International Journal of Mechanical Engineering and Technology (IJMET)
Volume 9, Issue 1, January 2018, pp. 1086–1095 Article ID: IJMET_09_01_115
Available online at http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=1
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

APPLICATION OF TOTAL INTERPRETIVE STRUCTURAL MODELLING FOR LEAN PERFORMANCE – A CASE STUDY

Nitin S Solke
Asst Prof, Symiosis Institute of Technology, Symbiosis International (Deemed University), Pune, Maharashtra, India

Dr. T.P. Singh
Former Director & Professor, Symiosis Institute of Technology, Symbiosis International (Deemed University), Pune, Maharashtra, India

ABSTRACT

Effective and efficient implementation of lean manufacturing in industries is dependent on the ways in which its measures like elimination of wastes, zero defects, optimum utilisation of resources etc. are understood in correct sense and successful handling of the uncertainties faced by the industry. Manufacturing flexibilities like labour flexibility, product flexibility, machine flexibility, volume flexibility, material handling flexibility and routing flexibility assist industry in a great way to take care of uncertainties and fluctuations driven by complexities of the market. Manufacturing flexibility parameters bear interrelations among themselves and need to be analysed judiciously to understand their effect on lean manufacturing. In the present study, total interpretive structural modelling (TISM) technique is used for finding out and analysing relationships among the factors which affect lean performance. TISM is applied while carrying out a case study in a company to understand the dynamism and complexity of factors guiding lean performance. The study brings out analysis of the driving and dependence power and helps in understanding the influence of hierarchy and level of factors identified by TISM technique on lean performance in a company as also the factors which merit attention of top management to achieve better results.

Keywords: Lean manufacturing, manufacturing flexibility, TISM, driving power, dependence power

Cite this Article: Nitin S Solke and Dr. T.P. Singh, Application of Total Interpretive Structural Modelling for Lean Performance – A Case study, International Journal of Mechanical Engineering and Technology 9(1), 2018. pp. 1086–1095.
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=1

1. INTRODUCTION

In today's world, industry needs to be competitive for its survival. In order to be professional, top management of the company need to be ceased with the problems associated with uncertainties, fluctuations and challenges posed by the competitors and environment (Chauhan et al., 2009). Manufacturing flexibilities-labour flexibility, machine flexibility, product flexibility, volume flexibility, routing flexibility and material handling flexibility among others enable managers to deal with uncertainties systematically and help in running the company profitably (Chauhan and Singh, 2013; Koste and Malhotra, 1999; and Sethi and Sethi, 1990). Eventually, it enables the manufacturer to enhance lean performance. These manufacturing flexibilities encompass a number of factors which have inter-relations affecting each other and consequently lean manufacturing. Understanding large number of factors having complex relationship is difficult and needs to be analysed systematically. Total Interpretive Structural Modelling (TISM) technique is used in this paper; as a methodology for dealing with analysing complex factors in an industry wherein interrelations between a large numbers of variables affect the outcome. TISM is used for analysis of relations between the factors affecting manufacturing flexibility and lean manufacturing.

Essential factors pertaining to manufacturing flexibility and affecting lean manufacturing are enumerated in identified in consultation with industry experts and from literature review. Interrelations among these factors have been analysed using TISM and used to identify dependent and driving parameters in a company as a case study. Parameters so identified would help the company in achieving its targets and ensure lean performance.

2. TISM TECHNIQUE

Total interpretive structural modelling (TISM) enables depiction of intricate and complex relations of inter related factors in the system in a graphical for and it is the next stage of Interpretive Structural modelling (ISM) technique (Sushil and Gerhard, 2015). ISM has been in use since 1970 and it is a methodology which helps in establishing complex and intricate relationships between multiple variables under complex environment (Warffield, 1974). Interpretive structural modeling(ISM) is process which learns itself from its own interactions (Sushil and Gerhard, 2015). In this method, judgment of experts decides whether and how items are related which make it 'interpretive'. On the basis of the relationship, an overall structure is formulated from the complex set of items which gives it structural dimension. The overall structure and specific relationships are used in this technique for portraying relationships called a digraph model, which gives it a modelling dimension (Sage, 1977). ISM is used for identifying structure existing in the system. The system may belong to any field which may be social, technical, or any system. The system contains elements having interrelations with each other in some way or the other (Farris and Sage, 1975).

