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Analyzing the factors affecting the flexibility in FMS using weighted interpretive structural modeling (WISM) approach

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Abstract A high degree of flexibility is required for advancement in technology, rapid delivery to market, meeting customers demands and flexible manufacturing system is ideal for solving these problems. There are some variables which not only affect the flexibility but also affect each other. In this paper, twelve factors have been identified through the literature review and they are further analysed with the help of weighted interpretive structural modeling approach. In this research, a questionnaire based survey was conducted to rank these factors and ISM based approach has been employed to analyse their mutual interaction and interpretation of factors in terms of their driving and dependence powers has been examined. The structural model developed using this methodology helps to understand the interaction between various factors affecting the flexibility and their managerial implications. A method of effectiveness index is used to identify the key factors. The effectiveness index evaluated in this paper will help the industries to benchmark their performance by focussing on the factors reported in this paper.

Keywords Flexible manufacturing system (FMS) · Flexibility · Key variables · Interpretive structural modeling (ISM) · Weighted interpretive structural modeling (WISM) · Effectiveness index (EI)

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1 Introduction

Modern lifestyle trends and globalization have put up tremendous challenge to manufacturing industries. In the current business scenario the competitiveness of any manufacturing industry is determined by its ability to produce high quality products at low costs and to respond quickly to the rapidly changing market demands. In the present high stress, turbulent business-environment, well run organizations strive continually to enhance their capabilities to create excellent value for their customers by improving the cost effectiveness of their operations (Attri et al. 2013a, b). The flexibility in production, quick response to unknown market changes and reduction of cost of goods and services, has become the key factor for maintaining the market share (Raj et al. 2012). The production is broadening, innovation cycle is shortened, and the products have new shape, material and functions. At this strategy, the most important parameter is the time and improving its shortening. The manufacturing organizations are facing high pressure due to rapidly developing technologies, competitive prices of the products, shortened product life cycles and high quality expectation by the customers. This pressure is of more intense nature in case of developing countries (Raj et al. 2007). The market conditions are becoming more dynamic and more customers driven. The manufacturing performance is no longer driven by the product price, instead other competitive factors such as flexibility, quality, and delivery have become equally important (Chan and Swarnkar 2006). New variety of products are pumped into the market by multinational companies (MNCs). In such a scenario, it has become quite difficult to survive for most of the manufacturing industries in developing countries. They have

realized that it is the time to upgrade their manufacturing systems or to shut down their business.

Flexibility of a manufacturing system can be defined as the ability of the system to respond to changes either in the environment or in the system itself. FMS is equipped with several computer-controlled machines interconnected by automated material handling systems to provide high productivity and manufacturing flexibility (Singholi et al. 2012). Meeting the mounting requirements of customized production firms adopt FMS (Kumar et al. 2006). FMS is capable of producing a variety of part types and handling flexible routing of parts instead of running parts in a straight line through machines (Chen and Ho 2005). In the global market, three keys that constitute the winning edge are proprietary products, high value-added products and global yet local services (Inman 1991). The ability to rapidly alter the production of diverse products can provide manufacturers with a distinct competitive advantage. In an attempt to improve their competitive edge, manufacturers have been moving to this advance manufacturing technology i.e., FMS (Ozbayrak and Bell 2003). Companies adopting flexible manufacturing technology rather than conventional manufacturing technology can react more quickly to market changes, provide certain economies, enhance customer satisfaction and increase profitability. Research shows that the future level of competitiveness of an organization can be determined by the adoption and use of technological bases. Corporate strategy based on flexible manufacturing technology enables firms to be better positioned in the battles that lie ahead in the global area. Companies do undertake projects in automation to improve productivity by reducing cost of labour, power bills, space utilization and produce better quality products (Raj 2004). Though FMS is used for enhancing the flexibility of a manufacturing system but there are some factors which affect this flexibility. Therefore, it is very essential to analyse these factors and determine some key variables which affect the amount of flexibility in FMS. The purpose of this paper is to identify and analyse these factors, which not only affect the flexibility but also affect each other. A total of 12 factors have been identified through literature, questionnaire based survey and opinions of experts both from industry and academia. The methodology of Interpretive Structural Modeling (ISM) has been applied for developing model that establishes interpretive relationship among these factors and a method of effectiveness index (EI) is used to analyse these factors. The interpretation of factors in terms of their driving and dependence powers has been examined.

The main objectives of this paper are as follows:

- To identify and rank the factors affecting flexibility of FMS
- To evaluate the effectiveness index (EI) of these factors
- To establish relationship among these factors using ISM
- To discuss managerial implication of this research along with scope of future research.

In the remainder of this paper, identification of various factors through literature, survey and discussion with experts is presented in Sect. 2. Evaluation of EI value and an overview of ISM technique is given in Sect. 3. Use of ISM approach in the modeling of various factors is discussed in Sect. 4. MICMAC analysis of these factors is presented in Sect. 5 and the results of this research followed by discussion in Sect. 6 and conclusion in Sect. 7, respectively.

2 Identification of various factors affecting the flexibility of FMS

Though an FMS is meant for enhancing the flexibility in a production system, it is a very difficult task to achieve real-life flexibility (Jain and Raj 2015). Scheduling and manufacturing flexibility are among the manufacturing strategies considered by researcher to improve the FMS performance. Several researchers have developed alternative taxonomies for manufacturing flexibility (Raj et al. 2012; Singholi et al. 2012; Nayak and Ray 2012; Browne et al. 1984; Swamidass 1988). Operational measures of flexibility have been developed by (Chung and Chen 1989, 1990; Graves 1988; Kumar 1987; Soon and Park 1987 and Brill and Mandelbaum 1989). According to Singholi et al. (2013) flexibility affects the overall performance of a flexible manufacturing system. In their research they considered two types of flexibility: machine and routing flexibility to show their effect on the performance of FMS. According to Kumar and Sharma (2015) the unexpected events, affect the overall performance of manufacturing system which can be handled by incorporating flexibility dimensions with respect to design, operation, and management of manufacturing system. Babu and Srinivasan (2010) also discussed the impact of volume, routing and product mix flexibilities on the performance of a job shop. A number of researchers have defined and suggested promising measures for various types of flexibility but have not provided guidance as to how one should compute these measures (Soon and Park 1987; Brill and Mandelbaum 1989). Swamidass (1988) attributes the difficulties of understanding flexibility to: the use of flexibility terms which have different meanings, the use of flexibility terms which are aggregates of others and the use of flexibility terms with scopes which overlap. This view has been endorsed by Chung and Chen (1990) and Bernardo and Mohamed

