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LOADING ISSUES IN FMS-INTERPRETIVE STRUCTURAL MODELING

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Abstract

With the rising competition in market today, manufacturers need to alter their processes to deliver faster and to ensure improved response to customer needs. When a computer-controlled system is incorporated in a manufacturing system to add some levels of flexibility, the obtained system is called as Flexible Manufacturing System (FMS). Huge potential is there in FMS and thus, complex problems are also associated with the system. Main production related problems are part selection type i.e., grouping of machines, productivity ratio, allocation of resources and loading issues. Solving these problems to get optimum results is to be done to get the better output, machine and manpower efficiency. The present study identifies the loading issues related to FMS and model their interrelationships using Interpretive Structural Modeling (ISM).

I. Introduction

A FMS (Flexible Manufacturing System) is a great way to achieve higher productivity and flexibility, as it uses integrated computers and gives flexibility to the processes. Three key components of FMS are work stations, material handling system and central computer. Automatic material handling systems are used to link various numerical controlled machines which in turn are controlled via a central computer. Although FMS provides high flexibility and enhances productivity but its design and planning are more complex for the practicing engineers as compared to traditional

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manufacturing processes. Various issues are encountered in management of FMS which are broadly classified as design issue, planning issues and operational issues. One of the major problems is loading and scheduling which falls under operational issues (Dixit and Ojha, [15]). The loading and scheduling in FMS differ from conventional manufacturing system. Assignment of tasks to different machine tools is called as loading (R. Singh et al., [12]). Kumar et al. [6] proposed a new methodology to handle complex FMS-loading problem which defines machine loading problem as a set of tools which is needed to make parts by using resources such are pallets, jigs, fixtures, material handling systems and finds out how the parts are assigned to machines to attain optimum productivity. This research is focused on loading issues in FMS and key objectives are:

- to identify various loading issues in FMS
- to establish relation among these issues
- to understand how these issues impact each other
- to discuss the implications and future scope of research

II. Identification of Key Issues

Comprehensive literature review was done along with discussion with many manufacturers and engineering practitioners, it is concluded that loading problems in FMS are much more complex and depends on a large number of factors. Loading includes deciding allocation of task to various machine tools for machining (Sahu and Tamralkar, [5]).

The workload is to be distributed to the existing manufacturing facility, keeping in mind the constraints in order to perform production processes as per plan. Work has to be divided in such a manner that capacity of man and machine is not exceeded. One solution to this problem can be to determine the route through which the part has to go on machines and also the tools which are to be loaded in tool magazines before the start of operations. This will help in minimizing the system unbalance and maximize throughput, minimize working time, number of tools needed and tool movement which will further reduce the manufacturing cost. A number of products needing different sets of operations are simultaneously produced in FMS. Loading problem is defined as combination of all of them, this being a complex task, requires experienced planners (Kathryn E. Stecke, [17]).

Setting a part or raw material on machine or a fixture plays a key role in identifying the loading problems. Part requiring more than one fixture for machining will affect other parts for which same fixtures are required. Moreover, the cycle time of a fixture in which it is available for reuse plays important role in on time loading. To get the optimal solution, computational methods with optimization techniques are required to be used (K. E. Stecke, [17]).

Tools have a vital role in running of a smooth production line. To efficiently plan and control the production, real-time monitoring of the production system is to be done and for that tools have very high importance. Non-availability of tools can certainly affect the production (Tani, [4]).

III. Methodology

Methodology used in this research involves a literature survey along with opinions from experts from industries and ISM approach to get the desired results. In section A, previous work of authors was studied to identify the issues in FMS loading. In section B, ISM-based model is explained along with steps involved in the modeling.

A. Literature Survey.

Literature survey was done to consider all the past developments in the field of loading issues. Some objectives for machine loading problems which are found by various researchers and compiled by Kumar et al., [1] are:

To maximize: Number of alternative routes, load difference among the machines, total profit To minimize: Flow time and work-in-progress; inventory cost; load of re-fixturing stations; load of tool transport system; load of work piece transport system; make-span; manufacturing cost; number of tool magazine configuration changes, system unbalance, tardy jobs.