TISM is a modified and upgraded version of interpretive structural modelling(ISM) adopted by Sushil (2012) and Nasim(2011). The model incorporates interpretation of relation between each variable, may it be a direct relation or transitive relation. A fully interpretive structural model is created by TISM technique which assists in creating a basis of the logic for meaningful interpretation of all the relations.

TISM is upgraded and modified form of Interpretive Structural Modelling technique of Warfield and it is used for creation of structural model from the factors for better understanding of the mutual relationship among these factors (Sushil, 2012; Sushil, 2005(a) and (b)). It is used to understand the relationships amongst factors as also to identify hierarchy amongst them.

2.1. Manufacturing flexibility factors affecting lean manufacturing

Lean manufacturing is influenced by the effect of manufacturing flexibility. In the present study nine factors of manufacturing flexibilities have been considered (Table 1) having interrelations among themselves and affecting the lean performance. These factors are selected on the basis of review of literature, views of academicians, and suggestions from experts from industry consisting head of the plant, operations manager and manufacturing excellence manager of the company. It is essential and of paramount importance to understand the characteristics and extent to which these individual parameters affect lean manufacturing. It is also essential that the managers understand the effect of these factors on company's performance.

3. RESEARCH METHOD

The total interpretive structural modelling technique is used to interpret the relations using interpretive matrix. The method involves taking opinion and recording the responses of experts from the industry. A discussion with experts from the industry helps to establish the relationships among these factors which is necessary for making the interpretive model. Views of the experts like CEO, head of the plant and academicians have been considered to establish interrelationship between various factors. The outcome of the discussions is used to represent the inter-relationships in structural self-interaction matrix which is further processed to differentiate the identified factors.

3.1 Application of TISM

Among the factors under consideration affecting lean manufacturing, the need is to reduce those factors which affect negatively and reduce their occurrence and effect during functioning of the plant. It is practically not feasible to pay same attention to all of these factors by the management. Hence it is essential to manage efforts to reduce their effect at root level of the problem. This can be achieved by identifying relationship of these factors with one another and with overall manufacturing flexibility and lean manufacturing to optimize efforts. The factors should be ranked based on their overall effect on lean manufacturing. This can be achieved by systematic interpretive logic represented by TISM.

Table 1 Factors of manufacturing flexibilities considered for analysis

Code	Explanation	Factor
F1	Skill level and ability of workers to work on different machines and do different jobs, training of workers resulting into cost effectiveness and reliability and productivity over job change	Labour multi skill
F2	Attitude of workers towards job change, do autonomous maintenance and inspection, cooperation to achieve targets	Labour attitude
F3	Adaptability of labour to change- amenable to change job without affecting productivity, cost effectiveness	Adaptability of labour to change
F4	Versatility of machines to adapt changes quickly cost effectively , with high productivity and high reliability	Versatility of machines to adapt changes
F5	Availability of state of the art machines over a prolonged period without getting obsolete	Immunity from obsolescence of equipment and machinery
F6	Flexibility to vary production level without paying penalty	Flexibility to vary production level without penalty- volume flexibility
F7	Financial and strategic ability to procure and mobilise resources	Financial and strategic ability to mobilise resources

F8	Ability to meet customers demand by introducing new products and varying product mix	Ability to meet customers' demand by providing large variety of products
F9	Adaptability to reroute processes, move stores and tools, fixtures etc and deal with breakdowns	Adaptability to deal with breakdowns

While applying TISM, factors relevant to the problem are identified. Subsequently group problem solving technique is applied followed by choosing a contextually relevant subordinate relation. A structural self-interaction matrix is developed based on pair wise comparison of factors or variables under consideration. In the next step, transitivity is checked and SSIM is converted into a reachability matrix. Once transitivity fixing is complete, a matrix model is formulated. The elements are partitioned and structural model known as interpretive structural model(ISM) is developed (Attri et al., 2013).

