Interpretive Structural Modelling for Implementing Lean Manufacturing System

Ajay Kumar Pandey *, Vijay Kumar

Assistant Professor
Department of Mechanical Engineering
School Of Engineering
Presidency University, Bengaluru

Abstract

In Indian context Lean Manufacturing System plays a very important role and emerged as an area of research. Its requirement has increased due to defects in semi-finished and finished products with subsequent increase in cost. The concept of lean manufacturing was developed for maximizing the utilization of resources through minimization of waste. The purpose of this study is to analyse and develop a structural model of the important Lean Manufacturing System variables from its implementation aspects.
Keywords: ISM, Interpretive structural modelling, Lean manufacturing system

1. Introduction

Lean concepts are mostly evolved from Japanese industries and Toyota contributed the most. Lean Manufacturing is a waste reduction technique, but in practice it maximize the value of the product by minimization of waste. Elimination of these wastes is achieved through the successful implementation of lean elements. Lean manufacturing is used as a conceptual framework in many industrial companies (Womack & Jones, 1994) and can be best explained as eliminating waste in a production process (Womak & Jones, 1996). Basically, lean manufacturing seeks to produce a product that is exactly what the customer wants at right time, (Womack & Jones, 1994). The lean transition is, an organizational culture transition to manage lean, specifically during the initial phases, is more about managing the change process than managing lean tools and techniques (Csokasy & Parent, 2007).

An Interpretive Structural Modelling (ISM), (a well-established methodology for identifying relationships among specific factors) is used to obtain the relationship between various variables important in implementation of lean management. The main objectives of this paper are:

1. By using interpretive structural modelling establish the relationship among these identified variables
2. To propose a structural model
3. Use MICMAC analysis to classify the identified variables into four categories

The remainder of this paper is organized as follows. Section 1 presents the Introduction. In section 2, an overview of ISM methodology is presented. The details of ISM approach to model variables are presented in section 3. MICMAC analysis. Section 4

* Corresponding author. Ajay Kumar Pandey, Tel.:+919882553661;

E-mail address: pandeyajay1@gmail.com

are the findings and discussion. And section 5 presents Conclusion and further research direction.

2. ISM Approach

2.1. An overview of ISM methodology

ISM was first proposed by Warfield in 1973. Warfield developed a methodology to find out the relationship between various complex issues. It is an interactive learning process in which a set of various issues (directly or indirectly related) is structured into a comprehensive model which is systematically drawn upon finite or discrete mathematics. When the relationship in between elements is not clear it complicates the system's structure. Hence, a methodology like ISM is required which helps to find out the structure within the system.

The terminology used in the ISM methodology to represent the relationship in between the variables are:
For any two random elements 'i' and 'j'
V: when i influences j
A: when j influences i
X: when both influences each other
O: when there is no relation in between i and j
First, we represent the available information in the matrix in terms of 'V', 'A', 'X' and 'O' called Structural Self-Interaction Matrix (SSIM). Then this information is converted into binary form in Initial Reachability Matrix (IRM) by the following rules.

- If the value of (i, j) in the SSIM is V, then in the Initial Reachability Matrix (i, j) becomes 1 and (j, i) becomes 0.
- If the value of (i, j) in the SSIM is A, then in the Initial Reachability Matrix (i, j) becomes 0 and (j, i) becomes 1.
- If the value of (i, j) in the SSIM is X, then in the Initial Reachability Matrix (i, j) and (j, i) both becomes 1.
- If the value of (i, j) in the SSIM is O, then in the Initial Reachability Matrix (i, j) and (j, i) both becomes 0.

The flow diagram is shown in the figure 2 showing all the steps involved in ISM approach.

2.2. ISM approach to modelling

The following paragraphs shall illustrate the structural relationship among variables as derived from ISM approach.

- **Identification of variables**

In the process of literature review 9 important variables are identified. These 9 variables are separately presented in the table 1.