Abazari et al. [2] said that machine loading problems are mainly related to assignment of tasks to machines within technical constraints to get desired performance. These constraints can range from algebraic to very complex situations like requirement of tools, tool magazine capacity, system unbalance cost and capacity of machine. FMS is concerned with time required and cost of a job to be done on a machine, stated by Ranbir Singh et al. [10]. FMS being a group technology, all the jobs in a group need to be finished at same time to reduce any overutilization or underutilization of machines.

Major issues pertaining to FMS planning are decision of part families, selection of machine tools and jobs to be done, physical configuration of parts, flexibilities needed (number and types) and output volume (Dixit and Ojha, [15]). Apart from this, 6 major design issues are found workstation types, variations in routing the process and layout of FMS, design of material handling system, buffer capacity and work in progress, tools type and numbers, types of fixtures and pallets (Kumar et al., [1]). Additionally, Operational issues majorly consist of machine loading, dispatching and scheduling, routing and grouping of parts, managing tools, allocating pallets and fixtures (Dixit and Ojha, [15]). Various articles and research papers were studied and referred to understand the effect of various Issues and their relationship and dependence with each other. Identified Issues and their sources are listed in table I.

Table I. References for loading issues in FMS.

S. No.	Loading Issues in FMS	References /Source
1	Fixture cycle time	Antonio Grieco et al. [3] Rahul Tamralkar et al.
2	Tool availability at start of part program	Expert opinion
3	Tool life issues	Antonio Grieco et al. [3], Rishu Sharma et al. [13], Tani [4]
4	Number of tool copies	Rishu Sharma et al. [13], expert opinion
5	Tool magazine capacity	Antonio Grieco et al. [3], Abazari et al. [2], Groover (2003), Sandhya Dixit et al. [14]
6	Tool transport system	Ranbir Singh et al. [11], Antonio Grieco et al. [3]
7	Part loading on fixture	Antonio Grieco et al. [3], Sarin et al. [16]
8	Characteristics of shifts	Antonio Grieco et al. [3], N. S. Mohamed et al. [7]
9	Tool room management	Antonio Grieco et al. [3], Expert opinion

10	Preventive maintenance schedule	Rahul tamralkar et al. [8], Antonio Grieco et al. [3]
11	Downstream assembly operations	Antonio Grieco et al. [3], Kumar et al. [6]
12	Cost of tool selection	Expert Opinion
13	Underutilization cost of machine	Abazari et al. [2], Antonio Grieco et al. [3]
14	Multi fixtured parts	Antonio Grieco et al. [3]
15	Configuration of machines	Expert opinion, Abazari et al. [2]

B. An Overview of ISM Approach

The main cause behind the difficulties faced while dealing with complex system is existence of enormous no. of factors and connections among them. The direct and indirect relations of these factors lead to ill-defined structure. ISM (Interpretive Structural Modeling) is a method to convert the imprecise, inexpressive rational model to a structured and neatly-defined model. Various factors which are directly or indirectly related, are taken and then a well-structured and detailed model is prepared by using ISM. The resulted model depicts a well-designed and organized model of the previously complex problem with use of pictures and words (Singh et al., 2003; Ravi et al., 2005; Dixit et al. [14]). Important Characteristics are:

1. The relation between the elements is determined by a group's judgment, which makes this method interpretive.

2. The overall structure being developed is drawn from the complex set of elements and the mutual relationship among them, this makes the approach structural.

3. A digraph model is constructed using the obtained relationships of elements, hence, it's a modeling technique.

4. Order and direction is provided to the otherwise complex relationships among elements of system by this method (Sage, 1977).

Apart from this, there are two essential concepts of ISM, first is concept of transitivity and second is reachability. For example, if S relates to N and N related to A then transitivity implies that S relates to A.