3.2 Structural Self Interaction Matrix (SSIM)

The factors F1 to F9 identified for the study are arranged in sequence for further study. Table 2 shows a matrix which assists in establishing relation between row factor and column factor (Fij). The relation between any two factors and the direction of relation between these two factors is decided in

Table 2 Structural Self Inter Action Matrix

	Variable	**F9**	**F8**	**F7**	**F6**	**F5**	**F4**	**F3**	**F2**	**F1**
F1	Labour multi skill	O	O	O	O	O	O	V	A	--
F2	Labour attitude	O	O	V	O	O	O	V	--	
F3	Adaptability of labour to change	O	V	V	O	O	O	--		
F4	Versatility of machines to adapt changes	V	V	X	V	A	--			
F5	Immunity from obsolescence of equipment and machinery	V	V	X	V	--				
F6	Flexibility to vary production level without penalty- volume flexibility	A	V	A	--					
F7	Financial and strategic ability to mobilise resources	X	V	--						
F8	Ability to meet customers' demand by providing large variety of products	A	--							
F9	Adaptability to deal with breakdowns	--								

Consultation with experts from the industry. Four symbols X, O, A, and V are used for indicating the nature of relation that exists between the two factors under consideration.

The symbols are:

1. X- is used when i relate to j and j relates to i;
2. O- is used when the relation between the elements does not appear valid.
3. A- is used when j relates to i but i does not relate to j;
4. V- is used when i relate to j but j does not relate to i;

The structural self-interaction matrix (SSIM) for the factors identified is then formulated by mapping the views of the experts on each pair-wise interaction between the factors (Sushil, 2012). This matrix indicates interrelations based on how experts in an organization view the correlation of each parameter. In the present study, opinion from the industry in which case study is undertaken has been considered and SSIM for the company has been prepared.

The matrix for the company is prepared as shown in Table 2 above.

3.3. Reachability Matrix (RM)

Reachability matrix is derived using the information from SSIM. Each entry of the SSIM is transformed into ones and zeros in reachability matrix (RM). Formulation of matrix made in this manner is based on the relation given in Table3. Table 4 shows the reachability matrix thus formulated from SSIM. A factor having relation with itself is indicated by 1 in the relevant column of the matrix.

Table 3 Rule for transforming SSIM to RM

(i-j) Entry	(i to j) Relation	(j to i) Relation
V	1	0
A	0	1
X	1	1
O	0	0

3.4. Level partitioning of factors of Reachability Matrix

The level partitioning is done to find the level-wise position of factors (Table 5). Reachability set for a factor represents variables having value 1 in the row of that factor. Similarly, antecedent set indicates the factor having value 1 in the column of that variable. Intersection of the reachability set and the antecedent set will be the same as the reachability set if the element is at the top level. The top level elements satisfying the above condition are removed from the element set and the iterations are carried out till all the levels are determined (Sushil, 2012) Iterations carried out for identifying levels are shown in Table 5 and Table 6 shows levels of all the factors obtained after iterations.

3.5. Diagraph with Significant Transitive Links

Diagrammatic graph is plotted indicating the level of factors showing the direct and significant links as per the relationships observed in the reachability matrix. Figure 1 below gives the graphical representation of total interpretive model arrived at from the case study.

Table 4 Reachability matrix with transitivity

	F1	F2	F3	F4	F5	F6	F7	F8	F9
F1	1	0	1	0	0	0	1*	1*	0
F2	1	1	1	1*	1*	0	1	1*	0
F3	0	0	1	1*	0	0	1	1	0
F4	0	0	0	1	0	1	1	1	1
F5	0	0	0	1	1	1	1	1	1
F6	0	0	0	0	0	1	0	1	0
F7	0	0	0	1	1	1	1	1	1
F8	0	0	0	0	0	0	0	1	0
F9	0	0	0	1*	0	1	1	1	1