(1992). So, despite of wide interest, flexibility remains to be poorly understood in theory and poorly utilised in practice (Beskese et al. 2004). In the present work discussion is related to machine, routing and product flexibility. Machine flexibility refers to the various types of operations that the machine can perform without requiring a prohibitive effort in switching from one operation to another, routing flexibility is defined as the ability of the manufacturing system to manufacture a product by alternate routes through the system and product flexibility can be defined as the ease with which new products can be added or substituted for existing products (Sethi and Sethi 1990; Azzone and Bertele's 1989). Based on the literature review and discussion with the experts both from industry and academia, 12 factors were identified out of 22 factors from the questionnaire survey due to some similarity in functions among the factors. All 22 factors are enlisted in Table 1.

The purpose of questionnaire based survey was to identify the impact of various factors on machine, routing and product flexibilities in Indian context. Later, with the help of the questionnaire results and expert's opinion the mutual relationship among different variables is defined and self structural interpretive matrix (SSIM) is prepared. This matrix is used as an input towards the development of ISM-based framework for the factors. Ranking of these factors is based on the mean scores obtained from the results of questionnaire based survey. Description of these 12 selected factors are given below:

1. *Set-up or changeover time*: To produce a variety of parts at faster rate i.e., faster customer delivery, reduction in set-up time and subsequently in manufacturing lead time is required. Set-up time of a machine can be defined as the amount of time spent in setting up the fixture, calculating tool offsets and performing all the necessary tasks to change from the last part of a production lot to the first good part of the next production lot. FMS generally employs CNC/NC machines which have automatic tool interchange capabilities that reduce the set-up time (Chan 1999). So, FMS helps in the process of rapid changeover.

2. *Tool magazine or tool turret capacity*: FMS is meant for handling a variety of workpart configurations and the production of these workparts requires a sequence of operations (Groover 2003). Complex parts may require dozens, or even hundreds, of processing steps and a number of cutting tools are

Table 1 Factors affecting machine, product and routing flexibilities and their references

S. no	Factors affecting different flexibilities	References/source
1	Setup or changeover time	De Groote (1988), Groover (2003)
2	Tool magazine or tool turret capacity	Groover (2003)
3	Machine Flexibility	Groover (2003)
4	Availability of technical know how	Expert opinion
5	Skills & versatility of workers in the system	Piore and Sabel (1984), Groover (2003)
6	Type of machines	Groover (2003)
7	Max. no. of tools available	Sethi and Sethi (1990)
8	Number of machines available in the system	Expert opinion
9	Variety of parts to be handled by the machine	Bayazit (2005), Groover (2003), Raj et al. (2012)
10	Space availability	Expert opinion
11	Max. no. of operations available	Expert opinion
12	Common tooling available	Groover (2003)
13	Similarities of parts in the system	Groover (2003)
14	Variety of products	Bayazit (2005), Groover (2003); Sujono and Lashkari (2007), Raj, Attri and Jain (2012)
15	Tool changing time of the machine	Browne et al. (1984)
16	Design changes required in the product	Primrose and Verter (1996), Sujono and Lashkari (2007)
17	Flexibility of material handling system	Groover (2003)
18	Similarity of workstations	Groover (2003)
19	No of existing part families matching the new product design	Groover (2003)
20	Maximum number of routes available	Groover (2003)
21	Type of operations to be done on the machine	Groover (2003)
22	Offline part programming preparation facility	Groover (2003)

required for performing these operations.CNC machine tools in FMS are generally equipped with large tool magazines to hold several cutting to perform various operations on variety of parts. Duplication of the most often used tools in the tool magazines is allowed to ensure the least non-operational time.

3. *Skills and versatility of workers*: More skilled and versatile workers means more flexibility of FMS. If the workers who know multiple and better working techniques and skills are available then major problems during operations are solved because such people can understand the system as a whole in less time (Raj et al. 2008). It will be useful to the industry to select workers with high cognitive ability and the ability to follow instructions (Cardy and Krzystofiak 1991; Cordero 1997). Cognitive ability helps them to understand the expert system, programming and limitations of FMS.

4. *Types of machine*: Various types of machine tools like CNC machines and machining heads in SPMs, etc., are used in FMS. Machine tools are the main component of flexible manufacturing systems. It has been reported in the literature that CNC machines are the basic component of FMS because of their softwired nature. According to Browne et al. (1984) flexibility of machine is dependent on the ease with which one can make changes in order to produce a given set of part types. Greater the range of operations and part styles a machine can handle, the greater will be the flexibility of that machine.

5. *Variety of parts to be handled by the machine*: More the variety of products to be handled by a particular production system, more will be its flexibility. Flexibility of FMS is directly related with the variety of parts to be manufactured. FMS are acclaimed for their ability to produce a diverse range of parts efficiently (Sujono and Lashkari 2007). Flexible automated system is capable of producing a variety of parts with virtually no time lost for changeovers from one part style to the next (Bayazit 2005).

6. *Space availability*: The optimum arrangement of devices and machines in the available space is one of the basic requirement in designing of FMS, since good solutions in the design of such a system are a basis for its efficient operation and for low operating costs (Ficko et al. 2004). The manner of arranging of working devices largely depends on the type of production. For example, AGVs are used as an automated material handling system in FMS. In case of bad layout of machines more AGVs are required but they are insufficiently utilized. So, in the FMS, the devices and machines must be arranged in best possible way to properly utilize the available space to enhance the overall flexibility of the system.

