International Journal of Emerging Research in Management &Technology ISSN: 2278-9359 (Volume-6, Issue-11)

Research Article | **November 2017**

Significant Parameters of Machine Flexibility Contributing to Lean Manufacturing

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Abstract:

In today's highly competitive environment manufacturing industries can't bear the wastage of resources. Machines and equipments are one of the most important resources of a manufacturing industry. It is necessary to employ efficient processes and practices to hold cost of manufacture and move towards the attainment of lean manufacturing. This paper presents a study carried out in manufacturing industry to assess the status of machine flexibility and its impact on lean manufacturing implementation. A survey was conducted using a specially designed questionnaire carrying multiple choice questions on various aspects of lean manufacturing and machine flexibility. From the analysis of the response, standing of each parameter of lean manufacturing and machine flexibility were found out. The relationships between these parameters were determined from the coefficient of correlation and significant parameters of machine flexibility contributing to lean manufacturing were found out from regression analysis.

Keywords: Elimination of waste; Machine flexibility; Lean manufacturing; Flexible machines.

I. INTRODUCTION

Advent of globalization and liberalization in India has brought about an unprecedented level of competition in manufacturing sector. New product introductions, while containing the price of the product have become a norm for survival and growth. Emphasis has shifted from mass production to the production of small lots, because of rapid changes in product designs brought about by technological advancements [1]. Today's market is determined by customers. They have many choices available and the products which come up to customers' expectations survive in the market. Industrial systems have become very complex owing to a large variety of products being made in a single manufacturing firm. A number of different types of materials, machines, tools, skill levels, and other inputs have to be employed in a production system. Still more, market uncertainties, because of scarcity of resources and rapid product innovations, add to the decision-making complexities in the manufacturing system [2] [3]. Cutting cost of production through elimination of wastage of resources is essential for survival. This requires a system to rapidly adjust itself to complexities, uncertainties, and changes.

II. LITERATURE REVIEW

Minimizing wastage of resources and moving towards implementation of lean manufacturing have become key strategies to achieve cost cutting. Lean manufacturing is aimed at removal of waste in every area of production including customer relations, product design, supplier networks and factory management [4]. The higher the quality of the product achieved and higher the service levels are offered, raise the price that customers have to pay. The profit is the difference between the cost of the product and its price [5]. The goal of lean manufacturing is to expend less human effort, less inventory, less time to develop products, and less space to become highly responsive to customer demand, while at the same time producing quality products in the most efficient and economical manner [6]-[7].

Lean manufacturing is a systematic approach for identifying and eliminating waste in operations through continuous improvement, reducing operating cost of the system and fulfilling customers' desire for maximum value at the lowest price [8]. It is an operational strategy focused on attaining the shortest possible path through removing the waste. It is derived from the Toyota Production System and its objective is to increase the value-added work by eliminating seven basic types of waste: Over-production, Motion (of operator, material or machine), Waiting of operator, material or machine, transportation, Non value addition processing, Inventory, Corrections (rework and scrap). This technique reduces the time between placing the order and shipment, and it is intended to improve profitability, customer satisfaction, throughput time, and employee motivation also. The benefits of lean manufacturing are lower costs, better quality, and shorter lead times [9]. Productivity, cycle time, and work-in-process inventory are measures to characterize the leanness of the underlying production system [10]. Waste elimination and JIT are the most important components of lean performance [11]. To implement lean manufacturing successfully, peoples must be educated by the management to align their thinking and behaviors with the changed processes, systems and new approaches to attain an optimistic change [12]. The major reasons for the low level of lean achievement are unease in altering the stance of workers, lack of knowledge, and training about the lean management model, cost and time concerned in lean realization [13]. One of the critical implementation factors of lean manufacturing is simultaneous adoption of leanness in supply chain. Lean Manufacturing composed of vastly incorporated components along with variety of management practices [14]. The hybrid lean-agile manufacturing system is expectedly most efficient among the manufacturing systems with normalized comparative improvement [15].