Table 5 Level partitioning

Variable	Reachability set(RS)	Antecedent set (AS)	AS ∩R S	level
F1	1,3,7,8	1,2		
F2	1,2,3,4,5,7,8	1		
F3	3,4,7,8	1,2,3		
F4	4,6,7,8,9	2,3,4,5,7,9		
F5	4,5,6,7,8,9	2,5,7		
F6	6,8	4,5,6,7,9		
F7	4,5,6,7,8,9	1,2,3,4,5,7,9		
F8	1	1,2,3,4,5,6,7,8,9	1	I
F9	4,6,7,8,9	4,5,7,9		
Iteration 2				
Variable	**Reachability set(RS)**	**Antecedent set (AS)**	**AS ∩R S**	**level**
F1	1,3,7,	1,2		
F2	1,2,3,4,5,7,	1		
F3	3,4,7,	1,2,3		
F4	4,6,7,9	2,3,4,5,7,9		
F5	4,5,6,7,9	2,5,7		
F6	6	4,5,6,7,9	6	II
F7	4,5,6,7,9	1,2,3,4,5,7,9		
F9	4,6,7,9	4,5,7,9		
Iteration 3				
Variable	**Reachability set(RS)**	**Antecedent set (AS)**	**AS ∩R S**	**level**
F1	1,3,7,	1,2		
F2	1,2,3,4,5,7,	1		
F3	3,4,7,	1,2,3		
F4	4,7,9	2,3,4,5,7,9	4,7,9	III
F5	4,5,7,9	2,5,7		
F7	4,5,7,9	1,2,3,4,5,7,9	4,5,7,9	III
F9	4,7,9	4,5,7,9	4,7,9	III
Iteration 4				
Variable	**Reachability set(RS)**	**Antecedent set (AS)**	**AS ∩R S**	**level**
F1	1,3,	1,2		
F2	1,2,3,5,	1		
F3	3,	1,2,3	3	IV
F5	5	2,5	5	IV
Iteration 5				
F1	1	1,2		V
F2	1,2	1		VI

Table 6 Variables and respective levels

Variables and respective levels		level
F8	Ability to meet customers' demand by providing large variety of products	I
F6	Flexibility to vary production level without penalty- volume flexibility	II
F4	Versatility of machines to adapt changes	III
F7	Financial and strategic ability to mobilise resources	III
F9	Adaptability to deal with breakdowns	III
F3	Adaptability of labour to change	IV
F5	Immunity from obsolescence of equipment and machinery	IV
F1	Labour multi skill	V
F2	Labour attitude	VI

4. DISCUSSION AND OBSERVATIONS

Diagraph in matrix format is manifested by interaction matrix. It shows overview of significant and direct links of a factor with all other factors. Interaction matrix as shown in Table 7 indicates relation between the factors. Direct link is shown by '*' and significant transitive link is indicated by '#'. Say for example, F1 is having direct relation with F3 indicating that labour multiskilling (F1) directly enables adaptability of labour to change (F3). Similarly F1 and F7 are having significant link established indirectly. It indicates that availability of multi skilled labour empowers management with strategic ability to mobilise human resources.

