and significant techniques development.

CHAPTER IV

MODELLING THE SOCIAL IMPLICATIONS OF FLEXIBLE MANUFACTURING SYSTEM THROUGH ISM IN INDIAN INDUSTRIES

4.1 INTRODUCTION

In the current scenario industries are facing techno commercial problems at global level due to unstable market. To improve the competitiveness industries are seeking such a dynamic manufacturing system which can enhance the productivity and flexibility in term of product cost, quality and required service simultaneously for their survival. According to the Stecke (1983) FMS is only one of the options that can compete this technological global war. FMS can be used for producing the diversity of components and automated material handling equipments for transportation purpose. Ranky (1983) has stated that FMS is a computerized modern manufacturing method to deal with various manufacturing related activities such as machines processing, visual inspection, complex data processing, AS/RS systems, managing of industrial robots, automatic assembly and AMH systems. Various authors (Raj et al., 2010; Nagar and Raj, 2012b) have suggested that FMS is only an effective way to improve in competence of the manufacturing in terms of improved product quality, overall cost minimization, system flexibility and processing time.

The main quality of FMS is to fulfil the manufacturing demand by making different kind of products through proper utilization of facility like automated machines, low-cost labour, optimum space and flexibility. The manufacturing cost of products can also be minimized by integrating hardware and software with central computer control in association with MHE like AGVS, robots and automatic conveyors by suitable assortment of tools with tool management. The use of this technology is advantageous in the form of better flexibility, increase in production, minimization in unit cost by reducing scrap rate, decrease in process inventory through proper machine utilization, opportunities for unattended production, minimization of process time etc. (Gilbert and Winter, 1986; Raj et al., 2008; Yazen and Valerity, 2010) In comparison of these benefits, some drawbacks are also linked with FMS such as higher charge of maintenance, unavailability of spares for high tech equipments in time, higher initial cost of execution, lack of skilled labour, unavailability of FMS vendors for a long term association, software's integration problem with other equipments (Toni and Tonchia, 1998).

In upcoming countries just like India are not keenly interested to follow FMS because of extremely costly and complicated technology for MH. India has a huge amount of manpower at cheaper rates due to which a labour agitation may occur in adopting such advance technologies (Nagar et al., 2013). They may feel fear of loss of incentives, retrenchment of workers and perks (Salahedin, 2007; Lefebvre et al., 1992). Hence, a valuable and systematic arrangement is an essential consideration for the working with FMS technology (Yazen and Valerity 2010).

In view of above description, some social implications have been found by the literature study, industry surveys and expert opinions. An ISM framework has been developed in this research work to provide leading and imminent technology.

The major aims of the chapter are as under:

1. To recognize and rank the variety of social implications of FMS.
2. To set up a correlation among the social implications through the ISM model.
3. To recognize key social implications of FMS.

Table 4.1 Social implications and their references

S. No	Social Implications	References
1	Unemployment	Groover (1987), Aven et al. (2007)
2	Reduction in labour force	Chan and Swarankar (2006)
3	Fear of technology change	Nelson (1986), Liorens et al. (2005), Hua et al. (2005)
4	Reduction of purchase power due to unemployment and high cost of product	Expert opinion
5	Initially high capital investment	Mandal and Deshmukh (1994), Kumar et al. (2006)
6	Retrenchment of employees	Shastri et al. (2010), Eddy (2005)
7	Employees' resistance in transition to FMS	Raj et al. (2007)
8	Improved quality of product.	Oluwayemi and Olusiji (2012)
9	Availability of more variety of products	Pisano (1994)
10	Change in social status of employees	Guber and Madrian (1994), Dutton and Dukerich (1991)
11	Long-term committed relationship with vendors	Raj et al. (2006), Kumar et al. (2006), Mandal and Deshmukh (1994), Aven et al. (2007), Hua et al. (2005)
12	Improvement in salaries/incentives	Dutton and Dukerich (1991), Nagar et al. (2012a)
13	Trend of labour towards service sector	Expert opinion
14	Improved technical skill and education of employees.	Liorens et al. (2005)
15	Supported policies of the Government**.**	Raj et.al. (2008), Aven et al. (2007)

4.2 MODELLING OF SOCIAL IMPLICATIONS BY ISM APPROACH

ISM method is used for interactive knowledge in structuring the combined or complex issues in the form of graph theory, or network representation between a set of elements (Sage, 1977). The procedure used for ISM model making for social implications of FMS is as follows:

1 Finding of the social implications.

2 Development of proper relationship among social implications.

3 Create a structural self-interaction matrix (SSIM) of particular elements.

4 Expanding a reachability matrix (RM) from the self-interaction matrix. Check the matrix for transitivity.

5 Segregation of RM in to different steps.

6 Exchange the (RM) matrix into conical form.

7 Developing a directed graph derived from above correlations given in RM.

8 Transforming the digraph into an ISM model.

9 Checking the model for conceptual discrepancy and make the required modifications if any.

Steps involve in ISM model development are:

Step 1: Development of the contextual relationship between Social implications

In this first step of ISM model 15 numbers of social implications have been identified during the literature survey and opinions of field experts, both from industry and academia as indicated in Table 4.1 After examine the provided social implications, a suitable relationship is developed between them. Existence of association between any two social implications (i and j) along with the linked direction has been set up based on contextual principle. Subsequent letters/symbols have been used for representing the direction of relation between any two social implications.

V – Element i affects element j

A - Element j affects element i

X - Elements i and j are used to achieve relation with each other.

O - Elements i and j are unrelated

Step 2: Construction of structural self-interaction matrix (SSIM)

A SSIM has been build up which is completely based on the pair wise contextual relationship between the social implications. It was discussed in a group of field experts. On the base of experts' responses, SSIM has been finalized and shown in Table 4.2.

Table 4.2 Development of structural self-interactive matrix (SSIM)

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

SSIM shows the direction of correct interaction between the social implications.

Step 3: Creation of the initial reachability matrix

This step has an initial reachability matrix from which SSIM has been developed. Evaluation of this process may be followed in two sub-stages. During the first stage of evaluation, SSIM format is changed into the initial RM data format by changing the ranking of each group of SSIM into binary digits (i.e. 1, 0) in the initial reachability matrix. Conversion process of the matrix is as under:

- If cell (i,j) contains letter V in SSIM, than initial RM digit 1 is fixed to cell (i, j) and 0 to cell (j,i).
- If cell (i,j) contains letter A in SSIM, than initial RM digit 0 is fixed to cell (i, j) and 1 to cell (j,i).
- If cell (i,j) contains letter X in SSIM, than initial RM digit 1 is fixed to cell (i, j) and 0 to cell (j,i).

- If cell (i,j) contains letter O in SSIM, than initial RM digit 0 is fixed to cell (i, j) and 1 to cell (j,i).

Step 4: Development of Final reachability matrix

In final RM matrix, transitivity conception has been considered to fill the gap, if any, in the views for SSIM development. According to the principle of relativity if social implication X is related Y and Y is related to Z then X is necessarily related to the social implication Z. The results of final RM have shown Table 4.4.

Table 4.3 Initial reachability matrix

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

Table 4.4 Development of final reachability matrix

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

1* → Indicates to incorporate transitivity to fill the gap

Step 5: Partitioning the reachability matrix

In this step final RM has been presented in Table 4.4. Authors (Warfield, 1974; Farris and Sage, 1977) have suggested that levels of reachability and antecedent set for every element is determined from the final RM. Common social implications are selected for the intersection set received from reachabilty set and antecedent set. This is the method used for finding the top-level (i.e. 1st level) elements of social implications. Similarly for the next levels the process will remain continue till all social implication levels are identified. These identified levels will be used in structuring the diagraph and the ISM model. In the present case, 15 social implications have been presented in Tables 4.5 to 4.10.

Table 4.5 Iteration-I

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

Table 4.6 Iteration-II

Social Implications	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
1	1,2,4,5,7,8,9,10,11,12,13,14,15	1	1	
2	2,4,5,7,8,9,10,11,12,13,14,15	1,2	2	
4	4,5,7,8,9,12,13,14	1,2,4,5,7,8,9,10,11,13,14,15	4,5,7,8,9,13,14	
5	4,5,7,8,9,12,13	1,2,4,5,7,8,9,10,11,13,14,15	4,5,7,8,9,13	
7	4,5,7,8,9,10,11,12,13,14	1,2,4,5,7,8,9,10,12,13,14,15	4,5,7,8,9,10,12,13,14	
8	4,5,7,8,9,10,11,12,13,14	1,2,4,5,7,8,9,10,11,13,14,15	4,5,7,8,9,10,11,13,14	
9	4,5,7,8,9,10,11,12,13,14	1,2,4,5,7,8,9,10,11,13,14,15	4,5,7,8,9,10,11,13,14	
10	4,5,7,8,9,10,12,13,14	1,2,7,8,9,10,11,12,14,15	7,8,9,10,12,14	
11	4,5,8,9,10,11,12,13,14	1,2,7,8,9,11,12,15	8,9,10,11,12	
12	7,10,11,12,13	1,2,4,5,7,8,9,10,11,12,13,14,15	7,10,11,12,13	II
13	4,5,7,8,9,12,13,14	1,2,4,7,8,9,10,11,12,13,14,15	4,7,8,9,12,13,14	
14	4,5,7,8,9,10,12,13,14	1,2,7,8,9,10,11,13,14,15	4,7,8,9,10,13,14	
15	4,5,7,8,9,10,11,12,13,14,15	1,2,15	15	

Table 4.7 Iteration-III

Social Implications	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
1	1,2,4,5,8,9,14,15	1	1	
2	2,4,5,8,9,14,15	1,2	2	
4	4,5,8,9,14	1,2,4,5,8,9,14,15	4,5,8,9,14	III
5	4,5,8,9	1,2,4,5,8,9,14,15	4,5,8,9	III
7	4,5,8,9,14	1,2,4,5,8,9,14,15	4,5,8,9,14	III
8	4,5,8,9,14	1,2,4,5,8,9,14,15	4,5,8,9,14	III
9	4,5,8,9,14	1,2,4,5,8,9,14,15	4,5,8,9,14	III
10	4,5,8,9,14	1,2,8,9,14,15	8,9,14	
11	4,5,8,9,14	1,2,8,9,15	8,9	
13	4,5,8,9,14	1,2,4,8,9,14,15	4,8,9,14	
14	4,5,8,9,14	1,2,8,9,14,15	4,8,9,14	
15	4,5,8,9,14,15	1,2,15	15	

Table 4.8 Iteration-IV

Social Implications	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
1	1,2,15	1	1	
2	2,15	1,2	2	
15	15	1,2,15	15	**IV**

Table 4.9 Iteration-V

Social Implications	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
1	1,2	1	1	
2	2	1,2	2	**V**

Table 4.10 Iteration-VI

Social Implications	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
1	1	1	1	**VI**

Step 6: Conical Matrix

In this conical matrix RM has been transformed in to a conical matrix as shown in the Table 4.11 in which social implications are clubbed together having the similar level. This matrix consists of most upper half diagonal are zero and lower half are 1. In this matrix drive power is obtained by adding the row elements and dependence power by adding the column elements.

Step 7: Construction of digraph

A digraph has been developed by considering every element (i.e. social implication) as recognized through different iterations. A final digraph (Figure 4.1) has been framed by removing the indirect links. In this digraph, 1st level social implication is positioned at the 1st position; second level at second position and so on.

Step 8: Formation of ISM model

Finally, change the digraph into an ISM model by replacing the social implication nodes with its statements as shown in Figure 4.2.

Step 9: Check for conceptual inconsistency

During the ISM model development, if there is any conceptual discrepancy then it is checked and replace by incorporate the transitivity in the model.

Table 4.11 Conical Matrix

Social Implications	3	6	7	10	11	12	13	4	5	8	9	14	15	2	1	Drive Power
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
7	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	12
10	0	1	1	1	0	1	1	1	1	1	1	1	0	0	0	10
11	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	11
12	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	6
13	0	1	1	0	0	1	1	1	1	1	1	1	0	0	0	9
4	0	1	1	0	0	1	1	1	1	1	1	1	0	0	0	9
5	0	1	1	0	0	1	0	1	1	1	1	0	0	0	0	7
8	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	12
9	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	13
14	1	1	1	1	0	1	1	1	1	1	1	1	0	0	0	11
15	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	13
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	14
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
Dependence power	9	13	12	10	8	13	12	12	12	12	12	11	4	2	1	

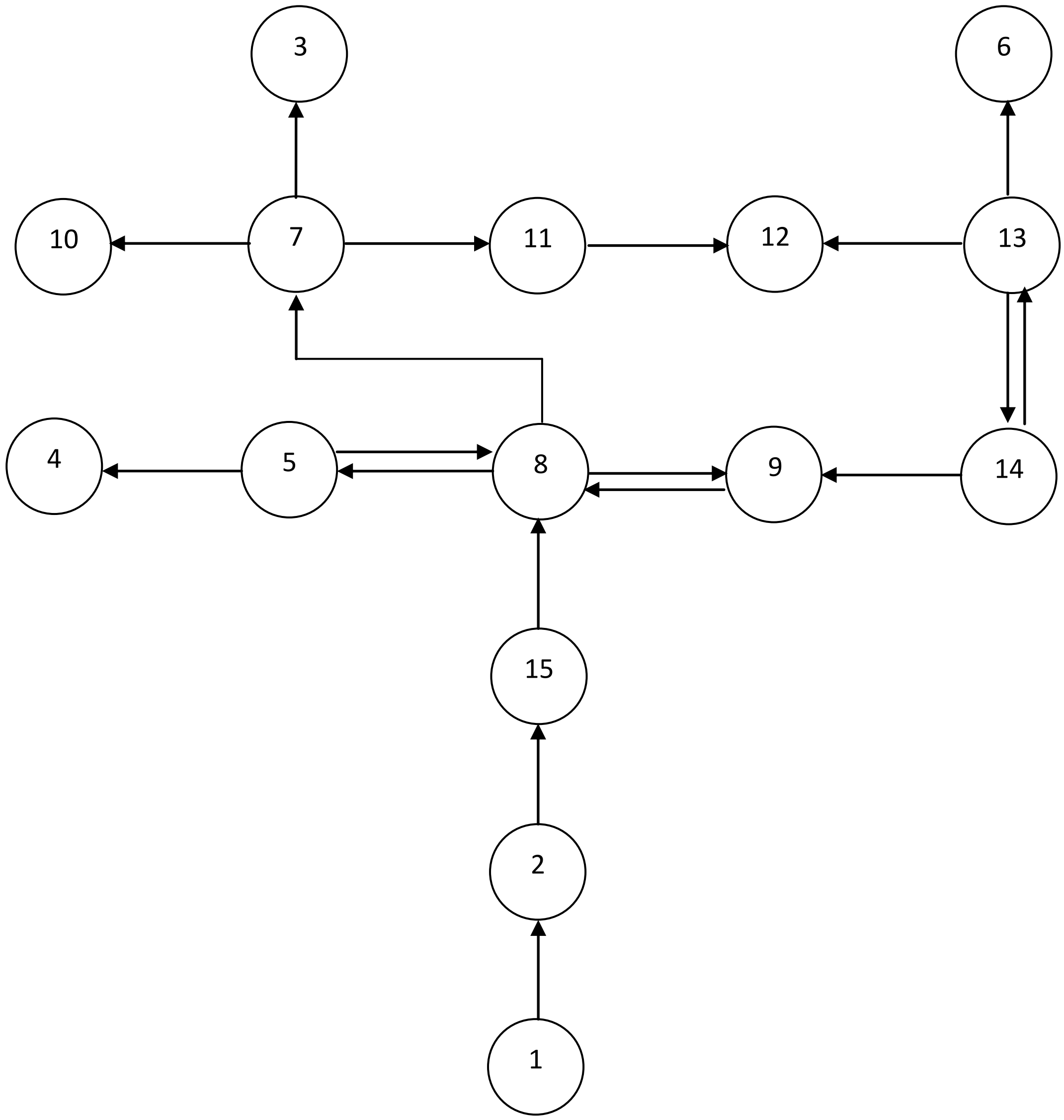


Figure 4.1 Digraph showing the level of social implications.

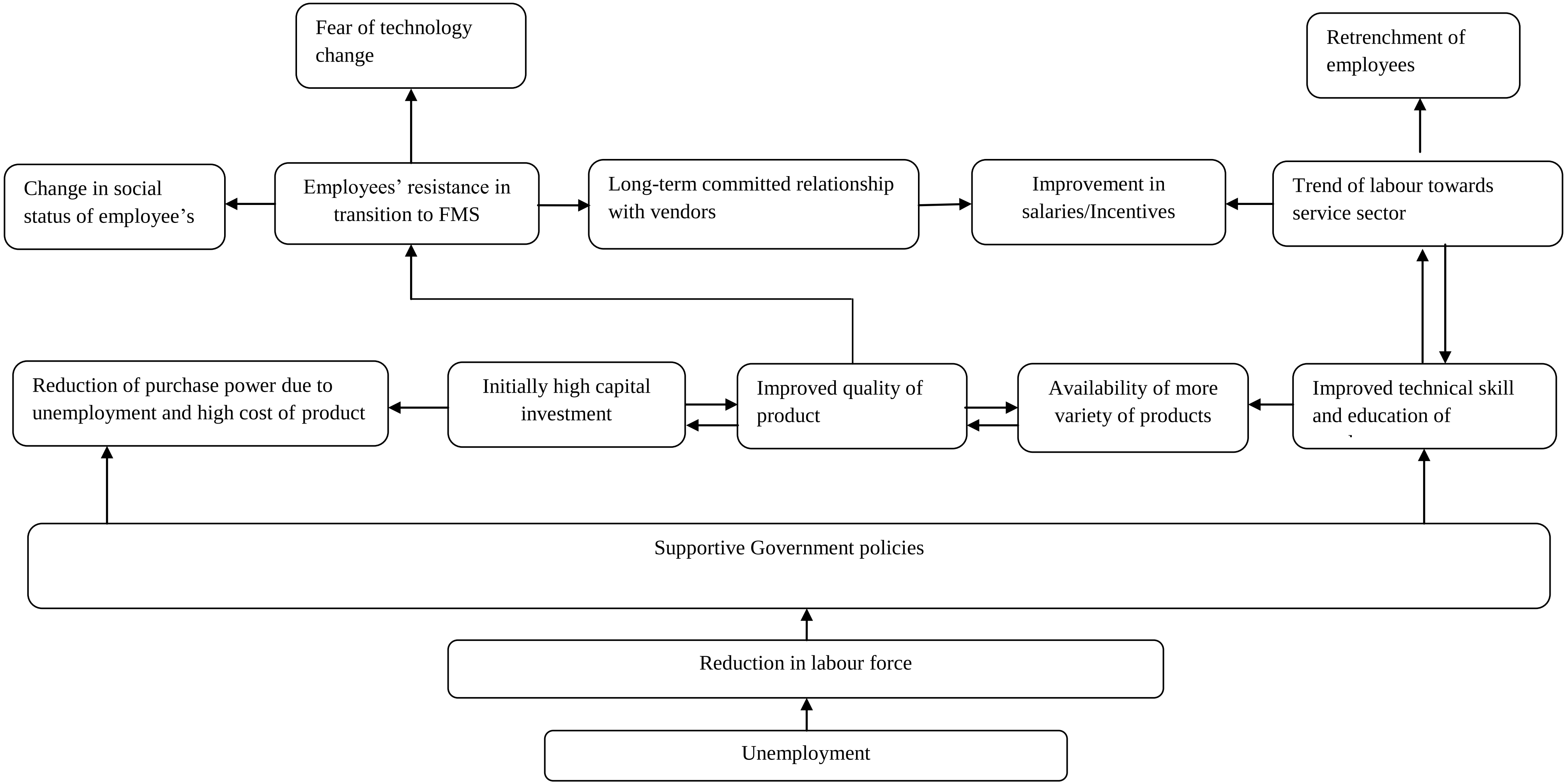


Figure 4.2 Presentation of social implications level through interpretive structural model (ISM)

4.3 CLASSIFICATION OF FACTORS OF SOCIAL IMPLICATIONS BY MICMAC ANALYSIS

MICMAC analysis means cross-impact matrix multiplication applied to classification and it is use to examine the drive and dependence power of social implications. According to Sharma et al. (1995) it is depends upon multiplication properties of matrices. It consists of drive power and dependence power which is based on conical matrix. In the present case, social implications have been classified into four clusters as discussed and shown below in Figure 4.3:

- Autonomous social implications (Cluster I): These Social implications consists of weak drive power and weak dependence.
- Linkage social implications (Cluster II): These consist of strong drive power as well as strong dependence power.
- Dependent social implications (Cluster III): This group consists of social implications having weak drive power but strong dependence.
- Independent social implications (Cluster IV): These include strong drive power but weak dependence.

Driving Power

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

Dependence Power

Figure 4.3 Clusters of Social Implications Affecting the FMS.

4.4 DISCUSSION

In this chapter various social implications of FMS have been identified so that management may effectively utilize them for their purpose. An ISM model has been developed for evaluating the interaction between different social implications. It also provides a prospect to know the impact of FMS on society. These may also be utilized to understand their relative importance and interdependencies by the manufacturing managers and its management. A virtual importance relation between driver power and dependence power of social implications based on Figure 4.3 is as follows:

- These autonomous social implications have weak drivers and weak dependence and there is no social implication has been found in this cluster means they do not have much impact on the FMS. So, these can be disengaged from the entire system.

- The social implications such as trend of labour towards service sector, increase in social status of employees', reduction in labour force, supportive government policies lies in the next cluster and having least drive power and most dependence power in the ISM hierarchy. Manufacturing managers should keep these communicative social implications in mind while seizing decisions respecting implementation of FMS.
- The next cluster consists a grouping of the linkage social implications such as retrenchment of employees', fear of technology change, improvement in salaries / incentives, long term and committed relationship with the vendors of FMS equipment, availability of more verity of products, reduction of purchase power due to unemployment and high cost of product, improved technical skill and education of employees which are strong in driving power and high dependencies. These are affected by medium level social implications and have impact on other social implications in the ISM frame work. The management should treat carefully these social implications while executing FMS in their industries.
- Independent social implication variables are treated as the key social implications of the system and have a strong capacity to affect other social implications. These require more care to deal with them.

4.5 CONCLUSION

The main emphasis of this chapter is developing a frame work using ISM method for social implications which will be very helpful in recognizing the authentic impact on the social life of people in growing countries like India. The knowledge regarding these social implications and their driving and dependence power is most important sign for executing FMSs in such developing countries.

The survey conducted in industries regarding the FMS execution shows that 'unemployment' is at rank number one, which has found at the base in the ISM model as a main social implication of FMS. This is the key social issue in India where people are in abundance at a cheaper rate in comparison to other developed countries. In accession to this, start up of FMS requires a huge capital investment which is also a big hindrance in implementation of advanced technology. No doubt in country like India people don’t want to accept such high technology because of some factual reasons like initial high cost of newer technology, high cost of maintenance, unavailability of vendors and spares, highly resistance by labour unions in India and shifting of labour towards service sector. The management can also shutout these issues by opting some positive initiatives which may be useful in shifting from conventional manufacturing system to FMS. The management should also think about suitable strategies necessary for tackle the negative implications of FMS such as unemployment, employee’s resistance in transition to FMS and initially high capital investment. To overcome these problems the management should initiate through the proper skill development programmes and carrier enhancing policies for their employees’ which will be not only reduce the retrenchment, unemployment and disputing issues between workers and staff but also helpful in motivating the workforce as upgrading their knowledge, skill, social status and personality. Hence an appropriate planning approach is must for adopting the latest generation technologies like FMS.

CHAPTER V

DESIGN AND OPERATION OF MATERIAL HANDLING SYSTEMS IN FLEXIBLE MANUFACTURING SYSTEM

5.1 INTRODUCTION

Now a days in modern manufacturing industries material movement has become a most major component of the manufacturing and non-manufacturing environment which contributes to a significant portion of the final products cost. The handling of materials must be performed safely, efficiently and accurately at right time. An AGVS has become the most accepted choice now a day's between available ranges of equipments for material handling in flexible manufacturing system (FMS) for future industries. AGVs were launched in 1955 and since then their use is increasing day by day as compared to other type of material handling devices (Berman and Edan, 2002). These devices are equipped with latest programming capability to adjust alternations in production volume, product mix, product route path selection and can be easily configured with requirements. These can be used even in complex transport applications. According to Rajotia et al. (1998) AGVs are much more flexible in its operations due to its easy integration with automated material handling systems and other devices like robots, NC machine tools, automated machine vision inspection stations and AS/RS. These flexibilities are most essential requirements for FMS environment. To execute the AGV operational strategies like task assignment, scheduling and dispatching, routing, collision and deadlock avoidance, a sophisticated computer control system is required. The main purpose of this research is to study and identify the different issues in the utilization of AGVs like material handling, design, control and dispatching methodologies so that the utilization of AGVs can be helpful in developing country like India (Figure 5.1).

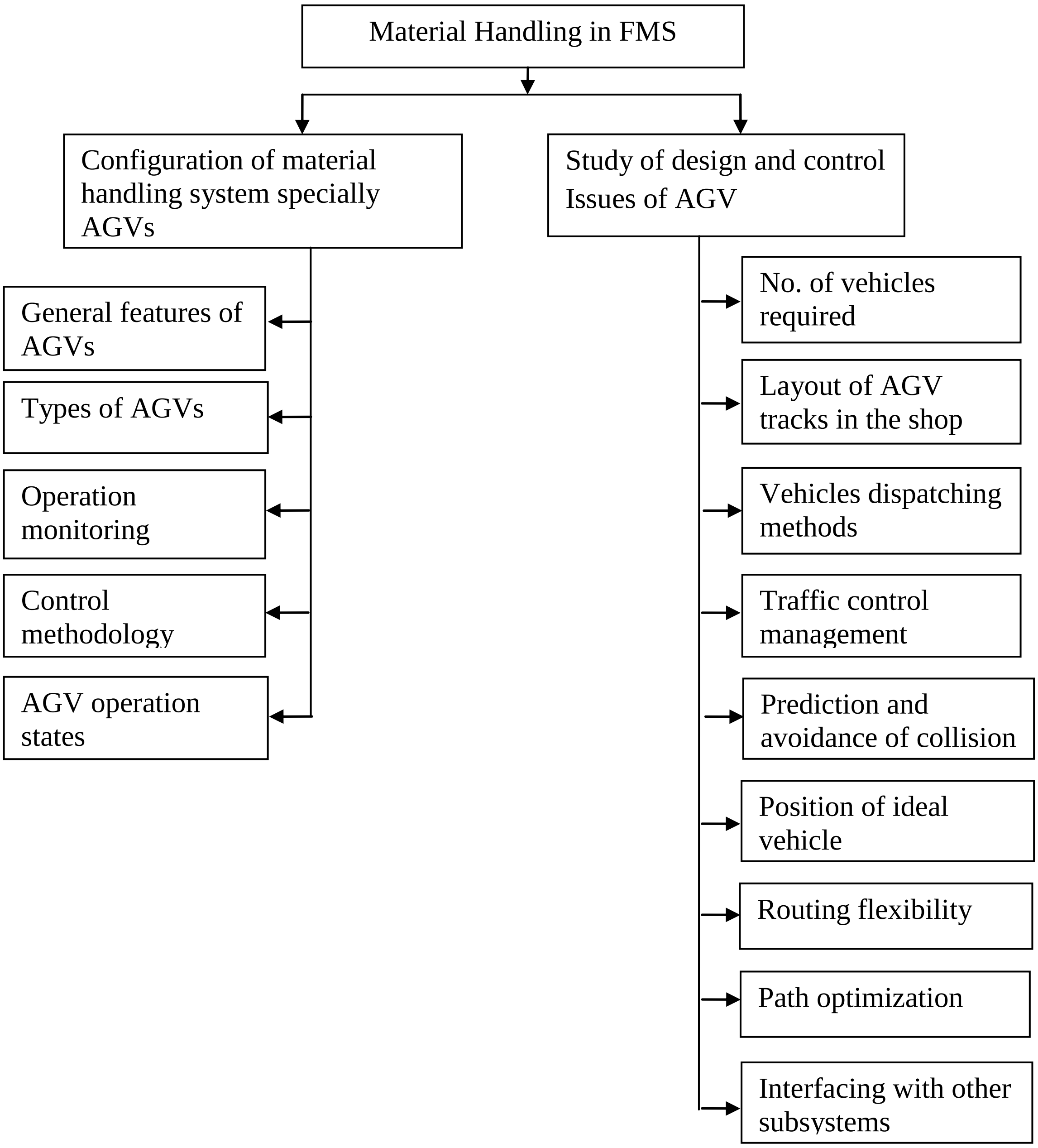


Figure 5.1: **Factors affecting the design and operation of an AGV**

5.2 MATERIAL HANDLING IN FMS

In this modern era, the importance of material handling can be understood on the basis of research and practice perspective. Now, the aspect of material handling technology has changed drastically as compared to the previous few years, due to the introduction of computers and automation as an element of flexible manufacturing system (FMS). The choice and configuration of MHEs plays a significant role in transportation, storage and loading or unloading of parts in a facility. It may also affect overall safety, work in process, and overall operation efficiency. Generally these five types of material handling equipments are utilized for moving parts and other materials in facility which is as: (1) conveyors, (2) automated guided vehicles (AGVs), (3) industrial trucks, (4) monorail and other rail guided vehicles, (5) cranes and hoist. In present chapter, main focus is on AGVs for material handling.

5.3 AUTOMATED GUIDED VEHICLES (AGVS)

According to Allegri, (1994); Tompkins and White, (1984) material handling is also an important aspect of manufacturing system as a time and cost related. According to Tompkins and White (1984) about 50% of the operational cost can be attributed to the activity of material handling. Thus, by optimizing the performance of material handling system, significant cost reductions can be achieved. AGV provides flexible material flow routes and are more suitable for FMS environment where product mix and priorities fluctuates rapidly. So, AGVs are most successful devices used in FMS environment now days.

5.3.1 Features of AGVs

Some authors' (e.g. Groover, 2007; Vis, 2006; Shanker and Vrat, 1999)
have described the following features of AGVs:

- The devices like AGV, robots, AS/RS and CNC machines etc. can be easily interconnected with other components of FMS. Hence, AGV is an essential element of FMS system.
- AGV has much more flexibility to adjust with the production systems.
- Use of AGV also offers great flexibility in the expansion of a manufacturing system. The number of vehicles and area covered by the AGV may easily be customized as per the need.
- AGV can easily accommodate the required changes necessary for production as well product routing.
- AGV can adopt changes without major capital investment like machines layout and product design.

- It is also capable to carry out low to medium volume unit load without any inconvenience.
- Compared to dedicated conveying system, AGV systems consist of fewer restrictions on planning the factory layout. This is due to ease movement (backward/forward and left/right) of the AGVs on the guide path.
- It is easy to maintain the AGV system. Individual breakdown of an AGV may be coped with the introduction of another AGV in the same route and removal of the break down AGV in to the parking area for repair / maintenance purpose.
- Operations of AGVs are silent and noise free.
- AGV system may facilitate the effective implementation of manufacturing information system. AGV system generates relevant information related to inventory control and production administration. Integration of such information is needed for the manufacturing information system.

5.3.2 Types of AGVs

According to Shanker and Vrat (1999) automated guided vehicles can be divided based on navigation system and network into four categories, as shown in Figure 5.2.

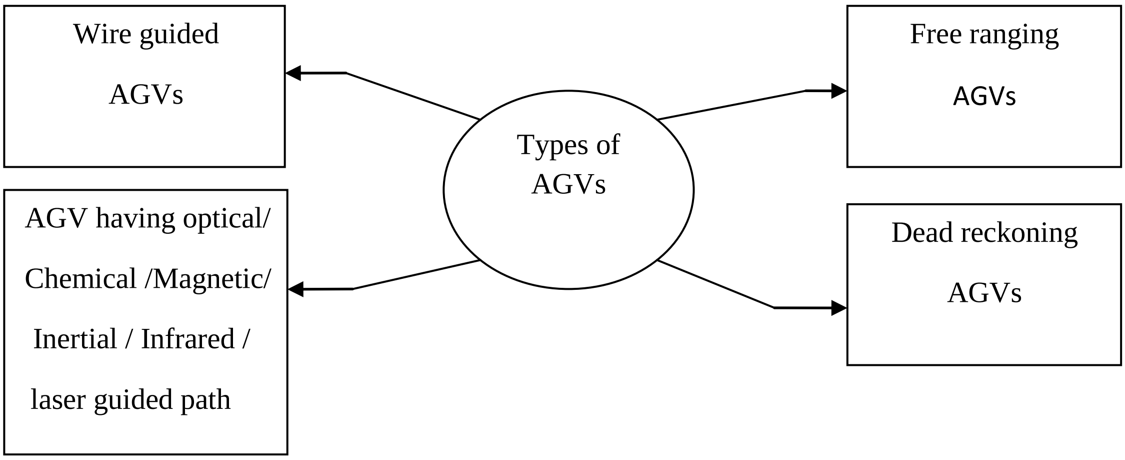


Figure 5.2: Types of AGVs (Source: Shanker and Vrat, 1999)

- **Wire Guided AGVs:** In a imbedded guide wire system, electrical wires are put in a small channel about 1/8 X 1/2 inch (wide, deep) in size. After the installation of guided wires, channel is covered up with cement and concrete to remove the unevenness in the floor. A frequency generator is used to provide low current guidance signal in a range 1-15 kHz. A magnetic field is generated with the pathway and tracked by sensors installed on board vehicle (Trebilcock, 2007).

Two sensors are mounted on the vehicle on either side of the guide wire. According to Groover (2007), if the vehicle is moving one side or other side, accordingly magnetic field intensity will change i.e. low in one side and higher at the other side to control the steering motor as per the requirement for tracking the guide wire.

- **Dead Reckoning AGVs:** This type of AGV is considered as the most simplest type routing system as it does not require any hardware. These AGV use memories in their on board microcomputer for storing distance table for stations, acceleration, deceleration information, speed and steering information. It is based on the principle of odometery (Borenstein, 2000, Shi et al., 2007). In the other guiding system magnetic beacons are also used along the path way to move the vehicle between beacons and the actual location. These beacons provide information regarding data updating for the computer's dead reckoning map and new pathway. This system is also a quick method explore the altered pathway to the plant facility as per need.
- **AGV Having Optical / Chemical / Magnetic / Inertial / Infrared / Laser Guided Path:** Some authors (e.g Jiahai and Zhiqiang, 2011; Brain Rooks, 2006; Zhan et al, 1998; Miller et al, 1989), have discuss the AGVs which uses a strip of optical/chemical/magnetic material on their path. It is detectable by a proximity sensor mounted on the vehicle. For example, the chemical guide path is excited when ultra-violet rays from the AGV fall on the path. They in–turn re-emit waves in the visible range. Hence location of the guide path and steering of the vehicle is done through the interpretation of the contrast ratio.
- **Free Ranging AGVs:** Due to recent advances in technology these intelligent free ranging AGV does not follow any physical guide path (Gaskins et al. 1989). These are also known as unlike wire guided AGVs, hence to increase the flexibility, free ranging AGVs will be a better choice for future industrial applications. The guidance of free ranging AGV may be based on the techniques: a) Position reference beacons b) Optical imaging of surrounding and stereoscopic vision.

a) Position reference beacons:

In this system, some beacons are fixed on the factory locations which are known to the AGV controller (Tsumura, 1986). In this on board devices are used to measure exact distance, direction and position of AGV with respect to beacons at any time (Frog Navigation system, 1999). This information is used to measure the position of AGV.

b) Optical imaging of surrounding and stereoscopic vision:

Authors Garibotto and Masciangelo (1992) have suggested the stereoscopic vision system which is used for the 3D imaging of the surrounding objects. It requires two cameras, separated at known distance (like human eyes) on the AGV. The image captured by each camera at any point is analyzed to find an object in surrounding. Much more accuracy work is still needed to integrate the sensor system with AGV system in a cost effective way. Shanker and Vrat (1999) have proposed a comparative statement of above all systems for the selection of a various AGV conditions, as exhibited in Table 5.1.

Table 5.1: Comparison of different types of AGVs

Features	Wire Guided AGV	Optical/Chemicl/ Magnetic Guide path AGV	Dead Reckoning AGV	Free Ranging AGV
Range	G	E	P	G
Accuracy	G	E	A	E
Flexibility	M	G	E	E
Reliability	E	M	G	M
Controllability	E	P	P	A
Vehicle equipment cost	G	M	G	P
Station equipment cost	M	E	E	G

Legend: E: Excellence, G: Good, M: Medium, A: Acceptable, P: Poor

5.3.3 Operation Monitoring

According to Berman and Edan (2002), movement of AGV is controlled by a central monitoring system. In this system, signals related to various occurrences are sent to the monitoring system through the internet and are recorded in the system. This recorded data can be used online as well as offline. Then stored data is used both for online system performance detection and for offline system analysis. It consists of two occurrences. First one is regular occurrences which is related to a particular production cycle while second one i.e., system occurrences are related with the problems of the system such as break down of system.

5.3.4 Control Methodology

Some authors (e.g. Mullar, 1983; Taghaboni and Tanchoco, 1988; Bozer and Srinivasan 1989; Manda and palekar, 1997; Watanabe et al., 2001; wijesoma et al., 2000; Wallace, 2001; and Fanti, 2002) have proposed a decentralized control of an autonomous AGV system for material handling. They also suggest that this type of control system can lead to system flexibility and robustness. This method concentrates on all facets of AGVs such as integrated control system management, intelligent control navigation and load transfer. Hierarchical fuzzy behavior-based control, Q-learning and artificial intelligence methodology is expanded to multi-robot control in semi structured environments.

5.3.5 AGV Operation States

Berman and Edan, (2002) have described the following seven types states of the operation of each AGV as shown in Figure 5.3.

State 1*:* Start: It shows th*e* AGV initiation stage. In this stage, AGV is placed manually every instance. It transit automatically into this stage but it requires recharge of battery. Later on, AGV is navigated for recharge of battery.

State 2*:* Target: It refers cycle initiation state. Here, AGV attain a target either in terms of load. Afterwards, AGV notifies the desired workstation for achievement of target.

State 3: Journey: It provides the information of travel of AGV to the desired location by using pre-decided route.

State 4: Load port entry: It basically refers to the entry of load port with precision and conflict free.

State 5: Service: It shows the accurate onset of load port on the desired location. Afterwards, information is transmitted from AGV to the workstation.

State 6: Load port exit: Here, load port exits the system. At this time, AGV moves to an ideal location in search of new target.

State 7: Fail: It shows that AGV is not capable of performing its function. This stage requires the operator to solve.

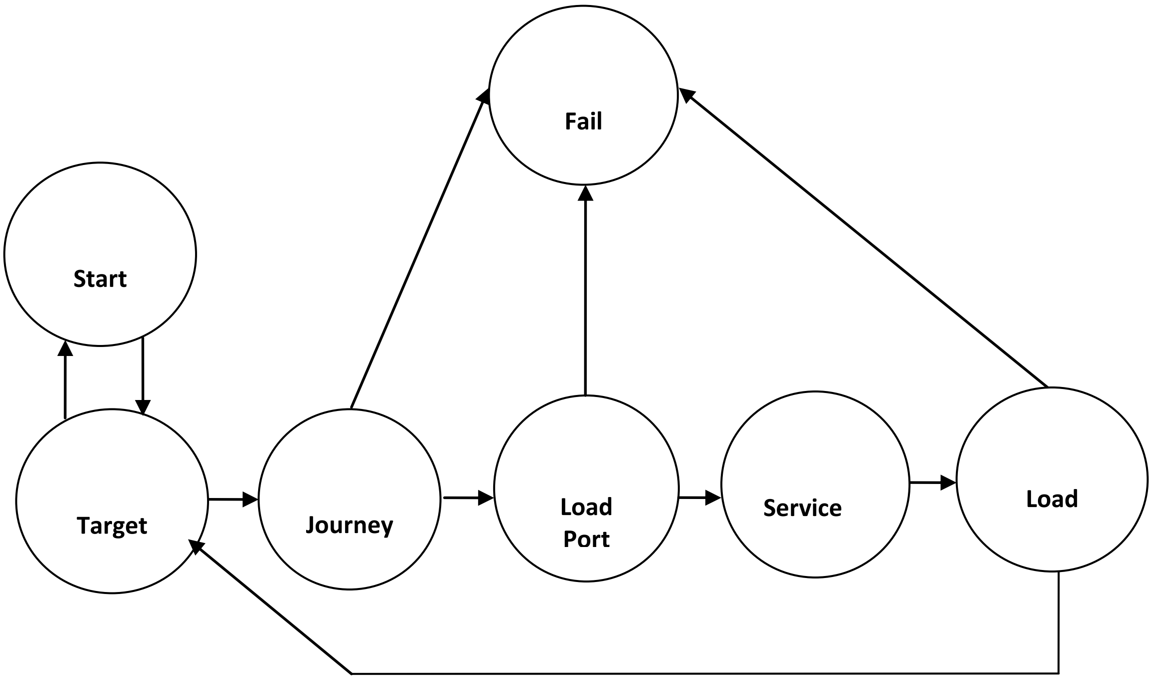


Figure 5.3: AGV States (Source: Berman and Edan, 2002)

5.4 STUDY OF DESIGN ISSUES FOR AGVS

Mahadevan and Narendran (1990) have suggested the following issues:

- The exact number of vehicles demanded
- Types of AGV layout track in the shop
- Vehicle movement policy
- Traffic control supervision
- Production and collision avoidance
- of Position of ideal vehicle
- Routing flexibility
- Path optimization

- Interfacing with other sub systems

Role of various authors for the design issues of AGVs are discussed in Table 5.2.