Key concept of ISM technique is reachability concept. Elements are taken

2 at a time and then compared for their interconnections. Further, this is data is represented in a matrix using '0' and '1' (binary). Consider 2 elements viz. i and j. Now, '0' or '1' will be written in the cell (i, j) depending upon i reaches j or not respectively i.e., '1' if reaches and '0' if not. Thereafter, transitivity property is then used to fill few more cells in reachability matrix using inference (Watson, 1978). If cell $(i, j) = 1$ and $(i, k) = 1$ then it can be concluded that $(i, k) = 1$. Thus, it's not required to compare i and k as transitivity can give the result for this comparison. (Attri et al., [9], Singh et al., 2015).

IV. ISM Approach for Modeling of Loading Issues

Following steps are involved for developing the model:

A. Step 1. Relation among the Issues

With the literature review, 15 key issues were successfully identified. In first step, a conceptual relationship is established among them. Type of relationship used here is "reaches to" type i.e., one element reaches to other. Notations used are V if i reaches to j, A if j reaches to i, X if both reach each other and O if none reach other.

B. Step 2. Construction SSIM (Structural Self-Interaction Matrix)

Once the relationship is defined among the issues, these relationships are taken 2 at a time and their dependencies are depicted in SSIM. Are then used to develop SSIM (Table II).

Table II. Structure Self-Interaction Matrix (SSIM).

Issues	A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1
A1	V	A	A	O	O	O	O	O	A	O	O	O	O	V	X
A2	V	O	A	V	A	O	V	O	O	V	O	V	V	X	
A3	O	O	A	O	A	O	A	O	O	A	O	A	X		
A4	V	O	X	V	O	O	V	O	O	O	O	X			
A5	O	O	O	O	A	O	O	O	O	V	X				
A6	X	O	A	O	A	O	A	O	O	X					
A7	O	X	A	O	A	O	O	V	X						
A8	O	O	A	O	A	O	A	X							
A9	O	O	A	O	O	O	X								
A10	O	O	A	O	O	X									
A11	V	O	O	O	X										
A12	O	O	O	X											
A13	V	V	X												
A14	O	X													
A15	X														

C. Step 3. RM (Reachability Matrix) formation

Structured Self-Interaction Matrix formed in step 2 is used to construct reachability matrix. This process is done in 2 sub-steps. First is SSIM is converted into initial RM (Table IV) by replacing each cell by 0 and 1 using the mentioned directives:

Table III. Filling initial RM.

(i, j) in SSIM	(i, j) in initial RM	(i, j) in initial RM
V	0	1
A	1	0
X	1	1
O	0	0

Table IV. Initial Reachability Matrix.

Issues	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
A1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
A2	0	1	1	1	0	1	0	0	1	0	0	1	0	0	1
A3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
A4	0	0	1	1	0	0	0	0	1	0	0	1	1	0	1
A5	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
A6	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1
A7	1	0	0	0	0	0	1	1	0	0	0	0	0	1	0
A8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
A9	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0
A10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
A11	0	1	1	0	1	1	1	1	0	0	1	0	0	0	1
A12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
A13	1	1	1	1	0	1	1	1	1	1	0	0	1	1	1
A14	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0
A15	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1

In second sub-step, transitivity concept is used for fill few cells of initial RM to get final RM (Table V).

Table V. Final RM.

Issues	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
A1	1	1	1*	1*	0	1*	0	0	1*	0	0	1*	0	0	1
A2	0	1	1	1	0	1	1*	1*	1	1*	0	1	1*	0	1
A3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
A4	1*	1*	1	1	0	1*	1*	1*	1	1*	0	1	1	1*	1
A5	0	0	1*	0	1	1	0	0	0	0	0	0	0	0	1*
A6	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1
A7	1	1*	0	0	0	0	1	1	0	0	0	0	0	1	1*
A8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
A9	0	0	1	0	0	1	0	1	1	0	0	0	0	0	1*
A10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
A11	1*	1	1	1*	1	1	1	1	1*	0	1	1*	0	1*	1
A12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
A13	1	1	1	1	0	1	1	1	1	1	0	1*	1	1	1
A14	1	1*	0	0	0	0	1	1*	0	0	0	0	0	1	1*
A15	0	0	1*	0	0	1	0	0	0	0	0	0	0	0	1

Note. 1* shows the entries due to transitivity.