Table 1: Identification of variables

SN	Variables	**Researchers**
1	Employee skill	Yu Lin & Hui Ho (2008); Womack, Jones & Roos (1990).
2	Value addition	Womack & Jones (1996)
3	Efficient scheduling	Poppendieck (2002); Heizer & Render (2006); Womack et al. (1990)
4	Quality control	Panizzolo (1998)
5	Efficient technology	Edwards (1996)
6	Improved quality of raw material	Forza (1996); Shah & Ward (2003); Taj (2008)
7	Safety and ergonomics	Walder, Karlin & Kerk (2007).
8	Marketing	Womack & Jones (1996).
9	Proper floor space utilization	Heragu (1997)

- **Modelling with ISM approach**

After the identification of variables the next steps are to model with ISM approach and find out the structural relationship between the variables.

- **Contextual relationship establishment among risks**

To identify the contextual relationship in between these 9 variables authors have obtained opinions from experts from the company and academic. On the basis of these opinions the contextual relationships and associated direction is decided.
Based on the contextual relationship, a Structural Self-Interaction Matrix (SSIM Table 2) is developed.

- **Development of the Initial Reachability Matrix (IRM)**

The SSIM (Table 2) is converted into a binary matrix, called as Initial Reachability Matrix (IRM). The relationship symbols V, A, X, O is replaced by 1 and 0 according to the rules explained in section 2 (table 3).

- **Development of the Final Reachability Matrix (FRM)**

After considering the transitivity among risk variables the Initial Reachability Matrix is converted to Final Reachability Matrix (table 4)

2.3. Level partitioning on the basis of reachability and antecedent set

After creation of Final Reachability Matrix the reachability and antecedent set is obtained. The reachability set is a combination of the variable i and other variables which influenced by it. Similarly the antecedent set consists of the variable j and other variable which influence it. After finding both sets (reachability and antecedent) the intersection set which consists of the common elements of both the sets is formed. The variables in which reachability and intersection set are same are given top priority in ISM hierarchy and that variable is removed from all the sets. And this process is repeated till all the levels are identified.

2.4. Conical matrix

A conical matrix can be developed by clubbing together variables in the same level across rows and columns of the final reachability matrix. Summing up the number of ones in the rows gives the driving power and similarly summing up number of ones in the columns gives dependence power.

- **Development of diagraph**

On the basis of conical matrix an initial digraph including transitivity links is obtained, and when the indirect links are removed, a final digraph is developed as shown in figure 1.

- **Development of ISM model**

The digraph is converted in to an ISM model by replacing the nodes by the names of variables as shown in figure 1.

Table 2. SSIM (Structural Self Interaction Matrix)

Variable	9	8	7	6	5	4	3	2
1	V	X	V	V	V	V	V	**V**
2	A	A	A	A	A	A	A	
3	V	A	V	A	A	X		
4	V	A	V	A	A			
5	V	A	V	V				
6	V	A	V					
7	A	A						
8	V							
9	**X**							

* Corresponding author. Ajay Kumar Pandey, Tel.:+919882553661;

E-mail address: pandeyajay1@gmail.com

Table 3. IRM (Initial Reachability Matrix)

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

Table 4. FRM (Final Reachability Matrix)

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

Table 5. Iteration 1

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

Table 6. Iteration 2

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

Table 7. Iteration 3

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,3,4,5,6,8,9	1,8	1,8	
3	3,4,9	1,3,4,5,6,8	3,4	
4	3,4,9	1,3,4,5,6,8	3,4	
5	3,4,5,6,9	1,5,8	5	
6	3,4,6,9	1,5,6,8	6	
8	1,3,4,5,8,9	1,8	1,8	
9	**9**	**1,3,4,5,6,8,9**	**9**	**III**