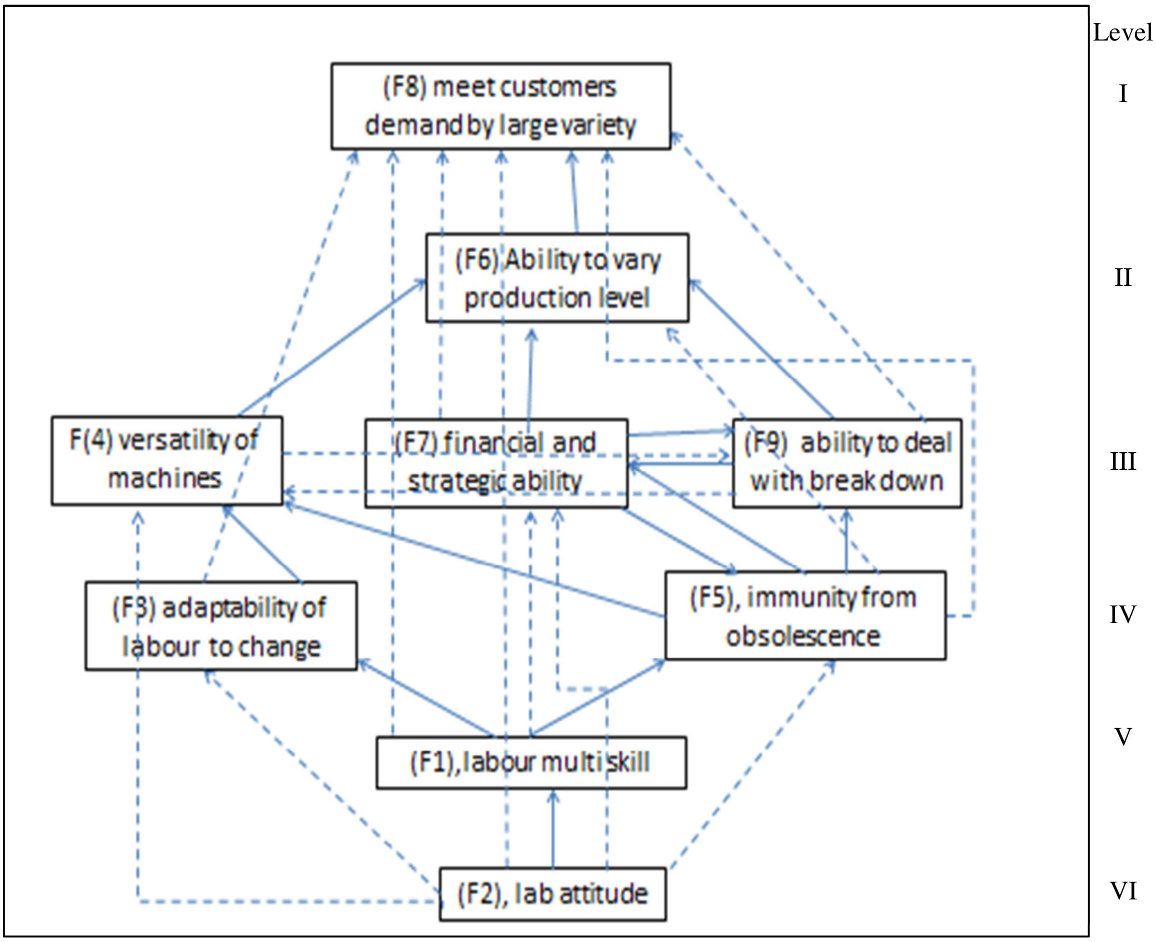

Figure 1 Diagraph showing relationship between parameters

Figure 2 shows driving power and dependence power of selected factors obtained from the model. Autonomous factors lie in Quadrant I, dependent factors in quadrant II, quadrant III indicates linkage factors and quadrant IV encompass independent (driver) factors [Sushil, 2102, Sandbhore and Botre, 2014, and Sandbhore et al., 2015). Attitude of labour (F2), labour multi skilling(F1), adaptability of labour to change(F3), and having state of the art of equipment with less likely hood of getting obsolete(F5) lie in the IV quadrant indicating independent factors that have weak dependence and strong driving power. Quadrant III includes linkage factors that have strong driving and strong