Machine flexibility refers to the various types of operations that a machine can carry out without an excessive attempt in changing from one operation to another. It depends on the ease with which one can make changes in order to produce a given set of part types [16]. Simplest possible manifestation of machine flexibility resembles the two queue single server case for which results indicate the superiority of the alternating priority rule when average job flow time is the measure of performance [17]. Machine flexibility deals with the ease of making changes among the operations required to produce a number of products. It is measured by the number of operations that a workstation performs and the time needed to switch from one operation to another [18]. Efficiency, versatility and redundancy are the main factors that should be considered in the measurement of machine flexibility [19]-[20]. Numerical control, easily accessible programs, automatic tool changing ability, sophisticated part loading devices, size of the tool magazine, standardized tools, number of axes are the main sources of machine flexibility [21]. Effect of machine flexibility on job shop performance is higher than the process plan flexibility and after a certain level of machine flexibility, the speed of scheduling performance improvement decreases considerably [22].

Flexible machines play an important role in implementation of lean manufacturing successfully in the long run [23]. A decrease in machine flexibility increases makespan and decreases routing flexibility, capacity flexibility and inventory [24]. A significant improvement in makespan and supply chain performance of an FMS can be achieved by the optimum implementation of machine flexibility, routing flexibility and part population inside the system [25]-[26].

III. METHODOLOGY

The research work is undertaken for analyzing engineering industry with an aim to design strategies for managing machine flexibility for improvement in lean manufacturing. An extensive survey of engineering industry of north India has been conducted. For survey, a comprehensive questionnaire covering important parameters of machine flexibility and lean manufacturing is designed. Questionnaire has multiple choice questions and a seven point likers scale for response. To ensure the relevance and effectiveness of questions to the industry, the questionnaire is pre-tested on a random sample of industry. Internal reliability of questionnaire items has also been tested using Cronbach's alpha coefficient. Cronbach alpha is 0.7144 and 0.9119 for machine flexibility and lean manufacturing respectively. As per Radhakrishna [27] the reliability coefficient (Cronbach's alpha) can range from 0 to 1, with 0 representing an instrument with full of errors and 1 representing total absence of errors. A value of 0.70 or above of Cronbach's alpha is considered acceptable. The survey was primarily conducted through mail but personal visits were also undertaken to the extent possible. The analysis is carried out to assess the status of each parameter of machine flexibility and lean manufacturing and the overall machine flexibility and lean manufacturing in surveyed units. Various statistical tools and techniques are employed for analysis of response. To find the relationships between various parameters of machine flexibility and lean manufacturing, Pearson's coefficient of correlations are calculated. Engineering industry in the states of Haryana, Himachal Pradesh, Uttarakhand, Uttar Pradesh and National Capital Region of Delhi are considered. A list is prepared by referring to the directory of industries. A total of 186 units are selected. The survey instrument is mailed to 186 organizations in the sample frame along with a write-up on the objective of the survey and its usefulness for the industry.

A total of 52 responses were received resulting in 27.96 % response rate. This response rate is satisfactory with other empirical research [28]-[30] and considered acceptable in operations management survey research [31]. Out of 186 industrial units to whom the questionnaire is sent, 142 are private sector firms and 44 belong to public sector. Out of the responding firms, 34 are from private sector and 18 from public sector. Analyzing it scale-wise, the response from large scale firms is 37.03 per cent and from medium scale, it is 24.24 per cent.

Each question on machine flexibility and lean manufacturing has seven options and thus a score between one and seven is awarded. Considering that, a maximum score of 7 for each question and 7×n (where n are the number of questions in each parameter) for each parameter is possible respectively. The actual score is divided by the maximum possible score for each parameter which gives the value of each parameter on a scale of 0–1. Each major parameter of machine flexibility and lean manufacturing has some sub-parameters contributing to the major parameter. Machine flexibility has seven sub-parameters, e.g. ability of machines to perform diverse set of operations. Each of these parameters is represented by a number of questions in the questionnaire. To calculate the value of these sub-parameters from the raw scores of the questionnaire, following equations are used:

Theoretical Parameter Value, $Pt_i = \frac{\sum Sai}{nSm}$ -- (1)

Where $\sum Sai$ is the sum of actual score of i_{th} parameter, which is further equal to

$\sum Sai = S_1 + S_2 + \text{-------} + S_n$ --- (2)

Sai is the score of a company in a question (i varies from 1 to 7) n is the number of questions in a parameter, and Sm is the maximum possible score of a question i. e. 7.

