Modeling the Enablers of Flexible Manufacturing Systems using Interpretive Structural Modeling

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Abstract

The objective of the study is to identify the interrelationship between enablers of flexible manufacturing system (FMS) whose richness plays a vital role in successful FMS implementation. The present study employed ISM methodology. ISM is an interactive planning methodology whereby a set of directly and indirectly related variables are structured into a comprehensive systematic model.

Variables such as FMS Workforce Commitment, FMS Workforce Motivation, Adaptation, Relationship management between in-house team & vendor, Skills of FMS workforce, Experience of FMS workforce, Cross Training, Continuous Experimentation, Cross functional cooperation, Team Building, and Job Rotation have been identified and categorised under enablers which will help managers and decision makers in enhancing productivity and profitability. Finally, the paper interprets FMS enablers in terms of driving and dependence powers that have been carried out.

Keywords: Flexible Manufacturing Systems (FMS), Enablers, Measures, ISM, MICMAC

Introduction

Manufacturing companies in the twenty-first century face uncertain, high-frequency market changes driven by global competition. To stay competitive, these companies must possess new types of manufacturing systems that are cost-effective and very responsive to all these market changes (Koren *et al.*, 1999).

The concept of flexible manufacturing systems evolved during the 1960s when robots, programmable controllers, and computerised numerical controls brought a controlled environment to the factory floor in the form of numerically controlled and direct numerically controlled machines (Kostal & Velisek, 2010).

The concept of the flexibility of manufacturing systems is contemporary and important for three reasons. First, the instability and volatility of the environment, in which manufacturers operate, have forced many firms to re-organise their production, if only to reduce the overall scale of their operations. Second, developments such as flexible manufacturing systems and robotics, mean that flexibility is being explicitly promoted as a desirable attribute of production equipment. Third, the relatively recent interest in the nature of production management objectives has widened the scope of production aims beyond cost and productivity issues, to include the flexibility of production systems (Slack, 1983).

World leading automobile companies such as Toyota and Honda are following flexible manufacturing system. Toyota is practicing FMS so as to flexibly respond to changes in market and enhance customer satisfaction (Masuyama, 1995). FMS is emerging as a key strategic advantage for Honda. Honda's manufacturing flexibility is almost as key to its success as its product lineup. To respond to changes in economic conditions, Honda is able to shuffle production among different plants as well as make different models in one plant.

Literature Review

The present study adopted systematic literature review approach for review of published papers and articles.

It is found that past researchers have mostly used traditional review; however systematic literature review is a recent trend adopted by researchers for conducting literature review (eg. Pittaway *et al.*, 2004; Van Aken., 2005; Lightfoot *et al.*, 2013) and synthesize/organise research findings. Therefore present review is done based on the technique of systematic literature review approach as recommended by Tranfield *et al.*, 2003. This eradicates the confusion related to the application of correct methodology and easily helps to develop the later sections of the study. In this process researcher has adhered to the principles that are an integral part of systematic literature review.

Here researcher made an attempt to understand, what work has been carried out in the past on "*flexible manufacturing system*". For literature review scholarly works from databases such as Science Direct, Compendex, Ebsco, Emerald, and Scopus has been utilised.

The literature review is limited to only include: scientific research from the last twenty years; flexible manufacturing system; performance measures; enablers. Moreover each reviewed paper need to match the filtering criteria such as: The research study must be written in English language and published in peer reviewed journals between 1984 and 2014 and manuscripts with non managerial focus were excluded from the review process.

The objectives of literature review are:

- To study the evolution of FMS, its definition and various dimensions of FMS
- To identify the enablers, which helps in successful implementation of FMS

Definitions of Flexible Manufacturing System (FMS)

Numerous definitions have been given on FMS by management gurus, practitioners, and academicians. The definitions from various literature sources are further presented in a tabulated form in the Table 1.

From Table 1, it can be concluded that, FMS is a philosophy and a systematic activity, to improve the value and efficiency of the product and services offered to the customers through maximisation of potential of all stakeholders.

Review of Tools and Mathematical Models

Mathematical models and tools are techniques employed to assess, appraise and to provide solutions to manufacturing issues. They are helpful in solving problems of flexible manufacturing system. The review on mathematical models applied in FMS study is listed in Table 2.