Table 5.2: Contribution of different authors in design issues of AGVs

Author	Year	Contribution
Maxwell and Muckstadt	1982	Proposed analytical modeling of AGVS operational features
Egbelu and Tanchoo	1986	Proposed a model of a bi directional flow guide-path through computer simulation
Bozer and Srinivasan	1989	Suggestions regarding tandem configuration and minimization of software and control complexity of AGV
Molmborg	1990	Computed empty vehicle time
Langevin et al.	1996	Presented a dynamic programming approach for planning the dispatching conflict-free routing and scheduling of AGVs in FMS
Rajotia et al.	1998	AGV Fleet size optimization for an FMS using mixed integer programming
Mahadevan and Narenderan	1990	Used analytical and simulation models for analyzing and solving the problems of multi vehicle systems

AGV design problems were studied by Maxwell and Muckstadt (1982). They have also done a revolutionary work as a logical modeling for AGV operational features. They have also suggested a time based model for estimating the minimum quantity of vehicles needed for material handling. Estimation was also done for empty vehicle travel time among the total numbers of part delivered and picked up from there. It also signifies the empty trips of AGV for every pick and place station. Hence, a transportation rule was formulated to reduce the empty vehicle travel time.

Egbelu and Tanchoco (1984) observed the impact of some heuristic rules for moving AGVs in a job shop situation. This study was only useful for large number of material flow volumes. Later on, Egbelu and Tanchoco (1986) found that bi-directional flow can be increased by use of small number of vehicles.

Ozden (1988) has performed a FMS simulation for a small system which was base on design parameters such as number of AGVs, traffic pattern and load sharing capacity of the machines. Bozer and Srinivasan (1989) also suggested a tandem type configuration for reducing AGV control software and its managing difficulty for MHS.

Malmborg (1990) recommended a method for calculating travel time of empty vehicle. This method was contradictory with the Maxwell method. The rate of empty vehicle movement is decided by total quantity of loads transported to each station compared to total flows. Moreover, Malmborg suggested a method of maximizing the empty travel time rather than minimizing it. It is concluded that each vehicle is routed away after unloaded at a delivery station. Thus, the total empty vehicle travel time was considered by Malmborg as an upper bond solution as compared to lower bond one of Maxwell's method. Further, he also recommends that the actual empty travel time would be a weighted average of upper and lower bonds.

Langevin et al. (1996) have suggested a new method for planning, dispatching, scheduling and conflict-free routing for automated guided vehicles in FMS. The problem was solved optimally in a combined manner, as compare to the traditional method and it was decomposed in three steps sequentially. The proposed algorithm acts as a dynamic programming for solving a possibility of rolling time. Three control criteria were found suitable to limit the size of the state space. The method is used to find the transportation plan that minimizes the completion time for all the tasks. A heuristic of the algorithm was also developed for extending to many vehicles. They have also suggested a dynamic programming based model to solve precisely instances with two vehicles of conflict free routing and dispatching.

Rajotia et al. (1998) advocated that the required numbers of AGVs are necessary to complete a MH task in a FMS by logical modeling. It includes an empty travel time, handling time, waiting and blocking time. The occurrence of vehicle waiting and blocking are also highlighted in many studies related to AGVs. The cumulative impact of these times has been estimated to find the AGV fleet size as forecasted by individual model. A simulation methodology has been used to validate the fleet size. The proposed model shows the minimum AGV requirement which is close to the simulation results. A mixed integer linear programming model has also been proposed to study the deterministic case for finding out the minimum number of vehicles for loading and unloading purpose.

Mahadevan and Narenderan (1990) have proposed the AGV dependent material handling systems utilized in FMS requires certain decisions such as number of vehicles, track layout, specific traffic pattern and solution of traffic control problems to be taken.

The problems occurring from multi-vehicle systems are analyzed and resolved by using analytical and simulation models.

5.4.1 Number of Vehicle Required

Groover (2007) has proposed a formula for finding the number of AGV as follows:

$T_{dv} = (D_d / v) + T_h + (D_e / v)$

Total time per delivery per cycle = loaded travel time + loading/unloading time + empty travel time

$N_d = (60*T_f) / T_{dv}$

Number of automated guided vehicles = N_{dr} / N_d

Where

D_d = Total loaded travel distance

D_e = Total empty travel distance

N_{dr} = Number of deliveries required per hour

N_d = Number of deliveries per vehicle per hour

T_h = loading and unloading time

T_{dv} = Total time per delivery per vehicle

T_f = Traffic factor that accounts for blocking and waiting of vehicles and at intersections.

If only 1 vehicle than $T_f = 1$

If Number of vehicles > 1 than $T_f < 1$

v = Vehicle speed

$T_{dv} = (D_d / v) + T_h + (D_e / v)$

5.4.2 Layout of AGV Track in the Shop

a) Path layout in wire guided AGV:

The floor embedded wires are arranged to form closed loop. These loops determine the guide path of the AGV. Each closed loop carries current of different frequencies with low voltage and low amperage. AC current up to the range of 16 kHz-18 KHz is used in each loop. In the traditional layout the guide path may be intersecting, like T-type, Y Type etc.

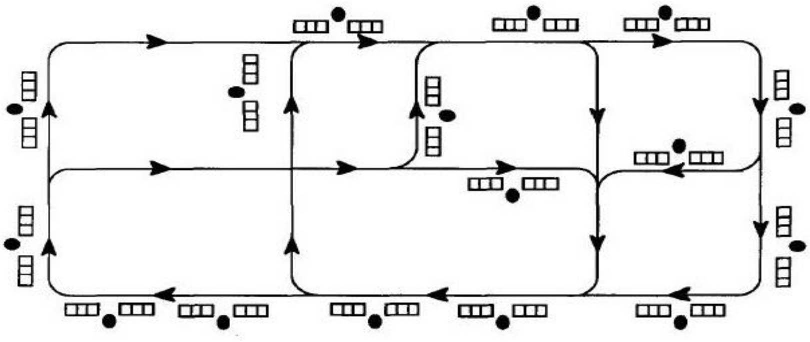


Figure 5.4: Conventional AGV system (Source: Bozer and Srinivasan, 1992)

Bozer and Sriniwasan (1989) have advocated tandem layout to achieve simplicity and flexibility. As compared to the traditional layout, tandem layout offers better control.

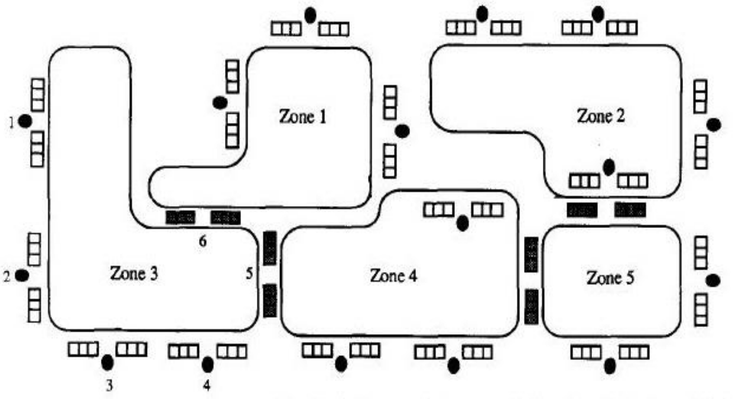


Figure 5.5: Tandem AGV System (source: Bozer and Srinivasan, 1992)

b) Communication in wire guided AGV system:

Communication of the AGV with the host computer is essential for the shop floor control and coordination of AGV system. For this purpose, four main elements interact:

- On board controller

- Floor embedded wire
- Read sensor
- Host (or off-board) computer.

An AGV continuously identifies its position and reports its status to the main host computer through the communication cables. At different points in the loop, guide read sensor (in the embedded wire) locate AGVs and communicate their status through the wires. Control commands from the host computer reach on board controller of AGV via read sensor on the AGV (Shanker and Vrat, 1999).

5.4.3 Vehicle Dispatching Methods

To manage the functions of an AGV mainly deals with problem of dispatching vehicles to the positions in the system where they are timely needed in an efficient manner. There are number of methods used in AGV system for dispatching vehicle. The dispatching methods include**.**

- **On board control panel:** In this system a control panel is mounted over an AGV for the controlling, programming and for other functions of vehicle. Most of the commercial vehicles are moving through a control panel to a particular workstation in layout. Dispatching of vehicles is easer through on board control panel as compare to the other possible methods. Use of this system is least expensive it also provides flexibility and sensitivity to the AGV according to changing demand on handling system. According to Muller (1983) efficiency depends on operator’s performance and varies from operator to operator.
- **Remote Contro**l**:** Remote control system permits the AGV to respond as per stipulate pattern in system. The control is simple and push buttons is located near load / unload station. Through this a signal is send to any passing vehicle to stop it at a station in order to carry out a load. Instructions are issued to vehicle from a remote control station via a human operator for dispatching purpose. According to Groover (2007) control system are used to send the required instructions directly to vehicle at a required location through on board control panel. The most complicated remote call station for communication purpose consists of various control panels mounted near the work stations in a layout. This method allows a

vehicle to be stopped at a specified station and its next destination to be programmed from remote call station.

- **Central computer control:** In central computer control dispatching of vehicle is planned according to pickups and deliveries schedule in the layout to reply the calls from the different (i.e. load/unload) stations in the defined layout. A host computer is used to provide commands to vehicle for path controller system concerning their destinations and operations perform. A process controller is used to posses the real time information regarding the position of each AGV in the system so that it can compose appropriate decision concerning the movement of vehicle to dispatch to a desired location.

5.4.4 Traffic Control Management

The idea of traffic control management to avoid collision between AGVs moving with the same pathway in layout. This is usually accomplished by a blocking system. The main purpose of blocking is to prevent the vehicle from hitting which is ahead of it and moving along a same guide path. The methods for accomplish blocking are (Blair et al. 2006; Egbelu and Roy 1988; Fujii and Sandoh 2016; Arkins and Murphy 1990; Kelly et al., 2007) as follows:

- **On board Vehicle Sensing*:*** Some authors (e.g Broten et al.,2006; Sudha et al., 2016; Groover, 2007) suggested that the optical or ultrasonic sensor system is the best way to sense the presence of vehicles in neighbouring on the same guided wire. Vehicle on board sensor are used to detect an obstacle in front of it and direct the vehicle to stops. When it clear, the vehicles continue.

- **Zone blocking:** According to Shah et al., (1997) AGV layout is divided into separate zones along with separate control units and operating rule is that when a vehicle enters in a given region, it activates the block in that region and no other vehicle is allowed to come in that zone if that zone is already engaged by the another vehicle. The size of zone is quite enough to hold one vehicle plus an allowance is also provided for safety purposes including number of vehicles, complexity of layout and size of vehicles (Groover, 2012).

5.4.5 Proximity Laser Scanner and Laser Scanner Interface (PLS/LSI) Technology

In this technology, proximity laser scanner (PLS) creates a sensing field with a pulsed light and light is returned back to the PLS through a rotating mirror and the distance of the object is calculated by the computer between the send out and received pulses, and the angle of the rotating mirror (Humberto et al., 2010). Mainly sensing field is alienated into three zones; safety zone, warning zone and surveyed zone. Where surveyed area identified as the maximum radius used by the PLS. Hazardous motion is immediately stopped, by the PLS as it determines the presence of an object in the safety zone. In case if object is identified in the warning zone, it provides a warning signal to avoid accident.

A laser scanner interface (LSI) is used to interpret information and to work upon it. The LSI can interpret the data maximum up to four PLSs utmost. When PLS and LSI uses as a combined unit, the PLS acts as the "eyes" and the LSI as a ‘brain’. LSI provide instructions to the PLS to adjust its vision based on the location inside the plant .AGV can also be easily detected even in corners due to self-checking feature.(John 2007 et al.; www.sickusa.com 2007; Humberto and David, 2010).

5.4.6 Prediction and Avoidance of Collisions and Deadlocks

The collision in between the AGVs moving on the same path can be avoided by using the modern sensors and transducers which are used for long and short range detection purpose (Zeng et al., 1991). These transducers may be 4-6 in numbers for wide coverage and an obstacle can be detected by the use of these transducers having a range approximately equal to 4 meters. To serve this purpose a special programming code RS-232 as well 10-30VDC operation is used for collision avoidance in vehicles.

5.4.7 Position of Idle Vehicle

In modern AGVs, vehicles are controlled by the computer with on board microprocessors. Position of pickup and delivery stations along with AGV feedback system can be obtained by using communication between vehicles via system controller (Eileen and Bhaba, 1998). To serve the purpose, two types of the systems i.e. R.F communication as well Electric signals are generally used for tracking the AGV and the material along the correct path (Jiahai Liang and zhiqiang Rao, 2011). Information regarding the vehicle tracking is provided to the System management computers through signals for optimising the AGV utilisation.

5.4.8 Routing Flexibility

The main function of traffic control for AGV is to avoid collision between vehicles moving along same guide path in layout. This purpose is generally accomplished by means of a control system travelling with a particular guide path in same way and prevent from striking any vehicle which is in front of it. The routing of the AGV can be changed easily to follow the optimum path. In this system, two types of controllers such as network controller for destination and embedded controller to navigate the vehicles are generally used.

5.4.9 Path Optimization

Path optimization means selection of the appropriate shortest path which can serve the purpose of path selection, in path optimization system network and embedded controllers are commonly used to navigate the vehicle along the required path (Mahadevan and Narendran, 1990; Langevin et al., 1994; Rajotia et al.,1998).

- Critical Path Method (CPM).
- Particle Swarm optimization (PSO)

5.4.10 Interfacing with Other Systems

AGVS system can be easily interfaced with other systems through the distributed processing network or by using host computer. Such systems are:

- Flexible Manufacturing systems
- Process Control Equipment
- Computer Numerical control
- Shop Floor control system
- Automated storage and retrieval system

5.5 CONCLUSION

This chapter presents an overview on automated guided Vehicles (AGVs) which are driverless and carry out material movement operations in both flexible and conventional manufacturing environment. The most key issues related to material handling in flexible manufacturing systems by AGVs, their configuration, study of AGV design issues for routing and scheduling of AGVs are discussed here. Through the above discussion, it can be concluded that further research should be focused on carrier integration of AGVs with other systems like CNC machine, coordinate measuring machine, machine vision and AS/RS systems etc.

It has been noticed that these AGVs offer limited flexibility, so design of new AGV should include more flexibility in material handling and its operations. Comparison should be done between AGVs and human labour to incorporate more features in AGVs through case studies.

CHAPTER VI

DEVELOPMENT ISM MODELS OF VARIABLES RELATED TO MATERIAL HANDLING EQUIPMENTS, PRODUCTIVITY AND FLEXIBILITY OF FMS

6.1 INTRODUCTION

Flexible manufacturing plays a significance role in material handling for achieving the required productivity and flexibility. It is beneficial for research and practice purpose due to globally technological advancement. Presently MH technology is in advance stage due to adoption of the newest automated production technologies. The volatile and competitive market is posing challenges to the manufacturing industries. Now days, customers are demanding numerous product variety in low cost and time due to the technological advancements (Raj et al., 2008).

Reduction of product and service cost and improvement in productivity has become key variables for retaining the market share (Chan and Swarankar, 2006). In order to achieve these benefits, use of automated machines tools and material handling equipments to process medium sized variety of parts and performing the operations as per the required sequence has become an important component of manufacturing process, in terms of cost and time. Tompkins and White (1984) stated that about 50% of operational cost accounts for material handling activity. The choice and configuration of MHEs improves the productivity by reducing labour cost, effective utilization of space and machines to produce superior quality products (Raj, 2004). According to Cordero, (1997) FMS promise to attain productivity as well flexibility all together and economy by optimizing the time based cost of product variety. Hence flexibility is usually considered as a step towards manufacturing excellence in enhancing the productivity (Olhager, 1993). Productivity and flexibility are the most common methods of an organization’s competitiveness. The advancement of FMS provides a great possibility for enhancing flexibility as well productivity in terms of cost- and modern manufacturing (Rao, 2007). According to Nagalingam and Lin (1999) the mechanized industries need to be modern, flexible, customize and responsive to changes in different technologies for their existence. To overcome these difficulties adoption of automation and advanced material handling systems (MHSs) may also be a substitute of this problem. Because FMS system not only increases the productivity of the plant but also improve its flexibility (Jahromi and Tavakkoli, 2012). Use of FMS offers various advantages over conventional manufacturing systems like fully machine utilization, less floor space, increased productivity, reduced number of machine tools, reduction in process inventory, reduced labour costs, reduced lead times, customer satisfaction and increase profitability (Palframann,1987; Green,1986). Hence, use of FMS is only a way of enhancing the productivity and flexibility for manufacturing System.

In this chapter, main concentration has been given on twelve number of MHE selection variables, 10 number of productivity and 12 number of flexibility variables. These variables have been recognized through literature review and expert opinions in their field. An ISM approach has been used to analyze these variables for material handling equipments selection and for enhancing the productivity and flexibility of FMS. Moreover, drive power and dependence power of variables have been computed so that planning can be done for the actual implementation. These identified variables will assist the manufacturing managers the management to effectively focus on development of strategies in the choice of MHEs for enhancement of productivity and flexibility.

This chapter focuses on the following aspects:

- To recognize and rank the variables which are useful in the MHEs selection and for enhancing the productivity and flexibility of FMS.
- To set up relationship between material handling equipment selection, productivity as well flexibility variables through ISM model.
- To identify material handling variables, productivity and flexibility variables having higher driving power and dominance.

6.2 ISM FOR MATERIAL HANDLING EQUIPMENTS SELECTION VARIABLES

6.2.1 ISM APPROACH

Interpretive structural modelling (ISM) was developed by Prof. John N. Warfield. It is a process of solving the multifaceted issues in the form of graph theory. It represents the poorly defined mental models either by a digraph (directed graph) or by a matrix (Porter, et al., 1980, Singh et al., 2003, Faisel et al., 2006, Attri et al., 2013). ISM methodology acts as a beneficial tool in case of multilevel research design (Klein and Kozlowski, 2000). The following steps used in development of an ISM model are as:

Step 1: Establishing the contextual relationship between variables

Table 6.1 shows the 12 MH variables have been enlisted after identifying through the extensive literature analysis and expert views (industry and academia).

In this step of ISM approach, an appropriate relationship is defined between the identified variables. On the basis of contextual relationship among two identified variables (i and j), the related relationship direction is determined. Here, four symbols (mentioned below) have been utilized for showing the relationship direction among two variables (i and j).

V - Variable i ameliorate to achieve variable j

A - Variable j ameliorate to achieve variable i

X - Variables i and j ameliorate to achieve each other

O - Variables i and j are unrelated

Table 6.1 Material handling variables with their references/sources

S. No	Material Handling Variables	References/sources
1	Speed of delivery	Koste and Malhotra, 1998; Pramod and Banwet, 2010
2	Flexibility	Eade et al.,1989; Greenwood et al., 1988; Buzacott, 1982; Gupta et al., 1996; Reveliotis, 1999
3	Space required	Expert opinion, 2013
4	Safety	Sezen, 2003
5	Material flow path	Shi et al., 2007; Bartholdi and Platzman, 1989; Bozer and Srinivasan, 1991; Tanchoco and Sinriech, 1992; Akturk and Yilmaz, 1996
6	Coordination with plant facilities	Sarker et al., 2011; Meyers et al., 2005
7	Throughput rate	Van der Meer, 2000
8	Automation	Malakooti, 1987; Barbera et al., 2005; Carpanzano et al., 2011
9	Plant layout	Malakooti and D'Souza, 1987; Lowe,1992; Chen and Sha, 2005; Ioannou, 2007; Liao and Chin, 2011
10	Load carrying capacity	Ozden, 1988
11	System networking	Satoshi et al., 2007; Park et al., 2009; Tanchoco and Sinriech, 1992; Chan et al., 2012
12	Economics	Tompkins et al., 1996; Sujono and Lashkari, 2007; Muller, 1983

Step 2: Development of structural self-interaction matrix (SSIM)

In this step, SSIM is developed on the basis of contextual relationship among the identified variables. To obtain approval, SSIM was finalized with the help of experts as presented in Table 6.2.

Table 6.2 Structural self interactive matrix (SSIM)

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

Step 3: Development of the initial reachability matrix

Here, reachability matrix is developed from SSIM in two sub-steps. In first one, SSIM is transformed into initial reachability matrix by exchanging the information of SSIM into binary digits (i.e. 0, 1) on the basis of following rules:

- If cell (i, j) is V in SSIM, then, cell (i, j) becomes 1 and cell (j, i) becomes 0 in initial RM.
- If cell (i, j) is A in SSIM, then, cell (i, j) becomes 0 and cell (j, i) becomes 1 in initial RM.
- If cell (i, j) is X in SSIM, then, cell (i, j) becomes 1 and cell (j, i) becomes 1 in initial RM.
- If cell (i, j) is O in SSIM, then, cell (i, j) becomes 0 and cell (j, i) becomes 0 in initial RM.

Table 6.3 Initial reachability matrix

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

Step 4: Development of the final reachability matrix

In this step of ISM approach, transitivity concept is incorporated in initial reachability matrix. This matrix will have few entries filled from pair wise comparison and few one from inferred entries. Transitivity concept is mainly used for filling the gap, if any. Principle of transitivity states that if variable A is associated to variable B and variable B associated to variable C, then variable A will be associated to variable C. Table 6.4 shows the final reachability matrix.

Table 6.4 Final reachability matrix

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

Note: 1* entries indicates incorporate transitivity to fill the gap if any, in the opinion collected during development of SSIM.

Step 5: Level partitioning

In this step of ISM approach, final reachability matrix is partitioned into different levels for deciding the levels in ISM model. Warfield (1974) and Farris and Sage (1975), stated that reachability set and antecedent set for each variable has to be found from the final reachability matrix. The variables having common reachability set and antecedent set are allocated at intersection set. Thus, reachability set, antecedent set and intersection set are computed. This leads to the development of iteration process for positioning the top-level element in ISM model. The top level element consists of same antecedent set and intersection set. Afterwards, the top-level elements are removed from the set. Then, this process is repeated to compute the next level element. This process is repeated till levels of the entire element have been found. Reachability set, antecedent set and intersection set of variables have been shown in Tables i.e. 6.5 to 6.10.

Table 6.5 Iteration I

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7,8,9,10,11,12	1	1	
2	2,3,4,5,6,7,8,9,10,11,12	1,2	2	
3	3,4,5,6,7,8,9,10,11	1,2,3,7,10,11,12	3,7,10,11	
4	4,6,7,9,10,11	1,2,3,4,5,6,10,11,12	4,6,10,11	
5	5	1,2,3,5,6,9,10,11,12	5	**1**
6	5,6,7,8,9,10	1,2,3,4,6,7,9,10,11,12	6,7,9,10	
7	3,4,6,7,8,10	1,2,3,4,6,,9,11,12	3,4,6,7	
8	8	1,2,3,6,7,8,10,11,12	8	**1**
9	4,5,6,7,9,10,11	1,2,3,4,6,9,11,12	4,6,9,11	
10	3,4,5,6,8,10,11	1,2,3,4,6,7,9,10,12	3,4,6,10	
11	3,4,5,6,7,8,9,11	1,2,3,4,9,10,11,12	3,4,9,11	
12	3,4,5,6,7,8,9,10,11,12	1,2,12	12	

Table 6.6 Iteration II

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,6,7,9,10,11,12	1	1	
2	2,3,4,6,7,9,10,11,12	1,2	2	
3	3,4,6,7,9,10,11	1,2,3,7,10,11,12	3,7,10,11	
4	4,6,7,9,10,11	1,2,3,4,6,10,11,12	4,6,10,11	
6	6,7,9,10	1,2,3,4,6,7,9,10,11,12	6,7,9,10	II
7	3,4,6,7,10	1,2,3,4,6,9,11,12	3,4,6,7	
9	4,6,7,9,10,11	1,2,3,4,6,9,11,12	4,6,9,11	
10	3,4,6,10,11	1,2,3,4,6,7,9,10,12	3,4,6,10	
11	3,4,6,7,9,11	1,2,3,4,9,10,11,12	3,4,9,11	
12	3,4,6,7,9,10,11,12	1,2,12	12	

Table 6.7 Iteration III

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,11,12	1	1	
2	2,3,4,11,12	1,2	2	
3	3,4,11	1,2,3,11,12	3,11	
4	4,11	1,2,3,4,11,12	4,11	**III**
7	3,4,	1,2,3,4,11,12	3,4	**III**
9	4,11	1,2,3,4,11,12	4,11	**III**
10	3,4,11	1,2,3,4,12	3,4	
11	3,4,11	1,2,3,4,11,12	3,4,11	**III**
12	3,4,11,12	1,2,12	12	

Table 6.8 Iteration IV

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,12	1	1	
2	2,12	1,2	2	
12	12	1,2,12	12	IV

Table 6.9 Iteration V

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2	1	1	
2	2	1,2	2	**V**

Table 6.10 Iteration VI

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
1	1	1	1	**VI**

Step 6: Development of conical matrix

Here, final reachability matrix has been transformed into conical matrix (shown in Table 6.11). This matrix consists of most of upper half diagonal elements as zero and most of lower half elements as one. It is transformed by clubbing variables together in the same level. Drive power of a variable is computed by summing up 1's in rows and its dependence power by summing up 1's in columns.

Table 6.11 Conical matrix

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

Step 7: Development of digraph

In this step of ISM approach, a digraph has been developed from conical matrix and level partitioning reachability matrix. Initial digraph consisting of transitivity links is generated by nodes and lines of edges. After removal of indirect links, a final digraph has been represented in Figure 6.1.

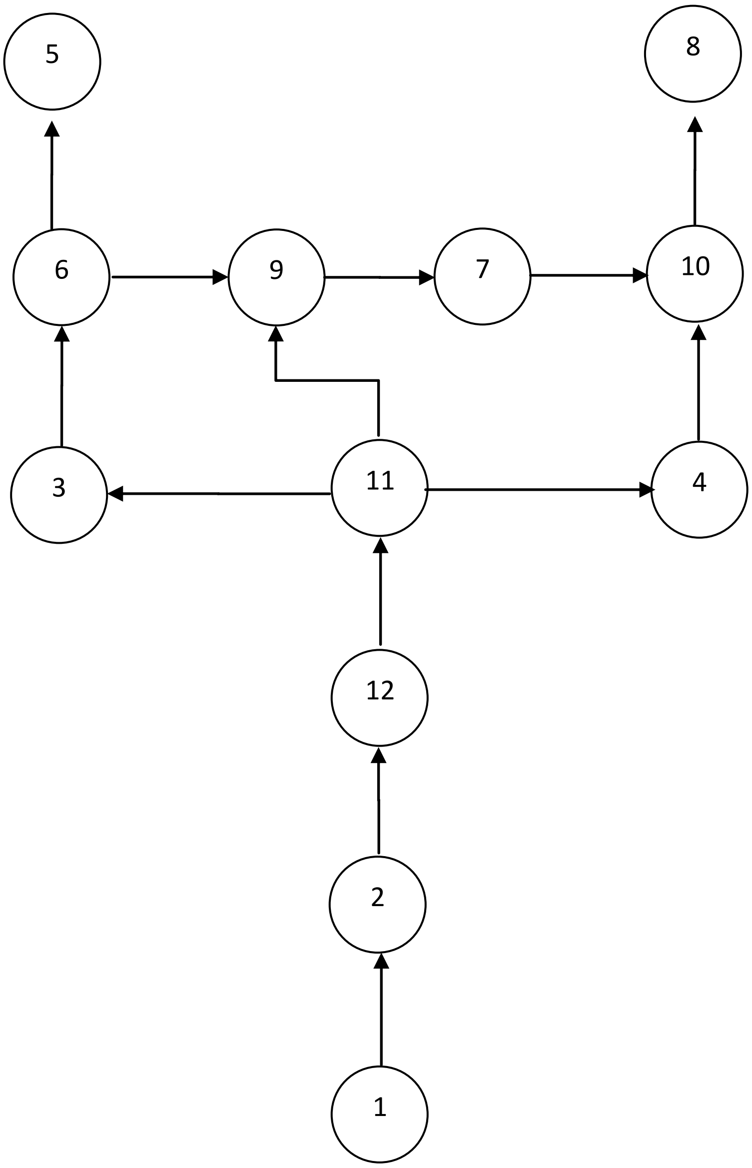


Figure 6.1 Digraph showing the level of material handling variables

Step 8: Development of ISM model

Here, the digraph (Figure 6.2) is transformed into an ISM model by changing elements nodes with statements.

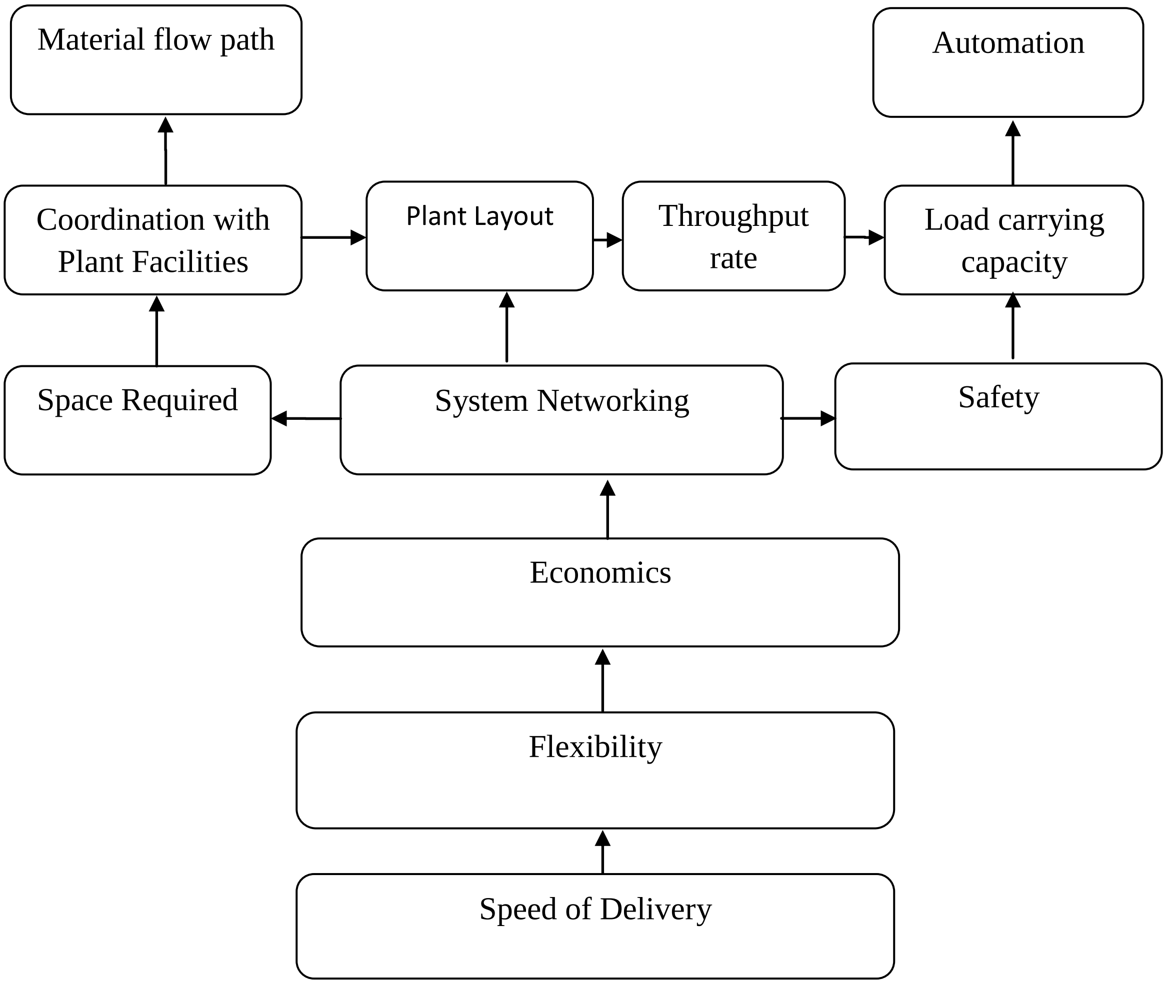


Figure 6.2 Interpretive structural model showing the level of MHE variables

Step 9: Check for conceptual inconsistency

In last step of ISM approach, conceptual discrepancy is verified by identifying and removing the intransitivity in model.

6.3 MICMAC analysis

MICMAC stands for cross-impact matrix multiplication applied to classification. MICMAC is based on multiplication properties of matrices (Sharma et al., 1995). MICMAC analysis aims to analyse the drive power and dependence power of variables. It is carried out to identify the key variables that drive the system. On the basis of drive power and dependence power, the variables, have been categorized into four categories (Figure 6.3) as follows:

- **Autonomous variables.** These variables have weak drive power but weak dependence power.
- **Linkage variables.** These variables have strong drive power as well as strong dependence power.
- **Dependent variables.** These variables have weak drive power but strong dependence power.
- **Independent variables.** These variables have strong drive power but weak dependence power.

Driving Power

12	1											
11		2										
10			**IV**						**III**	12		
9			3									
8												
7												
6						6					11	
5				4					9	10		
4							7					
3			**I**						**II**			
2												
1					5			8				
	1	2	3	4	5	6	7	8	9	10	11	12

Dependence power

Figure 6.3 Clusters of variables in the material handling in FMS

6.4 DISCUSSION

In this research, the variables affecting the selection of MHEs have been analyzed. For this purpose, ISM approach has been utilized for analyzing the interaction among the identified MHEs variables. The ISM based frame-work offers the management to know the hierarchy of actions to be adopted for proper selection of MHEs on the basis of these variables. The manufacturing managers can have basic idea from these identified variables in understanding their relative importance and interdependencies. The driving power and dependence power of identified variables can be identified by Figure 6.3. The significance of material handling variables emerging from the research is as follows:

- Autonomous variables are speed of delivery, system networking, space required and material flow path. These variables have weak driving power but weak dependence power. These variables do not have much influence on the considered system.
- Variables such as safety, load carrying capacity, throughput rate and plant layout are dependent variables. These variables have weak driving power but strongly depend on other variables. Thus, these variables must be properly handled for the selection of MHEs.
- Variable such as flexibility is linkage variable which have strong driving power as well as high dependence power. Flexibility in MHEs provides a greater alternative for adopting latest technologies such as robots and AGVs.
- At last, variables such as speed of delivery, automation and economics are dependent variables. These variables are having strong driving power but weak dependence power on other variables.

The present research work is focused on the development of framework for MHEs. The developed ISM based frame-work based will assist the manufacturing managers to take the proper decision regarding the selection of MHEs. Moreover, the awareness of these variables as well as their driving and dependence power will form the strong basis for making the proper decision for selection of MHEs. The ISM analysis shows that variables such as speed of delivery, automation and economics are more important for selection point of view. Hence, before opting the automated MHEs, the availability of different variables must be examined such as availability of high technology equipments and vendors. Availability of advanced production systems like computer numerical control (CNC), direct numerical control (DNC) and computer aided process planning (CAPP) etc. necessitates the effective material handling equipments for better production results. The variables having high driving power in ISM model needs to be cautiously examined on priority basis as few variables are affected by them. The manufacturing managers should effectively understand the relative importance and interdependencies. The developed ISM model will acts as basic directive in the selection of MHEs.

6.5 ANALYSIS OF FMS PRODUCTIVITY VARIABLES BY ISM APPROACH

For analyzing the FMS productivity and its framework an ISM method is used. Framework has been made by using the ISM to evaluate the effectiveness index (EI) of FMS productivity.

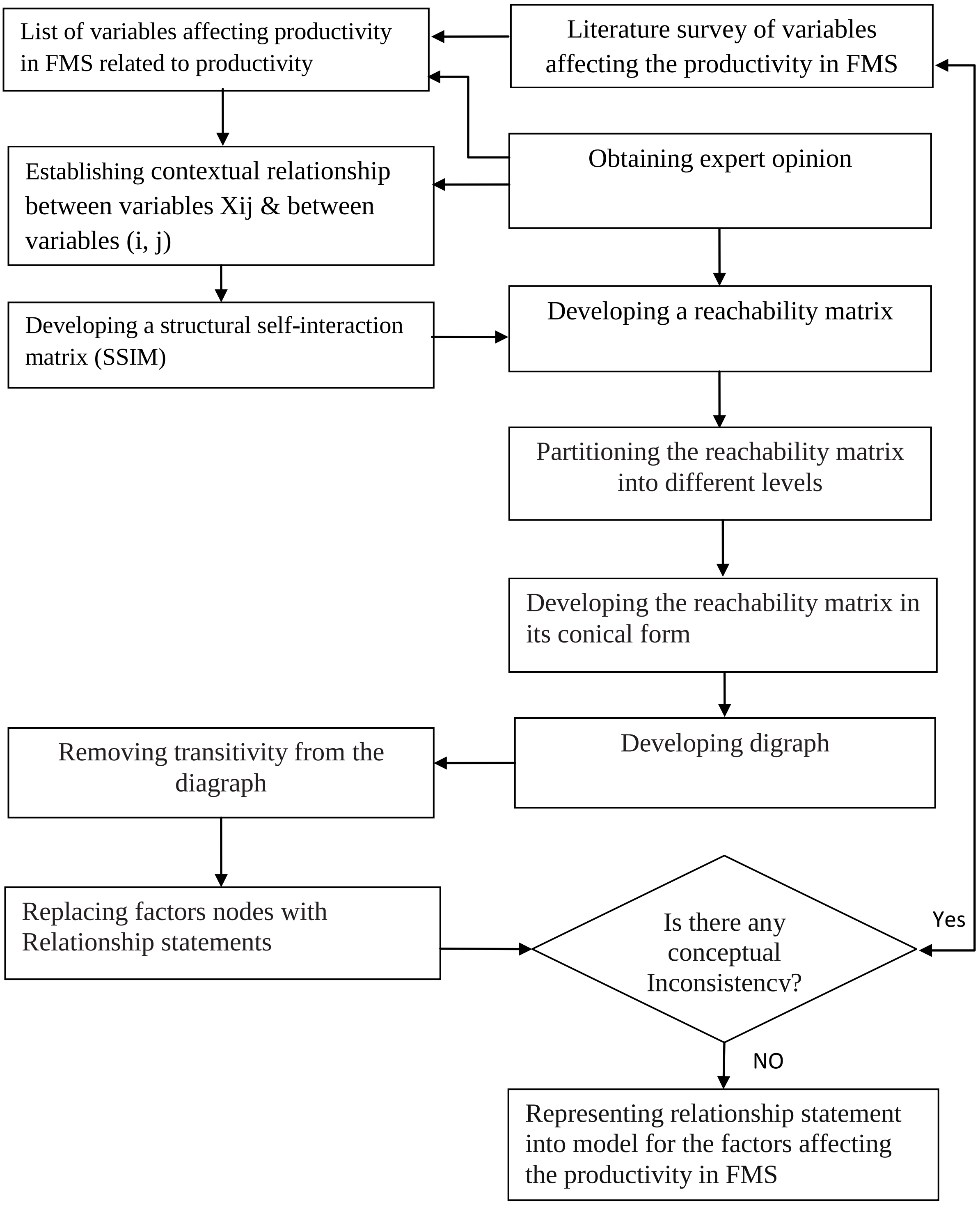


Figure 6.4 Flow chart for preparing ISM model

The various steps, used in development of ISM model are as follows:

Step 1 : Establishing the contextual relationship among variables

An analysis has been made for ten number of productivity variables identified by the literature survey, observations from industry and academia and opinions of experts are shown in chapter 2.