The value of a parameter has been worked out from equation 1. For finding out the values of machine flexibility and lean manufacturing following equations have been used:

Machine Flexibility (MF) = $\sum_{i=0}^{n} MFi * WFi$ -------------------------------------- (3)

Where MF_i is the i_{th} parameter value of machine flexibility and WF_i is its weight calculated from AHP.

Lean Manufacturing (LM) = $\sum_{i=0}^{n} LMi * WFi$ ------------------------------------- (4)

Where LM_i is the i_{th} parameter value of lean manufacturing and WF_i is its weight calculated from AHP.

IV. RESULTS

A. Measurement of machine flexibility

Machine flexibility deals with the variety of operations that a machine can perform without incurring high costs or expending prohibitive amount of time in switching from one operation to another. Machine flexibility allows small batch sizes which, in turn, result in lower inventory costs, higher machine utilization, ability to produce complex parts and improved products quality. The factors used for calculating machine flexibility status and their codes are listed in Table 1.

Table 1: Codes of Machine Flexibility Parameters

Sr. No.	Parameters	Code
1	Ability of machines to perform diverse set of operations	MF1

2	Machine setup or changeover	MF2
3	Time and effort needed to change the tools and operations	MF3
4	Cost effectiveness of operations over machine change	MF4
5	Productivity effectiveness due to change of machine	MF5
6	Obsolescence rate of machines at introduction of new products	MF6
7	Reliability of machines over job change	MF7

Although various parameters, as listed above, contribute towards machine flexibility yet their contribution cannot be assumed to be equal. Weights of some parameters may be more than the others. To determine their relative weights, Analytic Hierarchy Process (AHP) has been employed [32-33]. Each parameter has been compared with other parameters pair-wise. The comparison has been carried out by experts chosen for the purpose. The experts included industrial manager, an academician and researcher himself. The respondents compare the parameters on a qualitative scale of very low, low, medium, high and very high as the difference between the importance of two parameters with scores of 1, 3, 5, 7 and 9 respectively.

The weight of each parameter of machine flexibility is determined by calculating an Eigen vector and normalizing it. The weightage of each parameter contributing to machine flexibility as determined by experts are given in Table 2. A consistency index (CI) is also calculated to check the numerical and transitive consistency of judgments. Consistency ratio (CR) is also calculated by dividing the CI with the consistency random number for the same size of matrix. The value of CR is taken as 10 % or less for the judgment about weights to be acceptable. The higher value of CR reflects that the response of an expert is quite inconsistent in awarding weights to various parameters while comparing them with each other.

Table 2: Weightage and Status of Machine Flexibility Parameters

Sr. No.	Parameter code	Mean %age weight	Mean value	SD
1	MF1	40.38	0.6667	0.0963
2	MF2	03.71	0.6056	0.1455
3	MF3	07.84	0.6363	0.1128
4	MF4	03.58	0.6048	0.1265
5	MF5	10.34	0.6142	0.1599
6	MF6	19.97	0.6963	0.1561
7	MF7	14.18	0.7304	0.1312

As shown in table 2, most important parameter of machine flexibility is ‘ability of machines to perform diverse set of operations’ with 40.38% weightage. This has been followed in order by ‘obsolescence rate of machines at introduction of new products’ with 19.97% weightage, ‘reliability of machines over job change’ with 14.18% and ‘productivity effectiveness due to change of machine’ with 10.34% weightage. Other parameters which have got a weightage of less than 10% are: ‘time and effort needed to change the tools and operations’ (7.84%), ‘machine setup or changeover’ (3.71%) and ‘cost effectiveness of operations over machine change’ (3.58%).

Following this, various parameters of machine flexibility have been calculated by using equation 3 for all the companies. Table 2 shows the mean values and standard deviation of these parameters. The table depicts that ‘reliability of machines over job change’ has got the highest score (0.7304). This is followed by ‘obsolescence rate of machines at introduction of new products’ (0.6963) and ‘ability of machines to perform diverse set of operations’ (0.6667). Out of these the ‘ability of machines to perform diverse set of operations’ has the least standard deviation (0.0963), showing that the unit to unit variation in this aspect is quite low. Using Eq. (3), the values of status of MF of the surveyed units are found on 0–1 scale and are shown in Table 3.