D. Step 4. Dividing the reachability matrix

Once we obtain the reachability matrix, this is used to make digraph model. Warfield (1974) introduced a series of partitions induced by RM on different sets of elements. On the ideas of Warfield (1974), Farris and Sage (1975), Final RM matrix is used to derive reachability set and antecedent set. An issue (i) and other issues which could be reached from *i* are listed in reachability set i.e., all columns that contains 1 in the row of *i*. For antecedent set, issue *i* and all issues which reaches i are listed i.e., all rows that contains 1 in the column of *i*. After making reachability set and antecedent set, intersection of these two is found and hence levels are determined.

Table VI. Iteration 1.

Issues	Reachability	Antecedents	Intersection	Level
A1	A1, A2, A3, A4, A6, A9, A12, A15	A1, A4, A7, A11, A13, A14	A1, A4	
A2	A2, A3, A4, A6, A7, A8, A9, A10, A12, A13, A15	A1, A2, A4, A7, A11, A13, A14	A2, A4, A7, A13	
A3	A3	A1, A2, A3, A4, A5, A6, A9, A 11, A13, A15	A3	1
A4	A1, A2, A3, A4, A6, A7, A8, A9, A10, A12, 13, A14, A15	A1, A2, A4, A11, A13	A1, A2, A4, A13	
A5	A3, A5, A6, A15	A5, A11	A5	
A6	A3, A6, A15	A1, A2, A4, A5, A6, A9, A11, A13, A15	A6, A15	
A7	A1, A2, A7, A8, A14, A15	A2, A4, A7, A11, A11, A13, A14	A2, A7, A14	
A8	A8	A2, A4, A7, A8, A9, A11, A13, A14	A8	1
A9	A3, A6, A8, A9, A15	A1, A2, A4, A9, A11, A13,	A9	
A10	A10	A2, A4, A10, A13	A10	1
A11	A1, A2, A3, A4, A5, A6, A7, A8, A9, A11, A12, A14, A15	A11	A11	
A12	A12	A1, A2, A4, A11, A12, A13	A12	1
A13	A1, A2, A3, A4, A6, A7, A8, A9, A12, A13, A14, A15	A2, A4, A13	A2, A4, A13	
A14	A1, A2, A7, A8, A14, A15	A4, A7, A11, A13, A14	A7, A14	
A15	A3, A6, A15	A1, A2, A4, A5, A6, A7, A9, A11, A13, A14, A15	A6, A15	

Table VII. Iteration 2.

Issues	Reachability	Antecedents	Intersection	Level
A1	A1, A2, A4, A6, A9, A15	A1, A4, A7, A11, A14	A1, A4,	
A2	A2, A4, A6, A7, A9, A13, A15	A1, A2, A4, A7, A11, A13, A14	A2, A4, A7, A13	
A4	A1, A2, A4, A6, A7, A9, A13, A14, A15	A1, A2, A4, A11, A13	A1, A2, A4, A11, A13	
A5	A5, A6, A15	A5, A11	A5	
A6	A6, A15	A1, A2, A4, A5, A6, A9, A11, A13, A15	A6, A15	2
A7	A1, A2, A7, A14, A15	A2, A4, A7, A11, A13, A14	A2, A4, A7, A11, A13, A14	
A9	A6, A9, A15	A1, A2, A4, A9, A11, A13	A9	
A11	A1, A2, A4, A5, A6, A7, A9, A11, A14, A15	A11	A11	
A13	A1, A2, A4, A6, A7, A9, A13, A14, A15	A2, A4, A13	A2, A4, A13	
A14	A1, A2, A7, A14, A15	A4, A7, A11, A13, A14	A4, A13 A14	
A15	A6, A15	A1, A2, A4, A5, A6, A7, A9, A11, A13, A14, A15	A6, A15	2

Table VIII. Iteration 3.