7. *Tool changing time of the machine*: As there is a variety of machining operations to be performed by the machines on different part styles in a FMS environment, so in switching from one machining operation to another cutting tools must be changed. This is done on a machining center under NC program control by an automated tool-changer designed to exchange cutters between the machine tool spindle and a tool storage drum (tool magazine). The capacities of these drums commonly range from 16 to 80 cutting tools (Filote and Ciufudean 2010).

8. *Design changes required in the product*: Flexibility of a particular manufacturing system would be more if it is capable of handling a variety of new and unexpected products. With the changing demands of the customers on daily basis, changes in the product design are required frequently. According to Primrose and Verter (1996) FMS results in introduction of new products. FMS have the capability to produce a wide range of products, have more capacity to deal with fluctuations in demand and have a greater ability to cope with uncertainty. FMS are well known for their capability to respond quickly to part-mix changes (Sujono and Lashkari 2007).

9. *Flexibility of material handling system*: For loading and unloading the materials from one machine to another machine, to pick and drop the material AGV and industrial robots are used. This results in increasing the overall efficiency of the system by reducing the human intervention and human inaccuracy. Automated material handling devices enhances the overall efficiency of the facility by reducing the lead time, WIP and inventory level (Spano et al. 1993). Consequently, greater flexibility is added to the manufacturing system with regard to material handling, volume, routing and delivery (Rao and Deshmukh 1994).

10. *Maximum number of routes available*: In case of machine breakdown, routing flexibility allows the system to continue processing a set of parts types with alternate routes. Routing flexibility is seen as not only a way to cope with machine breakdown but also a means to improve the performance and flexibility of a manufacturing system (Chung and Chen 1989, 1990). So, more number of routes available, reduces the non operational time and enhance the flexibility of the manufacturing system.

11. *Type of operations to be done on machine*: Each machine in an FMS is quite versatile and capable of performing different operations. The system can machine several part types simultaneously and each

part may have alternate milling and drilling type operations in FMSs. These operations process non rotational parts using CNC machining centres. For rotational parts turning centres are used. Milling centres may also be used where there are requirements for multi-tooth rotational cutters (Groover 2003).

12. *Offline part programming preparation facility*: Implementing the offline program system saves valuable machine time, leaving the machine to utilize most of its time in operational activities. In industry the ability to prove out CNC part programs away from the machine in a clean and quite environment and store program on disk media has many obvious advantages. This facility improves the throughput by reducing the non operational time of the machine and maximize the output. FANUC offline software is very important for both educational and industry level. Unexpected scenarios which intensify the programming requirement for the CNC can be addressed better with the aid of offline programming because multiple parts can be programmed across computer terminals for the same machine (Anand 2012).

3 Methodology

A questionnaire based survey, ISM approach and a method of effectiveness index (EI) have been used to achieve the objectives of this research work. These methodologies and their results are discussed in the following sections.

3.1 Questionnaire-based survey

The main objective of the questionnaire was to rank the different factors as per the experts opinion for developing a relationship matrix as a first step towards developing an ISM model. The questionnaire had a wide range of research objectives and involved many questions. However, to remain within scope and objectives of this paper, only one question related to factors affecting different type of flexibilities in FMS is used and the results of this has been reported in this paper.

In the questionnaire the respondent were asked to rank the importance of the listed 22 factors on the basis of five-point Likert scale. On this scale, 1 and 5 corresponding to 'very low' to 'very high' respectively. The questionnaire was administered to chief-executives/managing directors/general managers/works managers/senior executives from Indian manufacturing industries. In total, questionnaires were sent to 550 Indian industries. Out of 550 questionnaires, 103 completed questionnaires were received. This gives a response rate of 19.2 %, which is not very low for such surveys (Malhotra and Grover 1998). Out of 22 factors, only 12 factors were selected after discussion with the experts for the development of the ISM model because of the similarities in functionality of some factors. The selected factors with their ranks are presented in the decreasing order in Table 2.

3.2 Evaluation of EI

The factors with their mean score and rank as shown in Table 2 are used for calculating the effectiveness index (EI). Here, some weight is assigned to each factor whose criteria is mentioned in the paper. After this rank, inverse rank and weight for each factor is to be determined. For each of the issues of effectiveness a weight is assigned. The criteria for weight (Wi) is as under:

$$Wi = 1 \, (\text{Strength}), \text{ when percentage score } 60\,\% \, (\text{When Log}k_i \text{ value is greater than } 0.6)$$
$$= 0 \, (\text{Neutral}), \text{ when percentage score is between } 40 \text{ and } 60\,\% \, (\text{When Log}k_i \text{ value between } 0.6 \text{ and } 0.4)$$
$$= -1 \, (\text{Weakness}), \text{ when percentage score } 40\,\% \, (\text{When Log}k_i \text{ value less than } 0.4).$$

This framework was given by Cleveland et al. (1989) is $Cj = \text{Sum} \, [Wi \, \text{Log} \, Ki]$. Chand, Raj and Shankar (2014a, b) and Chand and Singh (2010) have also used this model for study the select issues of SCM.

Sum of entries of last column ($Wi \, \text{Log} \, Ki$), will give effectiveness index (EI) = 7.0569. Theoretically, EI value

Table 2 Rank, mean score and EI of selected factors affecting the flexibility in FMS

S. no	Factors affecting different flexibilities	Mean score	Rank	Inverse rank (Ki)	Log Ki	Weight (Wi)	Wi*LogKi
1	Setup or changeover time	4.35	1	12	1.0791	1	1.0791
2	Tool magazine or tool turret capacity	4.33	2	11	1.0414	1	1.0414
3	Skills & versatility of workers in the system	4.31	3	10	1	1	1
4	Type of machines	4.27	4	9	0.9542	1	0.9542
5	Variety of parts to be handled by the machine	4.2	5	8	0.9031	1	0.9031
6	Space availability	4.2	6	7	0.9031	1	0.9031
7	Tool changing time of the machine	4.17	7	6	0.7781	1	0.7781
8	Design changes required in the product	4.17	8	5	0.6989	1	0.6989
9	Flexibility of material handling system	4.15	9	4	0.6021	0	0
10	Maximum number of routes available	4.12	10	3	0.4771	0	0
11	Type of operations to be done on the machine	4.11	11	2	0.301	−1	−0.301
12	Offline part programming preparation facility	4.11	12	1	0	−1	0

may range between −8.6101 and +8.6101. This EI value, helps the organisations to benchmark its performance with national and international standards. Here the qualitative values of the factors are converted into quantitative values, with the help of these values management can take the decision where there is need for improvement.