Table 3: Status of Machine Flexibility In Surveyed Companies

Company	Machine flexibility index	Company	Machine flexibility index	Company	Machine flexibility index
1	0.6958	19	0.6012	36	0.6726
2	0.4708	20	0.5898	37	0.7081
3	0.7844	21	0.5652	38	0.7019
4	0.6068	22	0.6031	39	0.7115
5	0.5004	23	0.6390	40	0.7053
6	0.5375	24	0.7020	41	0.7302
7	0.4732	25	0.7534	42	0.7534
8	0.4945	26	0.6537	43	0.7269
9	0.5785	27	0.7056	44	0.7170
10	0.6410	28	0.7125	45	0.7316
11	0.6157	29	0.7347	46	0.6774
12	0.5983	30	0.7255	47	0.6961
13	0.9436	31	0.6601	48	0.6928
14	0.8536	32	0.7505	49	0.6917
15	0.6722	33	0.7365	50	0.6340
16	0.5924	34	0.6872	51	0.7277
17	0.5469	35	0.7332	52	0.7451
18	0.6252			Average Value = 0.6694	

Figure 1 shows the status of MF in the surveyed units. There is only one unit with a score of above 0.90. One organization is close to a score of 0.85. In all, 6 units are above a score of 0.75 and can be termed as good. On the other extreme 4 units are below or near a score of 0.50. These can be termed as poor from MF point of view.

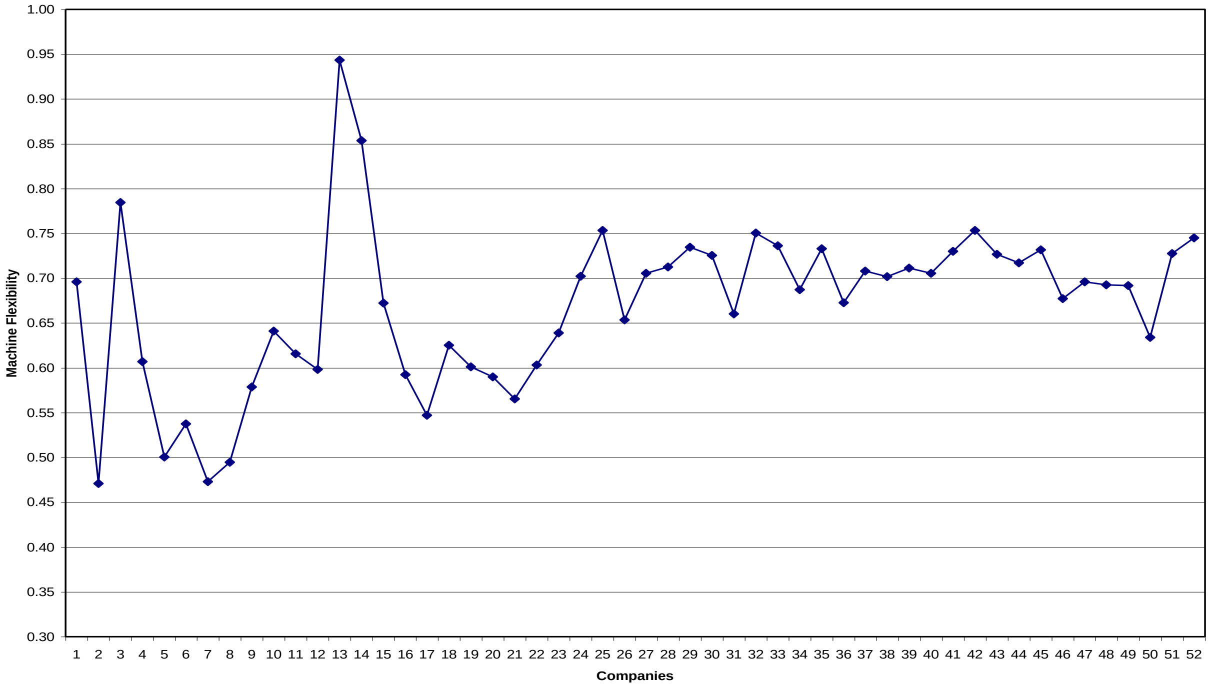

Figure 1: Status of Machine Flexibility in Surveyed Companies

B. Measurement of lean manufacturing

Parameters used to measure lean manufacturing and their codes are given in Table 4.