Issues	Reachability	Antecedents	Intersection	Level
A1	A1, A2, A4, A9	A1, A4, A7, A11, A14	A1, A4	
A2	A2, A4, A7, A9, A13	A1, A2, A4, A7, A11, A13, A14	A2, A4, A7, A13	
A4	A1, A2, A4, A7, A9, A13, A14	A1, A2, A4, A7, A11, A13, A14	A1, A4, A7, A13	
A5	A5	A5, A11	A5	3
A7	A1, A2, A7, A14	A2, A4, A7, A11, A13, A14	A2, A7, A14	
A9	A9	A1, A2, A4, A9, A11, A13	A9	3
A11	A1, A2, A4, A5, A7, A9, A11, A14	A11	A11	
A13	A1, A2, A4, A7, A9, A13, A14	A2, A4, A13	A2, A4, A13	
A14	A1, A2, A7, A14	A4, A7, A11, A13, A14	A7, A14	

Table IX. Iteration 4.

Issues	Reachability	Antecedents	Intersection	Level
A1	A1, A2, A4, A13	A1, A4, A7, A11, A14	A1, A4	
A2	A2, A4, A7, A13	A1, A2, A4, A7, A11, A13, A14	A2, A4, A7, A13	4
A4	A1, A2, A4, A7, A13, A14	A1, A2, A4, A11, A13	A1, A2, A4, A13	
A7	A1, A2, A7, A14	A2, A4, A7, A11, A13, A14	A2, A7, A14	
A11	A1, A2, A4, A7, A11, A14	A11	A11	
A13	A1, A2, A4, A7, A13, A14	A2, A4, A13	A2, A4, A13	
A14	A1, A2, A7, A14	A4, A7, A11, A13, A14	A7, A14	

Table X. Iteration 5.

Issues	Reachability	Antecedents	Intersection	Level
A1	A1, A4	A1, A4, A7, A11, A14	A1, A4	5
A4	A1, A4, A7, A13, A14	A1, A4, A11, A13	A1, A4, A13	
A7	A1, A7, A14	A4, A7, A11, A13, A14	A7, A14	
A11	A1, A4, A7, A11, A14	A11	A11	
A13	A1, A4, A7, A13, A14	A4, A13	A4, A13	
A14	A1, A7, A14	A4, A7, A11, A13, A14	A7, A14	

Table XI. Iteration 6.

Issues	Reachability	Antecedents	Intersection	Level
A4	A4, A7, A13, A14	A4, A11, A13	A4, A13	
A7	A7, A14	A4, A7, A11, A13, A14	A7, A14	6
A11	A4, A7, A11, A14	A11	A11	
A13	A4, A7, A13, A14	A4, A13	A4, A13	
A14	A7, A14	A4, A7, A11, A13, A14	A7, A14	

Table XII. Iteration.

Issues	Reachability	Antecedents	Intersection	Level
A4	A4, A13, A14	A4, A11, A13	A4, A13	
A11	A4, A11, A14	A11	A11	
A13	A4, A13, A14	A4, A13	A4, A13	
A14	A14	A4, A11, A13, A14	A14	7

Table XIII. Iteration 8.

Issues	Reachability	Antecedents	Intersection	Level
A4	A4, A13	A4, A11, A13	A4, A13	8
A11	A4, A11	A11	A11	
A13	A4, A13	A4, A13	A4, A13	8

Table XIV. Iteration 9.

Issues	Reachability	Antecedents	Intersection	Level
A11	A4, A11	A11	A11	9

E. Step 5. Conical Matrix

Final RM is referred to make the conical matrix. This is done by writing the same level issues (from RM) as illustrated in Table XV. Sum of 1s in rows is drive power and 1s in columns is dependence power. Ranks are calculated as the sum of 1s in rows and columns for an issue.

Table XV. Conical Matrix.