Table 8. Iteration 4

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,3,4,5,6,8	1,8	1,8	
3	3,4	1,3,4,5,6,8	3,4	**IV**
4	3,4	1,3,4,5,6,8	3,4	**IV**
5	3,4,5,6	1,5,8	5	
6	3,4,6	1,5,6,8	6	
8	**1,3,4,5,8**	**1,8**	**1,8**	

Table 9. Iteration 5

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,5,6,8	1,8	1,8	
5	5,6	1,5,8	5	
6	6	1,5,6,8	6	**V**
8	**1,5,8**	**1,8**	**1,8**	

Table 10. Iteration 6

Variables	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,5,8	1,8	1,8	
5	5	1,5,8	5	**VI**
8	**1,5,8**	**1,8**	**1,8**	

Table 11. Iteration 7

Variable	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,5,8	1,8	1,8	**VII**
8	**1,5,8**	**1,8**	**1,8**	**VII**

Table 12. Conical Matrix

Variables	1	2	3	4	5	6	7	8	9	Driver Power
1	1	1	1	1	1	1	1	1	1	**9**
2	0	1	0	0	0	0	0	0	0	**1**
3	0	1	1	1	0	0	1	0	1	**5**
4	0	1	1	1	0	0	1	0	1	**5**
5	0	1	1	1	1	1	1	0	1	**7**
6	0	1	1	1	0	1	1	0	1	**6**
7	0	1	0	0	0	0	1	0	0	**2**
8	1	1	1	1	1	1	1	1	1	**9**
9	0	1	0	0	0	0	1	0	1	**3**
Dependence Power	**2**	**9**	**6**	**6**	**3**	**4**	**8**	**2**	**7**	**47/47**

3. MICMAC analysis

MICMAC method was developed by Duperrin and Godet (1973), it is a structural analysis tool which describes a system using a matrix that links up its constituent components. They developed two hierarchies, one based on driver power and the second based on dependence power to study the diffusion of impacts. To analyse the driving and dependence power of the risk variables MICMAC (Matrice d'Impacts croises-multiplication appliqúe an classment (cross-impact matrix multiplication applied to classification) analysis is performed. This is done to classify the variables into four categories as follows:

1. Autonomous Variables: The variables which have weak driving and dependence power comes under the category of autonomous. They are relatively less connected to the system.
2. 2. Linkage Variables: The variables which have strong driving and dependence power comes under the category of linkage. They are also not very stable.
3. 3. Dependent Variables: The variables which have weak driving but strong dependence power comes under the category of dependent.
4. Independent Variables: The variables which have strong driving power but weak dependence power comes under the category of independent.

It is generally observed that a variable with a very strong drive power is called the 'key variable' and falls into the category of independent or linkage.

The driving and dependence power of variables is shown in table 12. After that a driving power and dependence power diagram is drawn (figure 2).
This diagram has been divided into four clusters. First cluster includes 'autonomous variables', second cluster includes 'dependent variables'', third cluster includes 'linkage variables'' and fourth cluster contains 'independent variables''.