Table 4: Parameters and Codes of Lean Manufacturing Parameters

Sr. No.	Parameters	Code
1	Elimination of Waste	LM1
2	Continuous Improvement	LM2
3	Zero Defects	LM3
4	Just in Time Deliveries	LM4
5	Pull of Raw Materials	LM5
6	Multifunctional Teams	LM6
7	Decentralization	LM7
8	Integration of Functions	LM8
9	Vertical Information Systems	LM9

The weights of each parameter affecting lean manufacturing found out by normalizing the Eigen vector are given in Table 5. As shown in the table, most important parameter of lean manufacturing, as per experts, is 'elimination of waste' with 35.15 % weightage. This has been followed in order by 'just in time deliveries' with a weightage of 19.56 % and 'multifunctional teams' with 12.59 %. Other parameters have got a weightage of less than 10 % as shown in the table depicting that they are comparatively less important in calculation of lean manufacturing. Elimination of waste is significant as it enables utilization of resources and maximization of the productivity of an organization.

Using Eq. (2), values of each major parameters of lean manufacturing have been calculated. Last two columns of Table 5 show the mean values of these parameters and their standard deviation (SD) in the surveyed companies. The table shows that LM1, 'elimination of waste' has achieved a maximum value (0.6748) followed by LM2 'continuous improvement' (0.6648), LM9 'vertical information system' (0.6398) and 'zero defects' (0.6385). This shows that the industry has put emphasis on these areas.

Table 5: Weightage and Status of Lean Manufacturing Parameters

Sr. No.	Code	Mean %age Weight	Mean	SD
1	LM1	35.15	0.6748	0.0824
2	LM2	04.53	0.6648	0.1067
3	LM3	09.63	0.6385	0.1030
4	LM4	19.56	0.5558	0.1312
5	LM5	06.32	0.5544	0.1329
6	LM6	12.59	0.5648	0.1615
7	LM7	02.19	0.6398	0.1195
8	LM8	07.84	0.5885	0.1599
9	LM9	02.19	0.6398	0.0848

Table 6: Status of Lean Manufacturing in Surveyed Companies

Company	Lean manufacturing index	Company	Lean manufacturing index	Company	Lean manufacturing index
1	0.8196	19	0.4963	36	0.6753
2	0.4713	20	0.5348	37	0.6812
3	0.6178	21	0.4858	38	0.6344

4	0.6267	22	0.5468	39	0.6646
5	0.6382	23	0.5315	40	0.6606
6	0.7244	24	0.5796	41	0.6567
7	0.5455	25	0.6780	42	0.6447
8	0.5802	26	0.5489	43	0.6372
9	0.6285	27	0.5850	44	0.6693
10	0.5112	28	0.5795	45	0.6246
11	0.5224	29	0.6299	46	0.5687
12	0.5005	30	0.7692	47	0.5928
13	0.9193	31	0.5694	48	0.6237
14	0.8830	32	0.6724	49	0.5876
15	0.5946	33	0.6135	50	0.5532
16	0.5547	34	0.6649	51	0.6322
17	0.5599	35	0.6680	52	0.6534
18	0.5143			Average Value = 0.6178	

Further LM1 and LM9 have low values of standard deviation (0.0824 and 0.0848) respectively. This indicates that the industry has uniformly paid attention to these areas. However, higher value of SD (0.1599) in case of 'integration of functions' LM8 points out large variations within the surveyed units with regard to this aspect. The lowest value has been achieved by LM5, 'pull of raw materials' followed by LM4, 'just in time deliveries' and LM6, 'multifunctional teams,' showing that these areas are neglected and have not come to a satisfactory level. LM8 also has a large value of SD depicting that in some companies integration of functions is done regularly while in others it is not. Using Eq. (4), the values of lean manufacturing of the surveyed units are found on 0–1 scale and are shown in Table 6.