Table 1:Table Definitions/Concepts of FMS

Author, Year	Definitions
Kostal & Velisek, 2010	Flexible manufacturing system is a system that is able to respond to changed conditions
Shivanand, 2006	A flexible manufacturing system is an arrangement of machineries interconnected by a transport system. Flexible manufacturing system consists of a group of processing work stations interconnected by means of an automated material handling and storage system and controlled by integer computer control system.
Liu *et al*., 2003	A flexible manufacturing system include at least one module, a operational unit mounted to said at least one module and a local controller operating connected to the operational unit. The local controller is adapted to control the operational unit. At least one module and the local controller together are capable of operating in a standalone operation or of integration into a flexible manufacturing system
Parker & Wirth, 1999	Flexible manufacturing system comprises of Machine flexibility, Process flexibility, Product flexibility, Product flexibility, Routing flexibility, Volume flexibility, Expansion flexibility, Operation flexibility, and Production flexibility.
Boer, 1994	Flexible manufacturing system is widely regarded as a major step towards "the factory of the future". They combine several items of hardware, software applications and controls based on a number of technological developments in a flexible manufacturing.
Mizoguchi *et al*., 1994	A flexible manufacturing system which includes a stack yard, a machine tool and a stacker crane.
Tetzlaff, 1990	A flexible manufacturing system can be defined as a computer controlled production system capable of processing a variety of parts
Stecke, 1986	A flexible manufacturing system is an integrated system of computer numerically controlled (CNC) machine tools, each having an automatic tool interchange capability, all connected by an automated material handling system.
Brown *et al*., 1984	A flexible manufacturing system is an integrated, computer controlled complex of automated material handling devices and numerically controlled (CNC) machine tools that can simultaneously process medium single sized volumes of a variety of part types.

Table 2: Mathematical Models Applied in FMS Study

Mathematical Models	Area of Application	Author, Year
Linear Programming	Prescribe production plans and adaptive control	Wilhem & Shin, 1985
DEA	Most appropriate flexible manufacturing system for manufacturing organisation	Sheng & Sueyosh,1995
Simulation Models	Develop scheduling mechanism	Kim & Kim, 1994
Stockhastic Models	Develop flexible manufacturing system	Buzacott & Shantikumar, 1993; Zhou & Venkatesh, 1999
Decision Support System	Develop flexible manufacturing system	Suri & Whitney, 1984
Inteer Programming	Problem of part type selection, machine loading, part input sequencing and operation scheduling	Sawik, 1990
AHP	Flexible manufacturing system machine grouping and loading problem	Stecke, 1986
Heuristic Methods	Scheduling problem in Flexible manufacturing system (minimisation of system unbalance and the no. of late jobs	Shanker & Tzen, 1985
Petri Nets	Measuring and analysis of performance measures of FMS	Petri, 1962, 1976; Tamimi *et al*., 2012

Performance Measurement of Flexible Manufacturing System

FMS has been a major component of competitive advantage for manufacturers to enhance profitability. Existing literature on performance measures are vast varying from industry to industry. Performance measures and metrics have received focus from practitioners due to its wide importance. The role of these measures and metrics in the success of an organisation cannot be overstated because they affect strategic, tactical and operational planning, and control. Performance measurement and metrics have an important role to play in setting objectives, evaluating performance, and determining future courses of actions (Gunasekaran *et al*., 2004). Review of FMS literature finds the below listed performance measures as tabulated in Table 3.

Table 3: Performance Measures of FMS

Measures	Author, year
Productivity	Son & Park, 1987
Quality	Son & Park, 1987; Alder, 1998
Flexibility	Son & Park, 1987
Cost	Alder, 1998
Time	Alder, 1998

Flexible Manufacturing System and Firm Performance

FMS implementation will have a positive effect on the firm's market share and profits, although mediated through customer satisfaction. The benefits of FMS are given in a tabulated form in Table 4.