Table 6.12 Variables affecting FMS productivity

S.No	Variables	Mean score	Rank	Sources
1	High production rate	4.53	1	Expert opinion
2	Reduced lead time	4.46	2	Keong et al., 2005; Saraswat et al. 2015
3	Flow path optimization	4.33	3	Bozer and Srinivasan, 1991
4	High machine utilization	4.20	4	Bayazit, 2005
5	Reduced scrap	4.15	5	Groover, 2007
6	Efficient layout arrangement	4.10	6	Naik and Kallurkar, 2016
7	Effective material handling	4.00	7	Expert opinion
8	Effective tool management	3.83	8	Expert opinion
9	Reduction in man power	3.80	9	Chan and Swarankar, 2006
10	High flexibility	3.75	10	Rao and Deshmukh, 1994

After identifying these variables, a contextual relationship is established. On the basis of contextual relationship among two variables (i and j), the direction of relationship has been evolved. For this purpose, following four symbols have been used.

- V - Variable i helps to achieve variable j;
- A - Variable j helps to achieve variable i ;

- X - Variables i and j helps to achieve each other; and
- O - Variables i and j are unrelated

Step 2 : Development of structural self-interaction matrix (SSIM)

A SSIM has been build up for making pair wise appropriate association among the variables. It was discussed with experts for their consent and SSIM has been finalized and is presented in Table 6.13.

Table 6.13 Structural self-interaction matrix (SSIM)

Variables of Productivity	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**
1	O	O	A	A	A	O	A	A	A
2	O	O	A	A	A	O	O	A	
3	A	O	O	O	A	O	V		
4	O	O	A	A	A	O			
5	O	O	A	O	O				
6	O	V	O	A					
7	O	O	O						
8	O	O							
9	O								

Step 3: Development of the initial reachability matrix (R.M)

In this step, a reachability matrix is developed from SSIM in two steps. In first step, SSIM is converted into initial reachability matrix by converting information of SSIM into binary digits. Following guidelines are used for converting SSIM into initial reachability matrix (Table 6.14):

- If cell (i, j) consists of symbol V in SSIM, then, cell (i, j) entry becomes 1 and cell (j, i) entry becomes 0 in initial RM.
- If cell (i, j) consists of symbol A in SSIM, then, cell (i, j) entry becomes 0 and cell (j, i) entry becomes 1 in initial RM.

- If cell (i, j) consists of symbol X in SSIM, then, cell (i, j) entry becomes 1 and cell (j, i) entry becomes 1 in initial RM.
- If cell (i, j) consists of symbol O in SSIM, then, cell (i, j) entry becomes 0 and cell (j, i) entry becomes 0 in initial RM.

Table 6.14 Initial reachability matrix

Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1	0	0	0	0	0	0	0	1	0
2	1	1	0	0	0	0	0	0	0	0
3	1	1	1	1	0	0	1	0	0	0
4	1	0	0	1	0	0	0	0	0	0
5	0	0	0	0	1	0	0	0	0	0
6	1	1	1	1	0	1	0	0	1	0
7	1	1	0	1	0	1	1	0	0	0
8	1	1	0	1	1	0	0	1	1	1
9	0	0	0	0	0	0	0	0	1	0
10	0	0	1	1	0	0	0	0	0	1

Step 4: Development of the final reachability matrix

In final reachability matrix, concept of transitivity is incorporated. In this step, some entries are filled from the pair wise comparison and some by the inferred entries. The final reachability matrix is shown in Table 6.15.

Table 6.15 Final reachability matrix

Variables	1	2	3	4	5	6	7	8	9	10	
1	1	0	0	0	0	0	0	0	1	0	2
2	1	1	0	0	0	0	0	0	1*	0	3
3	1	1	1	1	0	1*	1	0	1*	0	7
4	1	0	0	1	0	0	0	0	1*	0	3
5	0	0	0	0	1	0	0	0	0	0	1
6	1	1	1	1	0	1	1*	0	1	0	7
7	1	1	1*	1	0	1	1	0	1*	0	7
8	1	1	1*	1	1	0	0	1	1	1	8
9	0	0	0	0	0	0	0	0	1	0	1
10	1*	1*	1	1	0	0	1*	0	0	1	6
	8	6	5	6	2	3	4	1	8	2	

Step 5: Partitioning the reachability matrix

Warfield (1974) and Farris and Sage (1977) illustrated that the reachability set and antecedent set for each variable is to be found from the final RM. The variables having common reachabilty set and antecedent set are allocated to intersection set. Thus reachabilty set, antecedent set and intersection set are allocated. This leads the process of iteration for assigning the top-level (i.e. 1st level) variables. The top-level variables for each hierarchy are the variables in which antecedent set and intersection set are same in the ISM hierarchy. Similarly for the formation of the next table, the top-level variables will be removed from the set. After the top-level variables are separated from the hierarchy, the process is repeated to find the next level of variable. This process will be continued till all levels of each element are found. Reachability set, antecedent set, intersection set of levels and iterations I-VII is shown in different iteration Tables 6.16 – 6.22.

Table 6.16 Iteration I

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

Table 6.17 Iteration II

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

Table 6.18 Iteration III

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
1	1	1,2,3,4,6,7,8,10	1	**III**
2	1,2	2,3,6,7,8,10	2	
3	1,2,3,4,6,7	3,6,7,8,10	3,6,7	
4	1,4	3,4,6,7,8,10	4	
6	1,2,3,4,6,7	3,6,7	3,6,7	
7	1,2,3,4,6,7	3,6,7,10	3,6,7	
8	1,2,3,4,8,10	8	8	
10	1,2,3,4,7,10	8,10	10	

Table 6.19 Iteration IV

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
2	2	2,3,6,7,8,10	2	**IV**
3	2,3,4,6,7	3,6,7,8,10	3,6,7	
4	4	3,4,6,7,8,10	4	**IV**
6	2,3,4,6,7	3,6,7	3,6,7	
7	2,3,4,6,7	3,6,7,10	3,6,7	
8	2,3,4,8,10	8	8	
10	2,3,4,7,10	8,10	10	

Table 6.20 Iteration V

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
3	3,6,7	3,6,7,8,10	3,6,7	**V**
6	3,6,7	3,6,7	3,6,7	**V**
7	3,6,7	3,6,7,10	3,6,7	**V**
8	3,8,10	8	8	
10	3,7,10	8,10	10	

Table 6.21 Iteration VI

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
8	8,10	8	8	
10	10	8,10	10	**VI**

Table 6.22 Iteration VII

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
8	8,10	8	8	**VII**

Step 6: Development of conical matrix

Here in this step, final reachability matrix is converted into conical matrix (Table 6.23) by clubbing variables together in the same level, across rows and columns. Drive power of a variable is computed by summing up 1's in rows and its dependence power by 1's in columns.

Table 6.23 Conical matrix

Variables	5	9	1	2	4	3	6	7	10	8	Drive Power
5	1	0	0	0	0	0	0	0	0	0	**1**
9	0	1	0	0	0	0	0	0	0	0	**1**
1	0	1	1	0	0	0	0	0	0	0	**2**
2	0	1	1	1	0	0	0	0	0	0	**3**
4	0	1	1	0	1	0	0	0	0	0	**3**
3	0	1	1	1	1	1	1	1	0	0	**7**
6	0	1	1	1	1	1	1	1	0	0	**7**
7	0	1	1	1	1	1	1	1	0	0	**7**
10	0	0	1	1	1	1	0	1	1	0	**6**
8	1	1	1	1	1	1	0	0	1	1	**8**
Dependence power	**2**	**8**	**8**	**6**	**6**	**5**	**3**	**4**	**2**	**1**	

Step 7: Development of digraph

In this step of ISM approach, a digraph is developed on the basis of conical matrix. Directed graph is made by removing indirect links and a final digraph has been presented in Figure 6.5.

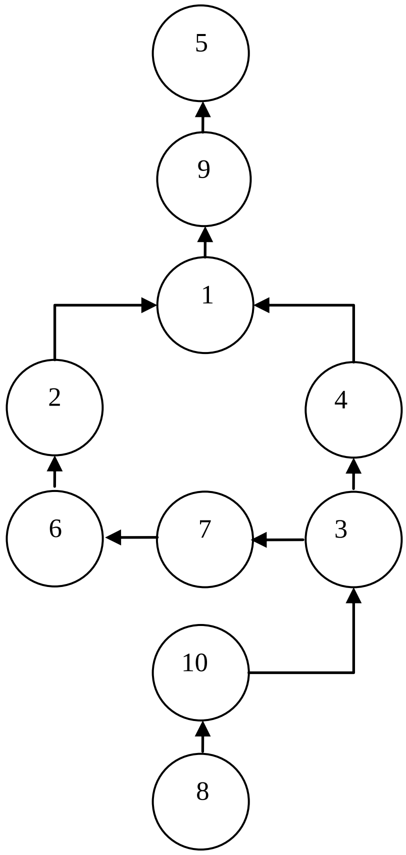


Figure 6.5 Digraph showing the level of productivity variables

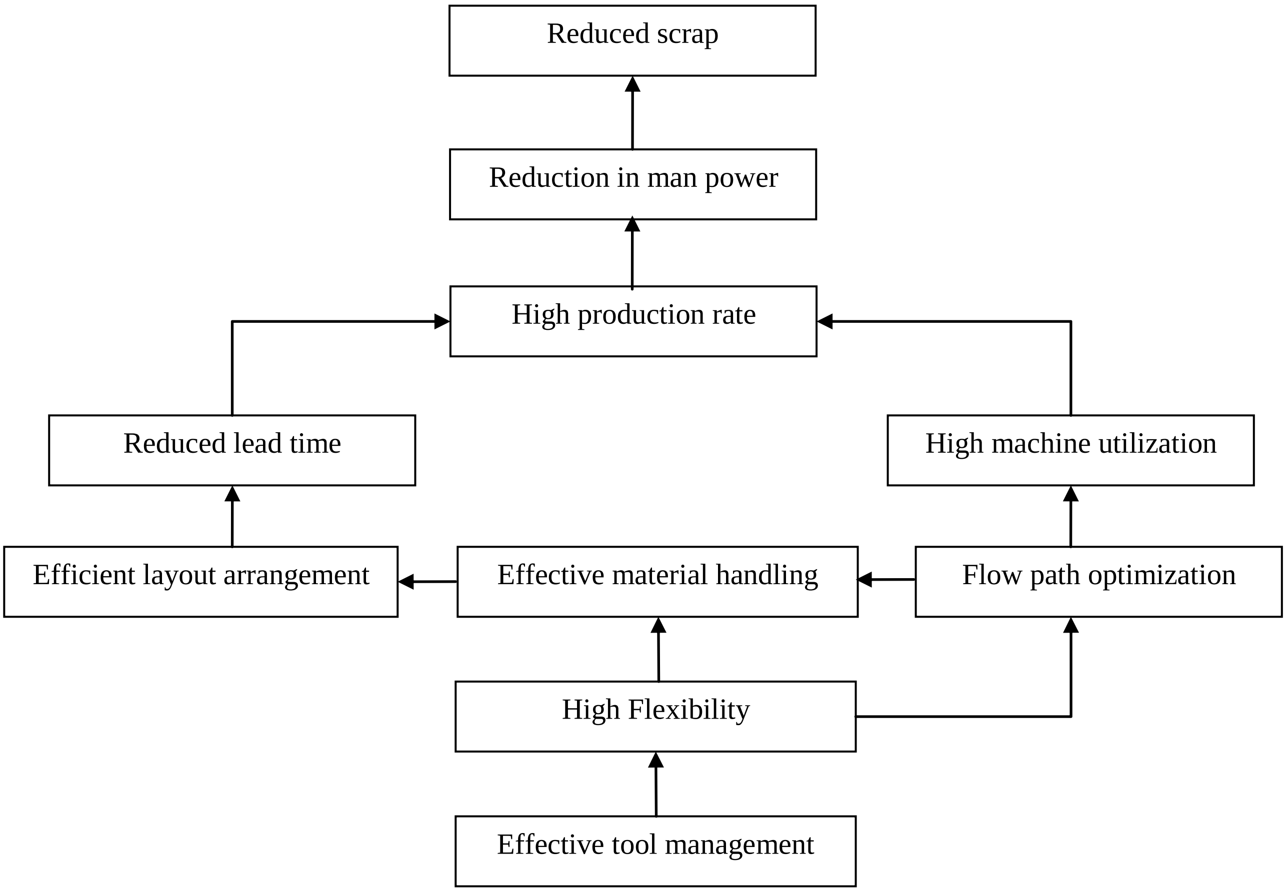


Figure 6.6 Interpretive structural model showing the level of productivity variables

Step 8: Development of ISM model

In this step, digraph (Figure 6.6) is converted into an ISM model by replacing nodes of the variables with statements.

Step 9: Check for conceptual inconsistency

In last step of ISM approach, conceptual inconsistency is checked and incorporated.

Driving Power

10										
9										
8	8		**IV**					**III**		
7			6	7	3					
6		10								
5										
4										
3			**I**			2,4		**II**		
2								1		
1		5						9		
	1	2	3	4	5	6	7	8	9	10

Dependence power

Figure 6.7 Clusters of variables affecting the productivity in FMS

6.6 RESULTS AND DISCUSSION

The specific purpose of current research work is assessment of various variables which are useful in enhancing the productivity for different organizations. For this purpose, an ISM based model has been framed to analyze the relations between various variables of productivity and to appreciate the hierarchy of performance to be taken for exploring the productivity based on these variables. The functional management can make proper decision on the basis of relative importance and interdependencies of variables. Drive power and dependence power of different variables can also be recognized through MICMAC analysis as shown in Figure 6.7. The importance of productivity variables is as under:

- Reduced scrap is the autonomous variable. This autonomous variable is weak driver and has weak dependence. Though, this variable has less influence on the system but it cannot be neglected from the system.
- Dependent variables like high production rate, reduced lead time, high machine utilization, reduction in man power are the weak drivers but strongly depend on each other.

- No linkage variables are present in the analysis.
- Last but not the least, variables like flow path optimization, efficient layout arrangement, effective material handling, effective tool management, high flexibility are dependent variables.

6.7 APPLICATION OF ISM FOR ANALYZING FLEXIBILITY VARIABLES

For analyzing the FMS flexibility and to prepare its framework an ISM method is used. This framework is further used to evaluate the effectiveness index (EI) of FMS productivity. Various steps, which initiate the development of ISM model are as follows:

Table 6.24 Flexibility critical variables with their references/sources

S. No	Critical variables	References/Source
1	Utilization of automated material handling systems	Ganesharajah et al. (1998); Kulak (2005); Sujono and Lashkari (2007)
2	Flexible fixturing	Bi and Zhang (2001); Groover (2006); Santosh et al. (2016)
3	Automation	Jovane et al. (2003)
4	Combination of operation	Groover (2006); Kumar et al. (2006)
5	Arrangement of machines	Expert opinion
6	Traffic Management	Vis et al. (2005); Vieira (2011)
7	Throughput Rate	Shang (1995)
8	Plant Layout	Heragu and Gupta (1994); Benjaafar et al. (1995)
9	Product variety	Chan and Chung (1997); Bayazit (2005); Groover (2003); Sujono and Lashkari (2007); Raj et al. (2012)
10	Tool Interchangeable capacity	Gray (1988); Zhang and Hinduja (1995)
11	Multitasking tools	Djassemi (2009); Kubota (2010)
12	Reconfigurable Tools	Padayachee et al. (2009); Malhotra et al. (2009)

6.8 ISM FOR THE CRITICAL VARIABLES OF FLEXIBILITY IN FMS

The steps used for making an ISM model, are as under:

Step 1: Establishing the appropriate relationship among critical Variables

An analysis has been made for flexibility critical variables which have been acknowledged during the literature review and opinions of their field specialists (industry and academia both) as shown in Table 6.24. After analyzing these critical variables, a contextual relationship has been developed among these critical variables. Following four symbols have been used to indicate the direction of the relationship.

- V - Critical variables i ameliorate to achieve critical variables j;
- A - Critical variables j ameliorate to achieve critical variables i ;
- X - Critical variables i and j ameliorate to achieve each other; and
- O - Critical variables i and j are unrelated.

Step 2: Development of structural self-interaction matrix (SSIM) structure

In this step, SSIM is developed on the basis of relationship identified among the variables and is shown in Table 6.25.

Table 6.25 Structural self interactive matrix (SSIM)

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

Step 3: Development of the initial reachability matrix

Here, a reachability matrix is developed from SSIM. It is carried out in two sub-steps. In first step, SSIM is converted into initial reachability matrix (Table 6.26) by exchanging information of SSIM into binary digits. This transformation is carried out by using following rules:

- If cell (i, j) consists of symbol V in SSIM, then, cell (i, j) entry becomes 1 and cell (j, i) entry becomes 0.
- If cell (i, j) consists of symbol A in SSIM, then, cell (i, j) entry becomes 0 and cell (j, i) entry becomes 1.
- If cell (i, j) consists of symbol X in SSIM, then, cell (i, j) entry becomes 1 and cell (j, i) entry becomes 1.
- If cell (i, j) consists of symbol O in SSIM, then, cell (i, j) entry becomes 1 and cell (j, i) entry becomes 1.

Table 6.26 Initial reachability matrix

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

Step 4: Development of the final reachability matrix

In final reachability matrix, concept of transitivity has been incorporated in initial reachability matrix on the basis of transitivity concept. The final reachability matrix is shown in Table 6.27.

Table 6.27 Final reachability matrix

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

Step 5: Level partitioning

Here in this step, RM is divided into different levels (Table 6.28). Warfield (1974) and Farris and Sage (1975) illustrated that the reachability set and antecedent set for each critical variable is to be found from final reachability matrix. The critical variables, which have common reachability set and antecedent set, are allocated at the intersection set. Thus reachabilty set, antecedent set and intersection set are located. This leads the process of iteration for locating the top-level (i.e. 1^{st} level) critical variable. The top-level critical variable for each hierarchy is the critical variables in which antecedent set and intersection set are same in the ISM hierarchy. Similarly for the formation of the next table, the top-level critical variables will be removed from the set. After the top-level critical variables are separated from the hierarchy, the process is repeated to find the next level of critical variable. This process will be continued till all levels of each critical variable are found. Reachability set, antecedent set and intersection set of levels (I to VIII) are shown in different iteration Tables 6.28 to 6.35.

Table 6.28 Iteration I

Critical variables	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7,8,9,10, 11,12	1,2,3,4,5,6,8,9,10,11,12	1,2,3,4,5,6,8,9,10, 11,12	
2	1,2,3,7	1,2,3,9,10,11,12	1,2,3	
3	1,2,3,4,5,6,7,8,9,10, 11,12	1,2,3,4,5,6,8,11,12	1,2,3,4,5,6,8,11,12	
4	1,3,4,5,6,7,8	1,3,4,10,11,12	1,3,4	
5	1,3,5,6,7,8	1,3,4,5,9,10,11,12	1,3,5	
6	1,3,6,7	1,3,4,5,6,8,9,10,11,12	1,3,6	
7	7	1,2,3,4,5,6,7,8,9,10,11, 12	7	**I**
8	1,3,6,7,8	1,3,4,5,8,9,10,11,12	1,3,8	
9	1,2,5,6,7,8,9	1,3,9,10,11,12	1,9	
10	1,2,4,5,6,7,8,9,10,11	1,3,10	1,10	
11	1,2,3,4,5,6,7,8,9,11	1,3,10,11	1,3,11	
12	1,2,3,4,5,6,7,8,9,12	1,3,12	1,3,12	

Table 6.29 Iteration II

Critical variables	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,8,9,10, 11,12	1,2,3,4,5,6,8,9,10,11, 12	1,2,3,4,5,6,8,9,10, 11,12	**II**
2	1,2,3	1,2,3,9,10,11,12	1,2,3	**II**
3	1,2,3,4,5,6,8,9,10, 11,12	1,2,3,4,5,6,8,11,12	1,2,3,4,5,6,8,11,12	
4	1,3,4,5,6,8	1,3,4,10,11,12	1,3,4	
5	1,3,5,6,8	1,3,4,5,9,10,11,12	1,3,5	
6	1,3,6	1,3,4,5,6,8,9,10,11,12	1,3,6	**II**
8	1,3,6,8	1,3,4,5,8,9,10,11,12	1,3,8	
9	1,2,5,6,8,9	1,3,9,10,11,12	1,9	
10	1,2,4,5,6,8,9,10,11	1,3,10	1,10	
11	1,2,3,4,5,6,8,9,11	1,3,10,11	1,3,11	
12	1,2,3,4,5,6,8,9,12	1,3,12	1,3,12	

Table 6.30 Iteration III

Critical variables	Reachability Set	Antecedent Set	Intersection Set	Level
3	3,4,5,8,9,10,11,12	3,4,5,8,11,12	3,4,5,8,11,12	
4	3,4,5,8	3,4,10,11,12	3,4	
5	3,5,8	3,4,5,9,10,11,12	3,5	
8	3,8	3,4,5,8,9,10,11,12	3,8	**III**
9	5,8,9	3,9,10,11,12	9	
10	4,5,8,9,10,11	3,10	10	
11	3,4,5,8,9,11	3,10,11	3,11	
12	3,4,5,8,9,12	3,12	3,12	

Table 6.31 Iteration IV

Critical variables	Reachability Set	Antecedent Set	Intersection Set	Level
3	3,4,5,9,10,11,12	3,4,5,11,12	3,4,5,11,12	
4	3,4,5	3,4,10,11,12	3,4	
5	3,5	3,4,5,9,10,11,12	3,5	**IV**
9	5,9	3,9,10,11,12	9	
10	4,5,9,10,11	3,10	10	
11	3,4,5,9,11	3,10,11	3,11	
12	3,4,5,9,12	3,12	3,12	

Table 6.32 Iteration V

Critical variables	Reachability Set	Antecedent Set	Intersection Set	Level
3	3,4,9,10,11,12	3,4,11,12	3,4,11,12	
4	3,4	3,4,10,11,12	3,4	**V**
9	9	3,9,10,11,12	9	**V**
10	4,9,10,11	3,10	10	
11	3,4,9,11	3,10,11	3,11	
12	3,4,9,12	3,12	3,12	

Table 6.33 Iteration VI

Critical variables	Reachability Set	Antecedent Set	Intersection Set	Level
3	3,10,11,12	3,11,12	3,11,12	
10	10,11	3,10	10	
11	3,11	3,10,11	3,11	**VI**
12	3,12	3,12	3,12	**VI**

Table 6.34 Iteration VII

Critical variables	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
3	3,10	3	3	
10	10	3,10	10	**VII**

Table 6.35 Iteration VIII

Critical variables	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
3	3	3	3	**VIII**

Step 6: Development of conical matrix

In the present step, final reachability matrix has been converted into conical form as shown in Table 6.36.

Table 6.36 Conical matrix

Critical variables	7	1	2	6	8	5	4	9	11	12	10	3	**Drive Power**
7	1	0	0	0	0	0	0	0	0	0	0	0	**1**
1	1	1	1	1	1	1	1	1	1	1	1	1	**12**
2	1	1	1	0	0	0	0	0	0	0	0	1	**4**
6	1	1	0	1	0	0	0	0	0	0	0	1	**4**
8	1	1	0	1	1	0	0	0	0	0	0	1	**5**
5	1	1	0	1	1	1	0	0	0	0	0	1	**6**
4	1	1	0	1	1	1	1	0	0	0	0	1	**7**
9	1	1	1	1	1	1	0	1	0	0	0	0	**7**
11	1	1	1	1	1	1	1	1	1	0	0	1	**10**
12	1	1	1	1	1	1	1	1	0	1	0	1	**10**
10	1	1	1	1	1	1	1	1	1	0	1	0	**10**
3	1	1	1	1	1	1	1	1	1	1	1	1	**12**
Dependence power	**12**	**11**	**7**	**10**	**9**	**8**	**6**	**6**	**4**	**3**	**3**	**9**	

Step 7: Development of digraph

In this step, digraph after removing the indirect links has been represented in Figure 6.8.

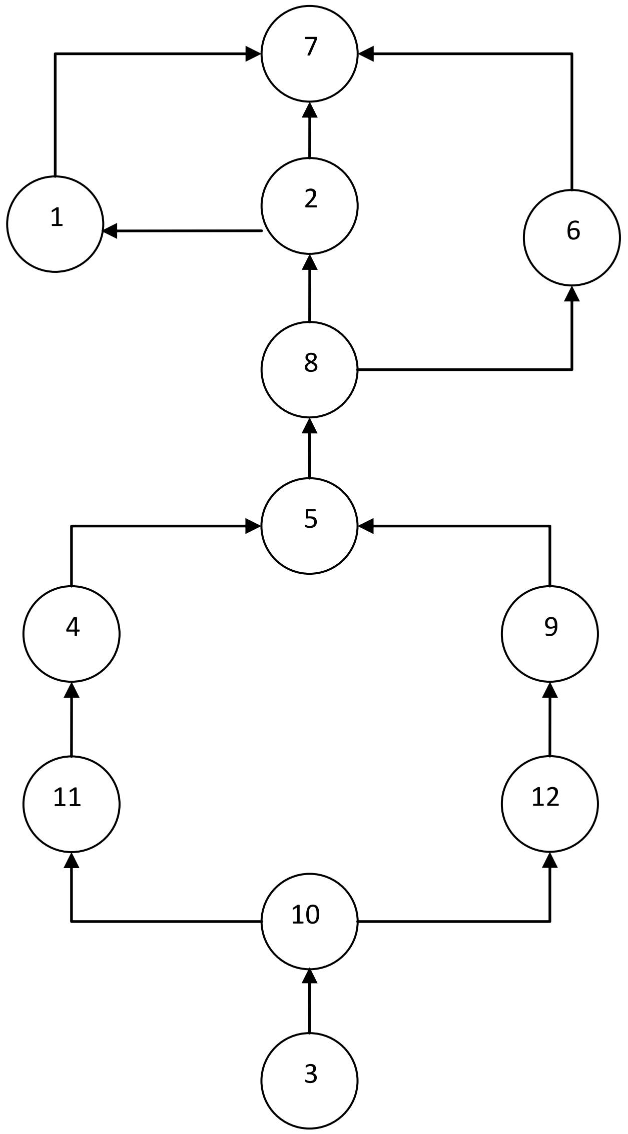


Figure 6.8 Digraph showing the level of flexibility critical variables

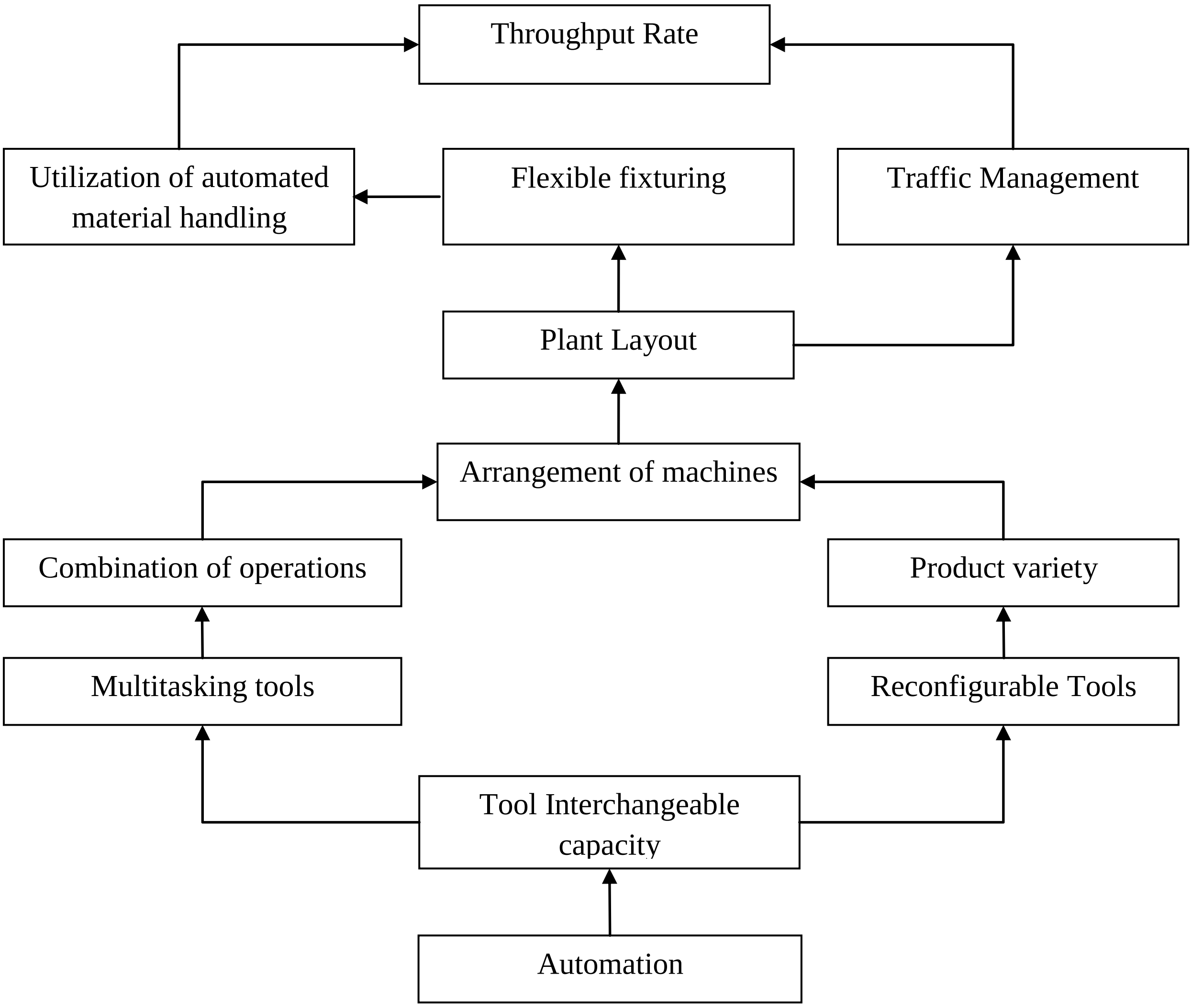


Figure 6.9 Interpretive structural model representing the level of flexibility critical variables

Step 8: Development of ISM model

In this step of ISM approach, digraph is changed into an ISM model as shown in Figure 6.9.

Step 9: Check for conceptual inconsistency

In this last of ISM approach, conceptual inconsistencies is checked and incorporated.

6.9 MICMAC ANALYSIS

MICMAC analysis of the flexibility critical variables depends on their dynamic and reliance power. This method was first proposed by Duperrin and Godet (1973). MICMAC technique is depends on multiplication properties of matrices (Sharma et al., 1995). The main idea of MICMAC study is to evaluate the drive control and dependence control of flexibility critical variables. Various authors (i.e. Raj et al., 2012; Attri et al., 2013b; Verma and Seth, 2011; Jain and Raj, 2015; Gothwal and Raj, 2016) have used this analysis approach in their research work. On the basis of driving power and dependence power, the identified critical variables (Figure 6.10) have been divided into following 4 categories:

- **Autonomous critical Variables:** These variables have weak drive power and weak dependence power.
- **Linkage critical Variables:** These variables consist of strong drive power and strong dependence power.
- **Dependent critical Variables:** These variables include weak drive power but strong dependence power.
- **Independent critical Variables:** These variables consist of strong power as well weak dependence power.

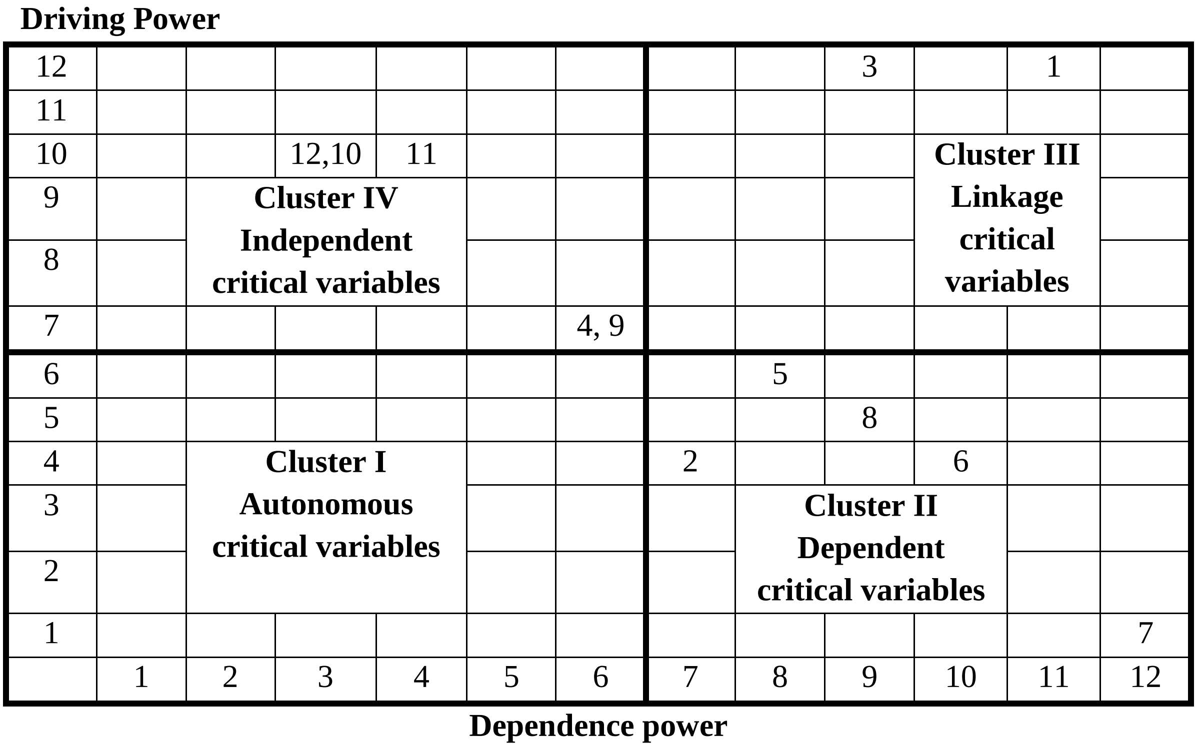


Figure 6.10 Clusters of critical variables affecting the flexibility in FMS

6.10 RESULTS AND DISCUSSION

The main aim of this research is mapping structural relations between the critical variables of FMS flexibility of a manufacturing system in various organizations. A model has been structured to examine the relations between various variables of flexibility and to understand the hierarchy of activities to be taken for exploring the flexibility in manufacturing for these variables. The management and its executives can get the initiative from these variables for improving their relative importance and interdependencies. Drive power and dependence power of different variables can also be identified through MICMAC analysis as shown in Figure 6.10. The importance of flexibility variables is as under:

- All the considered critical variables are important. Autonomous critical variable are weak drivers with weak dependence and do not have much more control on the system.
- Dependent critical variables like flexible fixturing, arrangement of machines, traffic management, throughput rate, plant layout are the weak drivers but strongly depend on each other. So at the time of selection of advance manufacturing system special care is needed to handle these critical variables.
- Linkage critical variables like utilization of automated material handling systems, automation have strong driving power as well as high dependencies. Flexibility in manufacturing as well in material handling provides an option to adopt latest technology like robots and AGVs.
- Critical variables like combination of operation, product variety, tool interchangeable capacity, multitasking tools, and reconfigurable tools are dependent critical variables. These have strong driving power and weak dependency on other critical variables of flexibility.

6.11 CONCLUSION

In this chapter ISM and WISM approaches have been applied for three cases firstly ISM for automated material handling equipment selection variables, secondly WISM for enhancing productivity and thirdly again ISM for flexibility purpose. From first case, it is found that the frame work and analysis used for selection of material handling equipment variables will be supportive in making proper decision for top executives depending on their drive and dependence power. Drive and dependence power diagram provides the useful clues regarding the selected variables which are more significant for MHE selection point of view. So, before selecting the automated MHE, the availability of different variables such as availability of high technology equipments and vendors must also be checked.

Second case is based on the assessment of productivity variables related to FMS. The major objective of this research is assessment of the various variables which can be supportive in examining and enhancing the productivity and flexibility of FMS used in various organizations. An ISM model has been made to analyze the relations among various productivity variables. This model helps to comprehend the hierarchy of steps to be taken for exploring the productivity and flexibility on the bases of these variables. The manufacturing managers can take the initiative from these variables for improving their relative importance and interdependencies. Driving power and dependence power of variables can also be recognized through MICMAC analysis as shown in Figure 6.7.

Third case is based on mapping the structural relationships among the critical variables of FMS flexibility of a manufacturing system. The knowledge of these critical variables along with their driver and dependence power is most vital in decision making for flexibility improvement. The management can more focus on these critical variables which are more significant for selection point of view like automation and tool interchange ability capacity. ISM frame work developed in this research to understand the hierarchy of actions to be taken for exploring the flexibility on the bases of these variables Critical variables such as flexible fixturing, arrangement of machines, traffic management and utilization of automated material handling equipments must be examined for the benefit of material handling systems interconnectivity with the other systems for improvement in productivity with flexibility.

CHAPTER VII

DEVELOPMENT OF FRAMEWORKS FOR THE SELECTION OF MATERIAL HANDLING EQUIPMENTS

7.1 INTRODUCTION

In today's manufacturing environment industries are facing competition for their survival because of rapidly development, in technology, reduced life cycle of goods and best quality product demand by the consumers at lesser cost. Advance manufacturing techniques (AMTs) have also become necessary for competition as well enhancement of production in association with advanced material handling equipments (Raj et al., 2008). So selection of MHE is an important purpose of a material handling system. Utilization of proper MHE can improve the production process and system flexibility (Tuzkaya et al., 2010). For getting these benefits, use of automated MHEs has become a considerable component of manufacturing system. The choice of suitable MHEs has its own significance in transportation, loading, unloading and storage of material in a facility. Industrial Managers should cautiously analyze the material handling variables before using these equipments in their industries. In the present scenario, MHEs like automated guided vehicles (AGVs), robots and automatic storage and retrieval system (AS/RS) have become main alternatives for safe and precise material handling (Tompkins and White, 1984). These MHEs are connected by a network of computers for their well-organized control. This new technology has been planned to accomplish the efficiency of well-balanced machine paced transfer lines for utilizing the flexibility of job shops in production of complex parts. In the current there are many MCDM techniques which are used for supporting the decision maker views in numerous and conflicting evaluations. Such type of methods can also be used for ranking and conflicting attributes solutions. Thus, MHE selection problem can also be solved by MCDM techniques.

In this chapter, main focus is on the utilization of techniques like, analytic hierarchy process/ modified grey relational analysis (AHP/MGRA) and fuzzy analytic hierarchy process (FAHP) which is extremely essential for choosing of MHEs. The purpose of this research is to select the variables of MHEs on behalf of experts opinion and literature review. Following, two important frameworks have been applied for solving MHE selection problem:

The main objectives of this chapter are as follows:

- To recognize and rank the attributes which are supportive in the choice of MHEs.
- Selection of material handling equipments for FMS by using FAHP
- Multi attribute selection of a mobile Robot (i.e. AGV) by using AHP/M-GRA

7.2 SELECTION OF MATERIAL HANDLING EQUIPMENT FOR FLEXIBLE MANUFACTURING SYSTEM USING FAHP

7.2.1 Fuzzy Analytic Hierarchy Process (FAHP) Method

The Fuzzy Analytic Hierarchy Process (FAHP) is an advanced MCDM approach and it was introduced by Saaty (1994 and 2000). AHP is a useful MCDM tool which deals with multifaceted crisis of problem in to a hierarchy (Bevilacqua et al., 2004). The steps used in this method are as follows:

Step 1: Conversion of linguistic terms in to fuzzy numbers.