Figure 2 shows the status of lean manufacturing in the surveyed units. There is only one unit with a score of above 0.90. Two more organizations are above a score of 0.80. In all 5 units are above a score of above 0.70 and can be termed as good. On the other extreme 4 units are below or near a score of 0.50. These can be termed as poor from lean manufacturing point of view.

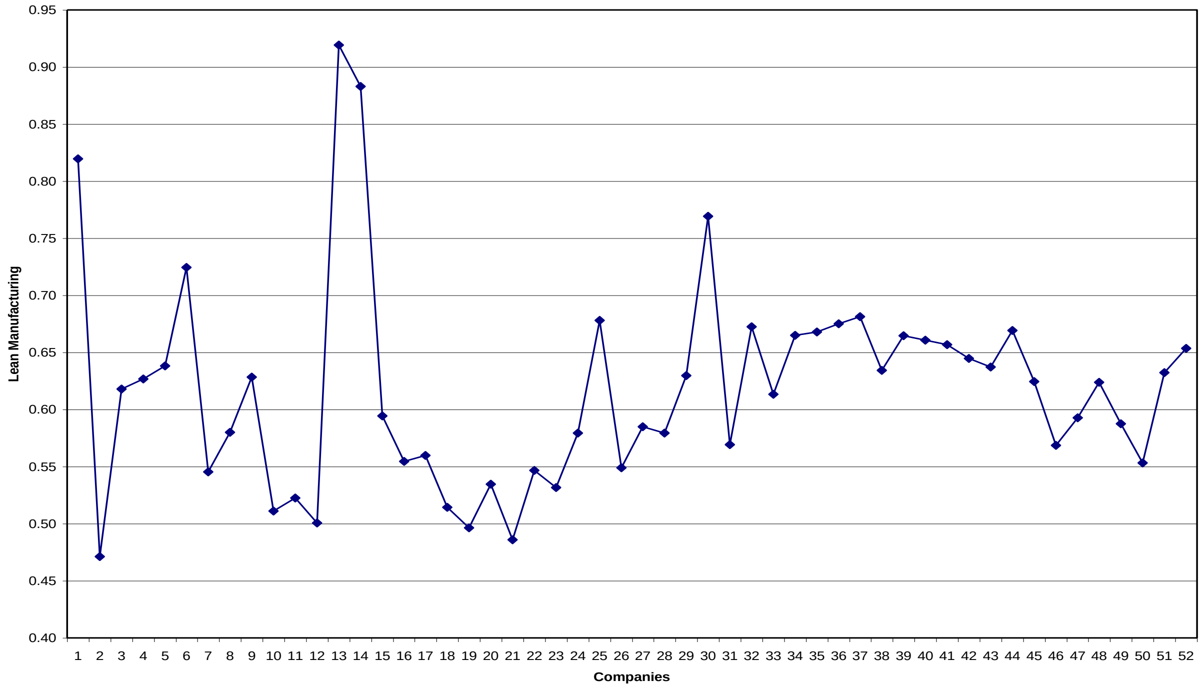

Figure 2: Showing Status of Lean Manufacturing in Surveyed Companies

C. Interrelationship between various parameters of machine flexibility

To find out the interrelationship among various parameters of MF, Pearson correlations have been worked out as shown in Table 7. A total of 56 correlations were found out, out of which 54 came to be significant. Further, 46 of these correlations are significant at a level of $p \leq 0.01$ and 8 at a level of $p \leq 0.05$. These results depict that, in general, all parameters are complementary to each other barring a few.

It is seen from the results of correlation analysis that 'ability of machines to perform diverse set of operations' (MF1) has a positive and significant relationship with all other parameters of MF as well as with entire MF except with 'cost effectiveness of operations over machine change' (MF4). This reflects a very interesting phenomenon that although more than one machine can perform a job but the efficiency of machines for various jobs is different and hence it may be little costly to perform jobs on machines other than regular.