Issues	A3	A8	A10	A12	A6	A15	A5	A9	A2	A1	A7	A14	A4	A13	A11	Drive Power
A3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
A8	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
A10	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
A12	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
A6	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	3
A15	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	3
A5	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	4
A9	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	5
A2	1	1	1	1	1	1	0	1	0	0	1	0	1	1	0	11
A1	1	0	0	1	1	1	0	1	1	1	0	0	1	0	0	8
A7	0	1	0	0	0	1	0	1	1	1	1	1	0	0	0	6
A14	0	1	0	0	0	1	0	0	1	1	1	1	0	0	0	6
A4	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	13
A13	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	13
A11	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	13
Dependence Power	10	8	4	6	9	11	2	6	6	6	6	5	5	3	1	89

F. Step 6. Development of Digraph and ISM model

In next step, a digraph is generated on the basis of conical matrix including the transitivity links. Nodes and lines are used to make this digraph. Indirect links are then removed to get the final digraph. Highest level Issue is at top followed lower levels. This digraph is later converted to ISM model after replacing nodes with statements.

G. Step 7. Conceptual inconsistency check

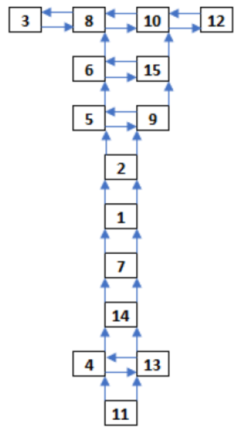

Figure 1. Digraph.

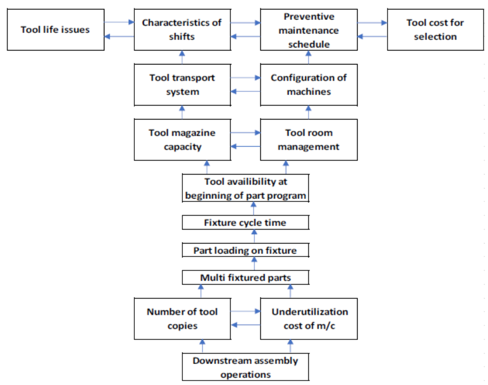

Figure 2. ISM with levels of Issues.

V. Discussion and Conclusion

Flexibility of a traditional manufacturing system can be improved by introducing FMS. This research work targets towards a major concern with FMS planning named as loading issues, these are the problems which are related to allocation of various tasks to different workstations and making plan to get the work done within least time to increase productivity. Key Issues are identified on the basis of literature survey and discussion with experienced manufacturing experts. ISM based methodology is followed to identify the relationship and dependence between these Issues and further these Issues were divided into levels depending upon their dependency as well as influence on other Issues. To get the optimum solution for these loading problems these Issues are to be considered and worked upon so that all other depending Issues can be manipulated to get the desired results.

After the ISM modeling and development of conical matrix, we need to focus mainly on those issues which have high Drive power. Following were the results from the model:

- There are few issues which have low drive as well as dependence power which are 'Tool magazine capacity' (A5), 'Part loading on fixture' (A7), 'Tool room management' (A9), 'Preventive Maintenance Schedule' (A10), 'Tool cost for selection' (A12), 'Multi fixtured parts' (A14). These issues do not have much impact on the loading problem and don't require much attention from management.

- Dependent factors are 'Tool life issues' (A3), 'Tool transport system' (A6), 'Characteristics of shifts' (A8), 'Configuration of machines' (A15) which have high dependence power but a low drive power.

- 'Tool availability at the beginning of part program' (A2) is one such factor which has high drive power as well as high dependence power.

- Issues 'Fixture cycle time' (A1), 'Number of tool copies' (A4), 'Downstream assembly operations' (A11), 'Underutilization cost of machines' (A13) have strong drive power and low dependence power. These are independent of others and may be called as root cause for other factors and can be treated as "Key issues" in loading problem.