First of all linguistic term will be converted into their corresponding fuzzy numbers. Particularly for this process we consider a five point conversion scales to illustrate the exchange of linguistic terms in to fuzzy numbers. Wenstop et al. (1976) have also used a conversion scales method for synthesizing and modifying their research works.

Step II: Conversion of Fuzzy Numbers in to Crisp Scores.

In this process a fuzzy scoring method has been utilized for conversion in to fuzzy ranking (Chen1985). Conversion process of fuzzy number “M” into crisp score is as:

$$\mu_{MAX(x)} = \begin{Bmatrix} x, 0 \le x \le 1, \\ 0, \text{otherwise} \end{Bmatrix}$$

$$\mu_{Min(x)} = \begin{Bmatrix} 1\text{-}\, x, 0 \le x \le 1, \\ 0, \text{otherwise} \end{Bmatrix}$$

The value of Max and Min fuzzy numbers can be calculated for the comparison purpose which is as follows:

$\mu_R\,(M1) = Sup\ [\mu max\ (x) \wedge \mu_{M1}\ (x)]$

$\mu_L\,(M1) = Sup\ [\mu min\ (x) \wedge \mu_{M1}\ (x)]$

Sum of fuzzy number (M1) is as:

$\mu_T\,(M1) = [\mu_R\, M_1 + 1 - \mu L_{\,M1}]\ /2$

Step III: Demonstration of the conversion method.

A 5- point scale has been used for exchange of fuzzy number into crisp scores by utilizing the linguistic terms as shown in Figure 7.1

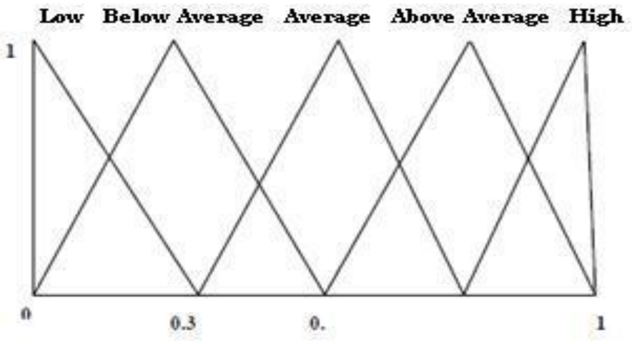


Figure 7.1 Linguistic terms to fuzzy numbers conversion (5-point scale)

Table 7.1 Conversion scale for linguistic variable to fuzzy number (5-point scale)

Linguistic Variables	Fuzzy Numbers
Low	M1
Below average	M2
Average	M3
Above average	M4
High	M5

The score of fuzzy number M are calculated as given below:

$\mu_R\,(M1) = Sup\ [\mu max\ (x) \wedge \mu_{M1}\ (x)]$

$\mu_L\,(M1) = Sup\ [\mu min\ (x) \wedge \mu_{M1}\ (x)]$

Overall score of fuzzy number (Mi) is as:

$\mu_T\,(M1) = [\mu_R\, M_1 + 1 - \mu L_{\,M1}]\ /2$

Crisp values can also be calculated from Figure 7.1 for their fuzzy numbers M1, M2 M3, M4 and M5 as follows:

$$\mu M1(x) = \begin{cases} \text{1-x} = 0 \\ \dfrac{(0.3-x)}{0.3}, & 0.0 \le x \le 0.3 \end{cases}$$

$$\mu M2(x) = \begin{cases} \dfrac{(x-0)}{0.25}, 0 \le x \le 0.3 \\ \dfrac{(0.5-x)}{(0.25)}, & 0 \le x \le 0.5 \end{cases}$$

$$\mu M3(x) = \begin{cases} \dfrac{(0-0.3)}{0.2}, 0.3 \le x \le 0.5 \\ \dfrac{(0.7-x)}{(0.2)}, & 0.5 \le x \le 0.7 \end{cases}$$

$$\mu M4(x) = \begin{cases} \dfrac{x-0.5}{0.25}, 0.5 \le x \le 0.75 \\ \dfrac{(1.0-x)}{(0.25)}, & 0.75 \le x \le 1.0 \end{cases}$$

$$\mu M5(x) = \begin{cases} \dfrac{(x-0.7)}{0.3}, & 0.7 \le x \le 1.0 \\ 1, x = 1 \end{cases}$$

The right, left and total score for fuzzy numbers can be calculated by using the following formulas as given below:

$\mu R\ (M1) = Sup\ [\mu max\ (x) \wedge \mu M1\ (x)] = 0.23$

$\mu L\ (M1) = Sup\ [\mu min\ (x) \wedge \mu M1\ (x)] = 0.1$

$\mu T\ (M1) = [\mu R\ M1 + 1 - \mu L\ M1]\ /2 = 0.115$

Calculated crisp values of right, left and total score of fuzzy numbers M1, M2, M3, M4 and M5 are shown below in Table 7.2 and 7.3:

Table 7.2 Shows right, left and total score for M1, M2, M3, M4 and M5

Fuzzy Number	µR	µL	µT
M1	0.23	1.0	0.115
M2	0.39	0.8	0.295
M3	0.58	0.59	0.495
M4	0.79	0.4	0.695
M5	1.0	0.23	0.895

Table 7.3 Shows linguistic variables along with their fuzzy numbers and crisp score

Linguistic Variables	Fuzzy Numbers	Crisp score
Low	M1	0.115
Below average	M2	0.295
Average	M3	0.495
Above average	M4	0.695
High	M5	0.895

7.3 METHODOLOGY

The fuzzy analytic hierarchy process (FAHP) is a simple MCDM approach to sort out complex, multi-attribute and unstructured problems. It is a most creative decision making tool used in modelling of complex problem. In this approach, identification of the decision system is the main aspect of FAHP. This procedure is essential for the reorganization of a multifaceted problem in a hierarchical structure. To solve a judgment problem with FAHP, there are some steps which are defined as below:

1. Definition of objective and evaluation of attributes.
2. Determination of attribute importance of different attributes with respective to the objective.
3. Comparison of the alternatives pair wise with respective to others.
4. Determination of complex performance scores for the substitutes.

5. Ranking of alternatives.

6. Choosing the highest ranking from the set of alternative

Step 1: Definition of objective and evaluate attributes.

A hierarchical structure (Figure 7.2) has been prepared by putting a goal at the upper most stage, the attributes at the middle and the others at the bottom stage.

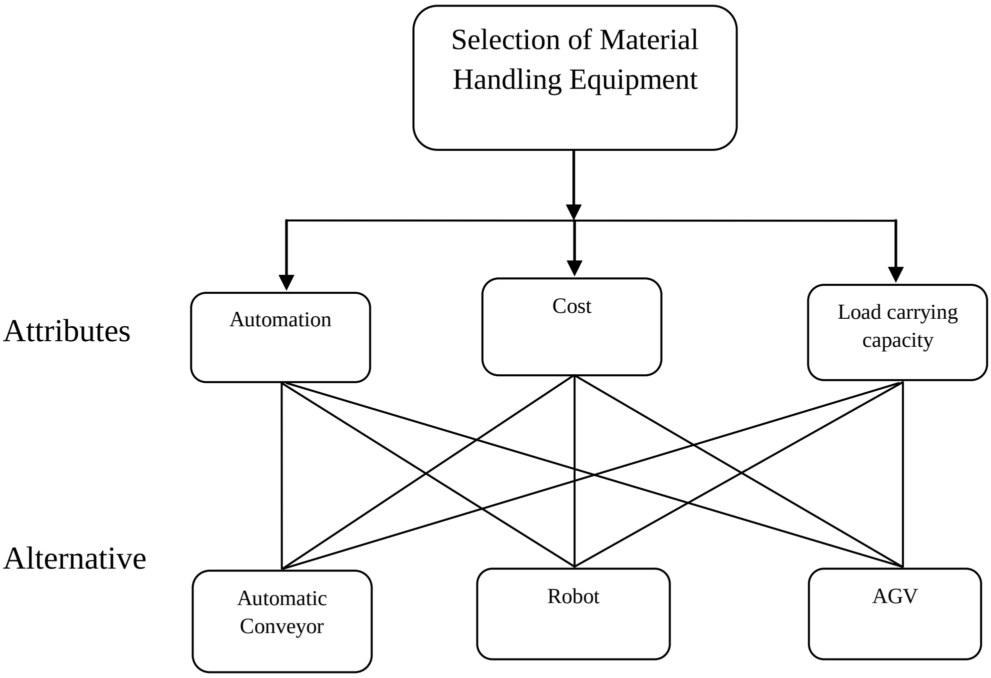


Figure 7.2 Structure of a decision-making hierarchy

Step 2: Determination of the comparative significance for different attributes relating to the objective.

In this step a decision matrix is developed on the basis of expert opinions and their judgments. When an attribute is compared its value is assigned as 1. So that the key diagonal entry of the pair wise comparison matrix can be entered as 1 for calculation purpose as shown in Table 7.4.

- Presuming M attribute, compare the pair-wise attribute i with attribute j provide a square matrix $B_{M \times M}$ where a_{ij} indicates the relative significance of attribute i with respect to attribute j. In the matrix, $b_{ij} = 1$ when $i = j$ and $b_{ji} = 1/ b$

Table 7.4 Scale of comparative values

Scale of importance	**Linguistic variable**	**Explanation for attributes**
1	Equal important	Two attributes are equally important
3	Moderate important	One attribute is moderately influential over the other
5	Strongly important	One decision attribute is strongly important over the other
7	Very important	One decision attribute has significantly more influence than the other.
9	Extremely important	One attribute is absolutely important over the other
2,4,6,8 Reciprocals	Compromise importance/ intermediate importance between two adjacent judgement1,3,5,7 and 9	Judgment values between equally, moderately, strongly, very strongly and extremely. If v is the judgment value when I is compared to j, than 1/v is the judgment value when j is compared to i.

Table 7.5 Scale of Random Index (RI) Values (Saaty 2004)

Attributes (m)	1	2	3	4	5	6	7	8	9	10
RI Values	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

- Geometric mean calculation: - It is made by elements multiplying of each row and then dividing by size of matrix. Then, adding GM for each row.

$$GM_i = \left[\prod_{j=1}^{m} a_{ij} \right]^{\frac{1}{m}} \qquad (1)$$

$$w_j = \frac{GM_j}{\sum_{i=1}^{m} GM_i} \qquad (2)$$

- Normalized weight Calculation: - Normalized weight is calculated for every row by dividing the GM of each row by total GM and then weights obtained are arranged in a matrix form as indicated by Q2.
- Calculate matrices Q3 and Q4

  Q3 = Matrix $Q1_{3X1}$ X Matrix $Q2_{3X1}$ Where Q1 = relative importance matrix

  Q2 = normalized Matrix

  Q4 = Matrix $Q3_{3X1}$ / Matrix $Q2_{3X1}$ Where Q2 = $[w1, w2. . . wj]^{T.}$
- Calculate λ max = Sum of Q4 elements / No. of Q4 elements
- Calculate consistency Index: CI = (λ max-m) / (m-1) Where m = Size of matrix.
- Calculate consistency ratio: CR = CI / RI Where RI = Random index (from Table 7.5)

If the calculated CR is < 0.1, then weights are assumed to be reliable.

Step: comparison of the alternatives pair wise with respect to other

This is used to evaluate the alternatives pair wise relating to others and shows the satisfaction level of each element.

If there are M number of N x N matrices of judgments than develop a pair wise comparison matrices with a scale of relative value and enter the judgements through the basic scale of the AHP. The remaining procedure is similar as shown in step 3.

Relative and arbitrary comparisons can be utilized for AHP. The relative mode is used in those cases where an evaluator has awareness regarding the attributes for other options. If alternatives are convenient then absolute mode can also be utilized. In case of absolute mode, the value of CI is constantly equal to 0, because the exact values of consistency are utilized in comparison matrices.

Step 4: Determination of composite performance scores for the alternatives

In this step overall performance scores is calculated for the given choices by multiplying relative normalized weight (w_j) for all attributes. Quantitative attributes are generally deals with some selection problems. If there is any difficulty arises in qualitative attributes or for the qualitative attributes where quantitative attributes values are not available. Generally in such type of problems a ranked value decision on a fuzzy conversion scale is accepted. A fuzzy set theory is used for deciding the values of its attributes as linguistic terms, its conversion into equivalent fuzzy numbers and than its crisp scores. According to the Chen and Hwang (1992) a numerical approximation method can also be used for conversion of linguistic terms into equivalent fuzzy numbers. Here a 5-point conversion scale is used as shown in Table 7.8. In this chapter we have considered a 3 point scale for better understanding and representation purpose by using equation 1 as shown in Table 7.6 and 7.7.

Table 7.9 has been used to show the 3 different criteria for their fuzzy AHP. This helps the users in assigning the values.

Table 7.6 Crisp value of fuzzy numbers on a 3- point scale

Material handling Equipments (Variables)	**Material Handling Equipment Selection (Attributes)**		
	Automation	**Load Carrying Capacity**	**Cost**
Auto. Conveyor	0.75	0.2323	1
Robot	0.66	1	0.553
AGV	0.1	0.1284	1

Table 7.7 Decision making matrix for material handling equipments

Material handling Equipments (Variables)	**Material Handling Equipment Selection (Attributes)**		
	Automation	**Load Carrying Capacity**	**Cost**
Auto conveyor	0.75	0.2323	1
Robot	0.66	1	0.553
AGV	0.1	0.1284	1

Table 7.8 Linguistic variable along with their fuzzy number and crisp score

Linguistic Variables	**Fuzzy Numbers**	**Crisp score**
Low	M1	0.115
Below average	M2	0.295
Average	M3	0.495
Above average	M4	0.695
High	M5	0.895

7.3.1 Illustrative Example

Here, an example has been used to express and authenticate the FAHP method for choosing the material handling equipments in an industry. The exhaustive steps concerned with the application of the FAHP technique for selecting material handling equipment are described below:

For this study we choose material handling equipments attributes as an input parameters shown in Table 7.9.

Table 7.9 Various attributes and alternatives for Fuzzy AHP

Material handling Equipments (Variables)	**Material Handling Equipment Selection (Attributes)**		
	Automation	**Load Carrying Capacity**	**Cost**
Automated Conveyor	Low	High	Average
Robot	High	Average	High
AGV	High	High	High

Step 1: Selection of material handling Equipment

The aim is to choose right material handling equipments with the available material handling equipments. Hence for this purpose we have selected only three linguistic variables i.e. Low, Average and High on a scale as shown in Table 7.10 and Table 7.11.

Table 7.10 Linguistic variables with fuzzy numbers

Linguistic Variables	Fuzzy Numbers
Low	M1
Average	M2
High	M3

These identified fuzzy numbers are then changed in to crisp score using Table 7.2 and Table 7.3.

Table 7.11 Crisp scores and fuzzy numbers

Linguistic Variables	Fuzzy Numbers	Crisp Score
Low	M1	0.115
Average	M2	0.495
High	M3	0.895

Based on above crisp score decision making matrix (DMM) has been formed which is as follows:

$$\begin{bmatrix} 0.115 & 0.895 & 0.495 \\ 0.895 & 0.495 & 0.895 \\ 0.895 & 0.895 & 0.895 \end{bmatrix}$$

Step 2: Calculation of the relative importance of various attributes relative to the objective:

These attribute requires higher values as a beneficial factor. For comparative results, the relative importance of all probable pairs of attributes with respect to the right material handling equipments is decided. These are arranged into a matrix form of, $Q1_{3x3}$. The judgments on the attributes are entered in the form of matrix as shown in Table 7.4.

a) Create a virtual matrix in which every attribute is evaluated with other attributes and weights are allocated based on expert reasoning, using table 7.4. Diagonal elements are always unity (1) as compared with it themselves. It is usually indicated by Q.

$$Q1 = \left[\begin{array}{ccc|l} Automation & LoadCarryingcapacity & Cost & \\ 1 & 5 & 3 & AutoConveyor \\ 1/5 & 1 & 1/2 & Robot \\ 1/3 & 2 & 1 & AGV \end{array}\right]$$

b) Calculate the relative normalized weight (w_i) as shown below in the comparison matrix:

I) Geometric mean calculation:

Q2 =

GM1	=	(1 X 5 X 3) / 3 = 2.466
GM2	=	(1/5 X 1 X 1/2) / 3 = 0.464
GM3	=	(1/3 X 2 X 1) / 3 = 0.870
Total GM	=	GM1+GM2+GM3 = 3.80

II) Normalized Weight calculation:

W1 = GM1 / GM =2.466 / 3.80 = 0.649

W2 = GM2 / GM = 0.464 / 3.80 = 0.1210

W3 = GM3 / GM = 0.870 / 3.80 = 0.229

Matrix $Q2_{3X1}$ is written as: $Q2_{3x1} = \begin{bmatrix} 0.649 \\ 0.1210 \\ 0.229 \end{bmatrix}$

III) Calculate Q3:

Matrix $Q3_{3X1}$ is written as

Q3 = Q1XQ2

$$Q3_{3X1} = \left[\begin{array}{ccc} \mathit{Automation} & \mathit{LoadCarryingcapacity} & \mathit{Cost} \\ 1 & 5 & 3 \\ 1/5 & 1 & 1/2 \\ 1/3 & 2 & 1 \end{array}\right] * \begin{bmatrix} 0.649 \\ 0.1210 \\ 0.229 \end{bmatrix} = \begin{bmatrix} 1.914 \\ 0.36 \\ 0.678 \end{bmatrix}$$

IV) Calculate Q4:

Matrix $Q4_{3X1}$ is written as

Q4=Q3/Q2

$$Q4_{3x1} = \begin{bmatrix} 1.914 \\ 0.36 \\ 0.678 \end{bmatrix} / \begin{bmatrix} 0.649 \\ 0.1210 \\ 0.229 \end{bmatrix} = \begin{bmatrix} 2.949 \\ 2.975 \\ 3.0818 \end{bmatrix}$$

V) Calculate λmax:

λmax = Total sum of Q4 / Size of Q2 = 3.001/3 =3.001

VI) Calculate CI

CI = λmax-m / m-1, m = size of matrix

= (3.001 – 3) / (3-1) = 0.0005

VII) Calculate CR:

CR = CI / RI for 3 criteria the value of RI=0.00096

The RI is obtained from Table 7.5 for three attributes used in the decision making in the present example and it is 0.58.

The CR is calculated as CR = CI⁄RI and in the present example this ratio is 0.00096 which is less than the allowed CR of 0.1 and hence the value is acceptable. Thus, there is a good consistency in the judgments and decision matrix is right.

Step 3: Pair - Wise Comparison: In this process a comparison takes place between alternative to alternative and perform for each criterion as under:

I) Criteria for Automation

$$Q1=\left[\begin{array}{ccc} \mathit{AutoConveyor} & \mathit{Robot} & \mathit{AGV} \\ 1 & 0.495 & 0.895 \\ 1/0.495 & 1 & 0.895 \\ 1/0.895 & 1/0.895 & 1 \end{array}\right]\begin{array}{c} \mathit{AutoConveyor} \\ \\ \mathit{Robot} \\ \\ \mathit{AGV} \end{array}$$

I) Geometric Mean Calculation:

GM1	=	(1 X 0.495 X 0.895) / 3 = 0.7623
GM2	=	(1/0.495 X 1 X 1/0.895) / 3 = 1.2182
GM3	=	(1/0.895 X 1/0.895 X 1) / 3 = 1.0767
Total GM	=	GM1+GM2+GM3 = 3.05

II) Normalized Weights Calculation:

W1 = GM1 / GM =.7623/3.05 = 0.2530

W2 = GM2 / GM = 1.2182/3.05 = 0.4840

W3 = GM3 / GM = 1.0767/3.05 = 0.3520

Matrix $Q2_{3X1}$ is written as

$$Q2_{3X1} = \begin{bmatrix} 0.2530 \\ 0.4848 \\ 0.3520 \end{bmatrix}$$

III) Calculate Q3:

Matrix $Q3_{3X1}$ is written as $Q3_{3X1} = Q1_{3X1} \times Q2_{3X1}$

$$Q3_{3X1} = \begin{bmatrix} \mathit{Automation} & \mathit{LoadCarryingcapacity} & \mathit{Cost} \\ 1 & 0.495 & 0.895 \\ 1/0.495 & 1 & 0.895 \\ 1/0.895 & 1/0.895 & 1 \end{bmatrix} * \begin{bmatrix} 0.2530 \\ 0.4848 \\ 0.3520 \end{bmatrix} = \begin{bmatrix} 0.7614 \\ 1.2167 \\ 1.0752 \end{bmatrix}$$

IV) Calculate Q4:

Matrix $Q4_{3X1}$ is written as $Q4_{3X1} = Q3_{3X1} / Q2_{3X1}$

$$Q4_{3X1} = \begin{bmatrix} 0.7614 \\ 1.2167 \\ 1.0752 \end{bmatrix} / \begin{bmatrix} 0.2530 \\ 0.4848 \\ 0.3520 \end{bmatrix} = \begin{bmatrix} 3.074 \\ 3.005 \\ 3.053 \end{bmatrix}$$

V) Calculate λmax:

λmax = Total sum of Q4 / Size of Q4 = 9.132 / 3 = 3.044

VI) *Calculate CI*

CI = λmax-m / m-1, m = size of matrix

= (3.044 – 3) / (3-1) = 0.022

VII) Calculate CR:

CR = CI / RI

for 3 criteria the value of RI chosen from Table 7.5 is 0.58.

CR = 0.022/0.58

CR = 0.0379

The value of CR is 0.0379 which is lower than the permissible value of CR (0.1), hence weights are consistent.

II) Criteria for Robot

$$Q1 = \left[\begin{array}{ccc|l} AutoConveyor & Robot & AGV & \\ 1 & 0.895 & 0.115 & AutoConveyor \\ 1/0.895 & 1 & 0.115 & Robot \\ 1/0.115 & 1/0.115 & 1 & AGV \end{array}\right]$$

I) Geometric Mean Calculation:

GM1	=	(1 X 0.495 X 1) / 3	= 0.7910
GM2	=	(1/0.495 X 1 X 1/0.895) / 3	= 01.2182
GM3	=	(1 X 1/0.895 X 1) / 3	= 1.0376
Total GM	=	GM1+GM2+GM3	= 3.0468

II) Normalized Weights Calculation:

W1 = GM1 / GM = 0.4686/5.2012 = 0.090

W2 = GM2 / GM = 0.5046/5.2012 = 0.0970

W3 = GM3 / GM = 4.2280/5.2012 = 0.8128

Matrix $Q2_{3X1}$ is written as $Q2_{3X1} = \begin{bmatrix} 0.090 \\ 0.0970 \\ 0.8128 \end{bmatrix}$

III) Calculate Q3:

Matrix $Q3_{3X1}$ is written as $Q3_{3X1} = Q1_{3X1}$ x $Q2_{3X1}$

$$Q3_{3X1} = \left[\begin{array}{ccc} Automation & LoadCarryingcapacity & Cost \\ 1 & 0.895 & 0.115 \\ 1/0.895 & 1 & 0.115 \\ 1/0.115 & 1/0.115 & 1 \end{array}\right] * \begin{bmatrix} 0.0900 \\ 0.0970 \\ 0.8128 \end{bmatrix} = \begin{bmatrix} 0.2701 \\ 0.2908 \\ 2.438 \end{bmatrix}$$

IV) Calculate Q4:

Matrix $Q4_{3X1}$ is written as $Q4_{3X1} = Q3_{3X1} / Q2_{3X1}$

$$Q4_{3X1} = \begin{bmatrix} 0.2701 \\ 0.2908 \\ 2.438 \end{bmatrix} / \begin{bmatrix} 0.0900 \\ 0.0970 \\ 0.8128 \end{bmatrix} = \begin{bmatrix} 3.001 \\ 2.997 \\ 3.002 \end{bmatrix}$$

V) Calculate λmax:

λmax = Total sum of Q4 / Size of Q4 = 9.00 / 3 = 3.00

VI) Calculate CI:

CI = λmax-m / m-1, m = size of matrix

= (3.0 – 3) / (3-1) = 0.00

VII) Calculate CR:

CR= CI / RI for 3 criteria the value of RI chosen from Table 7.5 is 0.58.

CR = 0/0.58

CR = 0.0

The value of CR is 0.0 .Hence weights are consistent.

I1I) Criteria for Cost

$$Q1 = \left[\begin{array}{ccc} Automation & LoadCarryingcapacity & Cost \\ 1 & 0.495 & 1 \\ 1/0.495 & 1 & 0.895 \\ 1 & 1/0.895 & 1 \end{array}\right] \begin{array}{l} \\ AutoConveyors \\ Robot \\ AGV \end{array}$$

I) Geometric Mean Calculation:

GM1	=	(1 X 0.495 X 1) / 3	= 0.7910
GM2	=	(1/0.495 X 1 X 1/0.895) / 3	= 01.2182
GM3	=	(1 X 1/0.895 X 1) / 3	= 1.0376
Total GM	=	GM1+GM2+GM3	= 3.0468

II) Normalized Weights Calculation:

W1 = GM1 / GM = 0.7910/3.0468= 0.2660

W2 = GM2 / GM = 1.2182/3.0468= 0.4980

W3 = GM3 / GM =1.0376/3.0468= 0.3406

Matrix $Q2_{3X1}$ is written as

$$Q2_{3X1} = \begin{bmatrix} 0.2596 \\ 0.3998 \\ 0.3406 \end{bmatrix}$$

III) Calculate Q3:

Matrix $Q3_{3X1}$ is written as $Q3_{3X1} = Q1_{3X1}$ x $Q2_{3X1}$

$$Q3_{3X1}= \left[\begin{array}{ccc} \mathit{Automation} & \mathit{LoadCarryingcapacity} & \mathit{Cost} \\ 1 & 0.495 & 1 \\ 1/0.495 & 1 & 0.895 \\ 1 & 1/0.895 & 1 \end{array}\right] * \begin{bmatrix} 0.2596 \\ 0.3998 \\ 0.3406 \end{bmatrix} = \begin{bmatrix} 0.7981 \\ 1.229 \\ 1.0469 \end{bmatrix}$$

IV) Calculate Q4:

Matrix $Q4_{3X1}$ is written as $Q4_{3X1} = Q3_{3X1} / Q2_{3X1}$

$$Q4_{3x1} = \begin{bmatrix} 0.7981 \\ 1.229 \\ 1.0469 \end{bmatrix} / \begin{bmatrix} 0.2596 \\ 0.3998 \\ 0.3406 \end{bmatrix} = \begin{bmatrix} 3.0743 \\ 3.0740 \\ 3.0736 \end{bmatrix}$$

V) Calculate λmax:

λmax = Total sum of Q4 / Size of Q4 = 9.221 / 3 = 3.073

VI) Calculate CI:

CI = λmax-m / m-1, m = size of matrix

= (3.073 – 3) / (3-1) = 0.036

VII) Calculate CR:

CR = CI / RI,

CR = 0.036/0.58

CR = 0.062 for 3 criteria the value of RI chosen from Table 7.5 is 0.58.

The value of CR is 0.062. Hence weights are consistent.

Step: 4 Matrix is created for pair wise comparison based on results i.e. weights received from step 4 for different criteria

$$Q1 = \begin{bmatrix} 0.2530 & 0.090 & 0.2660 \\ 0.4840 & 0.0970 & 0.4980 \\ 0.3521 & 0.8128 & 0.3406 \end{bmatrix} \begin{bmatrix} 0.649 \\ 0.121 \\ 0.229 \end{bmatrix} = \begin{bmatrix} 0.2319 \\ 0.3617 \\ 0.4047 \end{bmatrix}$$

Decision of material handling equipments is based on the higher ranking

Material handling Equipments	**Results**	**Ranking**
A1	0.2319	R3
A2	0.3617	R2
A3	0.4047	R1

Based on their final ranking received through pair wise comparison between alternatives of each attribute A3 (AGV) is a best material handling equipment.

7.4 DISCUSSION

The purpose of this research is to build up a frame work for choosing a proper MHE among the variety of available MHEs under the given conditions. For this purpose, a model has been prepared to analyze the connections between different attributes of MHEs. This frame work will be useful in understanding the hierarchy for the selection of various MHEs on the basis of these attributes. The managers of the manufacturing field can take initiative from these attributes in understanding their relative importance. This model has been developed by using FAHP approach. FAHP is an effective problem solving MCDM technique. The decision problem may have various attributes for calculating the linguistic variables. In fuzzy numbers numerical values of linguistic variables are used for calculation purpose. Hence Fuzzy AHP (FAHP) is a well suited technique to deal with such situations very well. The significance of MHE variables is as below:

- Attributes, automation, cost and load carrying capacities are the main attributes of the material handling equipments which has more influence on alternatives.
- The relationship between the attributes and alternatives of material handling equipment's can be understood by visualization of Figure 7.2.
- The automated conveyors can only be used for material handling for specific path and application .whenever the AGVs can move freely to carry the material within the layout.

- The automated conveyors cannot be easily interfaced with all equipments and machinery used for manufacturing facility whenever AGV can be easily interface with manufacturing facilities.
- Movement of the robots is limited between one work stations to the other for material handling. They generally move about their own axis whenever AGVs can easily move between the required work stations.
- Robots have small and limited load carrying capacity whenever the AGVs can carry the heavy load easily.

7.5 A MULTI ATTRIBUTE SELECTION OF MOBILE ROBOT USING AHP/M-GRA TECHNIQUE

7.5.1 Analytical Hierarchy Process (AHP) Method

According to Saaty (1980) AHP is a potential multi-criteria decision making approach that decomposes a complex problem into a hierarchical order (Abdi and Labib, 2003). AHP is a very closely mimics the human decision-making process and incorporates inconsistency (Hamid et al., 1999). AHP approach develops a widespread structure based on intuitive, rational and irrational values (Wabalickis, 1987). AHP is widely used for solving complex MCDM problems (Attri et al., 2014).

According to Saaty (1980) and Vaidya and Kumar (2006), AHP approach consists of following steps:

Step 1: Development of statement and overall objective of problem.

Step 2: Identification of attributes and sub-attributes affecting the overall objective of considered problem.

Step 3: Structuring the hierarchical of different levels of problem. It consists of objective at top level, attributes and sub-attributes at middle level and alternatives at bottom level (Figure 7.3). Here, attributes consists of different sub-attributes as specified underneath:

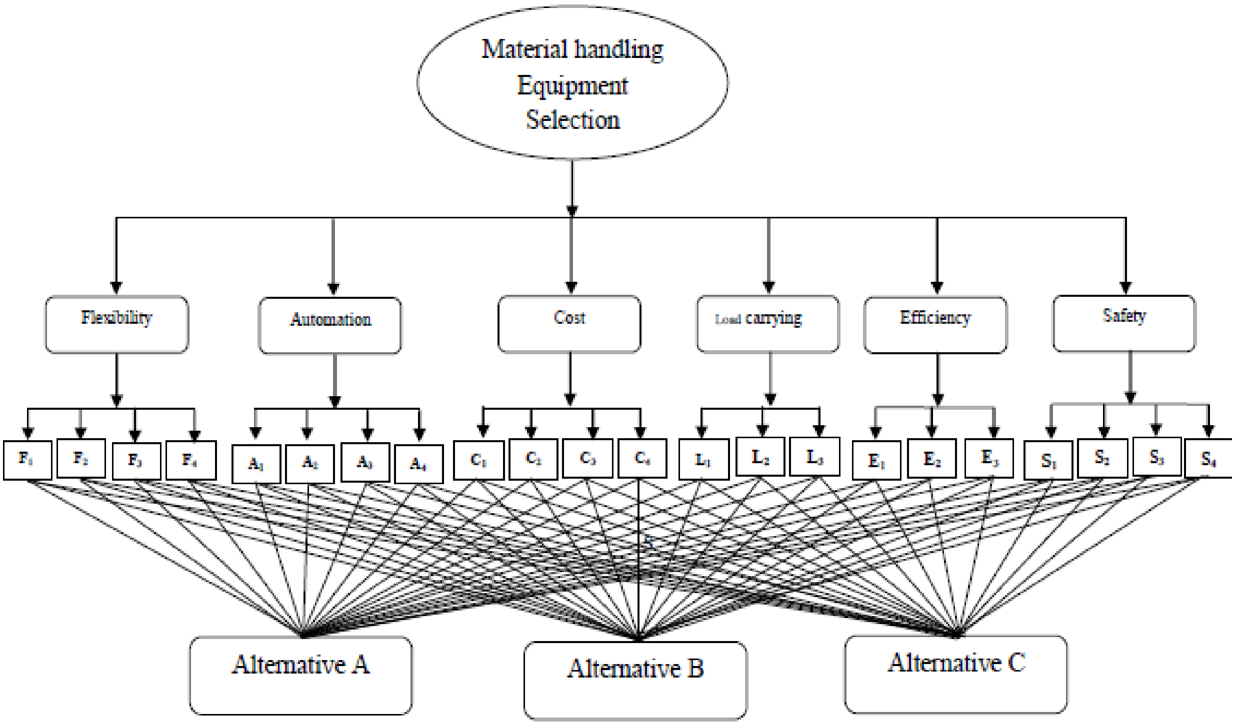


Figure 7.3 The hierarchy structure of the decision making problem

Step 4: Development of a pair-wise comparison matrix.

The process is in a similar manner as done in Fuzzy AHP approach.

$$Q1_{mxm} = \begin{array}{cc} \begin{array}{cccccc} K_1 & K_2 & \cdots & K_j & \cdots & Km \end{array} & Attribute \\ \begin{bmatrix} 1 & a_{12} & \cdots & a_{1j} & \cdots & a_{1m} \\ a_{21} & 1 & \cdots & a_{2j} & \cdots & a_{2m} \\ : & : & : & : & : & : \\ a_{i1} & a_{i2} & \cdots & 1 & \cdots & a_{im} \\ : & : & : & : & : & : \\ a_{m1} & a_{m2} & \cdots & a_{mj} & \cdots & 1 \end{bmatrix} & \begin{array}{c} K_1 \\ K_2 \\ : \\ K_i \\ : \\ K_m \end{array} \end{array} \qquad (3)$$

Step 5: Calculate maximum eigen values by development of priority vector.

Step 6: Determination of geometric mean of each element using equation (4).

$$GM_i = \left[\prod_{j=1}^{m} a_{ij} \right]^{\frac{1}{m}} \qquad (4)$$

Step 7: Determination of relative normalised weight

AHP is widely utilized for computing the relative normalised weights at each level of hierarchy. It is calculated by using Equation (5).

$$w_j = \frac{GM_j}{\sum_{i=1}^{m} GM_i} \tag{5}$$

Step 8: Consistency Check

Consistency may be checked in the similar manner as done in the AHP approach.

7.5.2 Modified Grey Relational Analysis (M-GRA) Model

In the present chapter, an M-GRA approach is utilized. The major rationale for using M-GRA method is to overcome the short comings of the GRA method. Kong and Liu, (2006) has specified the following limitations of GRA approach:

- Information loss during normalisation of attribute measures.
- Ranking changes when resolution coefficient has a different value.

Now, a new logarithmic normalisation process has utilized for normalisation of attributes. M-GRA consists of following steps:

Step I: State the goal of MCDM problem.

Step II: Identification of alternatives, its attributes and evaluate the entire alternative with respect to each attribute.

Step III: Development of decision matrix:

Here, all the information related to alternative and its attributes is transformed into matrix form (known as decision matrix). The solution of an MCDM problem starts with construction of a decision matrix. If there are *m* alternatives and *n* attributes, the *i*th alternative can be expressed as $Y_i = (y_{i1}, y_{i2} \ldots y_{ij} \ldots y_{in})$ in decision matrix form, where y_{ij} is the performance value (or measure of performance) of attribute *j* (j = 1, 2, 3, …., *n*) for alternative *i* (*i* =1, 2, 3, …., *m*). The general form of decision matrix Q is given as follows:

$$Q_{mn} = \begin{bmatrix} y_{11} & \cdots & y_{ij} & \cdots & y_{In} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ y_{i1} & \cdots & y_{ij} & \cdots & y_{m} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ y_{m1} & \cdots & y_{mj} & \cdots & y_{mn} \end{bmatrix} \tag{6}$$

Step IV: Generate comparability sequence or data processing (Ψ_{ij}):

The comparability sequence is carried out in GRA to normalise the performance measures of attributes. It is carried out for making the attributes dimensionless. MCDM problems are classified into two categories namely (a) beneficial attribute (higher values are desired) (b) non-beneficial attribute (lower values are desired).

Zavadskas and Turskis (2008) have developed a logarithmic normalisation method for normalisation purpose.

(a) For beneficial attribute:

$$\Psi_{ij} = \frac{\|\ln x_{ij})\|}{\|\ln(\prod^{m}{}_{j=1} x_{ij}\|} \qquad \text{For i=1, 2----, m} \quad \text{and} \quad \text{j= 1, 2-----, n} \tag{7}$$

(b) For non-beneficial attribute:

$$\Psi_{ij} = \frac{1 - \dfrac{\|(\ln x_{ij})\|}{\|\ln(\prod^{m}{}_{j=1} x_{ij})\|}}{m-1} \qquad \text{For i=1, 2----, m} \tag{8}$$

and j= 1, 2-----, n

Step V: Generate reference data sequence (Ψ_{0j}):

In comparability sequence, all offered values are scaled to [0, 1]. If an attribute *j* of alternative *i*, then the value x_{ij} which has been processed by data pre-processing is equal to one or nearer to one as compare to any other value and the presented alternative *i* is considered as best for the attribute *j*. A reference sequence is defined after the completion of normalisation procedure or the generation of comparability sequence. Usually, the it is described as Ψ_{0j}= (Ψ_{01}, Ψ_{02}, Ψ_{03}, . . . ,Ψ_{0n}) = (1, 1, 1, . ., 1). It indicates that the performance value of alternative i with reference to attribute j However, such an alternatives does not exist in reality. Therefore, in the current study the reference sequence is defined as:

$\Psi_{0j} = \text{maxi} \{ \Psi_{ij} \}$, j = 1, 2, 3, . . . ,n. (9)

Step VI: Compute the grey relational coefficient ($ß_{ij}$):

It is similar to GRA. The grey relational coefficient is calculated using Equation (7). A grey relational coefficient is used for determining how close Ψ_{ij} is to Ψ_{0j}.

$$ß_{ij}\left(\Psi_{oj},\ \Psi_{ij}\right) = \frac{min_i min_j \Delta_{ij} +\ \zeta\ max_i max_j\ \Delta_{ij}}{\Delta_{ij} +\ \zeta\ max_i max_j\ \Delta_{ij}} \text{ for i = 1, 2, 3, . . m}$$

and j =1, 2, 3, . , n define
(10)

$$ß_{ij}\left(\Psi_{oj},\Psi_{ij}\right) = \frac{\left(\Delta_{\min} + \xi.\Delta_{\max}\right)}{\left(\Delta_{ij} + \xi.\Delta_{\max}\right)} \quad \text{for i = 1, 2, 3, . . . , m and j =1, 2, 3, . . . , n}$$

$\Delta_{ij} =$ $ß_{ij}\left(\Psi_{oj} - \Psi_{ij}\right)$ Ψ_{oj} - Ψ_{oj} $ß_{ij}\left(\Psi_{oj},\Psi_{ij}\right)$

$\Delta_{\min}\left\{\Delta_{ij}, i = 1, 2....,m;\ j = 1, 2, ...n\right\}$

$\Delta_{\max}\left\{\Delta_{ij}, i = 1, 2....,m;\ j = 1, 2, ...n\right\}$

Where $\Delta_{ij} = \| \Psi_{oj} - \Psi_{ij} \|$

ζ= Distinguishing coefficient. ζƐ (0,1)

Step VII: Determination of grey priority grade:

The measurement formula for quantification in GRS called the grey relational grade. It is computed by using following equation.

$$(\ \Psi_{oj}\ .\ \Psi_{ij}\ ) = 1\text{-}\sum_{j=1}^{n} w_j\ .\ ß_{ij}\left(\Psi_{oj},\Psi_{ij}\right) \quad \text{for i = 1, 2, 3, . . . , m} \qquad (11)$$

Where $\sum_{j=1}^{n} w_j = 1$

Step VIII: Calculation of alternative utility index:

Multi attributes of mobile robot for material handling equipment alternative utility index is calculated by comparing multi attributes of mobile robot for MHE alternative with the most efficient material handling alternative using equation (11). Material handling alternative with greater value of ϕ_i is considered as efficient mobile robot for material handling alternative. In addition, $\phi_{max} = max_i \{\phi_i\}$.

$$\eta_i = \frac{\Phi_i}{\Phi_{\max}} X \ 100 \qquad (12)$$

Step IX: Ranking of alternatives:

In this step, first, alternative utility index is computed. Then, on the basis of index value, each alternative is ranked.