Table 4: List of FMS Benefits

Author, Year	Benefits
Dubey & Ali, 2014	Reduced lead time; reduced work in progress inventory; increased throughput
Kostal & Velisek, 2011	Achieve high flexibility in management of production facilities and resources (time, machines and their utilisation)
Stecke & Solberg, 1981	Improve the systems production rate
Boer, 1994	Improved market performance; Reduces cost/time of operations; improved operations management
Kim & Kim, 1994	Effectively use scheduling mechanism
Sarin & Chen, 1987	Minimise overall machining cost; Improve response time to various problem on shop floor
Avlonitis & Parkinson, 1986	Competitive advantage
Suri & Whitney, 1984	Improve productivity

Enablers of Flexible Manufacturing System

An attempt is made to identify enablers of FMS important for successful implementation of FMS (Table 5).

From Table 5, we can conclude that above FMS enablers are important for successful FMS implementation. Thus

Table 5: FMS Enablers

Author, Year	FMS Enablers
	Relationship between in-house team and vendor
	Skills of flexible manufacturing system workforce
	Experience of flexible manufacturing system workforce
	Cross training
Graham & Rosenthal, 1986;	Cross functional cooperation
	Job rotation
	Team building
Narain *et al*., 2004;	Continuous experimentation
	Adaptation
Belassi & Fadlalla, 1998; Maffei & Meredith, 1994	FMS workforce commitment
	FMS workforce motivation

each of the enablers identified, have been further used an input in ISM technique keeping the research objectives in mind.

Theoretical Framework

ISM is a proven and popular methodology for understanding relationships among specific items that define a problem. ISM is useful to achieve the objective in presence of large number of directly and indirectly related elements and complex interactions among them which may or may not be expressed in a proper manner. ISM plays a vital role in this kind of situation and helps in understanding a structure within a system. The ISM model depicts the structure of a complex problem in a carefully designed pattern.

ISM has been used in the past by several researchers due to multiple benefits. It guides and records the results of group response on complex issues in an efficient and systematic manner, (Source: Dubey & Ali., 2014; Attri *et al*., 2013; Sushil., 2012; Warfield, 1994, 1974).

ISM steps are as follows:-

Identifying the Leading Variables

Developing the Structural Self-Interaction Matrix (SSIM)

For developing SSIM, the below symbols have been used to denote the direction of relationships between variables (i and j):

V: i lead to j but j does not lead to i

Table 5: List of Leading Variables

No.	Identified Variables
1	Relationship between in-house team and vendor
2	Skills of flexible manufacturing system workforce
3	Experience of flexible manufacturing system workforce
4	Cross training
5	Cross functional cooperation
6	Job rotation
7	Team building
8	Continuous experimentation
9	Adaptation
10	FMS workforce commitment
11	FMS workforce motivation

Table 6: Structural Self-Interaction Matrix

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

Table 7: Initial Reachability Matrix

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**DRIVING POWER (Y)**
1	1	0	0	0	0	0	0	1	1	1	1	5
2	1	1	0	0	0	0	0	0	0	0	0	2
3	1	1	1	0	0	0	0	0	1	0	0	4
4	1	1	1	1	0	0	0	1	1	1	1	8
5	1	1	1	1	1	0	0	0	1	1	1	8
6	1	1	1	1	1	1	1	1	1	1	1	11
7	1	1	1	0	1	0	1	1	1	1	1	9
8	0	1	1	0	1	0	0	1	0	0	0	4
9	0	0	1	0	0	0	0	1	1	0	0	3
10	0	0	0	0	0	0	0	1	1	1	0	3
11	0	0	0	0	0	0	0	1	1	1	1	4
DEPENDENCE POWER (X)	7	7	7	3	4	1	2	8	9	7	6	

A: i do not lead to j but j lead to i

X: i lead to j and j lead to i

O: i and j are unrelated to each other

Develop Reachability Matrix

The SSIM has been converted into a binary matrix i.e., the rechability matrix (Table 8) by substituting V, A X and O by 1 and 0. The substitutions of ‘1’ and ‘0’ have been done as below:

i. If the (i, j) entry in the SSIM is V, then the (i.j) entry in the rechability matrix becomes ‘1’ and (j,i) entry becomes ‘0’

ii. If the (i, j) entry in the SSIM is A, then the (i.j) entry in the rechability matrix becomes ‘0’ and (j,i) entry becomes ‘1’

iii. If the (i, j) entry in the SSIM is X, then the (i.j) entry in the rechability matrix becomes ‘1’ and (j,i) entry also becomes ‘1’

iv. If the (i, j) entry in the SSIM is O, then the (i.j) entry in the rechability matrix becomes ‘0’ and (j,i) entry also becomes ‘0’