Figure 1: Diagraph and ISM Model

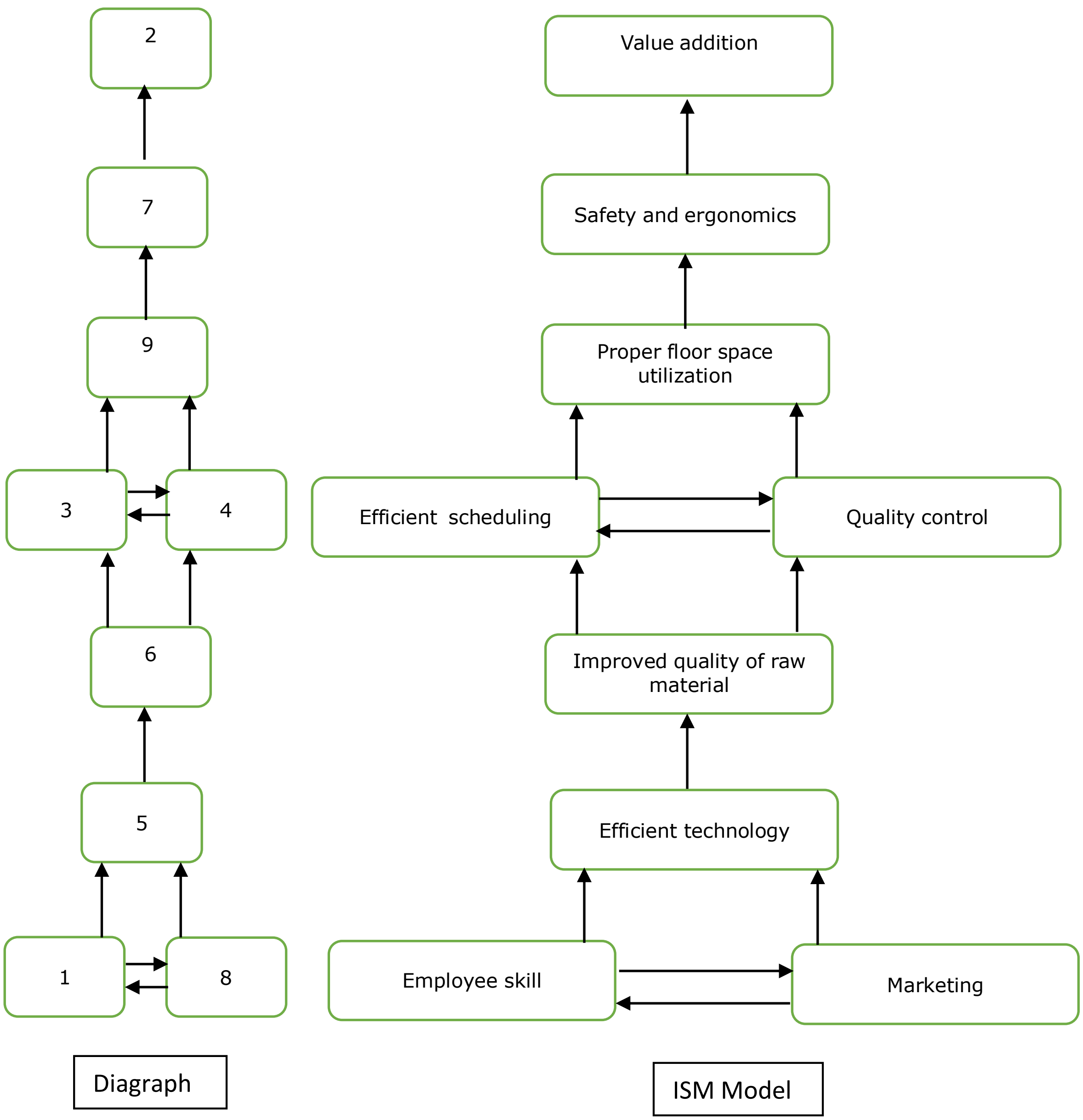
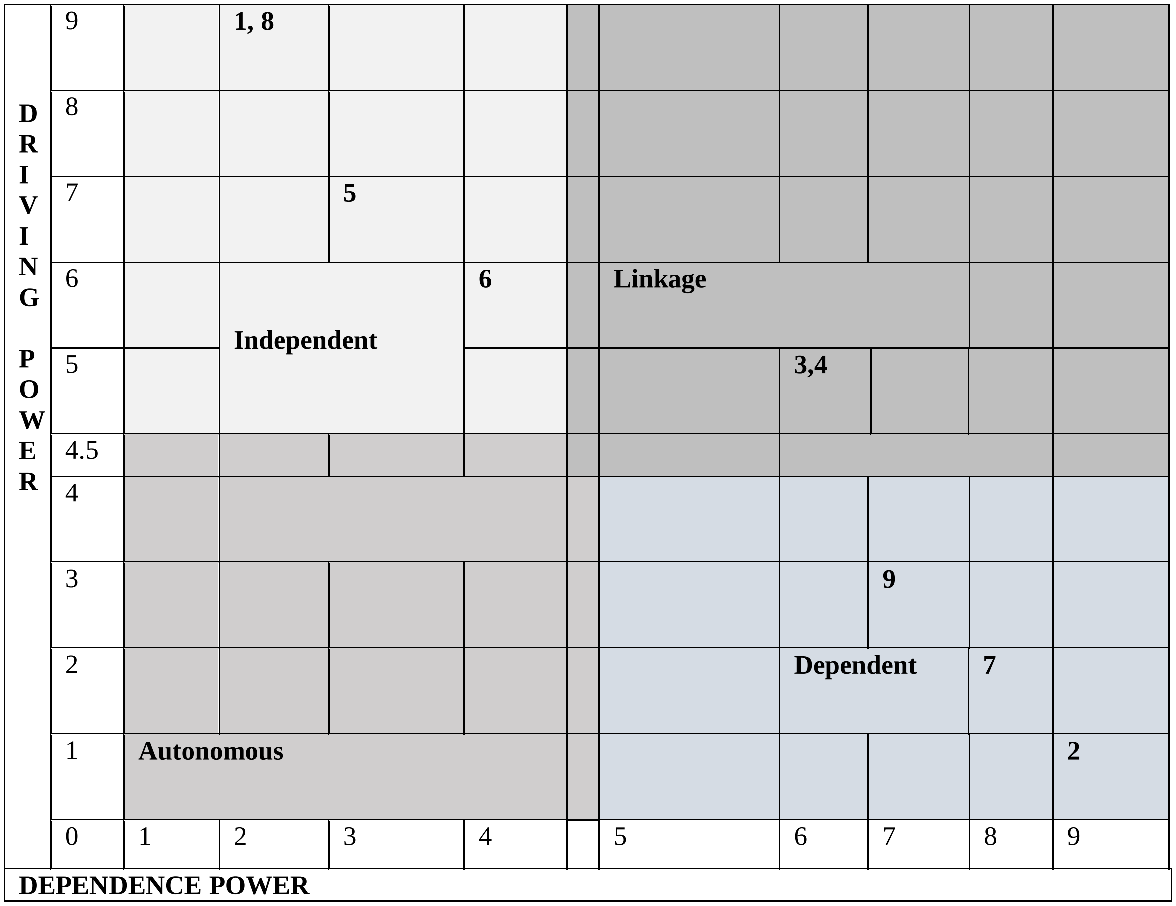