7.6 PROPOSED METHODOLOGY

Here in this section, AHP method and M-GRA methods have been combined for the selection of multi attributes of mobile robot for a given application. Details of AHP approach is illustrated in section 7.3. The main computational procedure of developed AHP/M-GRA model is as follows:

Step 1: Define the objective of given MCDM problem. Identify the relevant attributes, its measures and alternatives.

Step 2: Formulate the decision matrix.

Step 3: Generate grey relational or comparability sequence (Ψ_{ij}).

Step 4: Generate reference data sequence (Ψ_{oj}).

Step 5: Compute the grey relational coefficient ($ß_{ij}$).

Step 6: Generate pair wise comparison matrix using a scale of relative importance as given in Table 7.15.

Step 7: Compute a relative normalised weight of mobile robot selection attributes (w_j).

Step 8: Perform the consistency check for judgments to prepare pair-wise comparison matrix.

Step 9: Compute grey priority grade.

Step 10: Compute mobile robot alternatives utility index.

Step 11: Rank the multi attributes of mobile robot alternatives and select an appropriate attribute of mobile robot alternative.

It may be noted here that in above developed methodology, steps 1-5 and 9-11 are obtained from the M-GRA method and steps 6-8 from the AHP method for selection of mobile robot.

7.6.1 Illustrative Example

This example is considered to demonstrate and validate the proposed AHP/M-GRA method for multi attribute selection of a material handling equipment i.e. mobile robot for a given industrial application. The steps involved and their detail in the combined application of the AHP/M-GRA method for selecting an optimal attribute of mobile robot are described as follows:

Step 1: In this step of the proposed GRA method the objective is to select material handling equipment for a given industrial application. In the present work there are eight material handling equipment alternatives and six attributes are considered, and the attributes K1 (Flexibility), K2 (Automation), K4 (load Carrying Capacity), K5 (Efficiency) and K6 (Safety) are beneficial type, K3 (cost),) is non beneficial type.

Step 2: In this step, the material handling equipment alternatives, its attributes, and its measures are presented in tabulated form which are known as a decision matrix. Material handling equipment (i.e. mobile robot) selection alternatives are evaluated in linguistic terms with respect to their attributes measure, and qualitative data of its attributes are shown in Table 7.12.

Table 7.12 Qualitative data of material handling equipment (i.e. mobile robot) selection attribute for various alternatives

Alternatives	K1	K2	K3	K4	K5	K6
A1	BA	High	Low	AA	AA	High
A2	Low	Low	High	Low	AA	High
A3	Low	High	High	High	Average	Average
A4	High	Average	AA	Average	High	BA
A5	Low	AA	Average	Average	Average	AA
A6	High	Average	AA	High	BA	Average
A7	High	BA	Low	AA	Average	AA
A8	Average	Average	High	Low	AA	Average

Note: K1, Flexibility; K2, Automation; K3, cost; K4, load Carrying Capacity; K5, Efficiency; K6, Safety; BA, below average; AA, above average.

A1, Pallet trucks mobile robot; A2, Forklift truck mobile robot A3, Cart mobile robot; A4, Free ranging AGV mobile Robot; A5, Wheeled mobile robot; A6, Guided path mobile robot; A7, Pick and Place mobile robot; A8, Assembly AGV mobile robot

Table 7.12 contains the data in qualitative in nature. For using AHP/M-GRA method, this data has to be converted into quantitative data. For this purpose, a five point conversion scale to convert linguistic terms in to a crisp score for the present work has shown in Table 7.13. For details about the conversion of qualitative data into quantitative data, Rao and Padmanabhan (2007) can be referred.

Table 7.13 Value of material handling equipment (mobile robot) selection attributes (Rao 2007, Rao and Parnichkun 2009)

Qualitative measure of attribute	Low	Below average	Average	Above average	High
Assigned value	0.115	0.295	0.495	0.695	0.895

These qualitative values given in Table 7.12 are converted into a crisp score or quantitative value using Table 7.13. The crisp data of multi attributes selection of mobile robot are shown in Table 7.14.

Table 7.14 The crisp data for material handling equipment selection attributes (decision matrix)

Alternatives	K1	K2	K3	K4	K5	K6
A1	0.295	0.895	0.115	0.695	0.695	0.895
A2	0.115	0.115	0.895	0.115	0.695	0.895
A3	0.115	0.895	0.895	0.895	0.495	0.495
A4	0.895	0.495	0.695	0.495	0.895	0.295
A5	0.115	0.695	0.495	0.495	0.495	0.695
A6	0.895	0.495	0.695	0.895	0.295	0.495
A7	0.895	0.295	0.115	0.695	0.495	0.695
A8	0.495	0.495	0.895	0.115	0.695	0.495

Step 3: In this step here six attributes of material handling equipment selection are considered such as K1 (Flexibility), K2 (Automation), K3 (cost) K4 (load Carrying Capacity), K5 (Efficiency) and K6 (Safety). Out of these, six attributes of material handling equipment selection attribute only cost is non-beneficial attribute and remaining ones are beneficial attribute. Now, comparability sequence is generated using Equation (7) and Equation (8) and its results are shown in Table 7.15.

Table 7.15 Result of grey relational generating for multi attributes of mobile robot selection problem (Ψ_{ij})

Alternatives	K1	K2	K3	K4	K5	K6
A1	0.139594	0.018249	0.092117	0.054455	0.080268	0.025919
A2	0.247314	0.355792	0.140255	0.323699	0.080268	0.025919
A3	0.247314	0.018249	0.140255	0.016603	0.155134	0.164301
A4	0.012685	0.115678	0.134321	0.105244	0.024473	0.285234
A5	0.247314	0.059853	0.12636	0.105244	0.155134	0.085012
A6	0.012685	0.115678	0.134321	0.016603	0.269319	0.164301
A7	0.012685	0.200822	0.092117	0.054455	0.155134	0.085012
A8	0.080409	0.115678	0.140255	0.323699	0.080268	0.164301

Step 4: A reference sequence is calculated using Equation (9) and its values are as given below:

$\Psi_{0j} = \Psi_{o1} = 0.247314$, $\Psi_{o2} = 0.355792$, $\Psi_{o3} = 0.140255$, $\Psi_{o4} = 0.323699$, $\Psi_{o5} = 0.269319$, $\Psi_{o6} = 0.285234$

Step 5: Grey relational coefficients are calculated by equation (10) after calculating Δ_{ij}, Δ_{max}, Δ_{min}. For example $\Delta_{11} = | 0.247314 - 0.012685| = 0.234629$, $\Delta_{max} = 0.337543$, $\Delta_{min} = 0$. if $\zeta = 0.5$, then $ß_{ij} (\Psi_{0j}, \Psi_{ij}) = (0 + 0.5 \times 0.337543)/(0.234629 + 0.5 \times 0.337543) = 0.41837$. The entire results for grey relational coefficient are shown in Table 7.16.

Table 7.16 Results of relational coefficient for multi attributes of a mobile robot selection problem

Alternatives	K1	K2	K3	K4	K5	K6
A1	0.784505	0.428408	1.00000	0.495209	0.606193	0.506695
A2	1.00000	1.0000	1.00000	1.00000	0.406822	0.333333
A3	1.00000	0.333333	1.00000	0.354661	0.596457	0.582565
A4	0.342872	0.337685	0.953774	0.359141	0.333333	1.00000
A5	1.00000	0.333333	0.914158	0.40382	0.564435	0.424965
A6	0.395562	0.390051	0.962796	0.333333	1.00000	0.559413
A7	0.494947	0.631096	1.00000	0.452526	0.734545	0.545806
A8	0.418372	0.333333	1.00000	1.00000	0.388398	0.498183

Step 6: In this step, a 9-point scale has been used for finding relative importance between attributes (a_{ij}) as shown in Table 7.15 according to judgements of the decision maker to generate pair-wise comparison matrix. The decision maker has made the following relative assignments for mobile robot selection attributes.

$$\begin{array}{ccc} & \begin{array}{cccccc} C1 & C2 & C3 & C4 & C5 & C6 \end{array} & Variables \\ Q1= & \left[\begin{array}{cccccc} 1 & 2 & 5 & 3 & 3 & 2 \\ 1/2 & 1 & 3 & 5 & 5 & 5 \\ 1/5 & 1/3 & 1 & 3 & 2 & 3 \\ 1/3 & 1/5 & 1/3 & 1 & 3 & 3 \\ 1/3 & 1/5 & 1/2 & 1/3 & 1 & 3 \\ 1/2 & 1/5 & 1/3 & 1/3 & 1/3 & 1 \end{array}\right] & \begin{array}{c} C1 \\ C2 \\ C3 \\ C4 \\ C5 \\ C6 \end{array} \end{array}$$

Step: 7. A relative normalised weight of multi attributes of a mobile robot (w_j) are determined using AHP method and its values are given as: Wc1 = 0.3193, Wc2 = 0.3215, Wc3 = 0.1361, Wc4 =0.0992, Wc5 = 0.0736, Wc6 = 0.0501.

Step: 8. Finally a consistency test is carried out as explained in AHP section (given in section 7.3) and a pair wise comparison matrix Q1 (obtained in step 6).

Determine matrix Q3 as: Q1 x Q2

Where

$$Q1=\begin{array}{cccccc c} C1 & C2 & C3 & C4 & C5 & C6 & Variables \\ 1 & 2 & 5 & 3 & 3 & 2 & C1 \\ .5 & 1 & 3 & 5 & 5 & 5 & C2 \\ .2 & .3 & 1 & 3 & 2 & 3 & C3 \\ .3 & .2 & .3 & 1 & 3 & 3 & C4 \\ .3 & .2 & .5 & .3 & 1 & 3 & C5 \\ .5 & .2 & .3 & .3 & .3 & 1 & C6 \end{array} \qquad Q2=\begin{bmatrix} .3193 \\ .3215 \\ .1361 \\ .0992 \\ .0736 \\ .0501 \end{bmatrix}$$

$$Q3 = Q1XQ2 = \begin{bmatrix} 1 & 2 & 5 & 3 & 3 & 2 \\ .5 & 1 & 3 & 5 & 5 & 5 \\ .2 & .3 & 1 & 3 & 2 & 3 \\ .3 & .2 & .3 & 1 & 3 & 3 \\ .3 & .2 & .5 & .3 & 1 & 3 \\ .5 & .2 & .3 & .3 & .3 & 1 \end{bmatrix} X \begin{bmatrix} .3193 \\ .3215 \\ .1361 \\ .0992 \\ .0736 \\ .0501 \end{bmatrix} = \begin{bmatrix} 2.2618 \\ 2.00455 \\ .67147 \\ .67147 \\ .48201 \\ .36682 \end{bmatrix}$$

$$Q4 = \frac{Q3}{Q2} \begin{bmatrix} 2.2618 \\ 2.00455 \\ .67147 \\ .67147 \\ .48201 \\ .36682 \end{bmatrix} / \begin{bmatrix} .3193 \\ .3215 \\ .1361 \\ .0992 \\ .0736 \\ .0501 \end{bmatrix} = \begin{bmatrix} 7.082 \\ 6.234 \\ 4.9325 \\ 6.766 \\ 6.548 \\ 7.31435 \end{bmatrix}$$

Total sum=38.879

λ max = Total sum of Q2 / Size of Q2 = 38.879 / 6 = 6.4798

CI = λmax-m / m-1,   where m = size of matrix

= (6.4798 – 6) / (6-1) = 0.09596

CR = CI / RI,   for criteria 6 the value of RI=1.25

CR = 0.09596 / 1.25 = 0.076

Since value of CR is less than 0.1, therefore weights are consistent. Hence judgement taken to prepare a pair wise comparison matrix is accepted by the decision maker for material handling equipment selection problem.

Step 9: Calculation of a grey priority grade of each alternative by using following equation (11),

$$\phi\left(\Psi_{oj}\,.\,\Psi_{ij}\right) = 1-\sum_{j=1}^{n} w_j\,.\,ß_{ij}\left(\Psi_{oj},\Psi_{ij}\right) \quad \text{for } i = 1, 2, 3, \ldots, n$$

and its values are: ϕ1= 0.356548 , ϕ2 = 0.077258, ϕ3 =0.329165, ϕ4 = 0.541887,

ϕ5 = 0.346224, ϕ6 = 0.482566, ϕ7 = 0.376668, ϕ8 = 0.470402

Step 10: Computation of material handling equipment utility index for each alternative using equation (12) and its values are: η1 = 65.80%, η2 =14.26 %, η3 = 60.75%, η4 =100.00%, η5 =63.89 %, η6 = 89.052%, η7 =69.51%, η8 =86.81%.

Step 11: Finally, all material handling equipment alternatives are arranged in descending order according to value of a material handling equipment utility index, and the ranking order of these eight material handling equipment (mobile robot) alternatives is

A4>A6>A8>A7>A1>A5>A3>A2

A ranking order obtained using AHP/M-GRA model suggests that material handling equipment (i.e. mobile robot) alternative A4 is the best choice, and material handling equipment (mobile robot) alternative A2 is the last choice of the decision maker for a industrial application.

7.6.2 Sensitivity Analysis

Sensitivity analysis is a method of model making which can be used for a specific problem to explore the response in the output of a model with respect to input. It is applied on multi-attribute decision-making (MADM) techniques for checking the ranking reversal of the alternatives by changing the weights of relative importance of the attributes. Logically if the decision maker changes the assigned weights to attributes then there may be chance for rank reversals of the alternatives. The main advantage of AHP/M-GRA comparison with other methods is that it enables decision maker to represent the relative importance and interaction of multiple attribute in the material handling equipment selection. In the present case AHP/M-GRA technique has been used to analyse the impact of distinguishing coefficient on the final ranking of mobile robot alternatives. The value of distinguishing coefficient is set at 0.1 to 0.9 with an interval of 0.1 as shown in Table 7.17. The results based on of sensitivity analysis are shown in Figures 7.4 and 7.5.

Table 7.17 Grey Relational Grades for various distinguishing coefficient values

Alternative	**ζ=0.1**	**ζ=0.2**	**ζ=0.3**	**ζ=0.4**	**ζ=0.5**	**ζ=0.6**	**ζ=0.7**	**ζ=0.8**	**ζ=0.9**
A1	0.4597	0.5235	0.5724	0.6114	0.6434	0.6703	0.6932	0.7130	0.7303
A2	0.8895	0.9002	0.9091	0.9164	0.9227	0.9281	0.9327	0.9368	0.9404
A3	0.5221	0.5721	0.6116	0.6438	0.6708	0.6938	0.7136	0.7310	0.7463
A4	0.2362	0.3115	0.3694	0.4173	0.4581	0.4933	0.5242	0.5515	0.5758
A5	0.4745	0.5408	0.5874	0.6239	0.6537	0.6789	0.7004	0.7191	0.7355
A6	0.2802	0.3628	0.4251	0.4755	0.5174	0.5529	0.5834	0.6100	0.6334
A7	0.4412	0.5020	0.5505	0.5902	0.6233	0.6513	0.6754	0.6964	0.7147
A8	0.3212	0.3893	0.4447	0.4907	0.5295	0.5628	0.5916	0.6168	0.6391

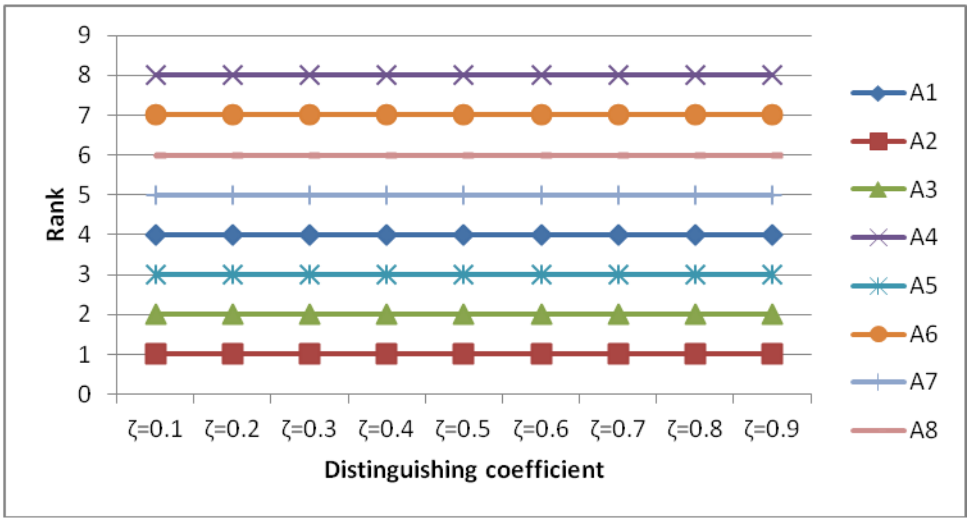


Figure 7.4 Ranking of mobile robot alternatives with different values of distinguishing coefficient

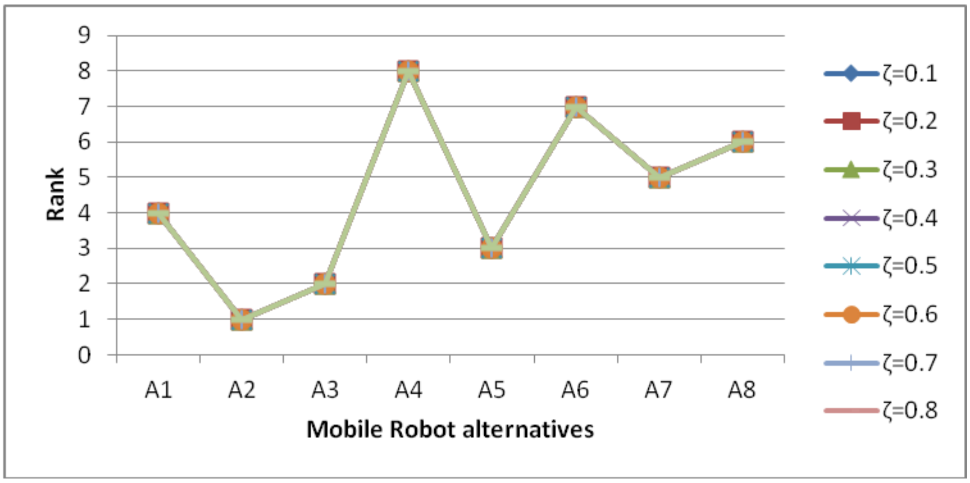


Figure 7.5 Effect of distinguishing coefficient on ranking of mobile robot alternative

7.7 CONCLUSION

In this chapter two different frameworks regarding Fuzzy AHP and AHP/M-GRA have been used for the MHEs selection based on different alternatives and multi attributes of equipment.

Firstly, on the bases of fuzzy AHP approach it has been found that the evaluation of different material handling equipment's for the FMS environment has been presented and a pair wise comparison was carried out between the various given alternatives for each considered attribute and finally weights were obtained. These weights are then utilized for deciding the ranking of material handling equipments and found that the material handling equipment A3 (AGV) is the best alternative among the considered alternatives.

Secondly, AHP/M-GRA technique framework has been utilized for selection of best material handling equipment based on multi attributes. This technique has been developed and implemented to examine its feasibility for selecting the most suitable material handling equipment for industrial applications. The proposed AHP/M-GRA method can be a better option for selecting a best material handling equipment (i.e. mobile robot or AGV) while qualitative multi-attributes are taken into account. Based on these multi attributes the management and its managers can take decision about the selection of a specific type of material handling equipment when planning to purchase new equipment.

CHAPTER VIII

ANALYSIS OF MATERIAL HANDLING EQUIPMENT'S EFFECTIVENESS IN FMS BY USING GTA

8.1 INTRODUCTION

Due to advancement and rapid changes in manufacturing and material transfer technology advance material handling systems (MHSs) such as AGVs, industrial robots, automated conveyors and storage and retrieval systems (AS/RS) have became most essential components of FMS. According to Raj et al. (2008) due to awareness of new technology products customer's expectations are becoming highly crucial for manufacturing industries. To meet the ever-changing customer demands for quality products of new varieties at the lowest possible cost and rapid demand by the market has become a big issue for national and international level manufacturing concerns (Raj et al. 2009). According to (Nagalingam and Lin, 1999) the manufacturing concerns have to be advanced, flexible, and responsive to adopt different technologies for their existence. To overcome these difficulties adoption of automation and advanced material handling systems may also be a substitute of this problem. According to Aized (2010) Material handling is also a key area of FMS because more than 80 % of total time is spend by the material on a shop floor either in waiting or in transportation, although both these activities are considered as non-value added activities. Therefore, optimization of material handling systems can lead to substantial cost reductions. In modern manufacturing industries, material movement is a most important part of the manufacturing environment which contributes to a significant portion of the final products cost (Mashaei and Lennartson, 2013). The handling of materials must be performed safely, efficiently and accurately because selection of an appropriate material handling system will not only increase the speed but it also reduce the material movement throughout the manufacturing facility (Bahale and Deshmukh, 2014).

In this modern scenario automation of material handling has also become an essential part of manufacturing for the future industries to supply the right quantity of material safely without damage at right time, in right position, at right place, in correct sequence and at control cost (Francis et al., 1982). The use of these effective material handling equipments makes effective utilization of workforce, energy, space, facility, human safety, reduction in production lead time, improvement in efficiency of material flow, increased productivity, reduction in total cost of product and error rates (Tompkins et al. 2003). According to Momani et al. (2011) a competent of MH system not only reduce the operating cost but it also increases the overall profit. These flexible material handling equipments can be easily interconnected with other components of FMS such as CNC machines, robots and AS/RS etc. (Nagar and Raj, 2012a). Hence these are necessary elements of FMS system, without which appropriate functioning of material handling is not possible (Shankar and Vrat, 1999). Numerous researchers (e.g. Beamon 1998; Malmborg 2002; Le-Anh and De Koste 2006; Kuo et al. 2007; 2008; Ekren and Heragu, 2011a; Zhang et al. 2009; Ekren and Heragu 2010; 2011b) have also evaluated the effectiveness and performance of automated and flexible material handling systems. The main objectives of this chapter are:

- To recognize the different variables affecting the effectiveness of MHE in FMS by literature review and experts' opinion of their field.
- To accumulate a mathematical model of identified variables using Graph Theoretic Approach (GTA).
- To recommend a single numerical index indicating the effectiveness of material handling equipment.

8.2 IDENTIFICATION OF VARIABLES AFFECTING THE EFFECTIVENESS OF MATERIAL HANDLING SYSTEMS

On account of the literature revise and exercise of production managers from national, multinational organizations and academicians, variables affecting the material handling and their influence in material handling system selection have been identified and categorized into the following six categories (as shown in Table 8.1):

- **Plant layout (V_1):** Plant layout refers to the systematic planning and arrangement of man, material and machine inside the plant or develop an operation sequence and equipment layout for all feasible system solutions in which all systems can be easily assimilate efficiently at right time. The main objective of plant layout design is to minimize the materials handling cost and time, maximize flexibility and production rate (Malakooti and D'Souza, 1987). Layout such as single row, double row, cluster type, loop, circular, tandem, cell type, work type and machine type may be utilized as per the requirement of plant set up. Plant layout has an significant role in effective utilization of facilities i.e. man, machine and material existing in plant in order to maximize the production rate at minimum cost. So, a good plant layout is the main necessity for the selection of effective MHEs.

- **Coordination with plant facilities (V_2):** Coordination basically refers to the interaction of manufacturing facilities with the MHEs because these plays an major role in governing the cost, fulfilling the customers demand and production rate in any manufacturing organization. Different types of the material handling systems like cranes pallet trucks, fork lift trucks, automated guide vehicles, storage and retrieval equipment, conveyor systems and robots are used for the movement of material from one location to another location within the plant. It may be noted that it is not possible to interface all the material handling systems, with each and every machine in the plant. This is due to the limitation of their design parameters and interfacing software's. In order to overcome this limitation, new-generation metamorphic material handling systems i.e. intelligent manufacturing systems, have been developed. These systems are based on the latest technologies with highly automated systems. The main purpose of this advanced technology is to provide flexibility to change its function in response to other equipments in the system. Moreover, it provides autonomous functions to enhance system reliability in material handling systems. So, good coordination of MHEs with plant facilities is possible through the utilization of new technology devices. These devices are highly responsive, flexible, autonomous, multi-level, and multi-functional having latest compatible communication module with the plant facilities for coordination purpose.
- **System networking (V_3):** It basically means interaction and mutual coordination in term of communication with plant facilities in order to improve the overall performance of an organization. Communication networking means controlling and integrating the automated MHEs with the host computer. The MHEs generally communicates and interface in two different ways. In first way, the communication is performed among AGV and interfaces through vision system,

remote control and scanner system, when the AGV arrives at a station for a pick up or delivery purpose. In second way, when a work station finishes its processing and then the part moves to the next station according to processing sequence and part routing. In such system, all communications passes through the host computer and there was no communication of one machine with another machine. In this regard, some communications are expected which allows the machine (CNC) to have direct input and output with the transport control. The information of traffic control lane is obtained from the vehicle mounted CCD or by reflected infrared photoelectric sensor to obtained automatic guidance (Hoshino et al., 2007). Normally, vehicle is controlled by different colours and pattern painted on the lane. Therefore, system networking is considered as an important variable in finding the effectiveness of MHEs.

- **Speed of delivery (V_4):** It is defined as the rate of materials transfer from one work station to another station or from raw material store to the finish goods store by the use of automated MHEs like AGVs, conveyors, robots and hoists etc. Material transfer rate depends upon various factors such as distance between workstations, location and layout of different workstations, bottlenecks /obstructions in the path of movement, load carrying capacity, speed of the material handling equipments, size, shape and quantity of parts to be moved (Koste and Malhotra, 1998). The proper distribution and transportation network will minimize the cost and maximize delivery speed (Pramod and Banwet, 2010). The speed of product delivery can be improved by maintaining the right flow of material and interfacing the plant facilities like automated MHEs for improving the efficiency of transportation, storage and retrieval system.
- **Flexibility (V_5):** Flexibility in case of MHEs may be defined in three ways as follows:
    - Ability to handle variety of parts having different shapes and sizes.
    - Ability to regulate the flow of materials through different paths.
    - Ability to configure with different workstations.

Material handling equipments have a key role in determining the flexibility of the entire system. Automated material handling management system may be a combination of conveyors, robots and automated guided vehicles (Eade, 1989).

By the use of effective material handling flexibility a high quality customized product can be produced at a reasonable price and may be delivered quickly to the customers with the help of efficient and effective automated material handling equipments. Reveliotis (1998) has advocated that the flexibility is an important aspect of modern manufacturing systems which is necessitated by the time based competition for the current manufacturing strategy. It also refers as a capability of the material handling system for moving different parts efficiently for a suitable position and processing throughout the manufacturing facility (Greenwood et al., 1988).

- **Economics (V_6):** Economy is the primary and most important requirement of a manufacturing system to work smoothly and enhancing the productivity of a system. Use of economy can assist in choosing the range of proper equipment, in taking the final decision. Initial investment, maintenance and operating cost are the main issues related to the cost consideration. Thus the economy is a prime factor in selection and decision making of appropriate material handling equipments.

Table 8.1 Material handling variables and their references /sources

S.No	Variables	Sub-Variables	Reference/Source
1	Plant layout (V_1)	1. Available area/space	McCutcheon, 1993; Cordero, 1997; Chan et al., 2000; Charantinath, 2006
		2. Type of machines	Expert Opinion
		3. Number of machines	Sha and Sheny, 1996
		4. Types of material handling Systems (MHS)	Sople, 2012
		5. Arrangement of machines	Heragu and Kusiak, 1990; Welgama and Gibson, 1993
		6. Flexibility in product and process routing for future expansion.	Bozer and Srinivasan, 1991; Gupta and Somers, 1992; Avittathur and Swamidass, 2007; Awasthi et al., 2001; Krishnamurthy et al, 1993; Qiu et al., 2002

2	Coordination with plant facilities (V_2)	1.Interface facility with workstation	Shankar and Vrat, 1998
		2. Communication System	Satoshi Hoshino et al., 2007
		3. Capability of Material handling systems (MHS)	Zhang et al, 2008.
		4.Standardization of Equipments	Groover, 2008; Aized, 2010; Chryssolouris, 1992
		5. Type of facilities, work rotation and storage devices	Expert opinion
		6. Traffic management	Vis et al., 2005; Yeh and Yeh, 1998
		7. Flexibility issues	ElMaraghy, 2009; Chan, 2002; Buzacott, 2002; Swamidass 1985
3.	System networking (V_3)	1.Vision system	Leopoldo et al., 2010
		2. Remote control interface	Chen, 2010
		3. Sensors	Tanchoco,1992; Zeng et al., 1991; Hsieh and Lee, 1998; Liang and Rao, 2011
		4. Automated control of flow path	Kritikos and George 2010; Kim and Tanchoco, 1993; Vis et al., 2005; Chin and Liao, 2011
		5.Automated inspection systems	Farnum, 1986; Yang et al., 2013; Meyer 1987
4.	Speed of delivery (V_4)	1.Response time of material handling systems MHS	Expert opinion
		2.Distancebetween machines	Francis et. al, 1992
		3.Type of product size availability	Expert Opinion
		4. Type of path layout	Ardavan and Marc, 2008; Jerin, 2012; De Koster et al., 2004
		5. Type of material handling systems	Chittratanawat and Noble, 1999
		6. Use of automated workstations	Gamberi, 2009

5.	Flexibility (V_5)	1. Machine flexibility	Wiendahl, 2007,2011; Chandra and Tombak, 1992; Sethi and Sethi, 1990
		2. Type of operations	Expert Opinion
		3. Number of operations	Sethi and Sethi, 1990
		4. Routing flexibility	Lawley and Reveloties, 1997; Sethi and Sethi, 1990
		5. Type of product	Expert Opinion
		6. Product variety	Sethi and Sethi, 1990; Zhou and Venkatesh, 1987
6	Economics (V_6)	1.Initial cost of material handling system equipment	Bayazit, 2005; Koltai et al., 2000
		2. Maintenance cost	Vieira et al., 2011; Apple, 1992
		3. Operational cost	Lahmar, 2007; Gunasekaran et al., 2001
		4. Machine depreciation cost	Chapman, 1972
		5.Overhead and Miscellaneous cost	Expert opinion
		6. Automation cost	Groover, 2008

8.3 GRAPH-THEORETIC APPROACH

GTA is an extremely influential technique that can be used for numerous fields to evaluate the inter-relationship between different variables or sub variables of material handling and offers an artificial score for the whole arrangement. Here, an effort has been done to utilize this method in deciding the effectiveness of variables influencing the implementation of automated material handling. The effectiveness of MH variables also depends upon the relations between various variables. The network presenting these variables and their connections in the form of a model called the graph representation. If relations are not based on direction- then it is shown by an undirected graph; if based on direction then it is called a digraph representation. Generally graphs are much more appropriate for visual study and can worked with computer in the form of mathematical unit, although the conventional representations like flow charts and block diagrams presented by visual analysis, do not show the connections between variables and are not appropriate for further study. There are six categories of material handling variables and their sub-variables, as shown in the earlier part, have been used to calculate the effectiveness index for material handling variables (EIV) in FMS environment. Thus

Effectiveness index of variables = $(EIV)_{MHS} = f$ (Variables)

The main aim of this chapter is to identify these six classes of material handling variables, their quantification in reference to their sub variables and their mutual interdependencies through GTA method. The method has a matrix representation, digraph depiction and permanent function representation. The digraph shows the visual descriptions of the material handling variables and their interdependence. The matrix is used to change the digraph into mathematical model which helps in determining the $(EIV)_{MHS}$Value as a permanent function.

8.3.1 Material Handling Variables Digraph

A directed digraph G = (V, *v*) with a set of objects V = [V1, V2 …] known vertices and one more set *v* = [v_1, v_2 ……..], whose elements are known edges. Deo (1999) also advocated that an edge that having the same ends is known as a self loop vertices.

. In variables digraph models, the variables of material handling in FMS environment are their inter-dependencies. The digraph having a set of joints V = {V_i}, with i = 1, 2, 3…n and a set of directed edges v = {v_{ij}}. In this system joint/node V_i has been used for the i^{th} variable and edges for the interdependence among these variables. Here nodes V are assumed as the number of variables for the material handling.

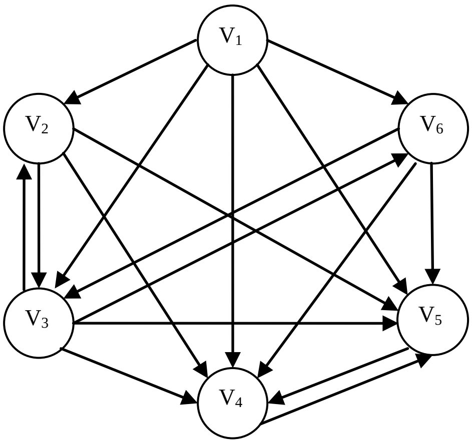


Figure 8.1 Material handling variables digraph

Here six major categories of variables have been selected from the section 8.2 for developing the variables digraph and are drawn according to interdependence of these variables as in Figure 8.1. For example, one variable how influence other variables; so edges are directed from V_1 to V_2, V_3, V_4, V_5 and V_6 and so on as presented in Figure 8.1. This digraph will help the specialists in visualization and analyzing the proposed automated material handling systems. But, as the number of nodes and their interdependence increase, the digraph is presented in a form of matrix.

8.3.2 Material Handling Matrix Digraph Representation

Though a digraph is much more suitable method for a visual analysis purpose, similarly a matrix is also a better method of showing a digraph by computer. Many proceed consequences of matrix algebra can be directly attach to study and can be useful for algebraic point of view (Deo 1999). Let us depict a digraph of n variables, having no self loops, by matrix K = [v_{ij}] where v_{ij} use to interact of the ith variable with jth variable. Here, $v_{ij} \neq v_{ji}$ because material handling variables are directional and $v_{ii} = 0$. Material handling matrix V for the material handling variables digraph is written as under:

$$K = \begin{array}{cccccc|c} \mathrm{V}_1 & \mathrm{V}_2 & \mathrm{V}_3 & \mathrm{V}_4 & \mathrm{V}_5 & \mathrm{V}_6 & \textit{Variables} \\ \hline \mathrm{V}_1 & \mathrm{v}_{12} & \mathrm{v}_{13} & .. & .. & \mathrm{v}_{1n} & V_1 \\ \mathrm{v}_{21} & \mathrm{V}_2 & \mathrm{v}_{23} & .. & .. & \mathrm{v}_{2n} & V_2 \\ \mathrm{v}_{31} & \mathrm{v}_{32} & \mathrm{V}_3 & .. & .. & \mathrm{v}_{3n} & V_3 \\ .. & .. & .. & .. & .. & .. & .. \\ .. & .. & .. & .. & .. & .. & .. \\ \mathrm{v}_{n1} & \mathrm{v}_{n2} & \mathrm{v}_{n3} & .. & .. & \mathrm{V}_n & V_n \end{array}$$

Hence, the flexible and automated material handling matrix corresponding to the flexible and automated material handling is shown in Figure 8.1 is written as:

$$K^* = \begin{array}{cccccc|c} \mathrm{V}_1 & \mathrm{V}_2 & \mathrm{V}_3 & \mathrm{V}_4 & \mathrm{V}_5 & \mathrm{V}_6 & \textit{Variables} \\ \hline \mathrm{V}_1 & \mathrm{v}_{12} & \mathrm{v}_{13} & \mathrm{v}_{14} & \mathrm{v}_{15} & \mathrm{v}_{16} & V_1 \\ 0 & \mathrm{V}_2 & \mathrm{v}_{23} & \mathrm{v}_{24} & \mathrm{v}_{25} & 0 & V_2 \\ 0 & \mathrm{v}_{32} & \mathrm{V}_3 & \mathrm{v}_{34} & \mathrm{v}_{35} & \mathrm{v}_{36} & V_3 \\ 0 & 0 & 0 & \mathrm{V}_4 & \mathrm{v}_{45} & 0 & V_4 \\ 0 & 0 & 0 & \mathrm{v}_{54} & \mathrm{V}_5 & 0 & V_5 \\ 0 & 0 & 0 & \mathrm{v}_{64} & \mathrm{v}_{65} & \mathrm{V}_6 & V_6 \end{array}$$

In this matrix K^{*}, the diagonal elements V_1, V_2, V_3, V_4, V_5 and V_6 shows the effect of various type of variables in the execution method of material handling equipments and v_{ij} shows the interdependency of variable i and variable j in the digraph.

8.3.3 Material Handling Variables Permanent Matrix

Digraph as well as matrix representations are not exclusive; they can be modified by altering the node labels. So, a permanent function of the material handling variables' matrix is developed. This inhibiting function which is used for material handling variables is also known as permanent function, *i.e.*, per (K^{*}) and also used in combination with mathematics (Jurkat and Ryser, 1966; Raj and Attri, 2010; Attri et al., 2013; 2014). It helps in analyse the effectiveness index of variables in the implementation of automated material handling equipments in industrial environment for their consideration. Due to non negative sign of permanent inhibiting function, there is no chance of any information missing. The expression has been written as shown in Figure 8.1 as follows:

$$
\begin{aligned}
\text{Per } K^{*} = {} & \boldsymbol{\prod_{i=1}^{6} V_i} + \underset{I\ ,j\ \ k\ \ l\ \ m\ n}{\Sigma\Sigma\Sigma\Sigma\Sigma\Sigma} (v_{ij}\, v_{jk}) V_k\, V_l\, V_m\, V_n \\
& + \underset{I\ \ j\ \ k\ \ l\ \ m\ \ n}{\Sigma\Sigma\Sigma\Sigma\Sigma\Sigma} (v_{ij}\, v_{jk}\, v_{ki} + v_{ik}\, v_{kj}\, v_{ji})\, V_l\, V_m\, V_n \\
& +[(\underset{I\ \ j\ \ k\ \ l\ \ m\ n}{\Sigma\Sigma\Sigma\Sigma\Sigma\Sigma} (v_{ij}\, v_{jk})(v_{kl}\, v_{lk}) V_m\, V_n \\
& + \Sigma\Sigma\Sigma\Sigma\Sigma\Sigma\, (v_{ij}\, v_{jk}\, v_{kl}\, v_{li} + v_{il}\, v_{lk}\, v_{kj}\, v_{ji}) V_m\, V_n))] \\
& +[\Sigma\Sigma\Sigma\Sigma\Sigma\Sigma\, (v_{ij}\, v_{ji})(v_{kl}\, v_{lm}\, v_{mk} + v_m\, v_{ml}\, v_{lk})\, V_n \\
& + \underset{I\ \ j\ \ k\ \ l\ \ m\ \ n}{\Sigma\Sigma\Sigma\Sigma\Sigma\Sigma}(v_{ij}\, v_{jk}\, v_{kl}\, v_{lm}\, v_{mi} + v_{im}\, v_{ml}\, v_{lk}\, v_{kj}\, v_{ji}) V_n] \\
& + [\underset{I\ \ j\ \ k\ \ l\ \ m\ n}{\Sigma\Sigma\Sigma\Sigma\Sigma\Sigma}(v_{ij}\, v_{ji})(v_{kl}\, v_{lm}\, v_{mn}\, v_{nk} + v_{kn}\, v_{nm}\, v_{ml}\, v_{lk}) \\
& + \underset{I\ j\ \ k\ \ l\ m\ \ n}{\Sigma\Sigma\Sigma\Sigma\Sigma\Sigma}((v_{ij}\, v_{jk}\, v_{ki})(v_{lm}\, v_{mn}\, v_{nl}) \\
& + \underset{I,\ j\ \ k\ \ l\ \ m\ n}{\Sigma\Sigma\Sigma\Sigma\Sigma\Sigma}(v_{ij}\, v_{ji})(v_{kl}\, v_{lk})(v_{mn}\, v_{nm}) \\
& + \underset{I\ \ ,j\ \ k\ l\ m\ n}{\Sigma\Sigma\Sigma\Sigma\Sigma\Sigma}(v_{ij}\, v_{jk}\, v_{kl}\, v_{lm}\, v_{mn}\, v_{ni} + v_{in}\, v_{nm}\, v_{ml}\, v_{lk}\, v_{kj}\, v_{ji})]
\end{aligned} \tag{3}
$$

Equation (3) shows the mathematical terms and contains a number of terms which are structure dependents. The arrangement of the grouping terms for physical importance is as follows:

- First group shows the connections of the six main variables (i.e., $V_1\ V_2\ V_3\ V_4\ V_5\ V_6$).