Level Partitioning

The final reachability matrix obtained in Table 8 is now partitioned into different levels. The reachability set for a particular factor consists of itself and the other variable which it may help to achieve.The antecedent set for a

Table 8: Final Reachability Matrix

	1	2	3	4	5	6	7	8	9	10	11	DRIVING POWER (Y)
1	1	0	0	0	0	0	0	1	1	1	1	5
2	1	1	**1***	0	0	0	0	0	0	0	0	2
3	1	1	1	0	0	0	0	0	1	0	0	4
4	1	1	1	1	0	0	0	1	1	1	1	8
5	1	1	1	1	1	0	0	**1***	1	1	1	8
6	1	1	1	1	1	1	1	1	1	1	1	11
7	1	1	1	0	1	0	1	1	1	1	1	9
8	0	1	1	0	1	0	0	1	0	**1***	0	4
9	0	0	1	0	0	0	0	1	1	**1***	0	3
10	0	0	0	0	0	0	0	1	1	1	0	3
11	0	0	0	0	0	0	0	1	1	1	1	4
DEPENDENCE POWER (X)	7	7	7	3	4	1	2	8	9	7	6	

particular factor consists of itself and the other variable which may help in achieving it. The intersection set for each pair is the intersection of the corresponding reachability and antecedent sets. If the reachability set and the intersection set are the same then that variable is considered to be in level 1 and is given the top position in the ISM hierarchy (Kannan & Haq, 2007), meaning that this variable would not help in achieving any other variable above its own level. With this partition, iteration 1 is completed. After the first iteration, the variable classified to level 1 are discarded and the above procedure is repeated on the remaining variables to determine the level 2. These iterations are continued until the level of each variable has been determined. The results for iterations 1 to 9 are summarised in Table 9.

ISM Model

The analysis above yields an ISM hierarchy in which FMS workforce commitment is at level 1 (the top level) followed by other levels. The resulting ISM model is illustrated in Fig.1.

Table 9: Level Partitioning

Variables	RS	AS	IS	Level
1	1,8,9,10,11	1,2,3,4,5,6,7	1	4
2	1,2,3	2,3,4,5,6,7,8	2	5
3	1,2,3,9	2,3,4,5,6,7,8,9	3,9	5
4	1,2,3,4,8,9,10,11	4,5,6	4	6
5	1,2,3,4,5,8,9,10,11	5,6,7,8	5	7
6	1,2,3,4,5,6,7,8,9,10,11	6	5	9
7	1,2,3,5,7,8,9,10,11	6,7	7	8
8	2,3,5,8	1,4,5,6,7,8,9,10,11	8	7
9	3,8,9,10	1,3,4,5,6,7,9,10,11	9	3
10	8,9,10	1,4,5,6,7,8,9,10,11	8,9, 10	1
11	8,9,10,11	1,4,5,6,7,11	11	2