3.3 Overview of ISM approach

Interpretive Structural Modeling was first proposed by Warfield (1973) to analyze the complex socioeconomic systems and Malone (1975) was the second one who conducted brief review of the ISM. This method is known as 'interpretive structural modeling' because all the variables and their interrelationships are decided by group judgment. ISM is a well-established methodology for identifying relationships among specific items, which define a problem or an issue (Jharkharia and Shankar 2005). ISM is a powerful technique, which can be applied in various fields (Bolanos et al. 2005; Faisal et al. 2006, 2007; Jharkharia and Shankar 2004; Qureshi et al. 2007; Singh et al. 2003; Thakkar et al. 2007, 2008). The theoretical foundation of W-ISM technique has been developed by Chand, Raj and Shankar (2014a, 2014b) derived from ISM developed by Warfield (1973, 1974). W-ISM is the extended version of ISM. Here to calculate the effectiveness index (EI), some weight is assigned to each factor based on the criteria. Chand et al. (2015) used the weighted-ISM technique for analysing the competitiveness of uncertainty and risk measures in supply chain. Chand et al. (2014a, b) analysed the operational risks in supply chain by using Weighted Interpretive Structural Modeling (W-ISM) technique. Mishra et al. (2012) used the ISM methodology for determining the interrelationship of drivers for agile manufacturing: an Indian experience. Nagar and Raj (2012) for the analysis of critical success factors for

implementation of humanised flexible manufacturing system in industries, Attri et al. (2013a, b) applied the ISM approach for identifying and analysing the mutual interaction of the factors in the implementation of Total Productive Maintenance (TPM), Singh (2011) for developing a framework for the coordination in supply chain of SMEs. Subramanian et al. (2010) for analysing the buyer supplier relationship factors: an integrated modelling approach, Raj et al. (2009) to analyse interaction between barriers of transition to flexible manufacturing system, Raj et al. (2008) for modelling the enablers of flexible manufacturing system: the case for India. Singh and Garg (2007) for improving the SMEs competitiveness, Faisal et al. (2006) for the analysis of risk mitigation in supply chain, Ravi and Shankar (2005) for the analysis of interactions among the barriers of reverse logistics, Singh et al. (2003) used this technique for the implementation of knowledge management in engineering industries.

ISM is an interactive learning process in which a set of different and directly or indirectly related elements affecting the system under consideration is structured into a comprehensive systemic model (Tonn and Peretz 2007). It is a modeling technique, as the specific relationships and overall structure are portrayed in a digraph model. It helps to impose order and direction on the complexity of relationship among various elements of a system (Singh et al. 2003). The various steps involved in the ISM technique are:

Step 1: Factors which are relevant to the problem are identified with the help of survey or group problem solving technique. Establishing a contextual relationship between factors with respect to which pairs of factors would be examined.

Step 2: A structural self-interaction matrix (SSIM) of factors is developed which indicates pair-wise relationship
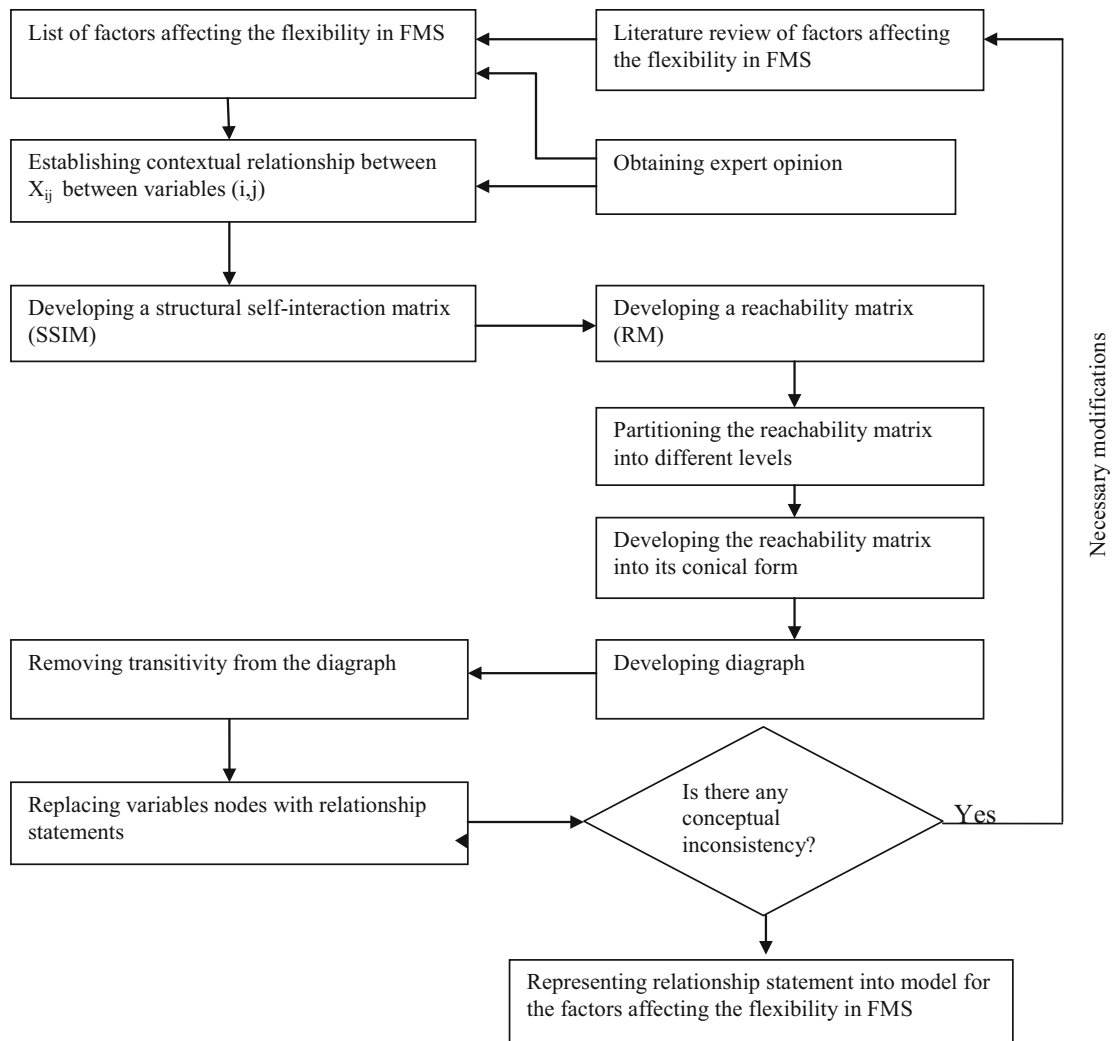
Fig. 1 Flow chart for preparing ISM