- Second group is missing, hence there is no interconnection in the digraph.
- Third group represents a two-element interdependence loop (i.e., $v_{ij}\ v_{ji}$) and the material handling in a manufacturing environment which is treated as an evaluation of the remaining four unrelated elements.
- Similarly fourth group signifies a set of three-element interdependence loops (i.e., $v_{ij}\ v_{jk}\ v_{ki}$ or $v_{ik}\ v_{kj}\ v_{ji}$) and the material handling in the remaining three unconnected elements.
- The fifth group having terms organized in two subgroups. The terms of the first subgroup having two-element interdependence loops (i.e., $v_{ij}\ v_{ji}$ and $v_{kl}\ v_{lk}$) and two material handling variables, i.e., $V_m V_n$. Similarly the terms of the second subgroup are a product of four-element interdependence loops (i.e., $v_{ij}\ v_{jk}\ v_{kl}\ v_{li}$ or $v_{il}\ v_{lk}\ v_{kj}\ v_{ji}$) and two material handling variables, i.e., $V_m V_n$.
- The sixth group is also managed in two subgroups. The first subgroup is a product of a two-element interdependence loop (i.e., $v_{ij}\ v_{ji}$) and a three-element interdependence loop (i.e., $v_{kl}\ v_{lm}\ v_{mk}$ or $v_{km}\ v_{ml}\ v_{lk}$) for material handling variable V_n.
- The terms used in second subgroup are a product of five-element interdependence loops (i.e., $v_{ij}\ v_{jk}\ v_{kl}\ v_{lm}\ v_{mi}$ or $v_{im}\ v_{ml}\ v_{lk}\ v_{kj}\ v_{ji}$) and material handling variables V_n.
- The seventh grouping has also managed in four subgroups. The first subgroup having those terms which is a product of two-element interdependence loop (i.e., $v_{ij}\ v_{ji}$) and four-element interdependence loop (i.e., $v_{kl}\ v_{lm}\ v_{mn}\ v_{nk}$ or $v_{kn}\ v_{nm}\ v_{ml}\ v_{lk}$). Terms of the second subgroup are a product of two interdependence loops of three elements each (i.e., $v_{ij}\ v_{jk}\ v_{ki}$ and $v_{lm}\ v_{mn}\ v_{nl}$). The terms used for the third subgroup are a product of three interdependence loops of two elements ($v_{ij}\ v_{ji}$, $v_{kl}\ v_{lk}$ and $v_{mn}\ v_{nm}$). Similarly the fourth subgroup also has a six-element interdependence loop (i.e., $v_{ij}\ v_{jk}\ v_{kl}\ v_{lm}\ v_{mn}\ v_{ni}$ or $v_{in}\ v_{nm}\ v_{ml}\ v_{lk}\ v_{kj}\ v_{ji}$).

If the values of the material handling variables matrix as shown in Equation (2) are put in Equation (3), then some of the terms in various groupings is reverse and the resultant is as follows:

$$\text{Per } K^* = V_1V_2V_3V_4V_5V_6 + [(v_{13}v_{31})V_2V_4V_5V_6 + (v_{45}v_{54})V_1V_2V_3V_6 + (v_{16}v_{61})V_3V_4V_5 + (v_{34}v_{43})V_1V_2V_5V_6 + (v_{13}v_{36}v_{61})V_2V_4V_5 + (v_{35}v_{54}v_{43})V_1V_2V_6 + (v_{24}v_{43}v_{32})V_1V_5V_6 + (v_{36}v_{64}v_{43})V_1V_2V_5 + (v_{31}v_{14}v_{43})V_2V_5V_6 + (v_{13}v_{31})(v_{45}v_{54})V_2V_6 + (v_{45}v_{54})(v_{16}v_{61})V_2V_3 + (v_{25}v_{54}v_{43}v_{32})V_1V_6 + (v_{36}v_{65}v_{54}v_{43})V_1V_2 + (v_{31}v_{15}v_{54}v_{43})V_2V_6] [(v_{31}v_{16}v_{65}v_{54}v_{43})V_2 + (v_{61}v_{16})(v_{24}v_{43}v_{32})V_5] + [(v_{61}v_{16})(v_{25}v_{54}v_{43}v_{32})] \qquad (4)$$

8.4 EFFECTIVENESS INDEX FOR MATERIAL HANDLING

EIT for material handling can represent as a conventional material handling system into flexible and automated material handling system for an industry. The permanent function has been proposed for material handling variables as shown in equation (4), for the evaluation of effective index of material handling (EIMH) systems. The numerical value of material handling variable matrix (also known as EIMH) which can be computed as:

$$\text{EIMH} = \text{Per }(K^*) = \text{Permanent function of material handling variable's matrix} \qquad (5)$$

This EIMH index can be calculated for different material handling systems in different organizations. To work out on this index, values of V_i and v_{ij} are needed. The value of any individual variable can be finding out by evaluating each variable V_i as subsystem and the GTA is helpful for everyone. Factors affecting each variable V_i are identified with their connections and then digraph is decided.

In case if a quantitative value is not obtainable; then, a ranked value on a scale of 10 (i.e.1-10) is used. For example, the value of ranked variables will be based on the availability of resources like plant layout, coordination with plant facilities, system networking, flexibility, economics, automated material handling with AGVs and robots.

If the availability of material handling variables is excellent in any system, then, a high rank value 9 or 10 is fixed; otherwise, a low rank value 1 or 2 is allocated to that specific type of variable. For allocating the numerical values to interdependence of variables v_{ij}, judgments of these field specialists can be documented, if not to measure the interdependence of variables than qualitative values can be accepted. Similarly the qualitative values of interdependence for these variables are also allocated on a scale of 5 (i.e. 1-5). The EIMH value for a number of material handling systems in an industry can be calculated by using the values of V_i and V_{ij} in equation (3).

8.5 METHODOLOGY

This methodology has been adopted to estimate the effectiveness index of material handling equipment implementation. The major points of this method are as under:

1. Identification of various variables that affect behaviour of material handling equipments effectiveness due to plant layout, coordination with plant facilities, system networking and their type.
2. Identify the sub variables affecting different categories and their interdependence in step (1).
3. Development of sub variables digraph considering attributes affecting each sub variable. The number of nodes should be equivalent to the quantity of key variable's categories, the direction and magnitude of these edges should matchup with their interdependence (v_{ij}), as shown in Figure 8.1.
4. A digraph has prepared between the sub-variables of material handling system equipments depends on the connections between them. Presented digraph is at subsystem level.
5. Development of the sub variables matrix at the subsystem level found on the above stated digraphs among the sub-variables.
6. Find the value of permanent function, *i.e.*, per (K^{*}), at each subsystem level. The results of these variables and their interdependence are based on the material handling equipments (MHE) effectiveness and data offered by the industry and the experience of material handling expertise. If a quantitative value is not accessible, then it is ranked on 1 to 10 scales as shown in Table 8.2. Similarly mathematical values to the interdependence of variables v_{ij} cannot be compute directly, hence, qualitative values may be assumed. These qualitative values of the interdependence of variables effectiveness are also assigned on a scale of 1 - 5 as suggested for this purpose in Table 8.3.

Table 8.2 Interdependency of effective material handling variables in FMS environment

S. no.	Qualitative measure for variables used in material handling	Assigned value for material handling variables (V_i)
1	Exceptionally low	1
2	Extremely low	2
3	Very low	3
4	Below average	4
5	Average	5
6	Above average	6
7	High	7
8	Very high	8
9	Extremely high	9
10	Exceptionally high	10

Table 8.3 Representation of interdependence variables values for effective material handling in FMS environment

S. no.	Qualitative measure of variables used for interdependence	Assigned value (v_{ij})
1	Very strong	5
2	Strong	4
3	Medium	3
4	Weak	2
5	Very weak	1

7. Develop sub-variables matrix n x n with diagonal elements of V_i for each variable and the off diagonal elements v_{ij} showing connections between them is determined by the professionals based on Table 8.3.

8. Find the value of Permanent function, *i.e.*, per (K^*), of the material handling variables' matrix using Equation (5) at the organization level. It's a value of (EIMH) which mathematically nature which reduces the strength of various variables in any organisation is dependent on the existence of different variables and their interdependence effectiveness.

9. List the different material handling equipments in ascending order based on their EIMH values.
10. The effectiveness of material handling equipments can be calculated and documented for further analysis based on the above- discussed methodology.

8.6 DATA ANALYSIS

To validate the future methodology, a case of industry has been considered. In this regard, the EIV value of this industry is decided by putting the values of legacy (V_i) and interdependencies (v_{ij}) of material handling variables in FMS matrix, equation (1). The values of variables are (i.e. V_1, V_2, V_3, V_4, V_5 and V_6) used for finding out the quantitative measure of each category of variables. To achieve this, questionnaire was planned for this organization from top to bottom level and 25 responses were collected in this regard. After getting these responses based on the questionnaire, a team of four professionals were approached for sharing the results and their judgment.

8.6.1 Determination of (EIMH)

The steps used for this procedure are as follows:

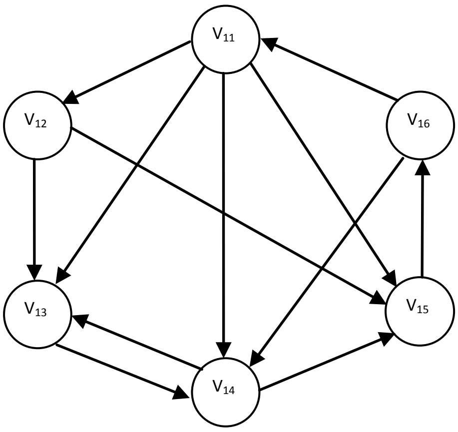
Step1. Six categories of MH variables have been recognized for the present case as shown in Table 8.1.

Step2. A digraph has made for these six main categories of material handing variables, as presented in Figure 8.1.

Step3. The sub-variables of effective material handling equipments are recognized and listed in Table 8.1.

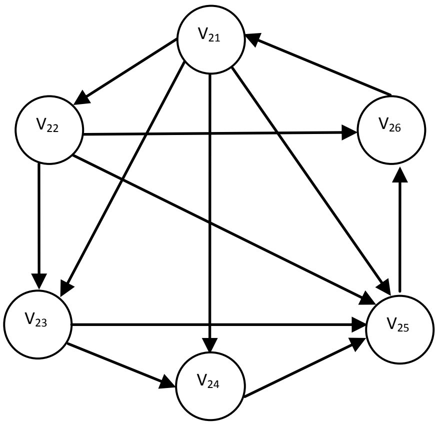
Step4. The digraphs for all categories of material handling variables (Figures 8.2-8.7) are developed by considering the sub-variables of material handling that affect the particular category of effective material handling variables. The nodes in the digraph represent the material handling sub- variables and their mutual interaction is shown by different edges.

Step5. The inheritance of sub-variables and their interdependencies has been shared with the experts (Based on two proposed scales i.e. 1 to 10 for inheritance and 1 to 5 for interdependencies) and matrix for each category of material handling variables is written as:-



1. Digraph for effective plant Layout variable

Figure-8.2

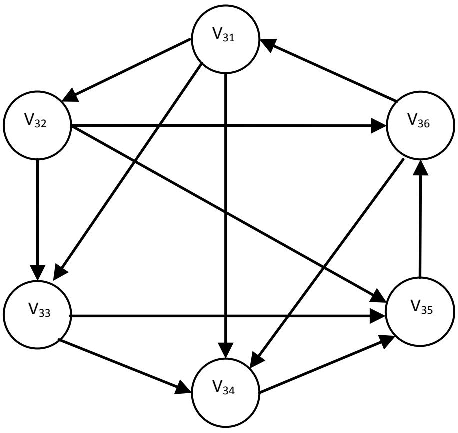


2. Digraph for effective Coordination with plant Facilities variables

Figure-8.3

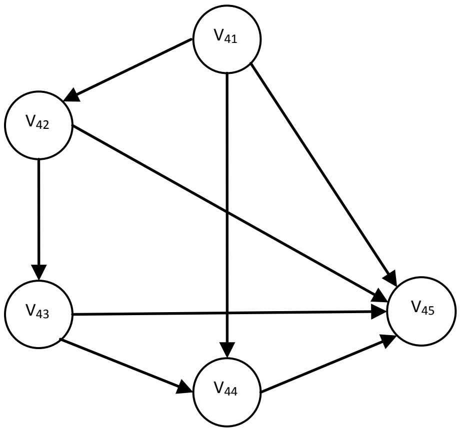
$$K_1^* = \begin{array}{c} \begin{array}{cccccc} V_{11} & V_{12} & V_{13} & V_{14} & V_{15} & V_{16} \end{array} \\ \begin{bmatrix} 8 & 4 & 2 & 0 & 3 & 1 \\ 0 & 7 & 3 & 0 & 3 & 0 \\ 2 & 4 & 6 & 4 & 0 & 0 \\ 0 & 0 & 1 & 5 & 1 & 0 \\ 0 & 0 & 0 & 0 & 5 & 1 \\ 2 & 0 & 0 & 0 & 0 & 6 \end{bmatrix} \end{array} \begin{array}{c} SubVariables \\ V_{11} \\ V_{12} \\ V_{13} \\ V_{14} \\ V_{15} \\ V_{16} \end{array}$$

$$K_2^* = \begin{array}{c} \begin{array}{cccccc} V_{21} & V_{22} & V_{23} & V_{24} & V_{25} & V_{26} \end{array} \\ \begin{bmatrix} 9 & 3 & 4 & 4 & 0 & 0 \\ 0 & 8 & 4 & 0 & 5 & 1 \\ 0 & 0 & 7 & 3 & 4 & 0 \\ 0 & 0 & 0 & 6 & 1 & 0 \\ 0 & 0 & 0 & 0 & 7 & 1 \\ 2 & 0 & 0 & 1 & 0 & 5 \end{bmatrix} \end{array} \begin{array}{c} SubVariables \\ V_{21} \\ V_{22} \\ V_{23} \\ V_{24} \\ V_{25} \\ V_{26} \end{array}$$



3. Digraph for effective system networking variables

Figure-8.4

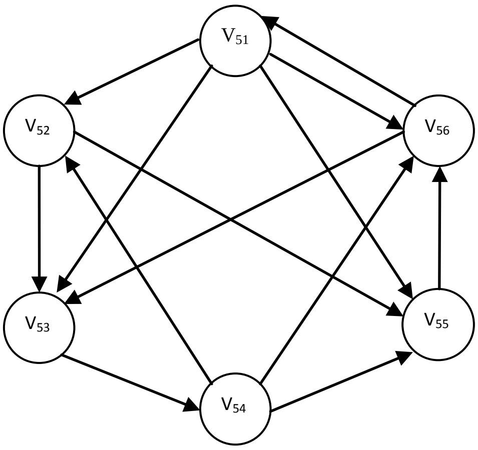


4. Digraph for effective speed of delivery variables

Figure-8.5

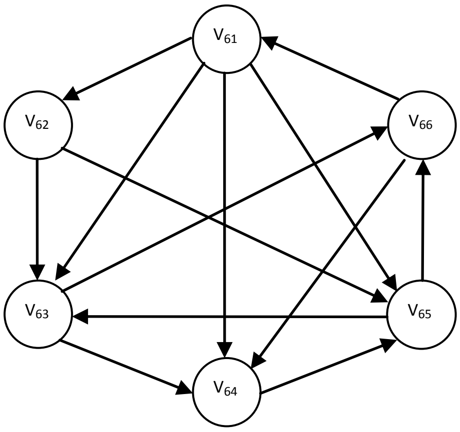
$$K_3^* = \begin{array}{cccccc|c} V_{31} & V_{32} & V_{33} & V_{34} & V_{35} & V_{36} & \textit{SubVariables} \\ 7 & 1 & 4 & 4 & 0 & 0 & V_{31} \\ 0 & 6 & 0 & 1 & 3 & 2 & V_{32} \\ 0 & 0 & 5 & 5 & 0 & 0 & V_{33} \\ 0 & 0 & 0 & 5 & 2 & 0 & V_{34} \\ 0 & 0 & 0 & 0 & 6 & 4 & V_{35} \\ 4 & 0 & 0 & 1 & 0 & 8 & V_{36} \end{array}$$

$$K_4^* = \begin{array}{ccccc|c} V_{41} & V_{42} & V_{43} & V_{44} & V_{45} & \textit{SubVariables} \\ 8 & 4 & 0 & 4 & 4 & V_{41} \\ 0 & 7 & 3 & 0 & 1 & V_{42} \\ 0 & 0 & 6 & 1 & 1 & V_{43} \\ 0 & 0 & 0 & 7 & 4 & V_{44} \\ 0 & 0 & 0 & 0 & 5 & V_{45} \end{array}$$



5. Digraph for effective flexibility variables

Figure-8.6



6. Digraph for effective economic variables

Figure-8.7

$$K_5^* = \begin{array}{cccccc|c} V_{51} & V_{52} & V_{53} & V_{54} & V_{55} & V_{56} & \textit{SubVariables} \\ 6 & 5 & 5 & 0 & 4 & 4 & V_{51} \\ 0 & 5 & 4 & 0 & 3 & 0 & V_{52} \\ 0 & 0 & 7 & 2 & 0 & 0 & V_{53} \\ 0 & 1 & 0 & 6 & 1 & 2 & V_{54} \\ 0 & 0 & 0 & 0 & 8 & 4 & V_{55} \\ 5 & 0 & 4 & 0 & 0 & 9 & V_{56} \end{array}$$

$$K_6^* = \begin{array}{cccccc|c} V_{61} & V_{62} & V_{63} & V_{64} & V_{65} & V_{66} & \textit{SubVariables} \\ 9 & 1 & 2 & 3 & 0 & 0 & V_{61} \\ 0 & 7 & 2 & 0 & 0 & 0 & V_{62} \\ 0 & 0 & 6 & 3 & 0 & 4 & V_{63} \\ 0 & 0 & 0 & 5 & 3 & 0 & V_{64} \\ 0 & 0 & 3 & 0 & 5 & 3 & V_{65} \\ 5 & 0 & 0 & 0 & 0 & 8 & V_{66} \end{array}$$

Step 6. Permanent function calculation process for each category as an example, the value of Per K^*_1 for the first category:

Per $K_1^* = V_{11} V_{12} V_{13} V_{14} V_{15} V_{16} + ((v_{11-12}\, v_{12-11}) V_{13} V_{14} V_{15} V_{16} + (v_{12-14}\, v_{14-12}) V_{11} V_{13} V_{15} V_{16} + (v_{13-14}\, v_{14-13}) V_{11} V_{12} V_{15} V_{16} + (v_{14-15}\, v_{15-14}) V_{11} V_{12} V_{13} V_{16}) + ((v_{11-12} v_{12-15}\, v_{15-11}) V_{13} V_{14} V_{16} + (v_{12-13}\, v_{13-14}\, v_{14-12}) V_{11} V_{15} V_{16} + (v_{12-11}\, v_{11-14}\, v_{14-12}) V_{13} V_{15} V_{16} + (v_{11-14}\, v_{14-15} v_{15-11}) V_{12} V_{13} V_{16} + (v_{15-16} v_{16-13} v_{13-15}) V_{11} V_{12} V_{14} + (v_{14-15} v_{15-16}\, v_{16-14}) V_{11} V_{12} V_{13} +$

$(v_{12-15}\ v_{15-16}\ v_{16-12})\ V_{11}V_{13}\ V_{14} + (v_{12-15}\ v_{15-14}\ v_{14-12})\ V_{11}V_{13}V_{16} + (v_{13-15}v_{5-14}\ v_{14-13})\ V_{11}V_{12}V_{16}) + ((v_{11-12}\ v_{12-11})(v_{13-14}\ v_{14-13})\ V_{15}V_{16} + (v_{11-14}\ v_{14-15}\ v_{15-16}\ v_{16-11})\ V_{12}V_{13} + (v_{2-14}\ v_{14-15}\ v_{15-16}\ v_{16-12})\ V_{11}V_{13} + (v_{11-12}\ v_{12-15}\ v_{15-16}\ v_{16-11})\ V_{13}V_{14} + (v_{13-14}\ v_{14-15}\ v_{15-16}\ v_{16-13})\ V_{11}V_{12} + (v_{11-12}\ v_{12-14}\ v_{14-15}\ v_{15-11})\ V_{13}V_{16} + (v_{11-12}\ v_{12-13}\ v_{13-15}\ v_{15-11})\ V_{14}V_{16}) + \{(v_{12-13}\ v_{13-14}\ v_{14-15}\ v_{15-16}\ v_{16-12})\ V_{11} + (v_{11-12}\ v_{12-13}\ v_{13-14}\ v_{14-15}\ v_{15}\ v_{11})\ V_{16} + (v_{14-15}\ v_{15-16}\ v_{16-11}\ v_{11-12}\ v_{12-14})\ V_{14} + (v_{15-16}\ v_{16-11}\ v_{11-12}\ v_{12-13}\ v_{13-15})\ V_{14} + (v_{11-12}\ v_{12-11})(v_{13-15}\ v_{15-14}\ v_{14-13})\ V_{16}\} + \{(v_{11-12}\ v_{12-11})(v_{13-14}\ v_{14-15}\ v_{15-16}\ v_{16-13}) + (v_{13-14}\ v_{14-13})(v_{15-16}\ v_{16-11}\ v_{11-12}\ v_{12-15})\} + [v_{11-12}\ v_{12-13}\ v_{13-14}\ v_{14-15}\ v_{15-16}\ v_{16-11}]$

$K_1{}^{*} = 85352$

Correspondingly, the permanent function for every group can be calculated as shown in step (7).

Step7. The Material handling variables’ matrix has been developed for system level as per Equation (5). For processing the matrix, the values of the diagonal elements are chosen from the sub-system level:

$V_1 = \text{Per } K_1^{*} = 85352$ $V_2 = \text{Per } K_2^{*} = 112192$ $V_3 = \text{Per } K_3^{*} = 60640$

$V_4 = \text{Per } K_4^{*} = 11760$ $V_5 = \text{Per } K_5^{*} = 174072$ $V_6 = \text{Per } K_6^{*} = 108818$

Step 8. To achieve variable permanent matrix values are substituted according to step 7.

$$
\begin{array}{ccc}
 & \begin{array}{cccccc} V_1 & V_2 & V_3 & V_4 & V_5 & V_6 \end{array} & \textit{SubVariables} \\
K^{*} = & \begin{bmatrix} 85352 & 4 & 3 & 3 & 2 & 1 \\ 0 & 112192 & 4 & 3 & 3 & 0 \\ 0 & 4 & 60640 & 3 & 3 & 2 \\ 0 & 0 & 0 & 11760 & 1 & 0 \\ 0 & 0 & 0 & 4 & 174072 & 0 \\ 0 & 0 & 2 & 1 & 1 & 108818 \end{bmatrix} & \begin{array}{c} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{array}
\end{array}
$$

Step 9. Permanent function (K^{*}) value has been calculated and found to be equal to 1.29×10^{29} which shows the total value of EIMH in the in the industry for concern and mathematically differentiate the effectiveness of material handling equipments for FMS environment which depends upon the presence of material handling variables and their interconnections.

8.6.2 Range of EIMH Index

Calculated values are the highest and smallest values of $(\mathrm{EIMH})_{\mathrm{FMS}}$. The strength of variables depends upon the legacy of all variables whether it is maximum or minimum. Strength of all variables can be computed by pertaining GTA at the subsystem level. Hence, the strength of every variable depends upon sub-variable and the value of $(\mathrm{EIMH})_{\mathrm{FMS.}}$ The value is considered as highest when the strength of sub-variables is greatest as shown in Table 8.2). Hence, matrix for the material handling variables' is as follows:

$$K_5^* = \begin{array}{cccccc|c} \mathrm{V}_{51} & \mathrm{V}_{52} & \mathrm{V}_{53} & \mathrm{V}_{54} & \mathrm{V}_{55} & \mathrm{V}_{56} & \mathit{SubVariables} \\ 10 & 5 & 5 & 0 & 4 & 4 & V_{51} \\ 0 & 10 & 4 & 0 & 3 & 0 & V_{52} \\ 0 & 0 & 10 & 2 & 0 & 0 & V_{53} \\ 0 & 1 & 0 & 10 & 1 & 2 & V_{54} \\ 0 & 0 & 0 & 0 & 10 & 4 & V_{55} \\ 5 & 0 & 4 & 1 & 0 & 10 & V_{56} \end{array}$$

Calculated value for fifth category is 1357800 means value of permanent function K_5^*.

Likewise, the value of per K_5^* of the flexibility variable is minimum than the strength of all sub variables is minimum (i.e.1) as shown in Table 8.3. Matrix of MH variables may be rewritten as follows:

$$K_5^* = \begin{array}{cccccc|c} \mathrm{V}_{51} & \mathrm{V}_{52} & \mathrm{V}_{53} & \mathrm{V}_{54} & \mathrm{V}_{55} & \mathrm{V}_{56} & \mathit{SubVariables} \\ 1 & 5 & 5 & 0 & 4 & 4 & V_{51} \\ 0 & 1 & 4 & 0 & 3 & 0 & V_{52} \\ 0 & 0 & 1 & 2 & 0 & 0 & V_{53} \\ 0 & 1 & 0 & 1 & 1 & 2 & V_{54} \\ 0 & 0 & 0 & 0 & 1 & 4 & V_{55} \\ 5 & 0 & 4 & 1 & 0 & 1 & V_{56} \end{array}$$

The smallest value of permanent function K_5^* for the fifth category is 3453.

The process is repeated for calculating the maximum and minimum values of every sub system as shown in Table 8.4. Presented value of permanent function K^* is also known as

MH index. Simply the maximum and minimum value means the range. This range can be used by the professionals to choose an entry value of MHEs for different industries.

Table 8.4 shows the maximum and minimum values of the permanent function (K^*)

Variable/Sub-Variable	*Maximum value*	*Minimum value*	*Current value*
Per K_1^*	1257392	461	85352
Per K_2^*	1015272	270	112192
Per K_3^*	425920	857	60640
Per K_4^*	100000	1.000	11760
Per K_5^*	1357800	3453	174072
Per K_6^*	1092870	1323	108818
Per K*	5249254	6365	552834
Per K	8.06×10^{34}	4.87×10^{14}	1.29×10^{29}

8.7 DISCUSSION

The current work is highly important for material handling industries in developing countries. Due to advancement and rapid changes in product variety and customers demand, industries from medium to large size are using advanced and automated material handling equipments like AGVs and Robotics for enhancing their productivity in their production lines. There is reluctance in system due to initial higher cost of automated material handling equipments. This research work will help in choosing the economical, comparative and effective automated material handling equipments to accomplish these goals. The process used in current chapter assists in calculating the effectiveness index of material handling variables. Hence, production managers with their long experience and experts of this field, can utilized their rich experience in taking decisions while implementing the automated and advance material handling technology for FMS environment to enhance the productivity. Table 8.4 also indicate a significant observation, *i.e.*, the effectiveness index of material handling variables in an organisation is close to the highest value (8.06×10^{34}). Then, the observed value of the effectiveness index of MH variables shows that the slow down strength of variables is high for material handling equipments in the organisation. Acceptance of advance technologies like AGVs and robots in material handling have a major role in increasing the production level and product variety as demanded by customers and market at minimal cost.

The proposed structural approach for the assessment of material handling aspects in FMS environment is depends on digraph and matrix method which is as follows:

- It recognizes variables related to material handling features in FMS environment.
- It allows modelling of dependence between variables.
- Use of GTA technique makes it more appropriate for visual study and computer evaluation.
- The existence of material handling aspects in FMS surrounding is shown by a single numerical index.
- This technique can also be used for self-analysis and comparison purpose.
- The method permits for the use of different factors in alternative environment.
- It's a well define method for changing the qualitative values to quantitative values and mathematical modelling provides a frame for the future techniques.

8.8 CONCLUSION

Automated material handling is a highly capital-investment and difficult system as compare to conventional material handling system. For achieving the best economic benefits, automated material handling equipment selection and its implementation should be carefully decided. Adoption and implementation of automated material handling and its integration requires hi-fi manufacturing systems like FMS. It needs an upper level of assessment, sufficient funding, effectiveness of equipments and trustworthy vendors for FMS environment. So, it becomes essential to recognize the nature of various variables along with their interrelationship and its impact while implementing the advanced and automated material handling systems.

In this chapter, a methodology has been suggested to estimate the effectiveness of MHEs in any FMS atmosphere. This is a qualitative cum quantitative approach for evaluating and modelling the material handling system and its integration with FMS environment. It also assists in modelling the variety of variables for automated MHEs and their interdependency.

This approach utilizes for finding the permanent and effectiveness function (EIMH) and its numerical value in any concern. A comparison can be made easily on the basis of their EIMH values for different types of material handling equipments used in advanced manufacturing system in an industry. To get the best results with this method, evaluation of some material handling equipment variables is suggested for finding effective EIMH values. For this purpose, a detail study should be made for their material handling variables like plant layout, coordination with plant facilities, speed of delivery and system flexibility which are essential for implementing automated material handling system in FMS environment. The values of permanent function (EIMH value) and its range should be set as per material handling variables used in manufacturing industries. The effectiveness index should be evaluated and their values should be set for those material handling equipments which are more effective for FMS environment.

CHAPTER IX

A CASE STUDY OF A PISTON MANUFACTURING SHOP FOR ENHANCING PRODUCTIVITY AND FLEXIBILITY WITH PROPER TOOL MANAGEMENT IN FMS

9.1 INTRODUCTION

Throughout the world manufacturing industries are under pressure due to rapid technological changes, creative product configurations and quality product demanded by the customer at competitive price. Industries are also facing financial crisis because of high cost automation needed for completion of market orders for their survival. Automation technology like Flexible manufacturing system (FMS) has a huge investment in their implementation. In recent years, FMS has been widely measured as a useful instrument toward this end because its arrangement with multitasking tools makes it more usable for a FMS to develop a variety of parts (Pandey et al., 2016)**.** Decision-making about the implementation of an FMS is not only strategic but it also involves issues at the functioning levels**.** The success and failure totally depends on the ability of decision maker (Lee, 1972). The managers are always looking for right decisions to makes it convenient for increasing the profit. This leads to pressure on management in finding the best planning, controlling and organizing the stages of production in the different productive industries. Managerial assumptions are set up to evaluate business environments and to resolve business problems like as functional and environmental issues in which the companies works. To solve such problems real case studies and quantitative techniques has been used to develop a model and to analyze these decision making problems.

In this chapter two methods have been adopted for piston manufacturing, one method is related to case study of a piston manufacturing and the other one is application of linear programming as a quantitative technique for model development. Here first method discusses about piston manufacturing processes, original plant layout, relocation of machines and introduction of combined tooling used for reducing of piston manufacturing time and cost. Piston manufacturing plants have complex manufacturing systems and to evaluate the performance of a piston manufacturing system a process sheet, arrangement of machines, layout diagrams and availability of parameters have been used for its study. So the performance of the piston manufacturing process is very important based on quality concerns in manufacturing (Jahromi and Tavakkoli 2012). In order to perform well, organizations should make use of their resources in a well mannered way without value added. According to Cordero (1997) plant layout arrangement is a one way to minimize the production cost and output enhancement. In the second method a linear programming technique has been adopted for model development used in any decision making for limited resources and uncertainties. The term 'linear' mean proportionality where elements are connected in a straight line when graphed (Akingbade, 1996). According to Jenness (1972) Linear programming is used for obtaining optimal solution of limited resources like machine, labour, tools, etc on a basis of given optimality. Generally, this technique is used to maximization of profit or minimization of costs, labour hours, processing or operation cost of machining and minimization of time involve in manufacturing a product. The basic purpose of this study is to maximize the profit with proper tool management through a mathematical model and by utilization of case study in this regard. The study becomes very important regarding piston manufacturing to improve its productivity and flexibility with proper utilization of tool management to maximize the benefits.

9.2 METHODOLOGY

A case study has been conducted of a piston manufacturing shop to evaluate the productivity and flexibility with the introduction of new tools (i.e. combined tools). An ABC company (name not disclosed) is engaged in manufacturing pistons and other automobile components. The company is a vendor of a multinational organization. Presently company is using conventional manufacturing system along with some automated machines like CNC and SPMs, for enhancing the productivity and flexibility of the plant. Here, in this chapter, some alternatives have been suggested to convert the conventional manufacturing system into fully FMS. In this study the main emphasis has been given in increasing the productivity, flexibility and profitability by reducing the machining operations time, reduction in number of machines, reduction in labour, reduction in number of tools by combining the tools through modification in tool design and overall cost reduction through creative thinking. The machine shop of a piston manufacturing plant is manufacturing 574 pistons per day.

The layout arrangement of a conventional piston manufacturing process line has been shown in Figure 4 (a). The numbers shown in squares in Figure 4 (a) depict the position of a machine tool being utilized for a particular operation. 20 numbers of operations (details given in figure 9.2) are utilized for making a piston (Figure 9. 1). Out of these 20 processes, 11 numbers of processes (shown in figure 9.3) are related to machine shop and have been taken for study purpose. The selected operations and the position of all machines is shown in figure 9.4 (b) by shaded squares for a piston manufacturing line. The data related to this study has been collected from the machine shop set up of the plant. The total space occupied by piston manufacturing set up in machine shop at present is about 100 m^2. The electricity load is 110 units per day and time consumption for manufacturing 574 pistons is 81000 sec per day. The production lines used are highly dedicated consists of automated machines like CNC and SPMs.

Piston Manufacturing Process Sheet

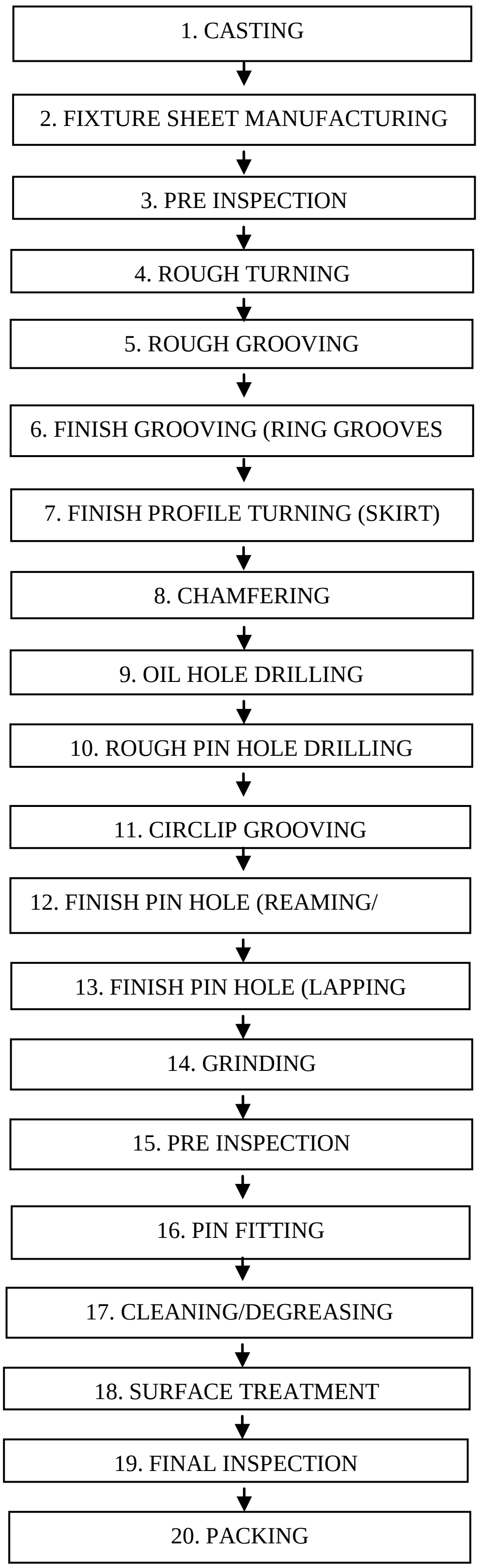


Figure 9.2 Flow chart of piston manufacturing Plant

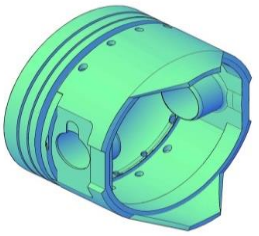


Figure 9.1 Piston

Piston Manufacturing Process Sheet

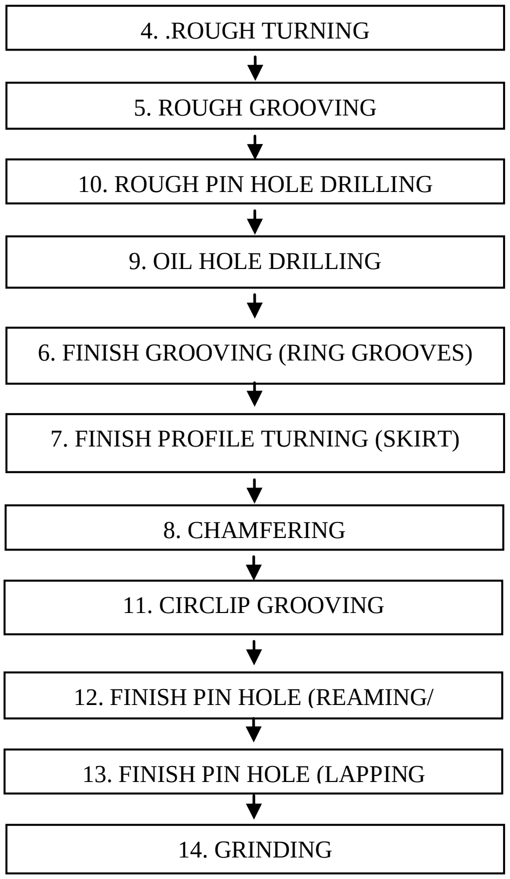


Figure 9.3 Flow chart of Piston manufacturing processes used in machine shop according to new sequence

9.3 PLANNING OF ALTERNATE CONFIGURATIONS OF MACHINE SHOP

In the current case study, the company is using conventional product type layout configuration for producing pistons in the desired volume and quality but the idea is to increase the productivity and flexibility by converting the present configuration into flexible manufacturing system (FMS) for reduction of space utilization, power consumption, material handling and production time through the modified FMS with combined tooling.

Table 9.1 Alternatives analysed in the case study

Alternatives	Description
A	Conventional product type configuration of the machine shop
B	Conversion into FMS with relocation of certain machines in machine shop
C	Modified FMS with combined tooling

9.3.1 Alternative 'A' (Conventional Product Type Configuration of Machine Shop)

Alternative 'A' with conventional product type configuration has been used along with 20 numbers of processes as mentioned in figure 9.2. It is shown in existing layout 9.4 (a) in which 11 numbers of processes related to machine shop area have been selected and rest of the processes are shown in existing layout 9.4 (b) by the shaded squares.