Figure 2: Driving power and dependence diagram.



5. Findings and discussion

The main objective of this research was to identify and analyse the variables that affect the implementation of Lean Management. An ISM based model was developed to find out the structural relationship among 9 selected variables. Some of the important findings of this study are as follows:
From the driving power and dependence power diagram it is observed that variables ‘Employee Skill’, ‘Marketing’, ‘Improved quality of raw material’ and ‘Efficient Technology’ come under independent variable category. The variables ‘Employee Skill’, ‘Marketing’ have the highest driving power, which means they are the key variables and can be considered as the root cause of the problem. The variables ‘Efficient Scheduling’ and ‘Quality Control’ falls under linkage category.

The risk variables ‘Proper floor space utilization’, ‘Safety and ergonomics’ and ‘Value addition’ have strong dependence power and weak driving power so they fall under dependence variables category. These variables comes on the top of the ISM hierarchy and hence can be considered as the most important and implementers should focus on these.

6. Conclusion

Waste minimization and improving efficiency have been identified as key objectives of lean manufacturing system implementation. To model the structural relationship among them Interpretive Structural Modelling (ISM) is used. Further, MICMAC analysis is performed to find out the driving power and dependency of variables. Results of the study indicates that the implementation of the lean manufacturing system can be improved by considering the key variables.
For future research directions Fuzzy ISM technique or structural equation modelling (SEM) can be used and also more variables can be included.

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