among factors of the system. This matrix is checked for transitivity. Transitivity of the contextual relation is a basic assumption in ISM which states that if element A is related to B and B is related to C, then A is related to C.

Step 3: Developing a reachability matrix (RM) from the SSIM.

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

Step 5: Converting the RM into its conical form, i.e., with most zero (0) elements in the upper diagonal half of the matrix and most unitary (1) elements in the lower half.

Step 6: Based on the relationships given above in the reachability matrix, drawing a directed graph (digraph) with the transitive links.

Step 7: The resultant digraph is then converted into an ISM-based model by replacing factors nodes with the statements.

Step 8: Reviewing the model to check for conceptual inconsistency and making the necessary modifications (Fig. 1).

4 ISM approach for modelling the factors of flexibility in FMS

The various steps which leads to the development of model, are illustrated below:

Step 1: Establishing the contextual relationship between factors

For analysing the 12 factors identified through the literature review and expert opinion, a contextual relationship of 'reaches to' type is chosen. This means that one factor reaches to another chosen factor. Based on this, a contextual relationship among the factors is developed. Some

experts, both from industry and academia, have been consulted in developing the contextual relationship among the factors. Keeping in mind the contextual relationship for each factor, the existence of a relation between any two factors (i and j) and the associated direction of this relation has been decided. The following four symbols have been used to denote the direction of the relationship between two factors (i and j):

- V is used for the relation from factor i to factor j (i.e. if factor i influences or reaches to factor j).
- A is used for the relation from factor j to factor i (i.e. if factor j reaches to factor i).
- X is used for both direction relation (i.e. if factors i and j reach to each other).
- O is used for no relation between two factors (i.e. if factors i and j are unrelated).

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

Based on the contextual relationship between factors, the SSIM has been developed. To obtain consensus, the SSIM was discussed in a group of experts. Based on their responses, SSIM has been finalized and it is presented in Table 3. The following statements explain the use of symbols in SSIM:

- Symbol V is assigned to cell (2, 5) because factor 2 influences or reaches to factor 5.
- Symbol A is assigned to cell (1, 4) because factor 4 influences the factor 1.
- Symbol X is assigned to cell (6, 9) because factors 6 and 9 influences each other.
- Symbol O is assigned to cell (7, 12) because factors 7 and 12 are unrelated.

Step 3: Development of the reachability matrix (RM)

The reachability matrix (RM) is obtained from SSIM. There are two type of reachability matrix, initial RM and final RM. The SSIM is converted into a binary matrix, called the initial reachability matrix by substituting V, A, X and O by 1 and 0. The substitution of 1 s and 0 s has been done with the following rules:

- If the cell (i, j) is assigned with symbol V in the SSIM, then this cell (i, j) entry becomes 1 and the cell (j, i) entry becomes 0 in the initial reachability matrix.
- If the cell (i, j) is assigned with symbol A in the SSIM, then this cell (i, j) entry becomes 0 and the cell (j, i) entry becomes 1 in the initial reachability matrix.
- If the cell (i, j) is assigned with symbol X in the SSIM, then this cell (i, j) entry becomes 1 and the cell (j, i) entry also becomes 1 in the initial reachability matrix.
- If the cell (i, j) is assigned with symbol O in the SSIM, then this cell (i, j) entry becomes 0 and the cell (j, i) entry also becomes 0 in the initial reachability matrix.

For developing final reachability matrix, the concept of transitivity is incorporated so that some of the cells of the initial reachability matrix are filled by inference. The transitivity concept is used to fill the gap, if any, in the opinions collected during the development of SSIM. The final reachability matrix after incorporating the concept of transitivity is presented in Table 5 (Table 4).

Step 4: Partitioning the reachability matrix (RM)

From the final reachability matrix, the reachability and antecedent set for each factor are found (Warfield 1974; Farris and Sage 1975). The reachability set consists of the factor (i) itself and the other elements which it may help achieve, whereas the antecedent set consists of the factor (i) itself and the other elements which may help in

Table 3 Structural self—interactive matrix (SSIM)

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

Table 4 Initial reachability matrix

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

Table 5 Final reachability matrix

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

1* entries are included to incorporate transitivity

achieving it. After finding the reachability set and antecedent set for each variable, the intersection for these sets is derived for the factors and levels of different factors are

determined. The factors for which the reachability set and antecedent set having same value is places at the top level in ISM hierarchy. Once the top level factor is identified, it is removed from consideration and the other top level factors of the remaining subgraph are found. This procedure is continued till all levels of the structure are identified. These identified levels help in the development of the diagraph and the final model. Top level factor is positioned at the top of digraph and so on. In the present case, the 12 factors, along with their reachability set, antecedent set, intersection set and levels are presented in Tables 6, 7, 8, 9, 10, and 11. Level identification process of these factors is completed in six iterations as shown in Tables 6, 7, 8, 9, 10, and 11.