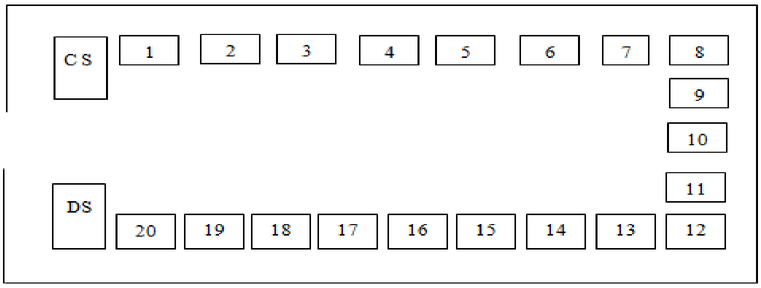


Figure 9.4 (a) Existing layout of machine shop as per alternative A (Conventional layout)

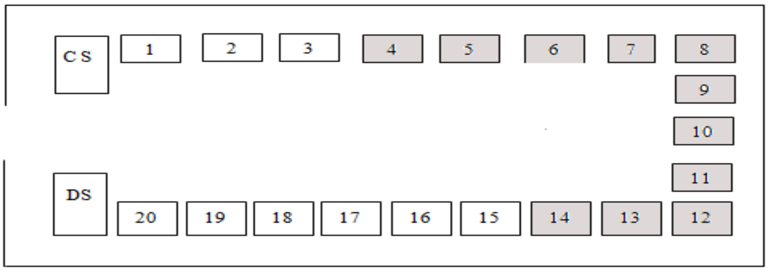


Figure 9.4 (b) Layouts of selected machines utilized for alternative A (Conventional layout)

9.3.2 Alternative 'B' (FMS Based Manufacturing System and Relocation of Machines)

For this study we have considered the machine shop area only where the machining processes have to be taken place. For this purpose alternative B of the machine shop, in addition to the present one, has been designed and presented in figure 9.5 as indicated in Table 9.1. This alternative signifies the rearrangement of machines in shop and new sequence of machining has been made by changing the position of machines with suggested Flexible Manufacturing Systems (FMSs). In the present case study, the company is considered as FMS environment. Therefore, a careful approach has been adopted.

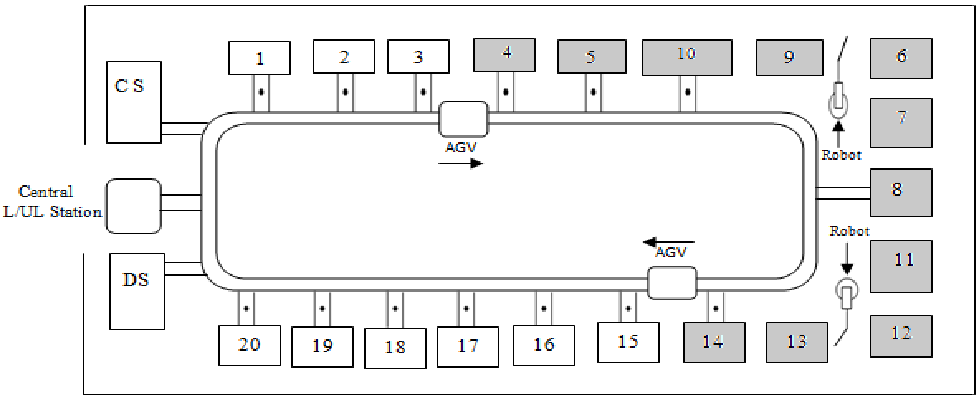


Figure 9.5 Layouts of machines in alternative B (After relocation)

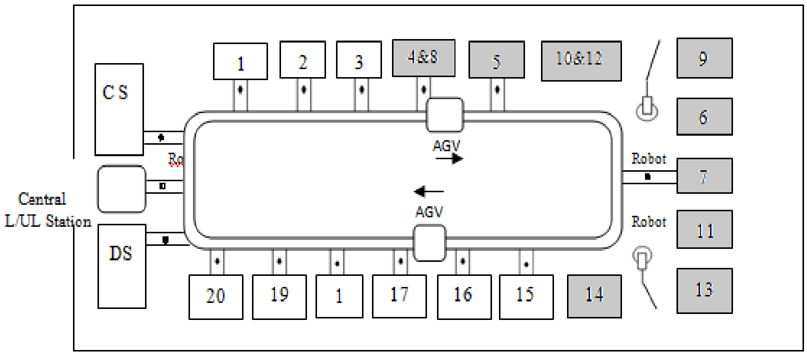


Figure 9.6 Layouts of machines in alternative C (After removing the surplus machine)

9.3.3 Alternative 'C' (FMS Based Manufacturing System and Combination of Operations with Combined Tools)

Alternative 'B' can be further improved by making some changes like use of combined tools as shown in figure 9.7 and 9.8 and removing some surplus machines by combining operations (i.e. Rough turning & Chamfering and Rough pin hole drilling & Finish pin hole reaming) on machines. This configuration of machines is named as alternative 'C' (or modified FMS with combined tooling) as shown in Figure 9.6. The space occupied by all machines is reduced due to reduction in number of machines by combining the operations. The space reduced from 100 m^2 to 95 m^2, power consumption is reduced 110 units to 90 units per day, number of operators reduced from 11 to 9 per day for the machining of 574 pistons per day. For achieving more productivity and flexibility by further reducing space utilization power consumption and man power more CNC machining centres and more flexi-SPMs have been proposed.

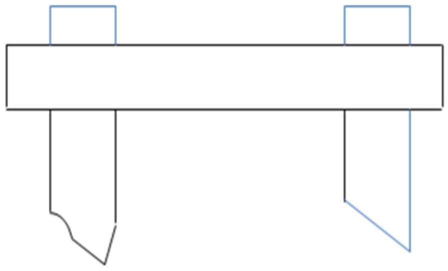


Figure 9.7 Combined tool for operation No. 4 and 8

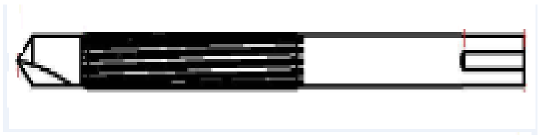


Figure 9.8 Combined tool for operation No. 10 and 12

Table 9.2 Operation sequence used in Piston manufacturing for machine shop

S. No.	Operation No.	Processes used in piston making	Machines used	Type of operation	No. of operations	Type of tool used	Tool material	RPM (N)	Cutting speed	Feed per rev	Time (Sec)
1	4	Rough turning	CNC lathe machine	Turning operation	01	Turning tool	Carbide	1500	250	0.15	**26.2**
2	5	Rough grooving-3 No	CNC lathe	Groove making	03	Groove cutter	Carbide	1000	140	0.08	**19.1**
3	10	Rough pin hole drilling	CNC drilling machine	Pin Hole drilling	01	Drill bit Ǿ 12 mm	Carbide	2500	120	0.1	**10.3**
4	9	Oil hole drilling Ǿ 2.00 mm-4nos Ǿ 1.5 mm -5 No	CNC-multi spindle drill machine	Drilling	01	Drill bit Ǿ 2 mm	Carbide	1500	30		**22.8**
5	6	Finish grooving- 3 No (Ring grooves)	CNC lathe	Groove cutter	03	Groove cutter	Carbide	2500	400	0.05	**8.0**
6	7	Finish profile turning (Skert)	CNC lathe	Profile	01	Profiler cutting tool	Carbide	3000	600	0.07	**24.4**
7	8	Chamfering-0.02mm	CNC lathe	Chamfering	01	Chamfer tool	Carbide	3200	600	0.07	**2.0**
8.	11	Circlip grooving – 2 No	VMC	Grooving (Boring Bar)	02	Groove cutter	Carbide	1274	60	0.04	**12.1**
9.	12	Finish pin hole (Reaming operation)	VMC	Reaming	01	Reamer	Carbide	3000	100	0.08	**6.0**
10.	13	Finish pin hole (Lapping operation)	VMC	Lapping	01	Lapping fine grit strips	Sullry paste	3000	60	0.5	**4.6**
11	14	Grinding	Automated grinder	Grinding	01	Grinding wheel	Carburan - dum	4500	80	0.04	**7.8**

Total time=**141.Sec**.

Table 9.3 Operation sequence for piston manufacturing after combining the tools

S. No	Operation No.	Processes used in piston making	Machines used	Type of operation	No. of operations	Type of tool used	Tool material	RPM (N)	Cutting speed	Feed per rev	Time (Sec)
1	4 & 8	Rough turning + Chamfering	CNC lathe machine	Turning operation + Chamfering	01 + 01	Turning Tool + Chamfer tool	Carbide + Carbide	1500 + 3200	250 + 600	0.15 + 0.07	**26.2**
2	5	Rough grooving-3 No	CNC lathe	Groove making	03	Groove cutter	Carbide	1000	140	0.08	**19.1**
3	10 &12	Rough pin hole drilling + Finish pin hole (Reaming operation)	CNC drilling machine + VMC	Pin Hole drilling + Reaming	01 + 01	Drill bit Ǿ 12 mm + Reamer	Carbide + Carbide	2500 + 3000	120 + 100	0.1	**10.3**
4	9	Oil hole drilling Ǿ 2.00 mm-4no Ǿ 1.5 mm -5No	CNC-multi spindle drill machine	Drilling	01	Drill bit Ǿ 2 mm	Carbide	1500	30	0.2	**20.8**
5	6	Finish grooving- 3 No (Ring grooves)	CNC lathe	Groove cutter	03	Groove cutter	Carbide	2500	400	0.05	**8.0**
6	6	Finish profile turning (Skert)	CNC lathe	Profile	01	Profiler cutting tool	Carbide	3000	600	0.07	**24.4**
7	11	Circlip grooving – 2 No	VMC	Grooving (Boring bar)	02	Groove cutter	Carbide	1274	60	0.04	**12.1**
8	13.	Finish pin hole (Lapping operation)	VMC	Lapping	01	Lapping fine grit strip	Sullry/ paste	3000	60	0.5	**4.6**
9	14.	Grinding	Automated grinder	Grinding	01	Grinding wheel	Carborun-dum	4500	80	0.04	**7.5**

Total time=**133. Sec**

9.4 COST AND TIME CALCULATION FOR PISTON MANUFACTURING

During case study of piston manufacturing within the plant real observations on machines have been taken carefully regarding the time. Finally It has been observed that time consumption was more before combining the operations and tooling by making through modification in tooling design. Cost and time calculation of piston manufacturing before and after modification in tooling is as follows:

Time taken by the machines before combining the operations for piston manufacturing =141.0 Sec.

Time taken by the machines after combining the operations (i.e. operation No. 4 & 8 and operation No. 10 & 12 = 133.0 Sec

Total Time saving = 141.0 -133.0 = 8.0 Sec/piston

Total time available for machining purpose /day = 3600 x 22.5=81000 Sec

Total quantity of pistons manufactured / day before combining the operations = 81000/141 = 574 Pistons

Total number of pistons produced / day after combining the operations = 81000/133 = 609 Pistons

Manufacturing of additional pistons/ day =609-574 =35 piston

Machining Cost per piston = Rs 13.26

Total saving per day in term of money = 35 x 13.26 =464/-

Total saving per month in term of money = 35 x 13.26 x 25= Rs. 11603 /-

Total saving per year in term of money = 34 x 13.26 x 25 x 12 = Rs. 139230 /-

Total time consumed / Piston before combining the operations = 574 x 141 = 80934

Total Time consumed / Piston after combining the operations = 574 x 133 = 76342

Total time saving per day = 80934-76342 = 4592Sec. or 1.28 Hrs

Saving in labor cost (2 labour) per day = 35000/25 = Rs 1400

Saving in power consumption cost per day (commercial) Rs12 /unit = 110- 90 = 20 x12 = Rs 240/-

Saving in machining Cost (i.e. operation cost) per day = (chamfering + reaming) = 57.40 + 430.50 =487.90 = Rs 488/-

Total saving in cost /day = saving in laour cost/day + Saving in power consumption cost/day+ Saving in machining cost/day + Saving in cost due to additional piston manufacturing = 1400 +240 + 488 +464 = Rs 2592/-

Total Saving in cost per month = 2592 X 25 = Rs 64800/-

Total Saving in cost per Year = 2592 X 25 x12 = Rs 777600/-

Table 9.4 Result Comparison of alternative (A, B and C)

Alternative layouts	Space Required (m^2)	Power Required (Units)	Total number of Operators required per day in machine shop	Saving in cost as additional pistons manufactured/day (Rs)	Time saving /day (Sec)	Total saving /day = (Labour Cost + power Unit Cost + Machining cost + additional piston manufacturing cost) (Rs)
A	100	110	11	---	---	---
B	100	110	11	---	---	---
C	95	90	9	464	4592	1400 +240 + 488 + 464 = 2592

9.5 RESULT AND DISCUSSION

In this chapter an attempt has been made regarding the case study of a piston manufacturing shop for enhancing the productivity and flexibility with the proper tool management. The productivity and flexibility of the plant has been increased by the introduction of new tools (i.e. combined tools) used for minimizing the piston manufacturing operational time by using different alternatives. The alternative ‘C’ is recommended along with the improvement in shape required, power required and total number of operations per day than the other two alternatives (‘A’ and ‘B’). In this way piston manufacturing time and cost can be reduced. The time saving per day in piston manufacturing is 4592 Sec and saving in cost in additional piston manufacturing is Rs 464. However 1st and 2nd cases are not acceptable. The result obtained in table 9.4 shows that the flexible manufacturing system with combined tooling and utilization of proper tool management can enhance the piston manufacturing productivity and flexibility.

9.6 DEVELOPMENT OF A LINEAR PROGRAMMING (LP) MODEL FOR MAXIMIZATION OF PROFIT BY PROPER TOOL MANAGEMENT IN FMS

9.6.1 Linear Programming (L.P)

Linear programming is a problem solving technique and it is also known as a mathematical modelling method useful for sharing of limited resources in various applications like labour, machine, materials, tools, time, warehouse space, capital, energy, etc. According to Jenness (1972) utility, time and distance, return on investment, profit cost and performance etc are the basic criterion for optimality.

9.7 METHODOLOGY

Linear Programming is a mathematical tool that can be employed to solve a wide variety and difficult professional problems. For this purpose, a case study has been conducted with a vendor of a company engaged in manufacturing automobile and mechanical components. The data has been collected from the same company. The name of the company cannot be disclosed due to some security reason of the company. Four types of piston models are manufactured and supplied to the company for its different bike models. The data collected in the form of time and cost operation wise on machines according to the rates availability in market for machining per hour. In this study we have considered three different cases for H.S.S tools, carbide coated tools and carbide tip tools used for piston manufacturing by the machines. Finally, we have considered total time and operation cost machine wise for each case. The major stress of this effort is to determine the quantity of the pistons for each case that will maximize the profit of the company by the utilization of proper tool management. The analysis was carried out using linear programming technique. A Simplex method was proposed by B.Dantzig in 1947 for solving the linear programming problems. Fagoyinbo (2011) and Martin (1989) advocated that optimization of a linear objective function is a type of linear programming problem of the form:

$P = C1X2 + C2X2 + C3X3 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots + CnXn$ (Objective function)

Subject to:

$a11x1 + a12x2 + a13x3 + \ldots\ldots\ldots + a1nxn\ (\leq \text{or} \geq)\ b1$

$a21x1 + a22x2 + a23x3 + \ldots\ldots\ldots + a2nxn\ (\leq \text{or} \geq)\ b2$

$am1x1 + am2x2 + am3x3 + \ldots\ldots\ldots + amnxn\ (\leq \text{or} \geq)\ bm$

$x1, x2, x3\ \ldots\ldots\ldots\ xn\ (\leq \text{or} \geq)\ 0$

LP problem has:

(i) Linear objective function used for maximization or minimization.

(ii) Variety of linear constraints as an algebraic statement of the limits of the inputs at the elimination.

(iii) Non-negative constraints.

The variables of the study are as follows:

1. Decision Variables: These are piston models of four types having different sizes and made on similar machines engaged in piston manufacturing having same operation sequences with different type of tool material. It is represented by X1, X2, X3 and X4 respectively.

Where

X1= piston A, X2= Piston B, X3=Piston C and X4= Piston D

2. Objective Function: In setting up of any business main purpose is to maximize profit. Here it is a case of profit maximization problem because the profit of pistons manufactured has to be maximized with proper tool management. Therefore, the objective function is given by:

Maximize: $P = C1X1 + C2X2+C3X3+C4X4$, Where C1, C2, C3 and C4 are time and cost associated to piston manufacturing in the company for this study.

3. Constraints: Availability of time for machines is a constraint for this study is the time and operation wise time used by the machine for piston manufacturing.

Basic Assumptions of Model

The following assumptions have been made for the model development is as:

(a) The unit cost of piston manufacturing is taken as per machining rate per hour in market.

(b) The judgment variables are linear to data of each piston manufactured on a machine.

(c) The objective function is also linearly related with the decision variables.

9.8 MODEL DEVELOPMENT

Data Analysis

The data collected from a machine shop of a vendor engaged in piston manufacturing and analysed to determine the maximum profit in each case**.** The whole analysis was performed by using L.P analysis package (Zweigmedia.com/Real world/Simplex.html) and Lindo 6.1 software for verification and implementation.

Table 9.5 in Appendix presents the machines, operations, tool used and tools material for three different cases (i.e. H.S.S, Carbide coated and Carbide tip tools) used in piston manufacturing. Table 9.6 shows Operation wise timings for different machines used in piston manufacturing with different tool material used for machining the pistons A, B, C and D for case 1, II and III along with availability of machine time. Similarly Table 9.7 indicates cost operation wise for machines used in piston manufacturing with different tool material used for case 1, II and III per sec as per market rate. Table 9.8 shows the comparative results of time, cost and profit for this study. On the basis of data collected during the present case a linear programming model has formed to determine the profit by using different tool material for each case as stated below:

Table 9.5 Type of machines, operations and tooling with different material for three different cases

			Tool materials used		
Machines used	**Operations**	**Tools used**	**Case-1**	**Case-II**	**Case-III**
CNC lathe	1.Turning	Turning insert(10x10x100 mm)	H.S.S	Carbide coated	Carbide tip tools
	2. Chamfering	Chamfering insert (10x10x100 mm)	H.S.S	Carbide coated	Carbide tip tools
	3. Grooving	Grooving insert (10x10x100 mm)	H.S.S	Carbide coated	Carbide tip tools
CNC drilling	1.Gudgeoned pin hole (drilling+ reaming)	Combined tool bit drill & reamer parallel shank with 10 mm dia	H.S.S	Carbide coated	Carbide tip tools
	2.Oil hole drilling	Drill bit dia 2 mm Drill bit dia 5 mm	H.S.S	Carbide coated	Carbide tip tools
VMC machine	1.Circlip grooving	Grooving Insert (5x5x10 mm)	H.S.S	Carbide coated	Carbide tip tools
CNC grinding	Grinding	Grinding wheel (Firing points) Aluminium oxide, Silicon Carbide	Aluminium oxide	Aluminium oxide	Silicon Carbide

Table 9.6 The production time of pistons machine wise (sec)

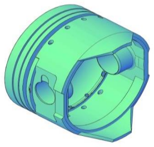
	Case 1 H.SS tooling				**Case II Carbide coating**				**Case III Carbide tip**				**Machine availability**
Machines used	X1	X2	X3	X4	X1	X2	X3	X4	X1	X2	X3	X4	(Sec)
CNC lathe	102	114	127	60	87	96	106	51	54	60	66	33	86400
CNC drilling	56	62	56	68	48	53	48	58	30	33	30	36	81000
VMC Machine	44	56	50	56	39	48	43	48	24	30	27	30	75600
CNC Grinding	38	32	32	38	34	29	29	34	21	18	18	21	70200
Machine time per piston	240	264	265	222	208	226	226	191	129	141	141	120	

Table 9.7 Production cost of pistons machine wise

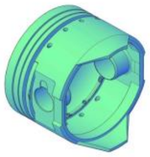
	Case 1 **H.SS Tools**				**Case II** **Carbide coating tools**				**Case III** **Carbide tip tools**				**Maximum cost available**
	Cost				**Cost**				**Cost**				
Machine used	X1	X2	X3	X4	X1	X2	X3	X4	X1	X2	X3	X4	
CNC lathe	5.1	5.7	6.4	3.0	4.35	4.80	5.30	2.55	2.70	3.0	3.33	1.65	4320
CNC drilling	7.0	7.8	7.0	8.5	6.00	6.63	6.00	7.25	3.75	4.13	3.75	4.50	10125
VMC machine	6.1	7.7	6.9	7.7	5.24	6.62	5.93	6.62	3.31	4.14	3.72	4.14	10500
CNC grinding	4.2	3.6	3.6	4.2	3.77	3.21	3.21	3.77	2..33	1.99	1.99	2.33	7800
Cost per Piston	22.4	24.7	23.8	23.4	19.4	21.3	20.4	20.2	12.1	13.3	12.8	12.6	

Table 9.8 Result Comparison

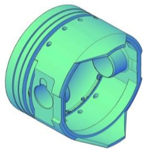
	Case 1 **H.SS tools**				**Case II** **Carbide coating tools**				**Case III** **Carbide tip tools**			
Pistons	X1	X2	X3	X4	X1	X2	X3	X4	X1	X2	X3	X4
Machining Time per Piston (Sec)	240	264	265	222	208	226	226	191	129	141	141	120
Machining Cost/Piston	22.4	24.7	23.8	23.4	19.4	21.3	20.4	20.2	12.1	13.3	12.8	12.6
Quantity produced per piston	284	---	---	957	339	--	--	1116	458	---	---	1868
Optimal value case wise	5750				5809				5816			



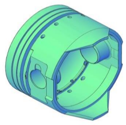
Piston A



Piston B



Piston C



Piston D

Case 1: High speed Steel (H.S.S) Tools

Model:

Maximize $P= 4.47X1 + 4.9X2 + 4.76X3 +4.68X4$

Subject to

$102X1 + 114X2 + 127X3 + 60X4 <= 86400$

$56X1 + 62X2 + 56X3 + 68X4 <= 81000$

$44X1 + 56X2 + 50X3 + 56X4 <= 75600$

$38X1 + 32X2 + 32X3 + 38X4 <= 70200$

$5.10X1 + 5.70X2 + 6.35X3 + 3.00X4 <=4320$

$7.00X1 + 7.75X2 + 7.00X3 + 8.50X4 <=10125$

$6.07X1 + 7.72X2 + 6.9X3 + 7.72X4 <=10500$

$4.21X1 + 3.55X2 + 3.55X3 + 4.21X4 <=7800$

Optimal Solution: $P = 5749.55$; $x1 = 283.893$, $x2 = 0$, $x3 = 0$, $x4 = 957.383$

Case II: Carbide Coated Tools

Model:

Maximize objective function (Profit):

Maximum $P= 3.87X1+4.25X2+4.08X3+4.03X4$

Subject to

$87X1+96X2+106X3+51X4\leq86400$ (Time Constraints)

$48X1+53X2+48X3+58X4\leq81000$ (Time Constraints)

$39X1+48X2+43X3+48X4\leq75600$ (Time Constraints)

$34X1+29X2+29X3+34X4\leq70200$ (Time Constraints)

$4.35X1+4.80X2+5.30X3+2.55X\leq4320$ (Cost Constraints)

$6.00X1+6.63X2+6.00X3+7.25X4\leq10125$ (Cost Constraints)

$5.24X1+6.63X2+5.93X3+6.62X4 \leq 10500$ (Cost Constraints)

$3.77X1+3.21X2+3.21X3+3.77X4 \leq 7800$ (Cost Constraints)

Optimal Solution: $P = 5809.3$; $X1 = 338.799$, $X2 = 0$, $X3 = 0$, $X4 = 1116.17$

Case III: Carbide Tip Tools

Model:

Maximize objective function (Profit):

Maximize $P= 2.42X1 + 2.65X2 + 2.55X3 +2.52X4$

Subject to

$54X1 + 60X2 + 66X3 + 33X4 \leq 86400$

$30X1 + 33X2 + 30X3 + 36X4 \leq 81000$

$24X1 + 30X2 + 27X3 + 30X4 \leq 75600$

$21X1 + 18X2 + 18X3 + 21X4 \leq 70200$

$2.70X1 + 3.00X2 + 3.33X3 + 1.65X4 <=4320$

$3.75X1 + 4.13X2 + 3.75X3 + 4.50X4 <=10125$

$3.33X1 + 4.17X2 + 3.75X3 + 4.17X4 <=10500$

$2.33X1 + 1.99X2 + 1.99X3 + 2.33X4 <=7800$

Optimal Solution: $P = 5816.72$; $X1 = 458.491$, $X2 = 0$, $X3 = 0$, $X4 = 1867.92$

Machining Cost/ Hr:

Cost of CNC Machining operation / Hrs = Rs 180

Cost of CNC Drilling operation / Hrs = Rs 450

Cost of VMC Machining operation / Hrs = Rs 500

Cost of CNC Grinding operation / Hrs = Rs 400

Availability of Machine Time

CNC Machine = 24.00 Hrs

CNC Drilling Machine = 22.30 Hrs

VMC Machining = 21.00 Hrs

CNC Grinding machine = 19.30 Hrs

9.9 RESULTAND DISCUSSION

The results were carried out by the analysis of the L.P model for three different tool materials i.e. H.S.S tools, carbide coated tools and carbide tip tools by using Simplex method and estimated the vales of objective function for these as 5750, 5809 and 5816 for four decision variables X1,X2,X3 and X4. The solution shows that only decision variables X1 and X4 contribute to improve the value of objective function of L.P models. Other results based on time, cost and quantity has also been shown in comparison table 9.8 for further analysis. The main requirement for this approach is that it requires good knowledge in mathematics and computer

9.10 CONCLUSION

Flexibility and productivity are the basic strategies for any organisation for its survival. Use of advance technologies like flexible manufacturing systems can fulfil these goals. In this study an attempt has been made to show how FMS can implement in a small industry for betterment of performance and productivity of its manufacturing system. In the current case study company is already doing its business by producing its automobile products in conventional system along with CNC and SPMs. Due to rapidly changes in technologies competitors can produce the same products within a short period of time and at minimal cost, whenever running companies are not ready for any instant changes. This is the reason that more alternatives along with FMS have been shown in Table 9.3. Introduction of new tooling (i.e. combined tooling) may also be one of them to reduce the production cost and time. Another technique (i.e. linear programming) has also been implemented for the maximization of profit by using proper tool management. The technique has been developed and implemented for selecting the most suitable quantity of different type of pistons to be manufactured for maximizing the profit of a manufacturing organisation. Based on machine tools it will be helpful to the management and its executives in taking decision about the quantity of pistons to be produced for maximizing the profit in FMS environment. The analysis was carried out using Simplex method solving online computer software Zweigmedia.com/Real world/Simplex.html and Lindo 6.1. It provides optimal solutions for maximizing the profit and the quantity required for maximizing the profit. Here researchers recommend to the industry management that only Pistons of X1 and X4 quantity should be produced in order to earn optimal profit.

However, Pistons having X2 and X3 quantity should be produced only for meeting the demands of their customers but in a limited amount. Hence it is concluded that by if proper tool management with combined tooling and techniques like linear programming are used in FMS the productivity and flexibility can be enhance easily. Moreover, the management can use this analysis for maximizing their profit in other product variants also for the benefit of their company.

CHAPTER X

DEVELOPMENT OF A PATH LAYOUT OPTIMIZATION MODEL FOR AGV IN FLEXIBLE MANUFACTURING SYSTEM USING PARTICLE SWARM OPTIMIZATION (PSO) APPROACH

10.1 INTRODUCTION

In the present scenario manufacturing concerns are adopting flexible manufacturing systems to avoid competition in term of technology at global level and to full fill customer's demand of highly quality products at competitive prices. Only FMS can be one of the techniques used to fill up the gap between the traditional job shop and advance automated transfer lines. According to Ponnambalam and Kiat (2008) about 15-70% of the production expense is leavened as a result of proper material management only.

Materials handling must be performed effectively in all respect i.e. the right kind of materials in the exact quantity to the correct location at right time in right condition with a precise manner without any damage. Scheduling of material handling systems in FMS are equally responsible as machines for actual time evaluation, so a good path layout design has a very high effect on the productivity time and its cost. Best corporeal layout design is also one important considerable issue and it should be sort out in the very beginning of the FMS (Fauadi and Murata, 2010). The arrangement of machines in a FMS is typical to handle the range of material handling devices to move raw materials, finished goods and tools from one location to another to facilitate the overall operations of manufacturing.

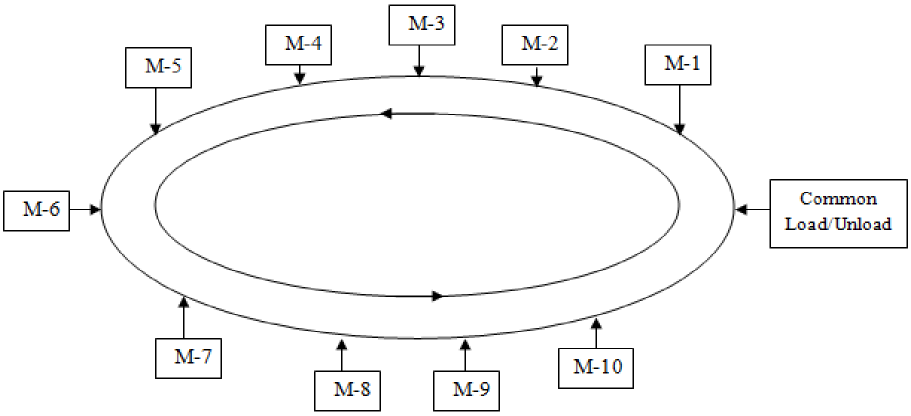


Figure 10.1 Machines loop layout

10.2 AUTOMATED GUIDED VEHICLE SYSTEM

Automated Guided Vehicle (AGV) is a self propelled, driverless and battery powered operated automatically steered computer controlled vehicles moving on a guided path layout for pickup and delivery the load at P&D stations. These vehicles are much more effective, accurate, efficient and demandable automated media for material handling as compared to other type of material handling devices (Berman and Edan, 2002).

10.3 PROBLEM DESCRIPTION

In flexible manufacturing system (FMS) environment a loop layout for 10 numbers of machines have been selected. These machines are set up in a loop network and material is moved by the single AGV in bidirectional manner. A significant step should be taken while designing a loop transportation system to choose the virtual order of machines in the bidirectional loop for minimization of transportation time, cost and number of backtracking if any occurs in the loop layout.

Assumptions: I. Tools used are assumed as new one at the initial stage. II. Breakdowns are assumed to be nil for all machines and material handling devices. One tool to one machine system is adopted. III. The distances between machines are same in the set up. IV The setup costs may differ as per the size and shape of the part. V. The Machines are not the same in specifications.

10.4 PARTICLE SWARM OPTIMIZATION

It is a computation base method used for search algorithm from a population base environment. This technique is stimulated by the fish schooling and bird flocking. This algorithm is accomplished by optimizing a non-linear and multidimensional problem which usually attains good solutions resourcefully while involve nominal parameterization. This wonderful technique was designed and initiated by Kennedy and Eberhart (1997). PSO is similar to many other non-conventional methods such as Genetic Algorithms (GA).In this technique there is no use of evolution operators are used such as crossover and mutation as used in (GA). Under this technique each particle has its coordination with the solution space and provides best solution (fitness) for that particular particle. It is called as pbest, means personal best. A new best value followed by PSO for any particle in the neighbourhood of that particle and it is known as gbest i.e. global best. An essential functioning of the PSO algorithm has been shown in Figure 2.

In PSO each particle position has been indicated by (1) and a velocity by (2). The calculation work for these particles is as under:

$Xi,d\ (it + 1) = xi,d\ (it) + vi,d\ (it + 1)$ - (1)

$Vi,d\ (it + 1) = vi,d\ (it) + C1 * Rand\ (0, 1) * [pbest,(it) * xi,d(it)] + C2 * Rand(0, 1) * [gbest\ (t) * xi,d(it)]$ - (2)

PSO can be implemented by adjusting the few constraints only. This technique is also useful in many different areas like function optimization, artificial neural network and fuzzy system control study in social behaviours and many more. It has also numerous advantages: It is easy, derivation free and computerized process. It is limited to adjust. It has no crossing over and change operators when obtain with GA. It is basic for artificial life and evolutionary computation, effective for a numerous problems such as optimization and structural work etc. and is trouble-free to implement.

Applications**:** PSO can be utilize in various fields as: Prediction and Forecasting, artificial neural network training purpose, Security purpose for military fuzzy system control, function optimization, Biomedical line, Robotics, Sensor Networks, Signal Processing etc. and in those areas where GA is applicable.

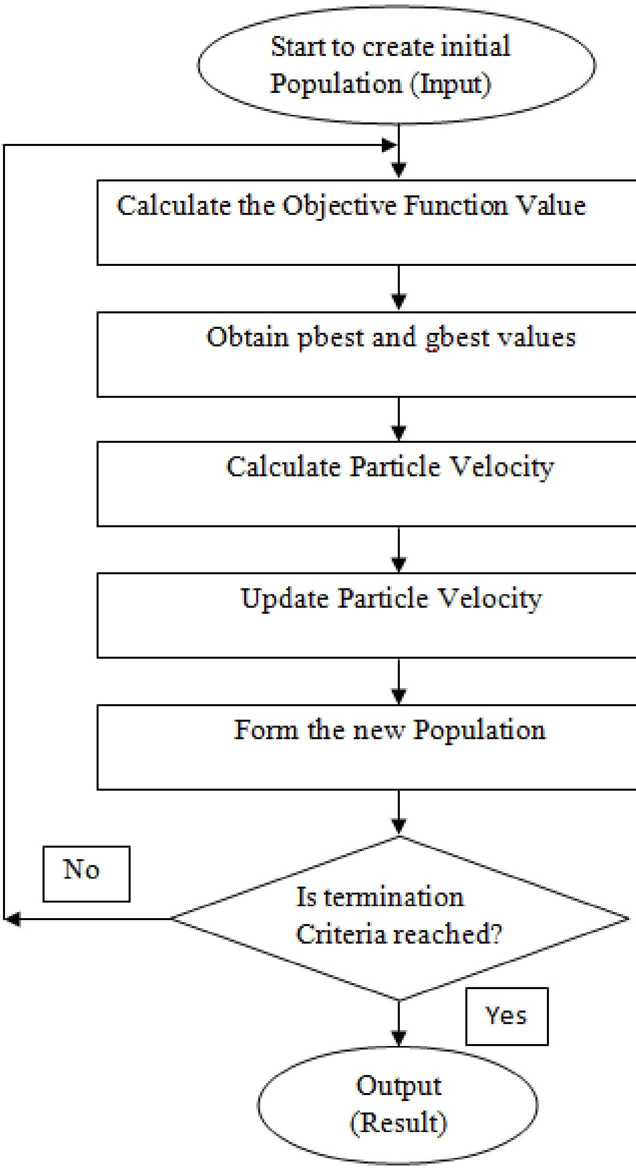


Figure 10.2 Flow chart of PSO Algorithm

10.5 PSO ALGORITHMS

The step wise procedure involved in PSO algorithm is as follows:

Step1: First of all initializes a population for n number of particles randomly.

Step 2: Make Calculations for best fitness value of each particle as a new pbest.

Step 3: Selection of particle with the best fitness value of all the particles as gbest.

Step 4: Calculate velocity for each particle, according to the equation as given below.

V [ ] = V [ ] + C1*rand ( ) *(Pbest [ ] – Present [ ]) + C2 *rand ( ) * (gbest [ ] – Present [ ])

Where, Present [ ] = present [ ] + V [ ].

V [ ] is the particle velocity.

Present [ ] is the current particle (solution).

rand ( ) is a random number between (0, 1).

C1, C2 are acceleration factors or learning factors. - (1 - 4).

Step 5: Particle velocities for each dimension are hold to a best velocity V max, If the summation of acceleration is based on the velocity for a given dimension, than it will also exceed to maximum velocity (Vmax).

Step 6: Terminate, if it fulfilled the condition of maximum number of iterations, otherwise repeat Step 2.

10.6 JAVA PROGRAMMING

Java is a programming language and it is used for numerical computation and programming purpose. This can be used to develop algorithms, models and applications from C and C++.

Java applications are usually run on any Java Virtual Machine (JVM). Currently Java is best one for programming languages work. Java programming for Particle swarm optimization (PSO) is as follows:

```
public void initialize Swarm() {
Particle p;
For (int i=0; i<swarm size; i++) {
p = new Particle ();
// randomize location inside a space defined in Problem Set double [] loc = new double [problem_dimension];
```

```
loc[0] = ProblemSet.loc_x_low + generator.nextDouble() * (ProblemSet.loc_x_high - problemset.loc_x_low);
loc[1] = ProblemSet.loc_y_low + generator.nextDouble() * (ProblemSet.loc_y_high - ProblemSet.loc_y_low);
Location location = new Location (loc);
// randomize velocity in the range defined in Problem Set double [] vel = new double [problem_dimension];
vel[0] = ProblemSet.vel_low + generator.nextDouble() * (ProblemSet.vel_high - ProblemSet.vel_low);
vel[1] = ProblemSet.vel_low + generator.nextDouble() * (ProblemSet.vel_high - ProblemSet.vel_low);
Velocity velocity = new Velocity (vel);
p.setLocation (location);
p.setVelocity (velocity);
swarm. Add (p);
                }
        }
```

10.7 LAYOUT OPTIMIZATION

The objective function for the loop layout optimization is based on minimization of time and is stated as follows.

T = W1*D+ W2* B / V

Where,

W1, W2 - The normalized weight factors. (The value of the objective function can be improved by using normalized weight factors but here in this problem normalized weight factors have not been used)

Where

D – Total distance moved by AGV for one cycle.

B – Total number of back tracking take places in one cycle if any.

V – Updated Velocity in Feet

T – Time in Seconds

10.8 OPTIMIZE PATH LAYOUT

Now in this proposed optimized path layout the movement of an AGV has been changed to bidirectional manoeuvre from the unidirectional movement in this layout. Delivery stations are also detached from picking stations and modified as per requirement. In this optimized path layout one common delivery post is considered having unloading equipments like robots etc. similarly every machine having separate loading station equipped with loading arrangement. The main aim of this proposed optimized path layout is to improve in productivity enhancement, total distance moved by AGV within the minimum time frame, minimization in backtracking of the AGV and reduction in the floor space requirement. Figure 10.3 shows the proposed path layout. Now by the utilization of PSO technique, a best machine sequence for FMS path layout is chosen, that is 3 8 7 2 9 10 1 4 6 5, the distance moved by AGV is 40 m or 131.2 feet per cycle and here no backtracking has been taken in account. The optimized machine path layout with proper sequence has been illustrated in Fig.10.3. There is 10 numbers of optimal orders from 100 iterations obtained from the computation and objective function values have been selected as shown in the Table10.1.

Details of the proposed Optimized plant layout are as follows:-

- Number of machines = 10
- Total distance travelled by AGV =40 m or 131.2 Feet
- Number of AGV = 01 (for bidirectional movement)
- Distance among the machines = 4m (Not same for all provided machines)
- Optimal machine sequence = 3 8 7 2 9 10 1 4 6 5

- Number of backtracking = Nil

The proposed optimized path layout consists of ten machines and is arranged as per the optimal sequence (Min value) of the loop layout as shown in fig.3.