The issues found in the research could be helpful for manufacturers to tackle the loading problems in FMS. This model is based on literature survey and guidance from industrialists and experts and is not statistically validated. This can be further validated using techniques such as SEM (Structural Equation Modeling). Though SEM can test an already developed model but can't develop the initial model. Hence, both these techniques can be seen as complementary and SEM can be implemented further on this ISM model to get the validated results.

References

[1] A. Kumar, Prakash, M. K. Tiwari, R. Shankar and A. Baveja, Solving machine loading problem of a flexible manufacturing system with a constraint-based genetic algorithm, European Journal of Operation Research 175(2) (2006), 1043-1069.

[2] A. M. Abazari, M. Solimanpur and H. Sattari, Optimum loading of machines in a flexible manufacturing system using a mixed-integer linear mathematical programming model and genetic algorithm, Computers and Industrial Engineering 62(2) (2012), 469-478.

[3] Antonio Grieco, Quirico Semeraro and Tullio Tolio, A review of different approaches to the FMS loading problem, The International Journal of Flexible Manufacturing Systems 13 (2001), 361-384.

[4] Giovanni Tani, Tool management in manufacturing systems equipped with CNC machines, Belo Horizonte 7(2) (1997), 177-187.

[5] Komal Prasad Sahu and Rahul Tamralkar, Flexible Manufacturing System, National Conference on Recent Trends in Renewable Energy Sources and Electronics, IJEEE 3(2) (2016).

[6] Kumar, Prakash, M. K. Tiwari, R. Shankar and A. Baveja, Solving machine loading problem of a flexible manufacturing system with a constraint-based genetic algorithm, European Journal of Operation Research 175(2) (2006), 1043-1069.

[7] N. S. Mohamad, Operations planning and scheduling problems in an FMS: An integrated approach, Computers Ind. Engng. 35(3-4) (1998), 443-446.

[8] Rahul Tamralkar and Komal Prasad Sahu, Flexible manufacturing system, National Conference on Recent Trends in Renewable Energy Sources and Electronics, IJEEE 3(2) (2016).

[9] Rajesh Attri, Nikhil Dev and Vivek Sharma, Interpretive Structural modeling (ISM) approach: an overview, Research Journal of Management Sciences 2(2) 3-8 February (2013), 2319-1171.

[10] Ranbir Singh, Rajender Singh and B. K. Khan, A critical review of machine loading problem in flexible manufacturing system, World Journal of Engineering and Technology 3 (2015), 271-290.

[11] Ranbir Singh, Rajender Singh and B. K. Khan, A review of modeling techniques for loading problems in flexible manufacturing system, Global Journal of Researches in Engineering: A Mechanical and Mechanics Engineering 15 (1) Version 1.0 (2015).

[12] Ranbir Singh, Sandeep Phogat and Kanwarpal, Intelligent approach for balancing of workload on machines for loading of machines in manufacturing, International Journal of Theoretical and Applied Mechanics 12(1) (2017), 125-134.

[13] Rishu Sharma, Piu Jain and Garima Sharma, Implementation issues in FMS: a literature review, International Journal of Innovations in Engineering and Technology 2 (2) April (2013), 2319-1058.

[14] Sandhya Dixit and Tilak Raj, Identification and modeling of the various factors affecting the productivity of FMS, Int. J. Productivity and Quality Management 17(3) (2016).

[15] Sandhya Dixit and Vimlesh Kumar Ojha, Review of different planning, design and operational issues of flexible manufacturing system, International Journal of Management, Technology and Engineering 8 XI (2018), 359-368.

[16] S. C. Sarin and C. S. Chen, The machine loading and tool allocation problem in flexible manufacturing system, International Journal of Production Research 25 (1987), 1081-1094.

[17] K. E. Stecke, Formulation and solution of non-linear integer production planning problem for flexible manufacturing system, Management Science 29 (1983), 273-288.

[18] K. E. Stecke and F. B. Talbot, Heuristic loading algorithms for flexible manufacturing systems, Proceedings of the Seventh International Conference on Production Research, Windsor, 22-24 August, 1983.