Step 5: Development of conical matrix

In this step, a conical matrix is developed by clubbing together factors in the same level, across rows and columns of the final reachability matrix. The driver power and dependence power of a factor is derived by summing up the number of ones in the rows and columns respectively. Drive power and dependence power ranks are calculated by

Table 6 Iteration 1

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

Table 7 Iteration 2

Factors	Reachability set	Antecedent set	Intersection set	Level
2	2,5,7,11	2,4,	2	
3	3,4,5,6,7,8,9,10,11,12	3,4	3,4	
4	2,3,4,5,6,7,8,9,10,11,12	3,4,10	3,4,10	
5	5,7,11	2,3,4,5,8,10	5	
6	6,9,11,12	3,4,6,8,9,10,	6,9	
7	7,11	2,3,4,5,7,8,9,10,11	7,11	II
8	5,6,7,8,9,11	3,4,8,10	8	
9	6,7,9,11,12	3,4,6,8,9,10,	6,9	
10	4,5,6,7,8,9,10,11,12	3,4,10	4,10	
11	7,11	2,3,4,5,6,7,8,9,10,11	7,11	II
12	11,12	3,4,6,9,10,12	12	

Table 8 Iteration 3

Factors	Reachability set	Antecedent set	Intersection set	Level
2	2,5	2,4	2	
3	3,4,5,6,8,9,10,12	3,4	3,4	
4	2,3,4,5,6,8,9,10,12	3,4,10	3,4,10	
5	5	2,3,4,5,8,10	5	III
6	6,9,12	3,4,6,8,9,10	6,9	
8	5,6,8,9	3,4,8,10	8	
9	6,9,12	3,4,6,8,9,10	6,9	
10	4,5,6,8,9,10,12	3,4,10	4,10	
12	12	3,4,6,9,10,12	12	III

Table 9 Iteration 4

Factors	Reachability set	Antecedent set	Intersection set	Level
2	2	2,4	2	IV
3	3,4,6,8,9,10	3,4	3,4	
4	2,3,4,6,8,9,10	3,4,10	3,4,10	
6	6,9	3,4,6,8,9,10	6,9	IV
8	6,8,9	3,4,8,10	8	
9	6,9	3,4,6,8,9,10	6,9	IV
10	4,6,8,9,10	3,4,10	4,10	

Table 10 Iteration 5

Factors	Reachability set	Antecedent set	Intersection set	Level
3	3,4,8,10	3,4	3,4	
4	3,4,8,10	3,4,10	3,4,10	
8	8	3,4,8,10	8	V
10	4,8,10	3,4,10	4,10	

Table 11 Iteration 6

Factors	Reachability set	Antecedent set	Intersection set	Level
3	3,4,10	3,4	3,4	
4	3,4,10	3,4,10	3,4,10	VI
10	4,10	3,4,10	4,10	VI

giving highest ranks to the factors that have the maximum number of ones in the rows and columns respectively.
Step 6: Development of diagraph

Based on the conical matrix, an initial diagraph including transitivity links is obtained. This is generated by nodes and lines of edges. After removing the indirect links, a final diagraph is developed (Fig. 2). In this development, the top level factor is positioned at the top of the diagraph and second level factor is placed at second position and so on, until the bottom level is placed at the lowest position in the diagraph.
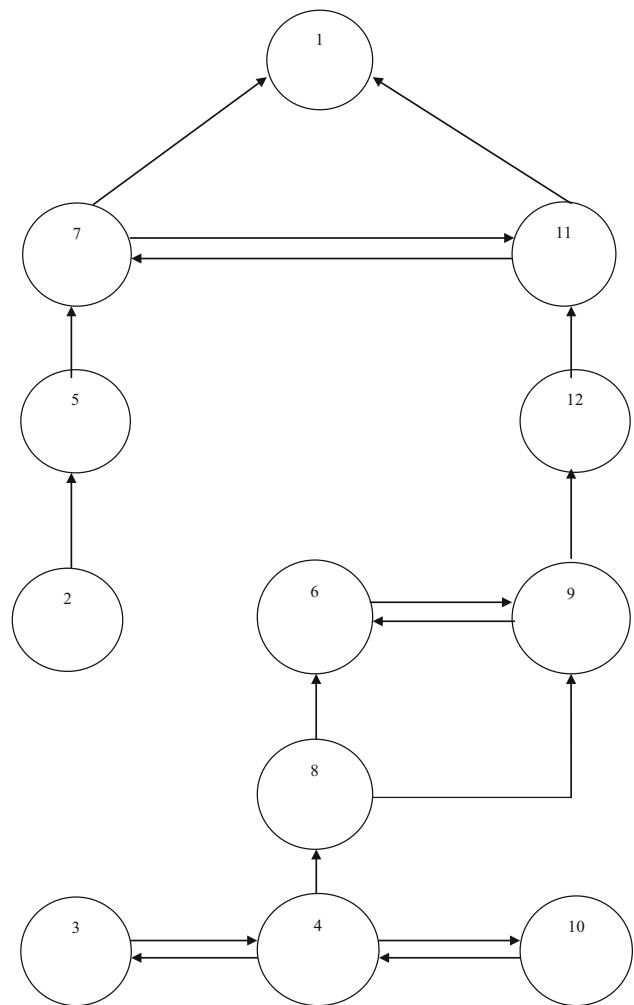

Fig. 2 Diagraph showing the levels of FMS factors

Step 7: Development of ISM model

Next, the diagraph is converted into an ISM model by replacing nodes of the elements with statements as shown in Fig. 3.

Step 8: Check for conceptual inconsistency

Conceptual inconsistency is checked by identifying and removing the intransitivity in the model.