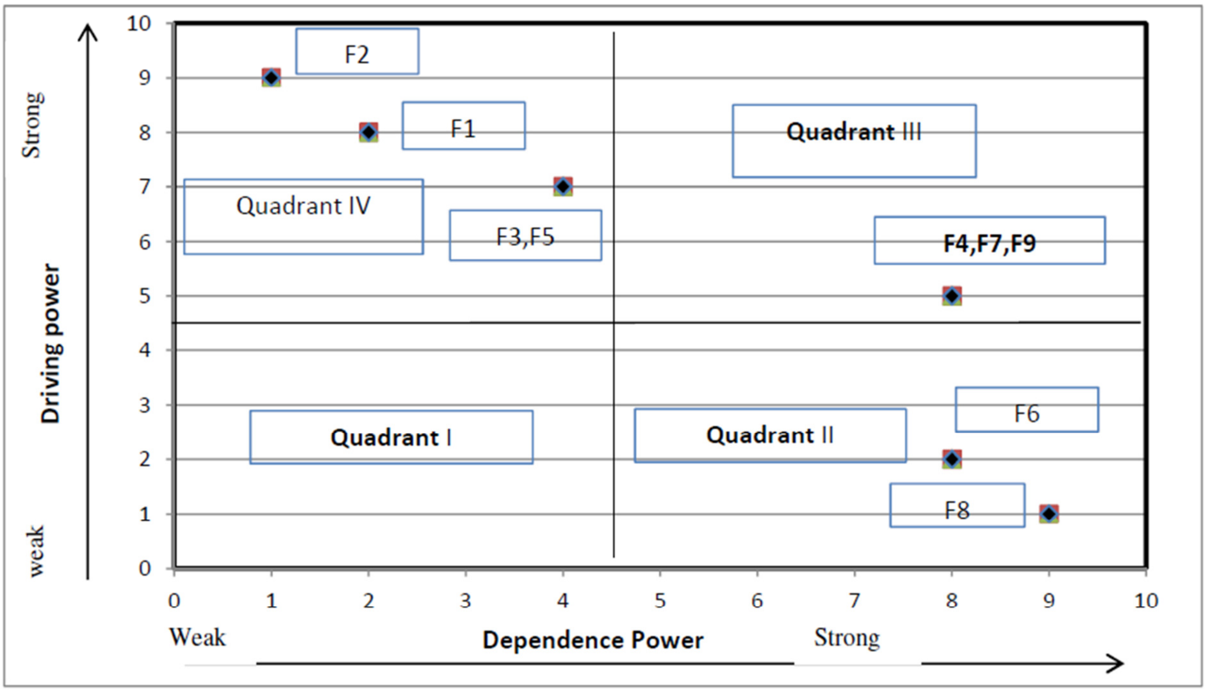

Figure 2 Driving power and dependence power diagram

Dependence power these factors are not stable and any actions on these factors will have an effect on others and on themselves also. Special care needs to be taken by Managers in managing these factors. Versatility of machines to adapt changes and quick change overs (F4), financial ability to procure and mobilise resources (F7) and ability to deal with breakdowns (F9) lie in quadrant III. Ability to vary production levels without penalty (F6) and ability to meet customers' demand by providing large variety of products (F8) fall in the quadrant II. It indicates that the dependent factors having strong dependence power and weak driving power lie above the central portion of TISM hierarchy.

The company under study has infrastructure and production facilities semi-automated. Shop floors have machines right from special purpose machines (SPMs), general purpose machines (GPMs) to computerised numerically controlled (CNC) machines. Still human interventions and human skill does matter in maintaining quality. Consequently it can be observed that labour attitude and labour multi skilling or ability of labour to work on different machines and job are strong driving power along with holding state of the art equipment which can last long without being replaced due to obsolescence. As

Table 7 Interaction matrix

Variable	F1	F2	F3	F4	F5	F6	F7	F8	F9
F1	--	0	1 *	1#	1*	0	1#	1#	0
F2	1 *	--	1#	1#	1#	0	1#	1#	0
F3	0	0	--	1*	0	0	0	1#	0
F4	0	0	0	--	0	1*	0	0	1*
F5	0	0	0	1*	--	1#	1*	1#	1*
F6	0	0	0	0		--	0	1*	0
F7	0	0	0	0	1	1*	--	1#	1*
F8	0	0	0	--	0	0	0	--	0
F9	0	0	0	1*	0	1*	1#	1*	--

- Direct link in indicated by '*'
- Significant link is indicated by '#'

company needs to produce products(engines) of different types and capacities leading to a requirement of producing varied assemblies and subassemblies, availability of versatile machines capable of quick setups and change overs is essential for different product mix and different levels of production as per requirement of orders placed internally on shop floor. This has been achieved very well in the company. Besides lay out of company, shop floor and holding of material handling (MH) handling equipment makes it possible to carry out production without interruption and breakdowns. There are no major incidences in the company where in production has stalled due to break down of machinery. The company has shown the strategic ability to acquire state of the art machinery which need not be replaced frequently due to obsolescence. It can be observed that the linkage factors in quadrant III, 'versatility of machines to adapt changes quickly' (F4), 'financial and strategic ability to mobilise resources' (F7) and 'adaptability to deal with breakdown' (F9) are taken care of by the company.

Ability to vary production level and product mix is strongly dependent on labour attitude, multi skilling and availability of state of the machinery.