Fig.1: ISM Model

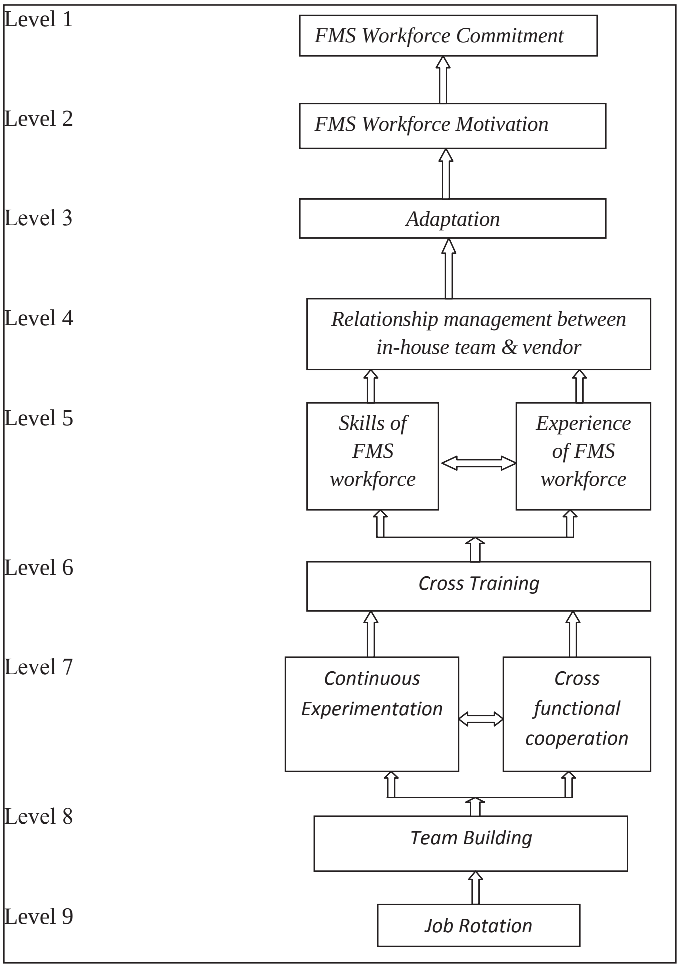


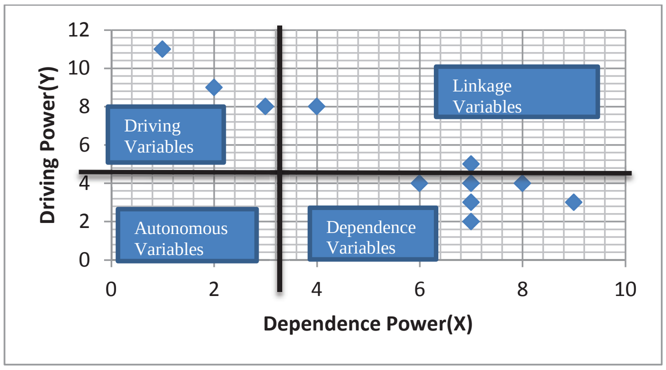
Table 10: Position Coordinates of Identified Variables.

Variables	Dependence Power (X)	Driving Power(Y)
1	7	5
2	7	2
3	7	4
4	3	8
5	4	8
6	1	11
7	2	9
8	8	4
9	9	3
10	7	3
11	6	4

MICMAC Analysis

Matrice d' Impacts Croises Multiplication Appliqué an Classment (cross-impact matrix multiplication applied to classification) is abbreviated as MICMAC. The objective of MICMAC analysis is to analyse the drive power and dependence power of variables. Based on the drive power and dependence power the variables have been classified into four variables: autonomous variables, linkage variables, dependent and independent variables and presented in Fig. 2.

Fig. 2: Plotting of Coordinates



Cluster 1: *Autonomous variables*

These variables have a weak drive power and weak dependence power. In this cluster we do not have any variable.

Cluster 2: *Dependence variables*

These variables have a weak drive power but strong dependence power. In this cluster we have six variables, i.e, 2 (skills), 3 (experience), 8 (continuous experimentation), 9 (adaptation), 10 (commitment), and 11 (motivation).

Cluster 3: *Linkage variables*

These variables have a strong drive power as well as strong dependence power. In this cluster we have two variables, i.e., 1 (Relationship between in-house team and vendor) and 5 (Cross functional cooperation).

Cluster 4: *Driving variables*

These variables have a strong drive power but weak dependence power. In this cluster we have three variables, i.e., 4 (Cross training), 6 (Job rotation), and 7 (Team building)

Conclusions

In the current uncertain business environment, flexible manufacturing system is necessary to compete in global markets. Organisations must understand and evaluate the resources available to them for flexible manufacturing system enabled production. It is observed that most organisations go ahead in implementing FMS without estimating the capabilities and limitations. The present study supports that FMS enablers are important for success of any FMS project. Findings show that cross training, team building, and job rotation are the major FMS drivers and can be considered as the key enablers.

The ISM model portrays a practical view of the interrelationships of FMS enablers. These enablers must be dealt with utmost care for success of any organisation.

Linkage variables are very sensitive and unstable that any action on the variables will trigger an effect on other variables and also a feedback on themselves. Present study provides a systematic approach in developing a structural FMS model pertaining to Indian manufacturing sector. Also this study provided hierarchy of variables which will help supply chain managers in decision making towards building a successful flexible manufacturing system.

Limitations and Future directions of research

The present study has employed ISM and MICMAC analysis. Like every methodology, ISM and MICMAC have their own limitations because these are purely based on expert opinion and need to be validated statistically.

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