Fig. 3 Interpretive structural model showing the levels of FMS factors
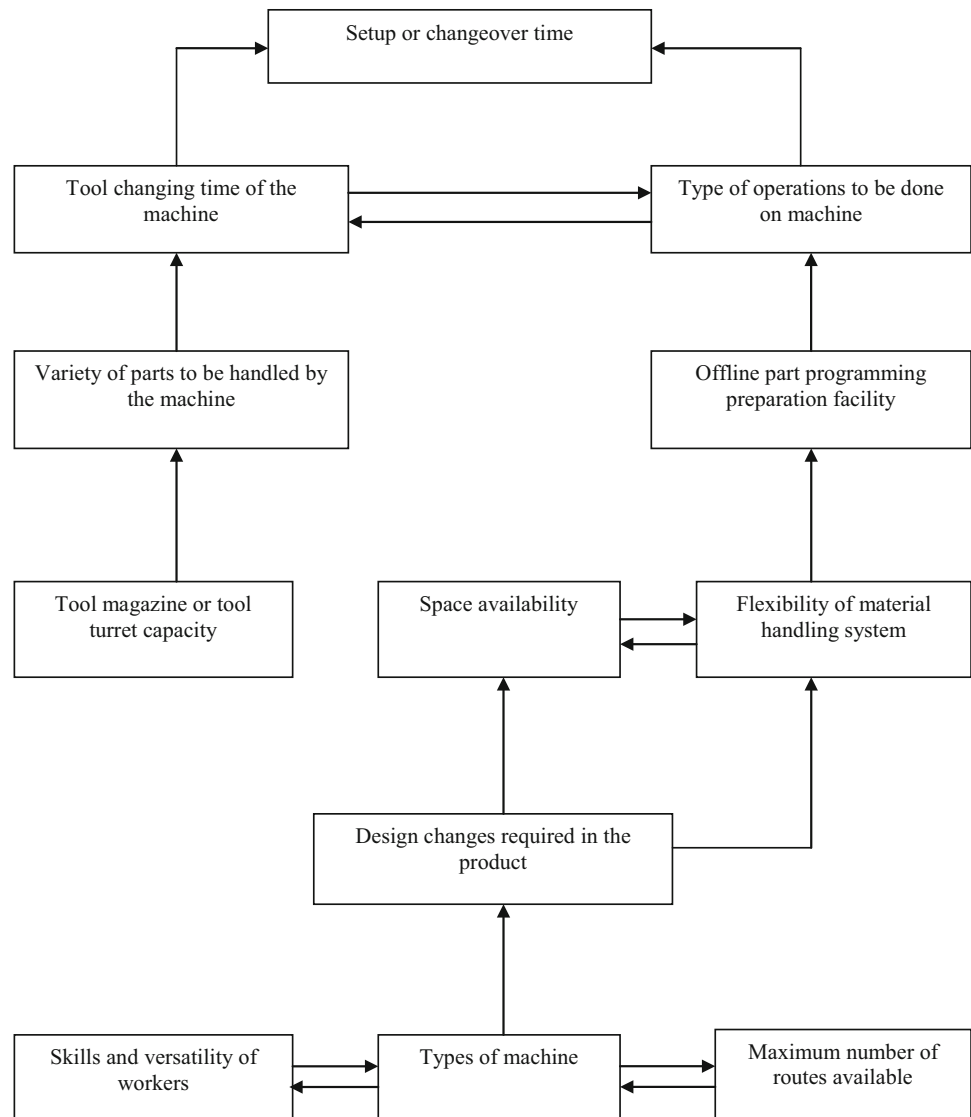
5 MICMAC analysis

After the final ISM model MICMAC analysis of the factors is done on the basis of their driving and dependence power. This principle is based on multiplication properties of matrices (Sharma et al. 1995). MICMAC was first proposed by Duperrin and Godet (1973). Singh and Kant (2008) proposed a classification of elements based on their driving and dependence power. Hence, all factors affecting the flexibility were classified based on their driving and dependence power. Using this classification, provided four categories included autonomous factor, linkage factor, dependent factor and independent factor. For partitioning the graph, similar approach was utilized by a number of authors in their research work (Raj et al. (2012); Verma (2014); Kumar and Sharma (2015); Attri (2013b); Jain and Raj (2015). On the basis 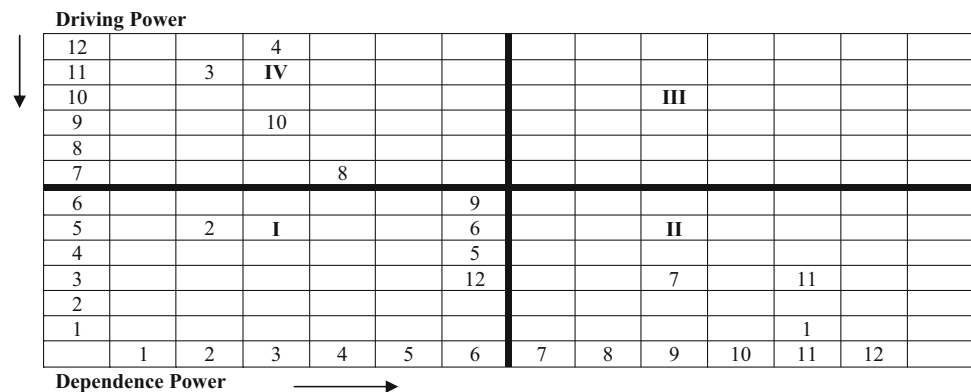of these dependence and driving power MICMAC analysis is done. The prime function of MICMAC analysis is to examine the driving and dependence power of the factors. Based on their drive power and dependence power the factors, in the present case, have been classified into four categories as follows:

1. Autonomous factors: Driving factors are those factors which influence the other factors and the dependent factors are those which are influenced by others. The autonomous factors in this study indicate that the considered factor has not much influence on the flexibility affecting the FMS because these factors have weak drive power and weak dependence power. They are relatively disconnected from the system, with which they have few links, which may be very strong, so management should pay attention to all other factors.