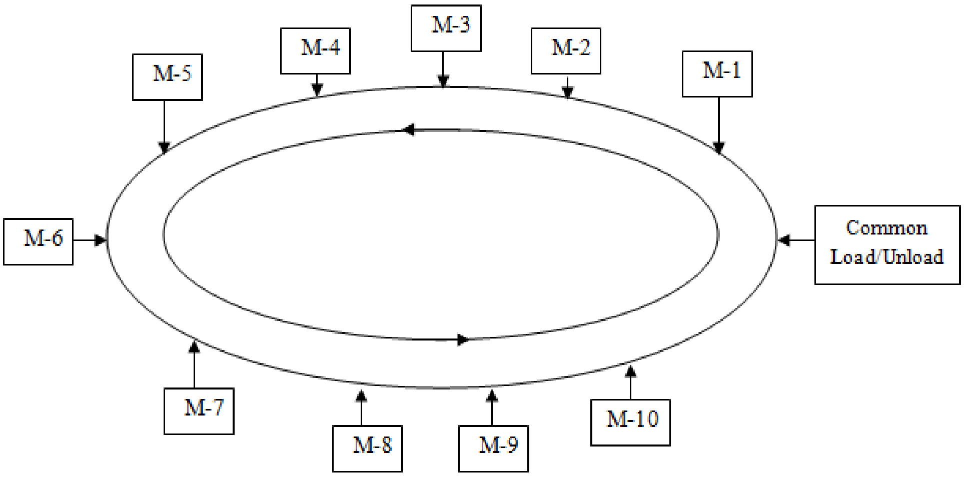


Figure 10.3 Proposed path layout

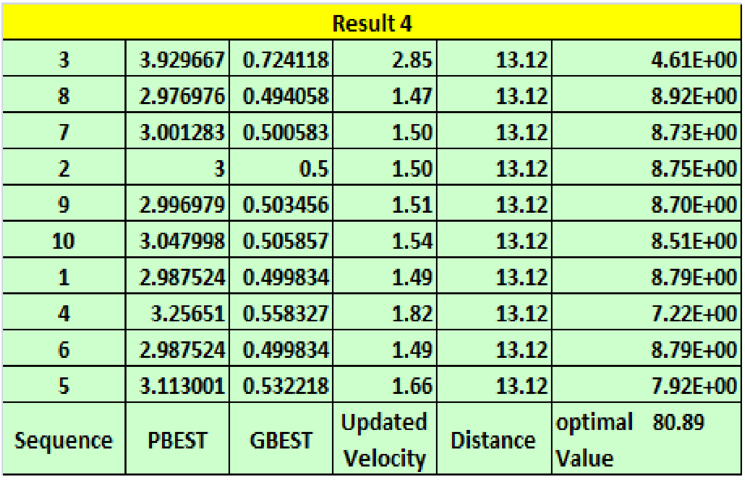
10.9 RESULT AND DISCUSSION

In this proposed optimized path layout the machines are placed in a suitable position and the distance moved by AGV is minimized so that the AGV idle time is reduced. The optimum machine sequence obtained after PSO application for the FMS layout is 3 8 7 2 9 10 1 4 6 5, the distance attained by the AGV is 40 m per rotation and the number of backtracking is considered as nil per cycle. Here some of the optimal sequences derived from the computation are shown below in the Table 10.1.

Table .10.1 .Optimal Sequences

S.No	Sequence	Objective Function Value
1	9 8 5 7 1 6 2 10 3 4	87.05
2	10 4 5 2 8 1 3 7 6 9	94.1
3	8 10 6 9 3 4 1 7 5 2	82.7
4	3 8 7 2 9 10 1 4 6 5	80.9 - Min
5	8 5 9 4 2 1 10 6 3 7	87.0
6	9 5 7 3 4 6 8 2 1 10	91.0
7	5 3 6 4 8 7 10 1 2 9	86.2
8	7 4 2 10 6 8 5 9 1 3	85.7
9	9 5 8 6 4 7 3 1 10 2	86.6
10.	4 3 8 7 10 9 5 6 2 1	85.7

Table 10.2 Snapshot of Java programming Output (Sample for result 4)



Result 4					
3	3.929667	0.724118	2.85	13.12	4.61E+00
8	2.976976	0.494058	1.47	13.12	8.92E+00
7	3.001283	0.500583	1.50	13.12	8.73E+00
2	3	0.5	1.50	13.12	8.75E+00
9	2.996979	0.503456	1.51	13.12	8.70E+00
10	3.047998	0.505857	1.54	13.12	8.51E+00
1	2.987524	0.499834	1.49	13.12	8.79E+00
4	3.25651	0.558327	1.82	13.12	7.22E+00
6	2.987524	0.499834	1.49	13.12	8.79E+00
5	3.113001	0.532218	1.66	13.12	7.92E+00
Sequence	PBEST	GBEST	Updated Velocity	Distance	optimal 80.89 Value

10.10 CONCLUSION

In this chapter proposed Particle Swarm Optimization (PSO) algorithm which is also known as a non-traditional optimization algorithm has been used for obtaining the best possible solution of bidirectional loop layout problem. The main motive of this research is to reduce the total time consumed and distance moved by AGV between the machines to reduce the number of backtracking per cycle if any. This algorithm has been used to provide a best solution for loop layout problem. A java programming has been used for 100 generations by 10 test runs for every occurrence in a problem. For a proposed objective function, optimum sequence of machines can also be found out for the proposed layout of a FMS. The optimum numbers of sequences in a Loop layout model can be found for a given optimum layout in FMS. The model is not limited up to a single solution only, but it also suggested a range of good solutions which may be different. From the result it has been concluded that this proposed approach regarding path layout is improved optimization approach like Simulated Annealing (SA) and Genetic Algorithm (GA). This approach can also be further extended to solve the loop layout and bidirectional loop problems based on MIN_MAX objective.

CHAPTER XI

SYNTHESIS OF RESEARCH WORK

11.1 INTRODUCTION

Issues related to material handling, tooling and society for flexible manufacturing environment can't be eliminated completely but they can be minimized. So analyzing the issues of material handling, tooling and related to society for the organizations are necessary for successful implementation of flexible manufacturing system to increase the productivity and flexibility for cost minimization and maximizing the profit. For this purpose, different type of issues has been analyzed. In this chapter, the synthesis of research work mention in the previous chapters has been presented. The major objectives of this chapter are as follows:

- To present the overall picture of the research work.
- To demonstrate the different studies done in previous chapters.
- To establish a relation among all the studies carried out in this research.

11.2 SYNTHESIS OF RESEARCH WORK

Research related information's in this thesis are the investigation regarding some selected issues of material handling, tooling and society in the context of Indian manufacturing industries. The research was succeeded with objectives as mentioned in chapter I. The achieved objectives are as follows:

- The literature regarding material handling, tooling and social issues have been studied and identified. Some critical issues related to flexible manufacturing system are also discussed.
- The current scenario in flexible manufacturing systems regarding Indian manufacturing industries have been analyzed by questionnaire based survey.
- Some important factors have been identified which are helpful in design and operation of AGV for material handling.
- Factors have been recognized through Indian industrial survey responsible for social implications and an ISM model has been build up for understanding the key issues.

- Variables related to material handling equipments selection, enhancing the productivity and flexibility of FMS for advance manufacturing system have been identified and analyzed by ISM and WISM technique and MICMAC analysis.
- FAHP and MGRA techniques have been used based on comparison for selection of appropriate material handling device from the available material handling devices.
- Analysis of material handling equipments effectiveness has also been evaluated by using GTA technique in FMS.
- A case study has been conducted for a piston manufacturing shop for enhancing productivity and flexibility and a linear programming (L.P) model has also been developed for maximizing the profit with proper tool management in FMS.
- A model has also been purposed for optimization of path layout of AGV in FMS.

In achieving these objectives, the methodologies used in the present research are presented in Table and Figure No.11.1.

Table 11.1 Methodologies used in the research

Objectives	**Methodology Used**	**Used No.**
To identify the major factors affecting the design and operation of material handling devices specially AGVs of FMS	Literature review and expert opinion	1
To conduct a survey of Indian industries for identifying the social implications of FMS	Questionnaire based survey	2
To develop an interpretive structural model to analyze the driving and dependence power of social implications of FMS	ISM approach	3
To develop ISM models of variables related to material handling, productivity and flexibility of FMS	ISM approach	4
To develop MCDM frameworks for the selection of material handling equipment.	FAHP and MGRA	5
To develop a case study of a manufacturing shop for enhancing productivity and flexibility with proper tool management.	Case study and Linear programming (L.P) Technique	6
To prepare a model for the optimization of path layout of AGVs in FMS.	PSO Technique	7

The studies conducted in this research have been explained below:

An extensive literature review have been accomplished and studies regarding the different issues related to material handling, tooling and social issues of flexible manufacturing systems are reported in Chapter II. In Chapter III, observation of Indian manufacturing industries towards the material handling, tooling and social issues of flexible manufacturing system have been presented. On the basis of results of survey, material handling, tooling and social issues were segregated and ranked which provided the base for the development of models by interpretive structural modelling technique (ISM). Chapters IV present the development of ISM based framework. This framework has been developed on the basis of social implication issues find out through literature review and questionnaire based survey. Chapter V has a study of design and operation of MH systems in FMS. Chapter VI deals with the development of ISM models of variables related to material handling equipments, productivity and flexibility of FMS. These models show the interrelationship and respective levels of material handling equipments variables as well productivity and flexibility variables. In chapter VII MCDM frameworks have been developed by using FAHP and M-GRA techniques for selection of MHE for flexible manufacturing systems. Chapter VIII deals with a quantitative analysis of six variables related to material handling equipment effectiveness based on their sub factors and interdependence has been done and presented in a form of Graph theoretic approach (GTA) and a framework has prepared for assessing the MHEs in FMS. Chapter IX has a case study of a piston manufacturing shop for enhancing productivity and flexibility with the proper tool management and a linear programming model (L.P) model has also been developed for the selection of optimum number of tools for maximization of profit in FMS. Chapter X presents a model for the optimization of path layout of AGVs in FMS. This study proposed a optimum path sequence for minimization of material movement time through model, which can be utilized by industrial managers to find the solution of optimal sequence in material handling for their set ups.

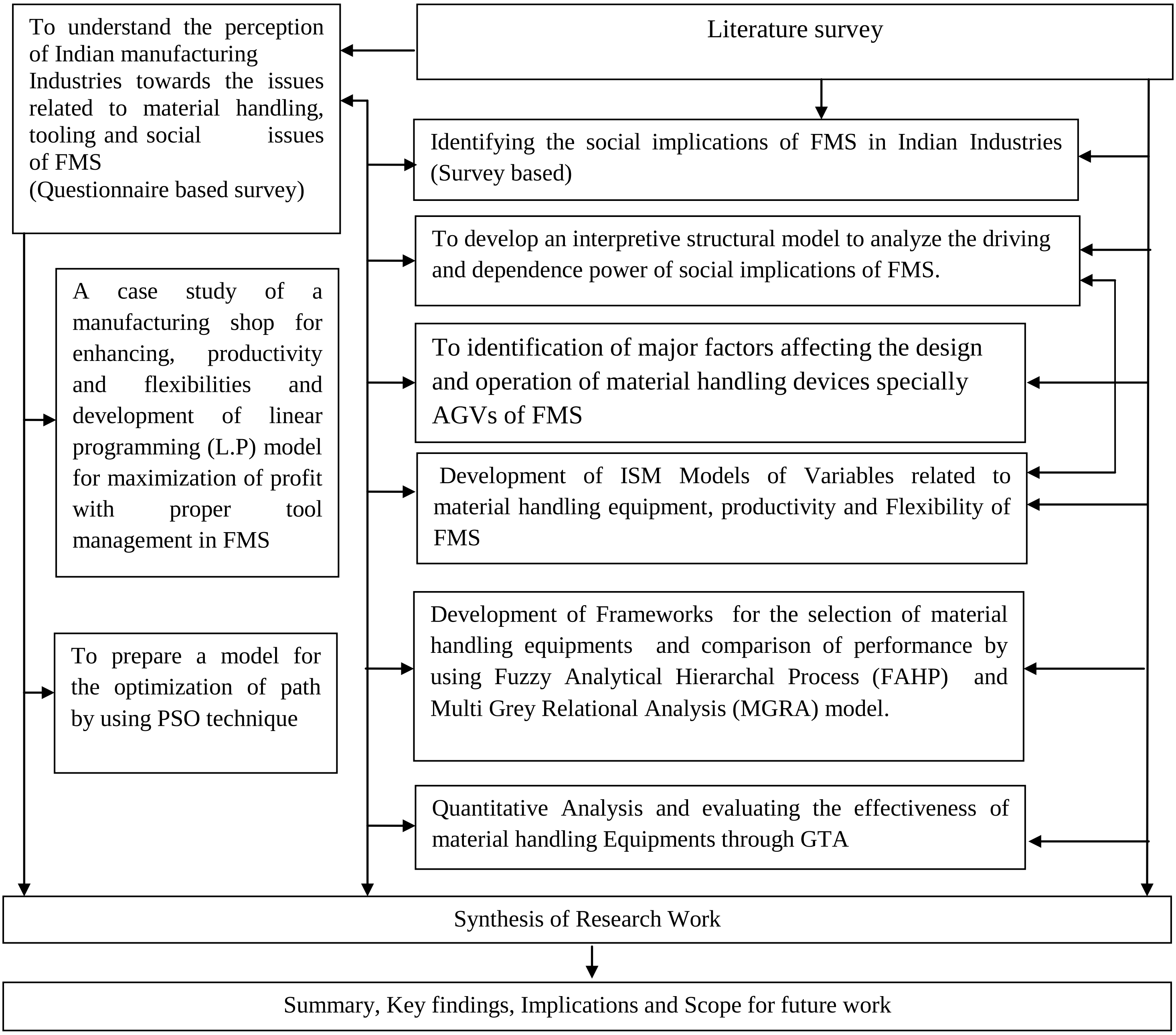


Figure 11.1 Integration of methodologies used in the research

11.3 CONCLUSION

This chapter presents the synthesis of research work presented in this thesis. Linkages between different approaches are reported in this chapter. A diagram is presented to illustrate the integration of different methodologies used in this research. Further, summary, conclusion, key findings, implications and scope for future work have been presented in the next chapter.

CHAPTER XII

SUMMARY, KEY FINDINGS, IMPLICATIONS AND SCOPE FOR FUTURE WORK

12.1 INTRODUCTION

Industries are facing technological and economical challenges at global level due to rapidly changes in customer's demand of new products at lowest cost. In this competitive environment industries are required to focus on product cost reduction and major issues of material handling, tooling and social implications of FMS for satisfying the demand of the customers. The various issues related to material handling, tooling and social implications have been explored extensively during the past decades, but they are not fully utilized by the manufacturing industries due to wide gap in between theoretical and practical aspects. Lack of awareness regarding material handling, tooling and social implications in Indian manufacturing industries has motivated the researchers to pursue the advance research via exploring and analyzing the material handling, tooling and social implications of FMS.

12.2 SUMMARY OF THE RESEARCH WORK

The current research has developed to authenticate the material handling, tooling and social implications of FMS. In this part, a concise review of the research work is presented. The research work is summarized as below:

- An exhaustive literature review was conducted to identify the some significant issues of material handling, tooling and social implications of Flexible Manufacturing System.
- A questionnaire was designed to obtain responses in consultation with experts' opinion of their field, academicians and from literature review. These questionnaire base survey responses will help in understanding the impact of material handling, tooling and social implication on FMS.
- Responses were analyzed and some important issues were studied based on survey responses. An ISM model, MICMAC analysis and effectiveness index have been used for identification of social implication factors having some positive and negative impact on society which affect the FMS.

- An ISM model, MICMAC analysis have also been used for identification and modelling the variables which affect the selection of MHEs in modern environment on the bases of their driving and dependence power in FMS. The developed ISM model will also help in understanding the mutual relationship of factors affecting selection of material handling equipments in FMS environment.
- A Fuzzy AHP approach has applied for selection and comparison of material handling equipment for flexible manufacturing system.
- AHP and M-GRA methods have been used for choosing multi attributes of a mobile robot being used for FMS.
- GTA based approach has been used for quantifying and evaluating the effectiveness of MHE variables in FMS.
- A Case Study has been developed for piston manufacturing shop for enhancing productivity and flexibility with proper tool management.
- A Linear Programming (L.P) approach has been used for development of a model which is useful in maximization of profit with proper tool management for FMS.
- A PSO method has been utilized for the optimization of path layout of AGV used in FMS.

12.3 KEY FINDINGS OF THE RESEARCH

The key findings of this research are as follows:

- The most of the Indian manufacturing industries wants to implement flexible manufacturing system.
- Improvement in productivity, quality, competitive prices and abruptly changes in customers demand are the main reasons for adopting the FMS.
- Material handling, tooling and social implications are considered as the major issues in flexible manufacturing system.
- Unemployment, employees’ resistance to FMS and high capital investment are the most significant drawback in the implementation of FMS in Indian industries due to availability of abundant man power in Indian scenario.
- The awareness regarding the selection of material handling equipments and their variables like speed of delivery, automation and economics are considered as most important selection variables based on their driver and dependence power in

FMS environment. Therefore, before selecting the automated material handling equipments for FMS, availability of high technology equipments and availability of its vendors must be examined.

- Dependent variables like safety, load carrying capacity, throughput rate and plant layout are the weak drivers but strongly depend on each other. Therefore special care should be taken while opting for the material handling equipments.
- Linkage variables like flexibility have strong driving power as well as high dependencies. Flexibility in manufacturing as well in material handling provides an option to adopt latest technology like robots and AGVs.
- By using FAHP approach a model has been prepared to analyze the interaction between various attributes of material handling equipments. The attributes, automation, cost and load carrying capacities are the most important attributes which has more influence on material handling alternatives. A pair wise comparison was carried out between the various alternatives for each considered attribute and finally weights were obtained. These weights are then utilized for deciding the ranking of material handling equipments. On the basis of higher ranking an AGV has been found the best alternative among the other alternative. It can easily move between workstations to carry heavy loads and easy interfaces with the other manufacturing facilities.
- The Suggested AHP/M-GRA technique may be a better choice for choosing a best MHE while qualitative multi-attributes are considered. Based on identified attributes the top level management and its executives can take idea to choice an exact type of MHE when planning to buy new equipment. This technique is logical, systematic, simple and easy in approach.
- An effectiveness index of material handling (EIMH) equipment selection variables has been proposed through GTA based frame work. Based on (EIMH) value the effectiveness index of material handling variables shows that the reduce strength of variables is much higher for material handling equipments in the organisation. Adoption of new technologies like AGVs and robots in MH have an significant and effective role in increasing production level and product variety as demanded by customers and market at minimal cost.

- ISM models of variables related to material handling equipment, productivity and flexibility have been developed. These identified variables have significant role in the selection of MHEs for FMS.
- A case study of piston manufacturing has also been developed in a light engineering industry for enhancing the productivity and flexibility of its production system. The results of the study show that in real application of FMS is beneficial in tool and machine reduction by combining the operations, reduction in manufacturing time and enhancing in productivity of pistons on daily basis which will improve the financial condition of the industry.
- A linear programming model (LP) has been developed and validated through Zweigmedia.com/Real world/Simplex.html and Lindo 6.1 for maximization of profit through proper tool management (i.e. using different tool materials, HSS, carbide coated and carbide tip tools) for selecting the most suitable quantity of different type of pistons to be manufactured. The top management and production executives can use this analysis for achieving the profit in their industries for variety of products.
- A PSO algorithm has been suggested for getting the best possible solution of loop layout problem. This algorithm will be used for finding the path (sequence) required by a material handling equipment (i.e. AGV) from the initial stage to the final destination. PSO algorithm can also be further utilized for solving the loop layout and bidirectional loop problems.

12.4 IMPLICATIONS OF THE RESEARCH

The finding of this research deals with the some important contribution to the literature and adoption of FMS in the field of material handling, tooling and social implications with real practical life problems in Indian industrial scenario presently. These research implications are most valuable for manufacturing industries, academicians, managers and for management**.** In this present research different type of tool and techniques are suggested, to deal with the different types of issues related to material handling, tooling and social implications which can improve the FMS performance. The questionnaire based survey presented for this research can be utilized as an instrument to carry out advance research in the field of material handling, tooling and social issues in FMS.

12.4.1 Implications for the Industry

The current research is helpful for all types of manufacturing industries. Resistance of labour and its supported trade unions towards the adoption of FMS is a big problem. Automated technology like FMS that uses robots and AGVs for material handling, automated selection and decision making regarding work and tooling by the machines leads to unemployment, initially high capital investment for implementation towards FMS in developing countries like India. Other benefits like social status and improvement in salaries and incentives make it more attractive for more adoption. The research carried out in the present work will motivate the firms to adopt FMS due to other factors also like better quality products, accessibility of more range of products and improvement in technical skill of employees. The new tools and techniques suggested in current research can improve the overall performance of manufacturing industries in FMS environment. Newly developed combination of tooling for different operations and optimization of path layout can be helpful in minimization of over all time and cost.

12.4.2 Implications for the Academicians

The current research work has some important implications regarding the academicians. The research can be carried out for the current study on the basis of insights provided in current research. The presented questionnaire can be used as an instrument for further research in FMS. The developed ISM, FAHP, MGRA/AHP, L.P and PSO approaches will helps in imposing command and direction on the complexity and relationship on different issues and related factors. Index calculation may direct the academicians to develop similar models and index of variables/factors. New design of combined tools (drill & reamer) and combined cutting bit (turning & chamfering) can be considered as a performance enhancing tools.

12.4.3 Implications for the Managers

The framework developed during current research can direct and guide manufacturing managers to take necessary action for tackle the weak issues in their organisations. This research also guides its managers to analyze the strengths and weakness while adopting FMS. Easily availability of cheap manpower in abundance quantity, availability of more variety of quality product, no long term relationship with the vendors for supply and maintenance of high technology equipments, non availability of trained professionals, retrenchment of employee and unemployment, selection of appropriate material handling equipments and their shortest path selection are some critical issues which must be taken in account while implementing FMS. The current research work provides the different approaches to the manufacturing managers for acquiring maximum benefit from FMS. Combination of tooling and reduction of machines may be beneficial in improving the methodology used for manufacturing.

12.5 CONCLUSION

The current research work was started with the aim to enhance the performance of FMS through study and analyzing the material handling, tooling and social implications of FMS system and to develop some related frameworks for enhancing the productivity performance and adoption of FMS by utilizing tools and techniques. In this study, issues related to automated material handling, tooling and social implications in FMS have been addressed. A questionnaire based survey has been carried out in Indian manufacturing industries to understand the importance of material handling, tooling and social implications in adoption and implementation of FMS. In this research a developed framework regarding the social implications will be supportive in accepting the actual effect of FMS on society. The understanding concerning these social implications and their dynamic and reliance power is most important for applying FMSs in developing nations like India. The study explains social implications whose effect is more on society in India like employees' resistance to FMS, unemployment and initially high capital investment etc. These factors may be considered as the basic reasons of all the factors for affecting the FMS.

For material handling equipment selection a frame work has been developed based on material handling variables which may prove useful in decision making for administration and its executives. The knowledge of decision variables and their driver and dependence power is essential while selecting MHEs. The study confirms important variables for selection point of view like speed of delivery, automation and economics. The management and its managers can take initiative from these variables in recognizing their comparative importance and interactions. These variables must be taken care of as key variables for the choice of MHE in FMS. Based on FAHP approach a model has been prepared to analyze the relations among various attributes of MHEs. The attributes, automation, cost and load carrying capacities are the main attributes which has more influence on material handling alternatives. A pair wise comparison was carried out between the various alternatives, for each considered attribute finally weights were obtained. These weights are then utilized for deciding the ranking of material handling equipments. On the basis of higher ranking an AGV has been found the best alternative among the other alternative. It can easily move between workstations to carry heavy loads and interfaces with the other manufacturing facilities. Similarly AHP and Multi grey analysis (M-GRA) has been done on the basis of higher ranking for finding the best material handling equipment out of various alternatives given and a qualitative multi-attribute approach has been taken into account. Manufacturing executives can decide after analysis about buying a particular type of MHE. GTA framework has also been prepared to quantify the significance for MH equipment's in FMS. The single numerical value named EIMH values has been evaluated to find out selection of material handling equipments which are more effective for FMS environment. A case study has also been done in a piston manufacturing automobile plant having FMS environment and on the basis of data collection a linear programming model has been developed based on software Zweigmedia.com/Real world/Simplex.html and Lindo 6.1 for maximization of profit by utilizing proper tool management. The analysis result shows that carbide tip tools can produce suitable quantity of different type of pistons for enhancing the profit. A case study has been conducted in which new tools have been designed for combining the operation in which operation timings have minimized for enhancing the productivity and flexibility for obtaining the overall financial benefit of the firm. A path layout optimization model for an AGV has been developed by utilizing PSO approach for finding the optimum path (sequence) required by AGV from the initial point to the final point.

12.6 LIMITATIONS AND SCOPE FOR FUTURE WORK

The present research provides some prolong insights into the issues of material handling, tooling and social implications in flexible manufacturing. Although a lot of attempts have been made in this research work to analyze the impact of material handling, tooling and social implications in FMS yet this research is not limitation free. The one of the major limitation is that all issues related to flexible manufacturing system were not considered in the present research, only some selected issues of material handling, tooling and social implications of Flexible manufacturing system were identified for analysis. Expert opinions required to build up the appropriate relations for ISM model and for inner dependence matrix in FAHP may be biased. Specifically for Indian manufacturing industries, these research outcomes may differ slightly than other countries for their industries depending upon government policies, funding and social security. However, some more work is required in future and the current research can be extended as per following guidelines:

- The ISM based frameworks developed in this research can be authenticated through structural equation modelling (SEM) to validate such ISM models.
- More number of variables for material handling, tooling and social implications issues which affect flexible manufacturing systems can be identified and analyzed.
- The FAHP method presented in this research is based upon decision matrices and pair wise comparisons for FAHP. This can be improved by relating other technique like fuzzy TOPSIS and sensitivity analysis on collected data.
- Interpretive structural modelling (ISM) techniques can be further extended to weight interpretive structural modelling and total interpretive structural modelling (T-ISM).
- Linear Programming is impractical and supposed that factory part remains constant. In addition to this the correlation in terms of input and output, production and total revenue are assumed to be linear. Usually L.P models are used for trial and error solutions where difficulty arises in finding out really optimal solutions to various business problems.
- Other than PSO, optimization techniques like GA and SA may be a substitute of the current approach. On the basis of comparison analysis a better option for path layout optimization can be find out.
- Current research work can be further evaluated by using some other optimization methods like simple additive weighting (SAW) technique, simulated annealing (SA) and genetic algorithm (GA) etc.

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APPENDIX
QUESTIONNAIRE

YMCA UNIVERSITY OF SCIENCE AND TECHNOLOGY
FARIDABAD, HARYANA - 121106

Research Supervisor: **Professor Tilak Raj**, YMCA University of Science and Technology, Faridabad.

Subject: A research project on “Material handling, Tooling and Social Issues of Flexible Manufacturing Systems”.

Dear Sir/Madam,

Flexible manufacturing system (FMS) is a system which provides an opportunity to produce more customized products of highest quality and lowest cost which are acceptable in the rapidly changing market. As a part of Ph.D. research, a survey of Indian industries is being conducted related to the material handling, tooling and social issues related to the manufacturing i.e. Flexible Manufacturing System. To make it possible, the industry and academia must share their views. Your feedback in this regard will be a significant input to this study. It is requested that you will spare your valuable time in responding to the enclosed questionnaire. This has been divided into the following sections:

Section 1: Organization profile

Section 2: Issues related to FMS

I would be grateful if you kindly fill it in and send it at the earliest. The objective of the survey is purely research and academic in value. Therefore, all responses will be kept strictly confidential and will be used only for this academic work.

With thanks and regards,

Yours faithfully,

Encl: Questionnaire on FMS

(SURINDER KUMAR)
Research Scholar

APPENDIX A1: QUESTIONNAIRE ON MATERIAL HANDLING, TOOLING AND SOCIAL ISSUES OF FMS

Section 1: Organization profile

1. (A) Name of organization…………………………………….
(B) Type of business……………………………………….

2. Please indicate the number of employees at your organization:
(A) Less than 100 [ ] (B) 101 to 500 [ ] (C) 501 to 1000 [ ]
(D) 1001 to 3000 [ ] (E) More than 3000 [ ]

3. Please indicate the total turnover of your organization in Rs. of Crores:
(A) Less than 10 [ ] (B) 10 to 50 [ ] (C) 50 to 100 [ ]
(D) 100 to 500 [ ] (E) 500 to 1000 [ ] (D) 1000 to 2000 [ ] (E) More than 2000 [ ]

4. Please indicate the number of models of your product (variety) being manufactured:
(A) 1-5 [ ] (B) 6-10 [ ] (C) 11-20 [ ] (D) More than 20 [ ]

5. Please indicate the change-over time (in minutes) from one model to another:
(A) Less than 15 [ ] (B) 15-30 [ ] (C) 30-60 [ ] (D) 60-90 [ ]
(E) More than 90 [ ]

6. Please indicate the total percentage of components being manufactured inside the plant
(A) Less than 25 [ ] (B) 25-50 [ ] (C) 50-75 [ ] (D) 75-90 [ ] (E) 90-100 [ ]

7. The current productivity level in terms of units per man per day is approximately:
(A) Less than 10 [ ] (B) 10-25 [ ] (C) 25-50 [ ] (D) 50-100 [ ]
(E) More than 100 [ ]

Section II: Issues related to FMS

8. Please indicate the position of your organization on implementation of Material Handling and Tooling in FMS environment:

A	Interested in conventional manufacturing.	☐
B	Interested in implementing AGVs for material handling in manufacturing environment.	☐
C	Interested in implementing robot with CNC machine tools.	☐
D	Interesting in implementation of automated conveyor system for material handling.	☐
E	Interested in combination of all above material handling devices in industry.	☐

9. Please rank the following variables in improving the manufacturing system**:**

		Very low **1**	**Low** **2**	**Moderate** **3**	**High** **4**	**Very high** **5**
A	Lead time reduction	☐	☐	☐	☐	☐
B	Reduction of maintenance cost	☐	☐	☐	☐	☐
C	Improvement in Quality	☐	☐	☐	☐	☐
D	Work-in-process inventory reduction	☐	☐	☐	☐	☐
E	Set-up time reduction	☐	☐	☐	☐	☐
F	Manpower reduction	☐	☐	☐	☐	☐
G	Reduction in material handling time and distance by using AGV, Robot, Conveyor and other material handling systems	☐	☐	☐	☐	☐
H	Reduction in tool changing time	☐	☐	☐	☐	☐
I	Reduction in space utilization	☐	☐	☐	☐	☐
J	Reduction in scrap through proper cutting tools.	☐	☐	☐	☐	☐
K	Speed of response	☐	☐	☐	☐	☐
L	Increase in machine utilization	☐	☐	☐	☐	☐
M	Reduction in tooling cost	☐	☐	☐	☐	☐
N	Combination of operations	☐	☐	☐	☐	☐
O	Reconfiguration of machine tools	☐	☐	☐	☐	☐
P	Capability to handle new products	☐	☐	☐	☐	☐
Q	Flexibility in production	☐	☐	☐	☐	☐
R	Automation	☐	☐	☐	☐	☐
S	Use of flexible fixtures	☐	☐	☐	☐	☐
T	Skilled workers	☐	☐	☐	☐	☐

10. Please indicate the following reasons for adopting material handling systems like AGV, Robot, Conveyor etc and tooling in FMS**:**

		Very low **1**	**Low** **2**	**Moderate** **3**	**High** **4**	**Very high** **5**
A	Smooth flow of material from one machine to another.	☐	☐	☐	☐	☐
B	To improve productivity	☐	☐	☐	☐	☐

C	To improve consistency	☐	☐	☐	☐	☐
D	To improve space utilization	☐	☐	☐	☐	☐
E	To get unmanned operations	☐	☐	☐	☐	☐
F	Forced by technology/market demand.	☐	☐	☐	☐	☐
G	To Reduce waiting time	☐	☐	☐	☐	☐
H	Automated loading and unloading the parts on machines.	☐	☐	☐	☐	☐
I	Freedom from labour related threats.	☐	☐	☐	☐	☐
J	For improving machines integration	☐	☐	☐	☐	☐

11. Please indicate your preference for future automated material handling, tooling in manufacturing system of your company**:**

		Very low **1**	**Low** **2**	**Moderate** **3**	**High** **4**	**Very high** **5**
A	CNC machines supported by conventional material handling devices.	☐	☐	☐	☐	☐
B	Flexible Manufacturing System (FMS) with material handling devices.	☐	☐	☐	☐	☐
C	Total computer integrated manufacturing (CIM) system	☐	☐	☐	☐	☐
D	Humanized Flexible Manufacturing System in which human resources are utilized as a leverage to FMS (HFMS)	☐	☐	☐	☐	☐
E	CNC Machines supported by automated material handling systems like AGVs, Conveyor, robots and other advance material handling systems.	☐	☐	☐	☐	☐

Section lII: Issues related to Material Handling

12. Please indicate the use of following material handling devices in your company:

		Very low 1	Low 2	Moderate 3	High 4	Very high 5
A	All mechanical equipments operated by human labor					
B	Remote controlled equipments					
C	Automated guided vehicles					
D	Robotics					
E	Automated conveyor system					
F	Cranes of any type					
G	Monorail-guided trolleys					
H	Hoist					
I	Forklift trucks					
J	Wire Rope ways					

13. Kindly rank the effectiveness of following functions in managing Material handling Equipment:

		Very low 1	Low 2	Moderate 3	High 4	Very high 5
A	Dispatching of Automated guided vehicles					
B	Quality improvement					
C	Integration of facilities					
D	Simulation techniques					
E	Managing operational techniques					
F	Accommodating new models in the system					
G	Speed of delivery					
H	Available area/space					
I	Communication System					
J	Flexibility					

K	Type of material handling systems					
L	Overhead and Miscellaneous cost					
M	Operational Cost					
N	Space required					
O	Number of machines					
P	Number of operations					
Q	Safety					
R	Distance between machines					
S	Sensors					
T	Material flow path					
U	Arrangement of machine					
V	Capability of material handling systems					
W	Traffic management					
X	Coordination with plant facilities					
Y	Flexibility issues					
Z	Type of machines					
A1	Type of facilities, work rotation and storage devices					
B1	Throughput rate					
C1	Type of operations					
D1	Routing Flexibility					
E1	Maintenance cost					
F1	Automation					
G1	Automation Cost					
H1	Standardization of equipments					
I1	Remote control interface					
J1	Plant Layout					
K1	Type of path layout					
L1	Type of material handling systems(MHS)					
M1	Automated control of flow path					

N1	Load carrying capacity					
O1	Flexibility in product and process routing for future expansion					
P1	Product variety					
Q1	System networking					
R1	Automated inspection systems					
S1	Interface facility with workstation					
T1	Vision system					
U1	Machine flexibility					
V1	Automated inspection systems					
W1	Interface facility with workstation					
X1	Vision system					
Y1	MHS response time of material systems					
Z1	Economics					
A2	Type of product size availability					
B2	Use of automated workstations					
C2	Type of product					
D2	Machine depreciation cost					
E2	Cost					
F2	Load carrying Capacity					
G2	Efficiency					

14. Please rank the following factors for **a**chieving high productivity through material handling and tooling in FMS**:**

		Very low 1	**Low 2**	**Moderate 3**	**High 4**	**Very high 5**
A	High production rate					
B	Reduced lead time					
C	Flow path optimization					
D	High machine utilization					

E	Reduced scrap	☐	☐	☐	☐	☐
F	Efficient layout arrangement	☐	☐	☐	☐	☐
G	Effective material handling	☐	☐	☐	☐	☐
H	Effective tool management	☐	☐	☐	☐	☐
I	Reduction in man power	☐	☐	☐	☐	☐
J	High flexibility	☐	☐	☐	☐	☐

Section lV: Issues related to Tooling

15. Please rank the following factors for the tool management in FMS **:**

		Very low **1**	**Low** **2**	**Moderate** **3**	**High** **4**	**Very high** **5**
A	Number and types of machine tools	☐	☐	☐	☐	☐
B	Capacity of tool magazines of CNC machines	☐	☐	☐	☐	☐
C	Part types and their processing requirements	☐	☐	☐	☐	☐
D	Cutting tool material properties	☐	☐	☐	☐	☐
E	Multi-tasking tools	☐	☐	☐	☐	☐
F	Tool cost	☐	☐	☐	☐	☐
G	Tool inventory	☐	☐	☐	☐	☐
H	Tool life	☐	☐	☐	☐	☐
I	Tool standardization	☐	☐	☐	☐	☐
J	Tool interchangeable capacity	☐	☐	☐	☐	☐
K	Frequency of tool movement	☐	☐	☐	☐	☐
L	Effective tool management	☐	☐	☐	☐	☐
M	Selection of proper tooling	☐	☐	☐	☐	☐
N	Availability of tool copies or sister tooling	☐	☐	☐	☐	☐
O	Varity of tooling	☐	☐	☐	☐	☐

Section 5: Social Issues related to workforce

16. Please rank the following factors for the social implications in FMS **:**

		Very low 1	Low 2	Moderate 3	High 4	Very high 5
A	Fear of unemployment.					
B	Reduction in labour force					
C	Fear of technology change					
D	Reduction of purchase power due to unemployment and high cost of product					
E	Initially high capital investment					
F	Retrenchment of employees					
G	Employee’s resistance in transition to FMS .					
H	Improved quality of product					
I	Availability of more variety of products					
J	Change in social status of employees					
K	Long-term committed relationship with vendors					
L	Improvement in salaries/Incentives					
M	Trend of labour towards service sector					
N	Improved technical skill and education of employees					
O	Supported policies of the Government**.**					

Respondent Profile

1. Name (If you please):

2. Designation:

(a) CEO [ ] (b) Sr. Manager [ ] (c) Manager [ ] (d) Supervisor [ ]
(e) Junior staff [ ]

3. Your functional area:

(a) Production [ ] (b) Marketing [ ] (c) Maintenance [ ] (d) Quality Control [ ] (e) Any other [ ] please specify

4. Your association in years with current organization:

(a) Less than 5 [ ] (b) 5-7 [ ] (c) 8-10 [ ] (d) More than 10 [ ]

5. Would you like to share the findings of the survey (a) Yes [ ] (b) No [ ]

Thank you very much for your valuable feedback

BRIEF PROFILE OF THE RESEARCH SCHOLAR

Surinder kumar is working as an Associate professor in Mechanical Engineering Department at Shri Ram College of Engineering and Management, Palwal India. He has completed his BE in Mechanical Engineering from Jamia Millia Islamia New Delhi in 1998, M.Tech in Manufacturing and Automation (Mechanical Engineering) from YMCA College of Engineering, Faridabad in 2008 and pursuing his PhD from YMCA University of Science and Technology, Faridabad, India. He is working in the field of Flexible manufacturing System, manufacturing technology. He has published over 10 research papers in various international journals and conferences. Some of reputed and Scopus indexed journals including International Journal of Operation Research, International. Journal of Modelling in Operations Management, International Journal of Information and Decision Sciences, International Journal of Operations Research and Information Systems, International Journal of Recent advances in Mechanical Engineering etc. and national and international conferences at YMCAUST Faridabad, SRCEM Palwal and Delhi Technical University (DTU) Delhi etc.

LIST OF PUBLICATIONS OUT OF THESIS

List of Published papers in International Journals

Sr. No	Title of the paper	Name of Journal	Publisher	Vol. & Issue No	Year of Publication	Page No.	Indexing Scopus
1.	Modelling the social implications of flexible manufacturing system through ISM: a case of India	International Journal of Modelling in Operations Management	Inderscience	Vol. 4, Nos. 1/2,	2014	72-94	---
2.	An ISM approach for modelling the variables affecting the selection of material handling equipments in advance manufacturing system	International Journal of Information and Decision Sciences	Inderscience	Vol. 7, No.4	2015	358-379	Scopus
3.	Selection of material handling equipment for flexible manufacturing system using FAHP	International Journal of Recent advances in Mechanical Engineering	Wireilla Publication	Vol.5, No.1,	2016	25-45	---
4.	A multi attribute selection of mobile robot using AHP/M-GRA technique	International Journal of Operations Research and Information Systems	IGI Publication	Vol. 7, No. 4	2016	94-114	---

List of Papers Accepted in International Journals

Sr. No	Title of the paper	Name of Journal	Publisher	Vol. & Issue No.	Year of Publication	Page No.	Indexing Scopus
1.	GTA-based framework for evaluating the effectiveness of material handling equipment's in FMS environment	International Journal of Operational Research	Inderscience	Not Assigned	2018	Not Assigned	Scopus

List of Papers in National Conferences

Sr. No.	Title of the paper	Name of Conference	Year of Conference	Place of Conference
1.	A Case Study of a Piston Manufacturing Shop for Enhancing the Productivity and Flexibility with Introduction of New Tools in FMS	National Conference on Recent Trends in Engineering Science & Management	April 18-19, 2017	Shri Ram College of Engineering and Management, Palwal (Haryana)
2.	Development of A Linear Programming (L.P) Model For Maximization of Profit With Proper Tool Management In Flexible Manufacturing System	TAME-2017	March 16-17, 2017	YMCAUST, Faridabad (Haryana)

List of Papers Accepted in International Conferences

S. No.	Title of the paper	Name of Conference	Year of Conference	Place of Conference
1.	Assessment of FMS Productivity Factors by using Weighted Interpretive Structural Modelling (WISM) Technique	NFEST-2018	January 8-12, 2018	Delhi Technical University (DTU), New Delhi