5. CONCLUSION

Lean manufacturing is very significant for sustenance of any industry in today's competitive world. Application of TISM to identify and interpret the factors contributing to lean manufacturing enables management to analyse the situation and plan the corrective actions to improve upon overall performance of the industry. Factors considered for analysis and TISM are selected based on views and opinion of the experts from the industry and literature review. Based on the model evolved from the study, the company should give more importance to factors having high driving power to avoid the effect of dependent factors having less significance. The company could analyse its functioning ethos and find the root cause in terms of factors affecting the efficient functioning of the company and initiate corrective measures for enhancing the performance of the company.

TISM of the company under study brings out that in a company where there is semi automation and human skills are used at critical places for maintaining quality; labour skill and labour attitude are strong driving powers and availability of state of the art versatile machines capable of undertaking quick change overs and reduced setup time act as important variables to meet customers' demands in terms of volume and meeting large variety products/ product mix.

If company goes for full automation, intervention of human skill and attitude can still be reduced and improve of upon the quality and enhance lean performance.

REFERENCES

[1] Chauhan, G.; Singh, T.P. and Sharma, S.K. (2009). Cost reduction through lean manufacturing: A case study, International Journal of Industrial Engineering Practice, 1(1), pp.1-8.

[2] Chauhan, G. and Singh, T.P. (2013). Development and validation of resource flexibility, Journal of Industrial Engineering and Management , JIEM, 2014-7(1): pp.21-41

[3] Koste, L.L. and Malhotra, M.K. (1999). A theoretical framework for analysing the dimensions of manufacturing flexibility, Journal of Operations Management, 18(1), pp.75-93.

[4] Sethi, A. K. and Sethi, S.P. (1990). Flexibility in manufacturing: A survey, International Journal of Flexible Manufacturing Systems, 2(4), pp.289-328.

[5] Sushil; and Gerhard (2015). Flexible Systems Management, Springer India.

[6] Warfield, J.N. (1974). Towards interpretation of complex structural models, IEEE Transactions: System, Man and Cybernetics, 4 (5) pp.405-17.

[7] Sage, A.P. (1977) Interpretive Structural Modelling: Methodology for Large Scale Systems, McGraw-Hill, New York, NY, pp.91-164.

[8] Farris, D.R.; Sage A.P. (1975) On the use of interpretive structural modelling for worth assessment, Computers & Electrical Engineering, 2 (2–3), pp.149–174.

[9] Sushil(2012) Interpreting the interpretive structural model: organization research methods, Global Journal of Flexible Systems Management, 13 (2), 87–106.

[10] Nasim, S. (2011) Total interpretive structural modeling of continuity and change forces in e-government, Journal of Enterprise Transformation, 1 (2), pp. 147-68.

[11] Sushil (2005a) Interpretive matrix: a tool to aid interpretation of management in social research, Global Journal of Flexible System Management, 6 (2), pp.27-30

[12] Sushil,(2005b) A flexible strategy framework for managing continuity and change, International Journal of Global Business and Competitiveness, 1 (1), pp. 22-32.

[13] Attri, R.; Dev N. and Sharma V. (2013). Interpretive Structural Modelling (ISM) approach: An Overview, Research Journal of Management Sciences, 2 (2), pp.3-8.

[14] Sandbhor, S and Botre, R (2014) Applying total interpretive structural modelling to study factors affecting construction labour, Australasian Journal of Construction Economics and Building, 14 (1) pp.20-31.

[15] Sandbhor, S.; Mugdha, Kshirsagar; Choudhari, S.; Arora, A.; and Katoch, P. (2015). Analyzing factors leading to Construction Project Success Using Total Interpretive Structural Modeling, International Journal of Applied Engineering Research, Research India Publications, 10(2) pp.2855-2868.

[16] P.Kezia, K. Shravan Kumar and B.L.N.Krishna Sai Lean Manufacturing in Food and Beverage Industry, International Journal of Civil Engineering and Technology, 8(5), 2017, pp. 168–174.

[17] K. Shyam Chamberlin, SS. Asadi and D. Sai Chaitanya, Evaluation of Latest Trends and Developments in Lean Construction in India: A Model Study. International Journal of Civil Engineering and Technology, 8(10), 2017, pp. 461–471.