Table 12 Conical matrix

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

Table 13 Clusters of factors affecting the flexibilities in FMS

Driving Power

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

Dependence Power ⟶

2. Linkage factors: These have strong drive as well as strong dependence. They are also unstable. Any action on them will have an effect on others and also a feedback effect on themselves.

3. Dependent factors: This category includes those factors which have weak drive power but strong dependence power.

4. Independent factors: These have strong drive power but weak dependence power. It is generally observed that a factor with very strong drive power, called the 'key factor' falls into the category of independent or linkage.

The drive power and dependence power of factors is shown in Table 12. Thereafter, the drive power and dependence power matrix is drawn as shown in Table 13. As an illustration, it is observed from Table 12 that factor 10 has drive power of 9 and dependence power of 3, hence in Table 13, it is positioned at a place which corresponds to drive power of 9 and dependence power of 3, i.e. in the fourth cluster. Now its position in the fourth cluster shows that it is a independent factor. Similarly, all the factors are positioned at place corresponding to their driving power and dependence power.

6 Result and discussion

The main objective of this research is to identify the factors, which significantly inhibit the flexibility of FMS in manufacturing industries so that the management can effectively deal with these factors. In this research, the survey has been used to rank the importance of the factors through the perception of the respondents and ISM approach has been used. An ISM based model has been developed to analyse the interrelationship among these variables. This provides the hierarchy of actions which has to be performed by the management in order to handle the different factors which affect the flexibility of FMS. The manufacturing managers can get an insight of these factors to understand their relative importance and interdependencies. The drive power-dependent power matrix (Table 13) gives some valuable sights about the relative importance and inter-dependence among the FMS factors. The important managerial implications emerging from this study are as follows:

- Table 13 shows that there are five autonomous factor, i.e. 'tool magazine or tool turret capacity' (factor 2),

'variety of parts to be handled by the machine' (factor 5), 'space availability' (factor 6), 'flexibility of material handling system' (factor 9) and 'offline part programming preparation facility' (factor 12) affect the flexibility of FMS. Autonomous factors are weak drivers and weak dependents and do not have much influence on the system. The autonomous factors in this study indicate that the considered factor has not much influence on the flexibility affecting the FMS management should pay attention to all other factors.

- Dependent factors are 'setup or changeover time' (factor 1), 'tool changing time of the machine' (factor 7) and 'type of operation to be done on machine' (factor 11). These factors are weak drivers but strongly depend on one another. So, the managers should take special care to handle these factors.
- There is no factor in the third cluster, i.e. linkage factor. This shows that all the factors stated above are stable.
- Factors 'skills and versatility of workers' (factor 3), 'type of machine' (factor 4), 'design changes required in the product' (factor 8) and 'maximum number of routes available' (factor 10) are independent factors, i.e. they have strong driving power and weak dependency on other factors. They may be treated as the 'key factors' for affecting the flexibility of FMS.

Based on response from questionnaire survey on various factors, EI for the factors affecting flexibility in FMS has been evaluated as shown in Table 2. Here the qualitative values of the factors are converted into quantitative values, with the help of these values management can take the decision where there is need for improvement. From the Table 2, it has been observed that organisations are doing quite well in terms of setup time, tool magazine, skills and versatility of workers, types of machine, variety of parts to be handled by machine, space availability, tool changing time and design changes in product, however there is need for improvement in area of flexibility of material handling system, number of routes available, types of operations to be done on machine and offline part programming preparation facility related problems for dealing well with the flexibility affecting factors considered in this research work. Maximum value of EI can reach up to 8.6101, in present case EI has been found to be 7.0569 and this value of EI is quite high. The effectiveness index evaluated can be utilized by the industries to benchmark their performance by focusing on the factors. With the help of EI and MICMAC analysis, some valuable insights about the relative importance, interdependencies of the measures and the need of improvement could be known, so that management could take the action accordingly.

7 Conclusion

The major objective of this study is to identify the factors that significantly affect the flexibility of FMS so that management may effectively deal with such type of factors. In this research, an ISM- based model has been used to show an interpretation of flexibility factors in terms of their driving and dependence power. Those factors having higher driving power in the ISM model need to be taken care on a priority basis because there are few other dependent factors being affected by them. The ISM results provide strategic insight also. This study has strong implications for researchers as well as manufacturing managers. The researchers may be prompted to identify some other issues, which may be significant in addressing these factors. The manufacturing managers can get an insight of these factors and understand their relative importance and interdependencies and try to overcome these factors which affect the flexibility of FMS. The autonomous factor i.e., 'tool magazine or tool turret capacity', 'variety of parts to be handled by the machine', 'space availability', 'flexibility of material handling system' and 'offline part programming preparation facility' don't have much influence on the flexibility affecting the FMS, so management should pay attention to all other factors. Dependent factors i.e., 'setup or changeover time', 'tool changing time of the machine' and 'type of operation to be done on machine' strongly depend on one another. So, the managers should take special care to handle these factors. There is no factor in the third cluster, i.e. linkage factor. This shows that all the factors stated above are stable. Independent factors 'skills and versatility of workers', 'type of machine', 'design changes required in the product' and 'maximum number of routes available' have strong driving power and weak dependency on other factors. They may be treated as the 'key factors' for affecting the flexibility of FMS. Therefore, ISM methodology strengthens the practical views of manufacturing managers and depicts a clear picture about the significance of different factors. In this way, different factors can be identified and dealt with utmost care.

Finally, it would be useful to suggest the direction of future research in this area. In this research, the relationship model among the identified flexibility factors has not been statistically validated. Structural equation modelling (SEM), also referred to as linear structural relationship approach, has the capability of testing the validity of such hypothetical models. Thus, this approach can be applied in the future research to test the validity of this model. ISM is a tool which can be helpful to develop an initial model whereas SEM has the capability of statistically testing an already developed

theoretical mode. Hence, it has been suggested that future research may be targeted to develop the initial model through ISM and then testing it using SEM.

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