Table 7: Coefficient of Correlation Between Various Parameters of Machine Flexibility

Parameter	MF1	MF2	MF3	MF4	MF5	MF6	MF7	MF
MF1	1	0.500**	0.334*	0.070	0.458**	0.386**	0.466**	0.805**
MF2		1	0.416**	0.531**	0.501**	0.588**	0.382**	0.712**
MF3			1	0.416**	0.281*	0.557**	0.327*	0.595**
MF4				1	0.513**	0.501**	0.571**	0.534**
MF5					1	0.365**	0.606**	0.710**
MF6						1	0.290*	0.748**
MF7							1	0.697**
MF								1

** Correlation is significant at $p \leq 0.01$ level * Correlation is significant at $p \leq 0.05$ level

Machine setup or change over (MF2) has significant relationships with all the factors of machine flexibility. This indicates towards the important aspect that machine flexibility is largely dependent on how fast the changeovers are made on the machine. If the changeovers or setups are fast and efficient all other areas of machine flexibility are also contributed positively. Time and effort needed to change the tools and operations (MF3) which, of course, are a part of machine or setup changeover are also significant and positively correlated with all other aspects of machine flexibility.

Cost effectiveness of operations over machine change (MF4) is significantly correlated with all other aspects of machine flexibility except 'ability of machines to perform diverse set of operations' (MF1). All other parameters namely 'productivity effectiveness due to change of machine' (MF5), 'obsolescence rate of machines at introduction of new products' (MF6) and 'reliability of machines over job change' (MF7) have positive and significant relations with all other parameters of machine flexibility indicating towards their complementary nature.

D. Interrelationship between various parameters of lean manufacturing

To assess the interrelationships of various parameters of lean manufacturing Pearson correlations have been worked out. Table 8 shows these relationships. A total of 90 correlations are found out, out of which 88 came to be significant. Further, 80 of these correlations are significant at a level of $p \leq 0.01$ and 8 at a level of $p \leq 0.05$.

This reflects that all factors of lean manufacturing are complementary to each other. If an improvement is made in one, the others also get improved. One relationship which has not shown strong relationship is between 'elimination of waste' (LM1) and 'integration of functions' (LM8). This depicts that integration of various functions has not taken place in organization in direct proportion to elimination of waste. It points out to the fact that presently waste elimination is not an integrated effort among various functions. Rather it is the result of individual efforts made by various functions.

Table 8: Coefficient of Correlation Between Various Parameters of Lean Manufacturing

Parameter	LM1	LM2	LM3	LM4	LM5	LM6	LM7	LM8	LM9	LM
LM1	1	0.498**	0.378**	0.544**	0.347*	0.285*	0.442**	0.252	0.635**	0.699**
LM2		1	0.763**	0.797**	0.704**	0.740**	0.634**	0.574**	0.503**	0.861**
LM3			1	0.632**	0.592**	0.625**	0.412**	0.526**	0.535**	0.741**
LM4				1	0.778**	0.731**	0.599**	0.659**	0.422**	0.922**
LM5					1	0.809**	0.511**	0.495**	0.285*	0.797**
LM6						1	0.573**	0.662**	0.297*	0.820**
LM7							1	0.518**	0.679**	0.680**
LM8								1	0.414**	0.712**
LM9									1	0.598**
LM										1

** Correlation is significant at $p \leq 0.01$ level * Correlation is significant at $p \leq 0.05$ level

E. Relationship between various parameters of machine flexibility and lean manufacturing

In order to examine the nature and extent of relationship between various parameters of MF and lean manufacturing, Pearson coefficient of correlations have been found out. The results of the correlations are shown in table 9.

Table 9: Correlation Between Machine Flexibility and Lean Manufacturing Parameters

Parameter	LM1	LM2	LM3	LM4	LM5	LM6	LM7	LM8	LM9	LM
MF1	0.419**	0.608**	0.412**	0.708**	0.754**	0.694**	0.532**	0.487**	0.318*	0.727**
MF2	0.383**	0.316*	0.439**	0.353*	0.245	0.348*	0.394**	0.417**	0.393**	0.465**
MF3	0.438**	0.215	0.168	0.119	0.220	0.288*	0.395**	0.306*	0.509**	0.353*
MF4	0.545**	0.146	0.192	0.059	-0.121	-0.037	0.291*	-0.012	0.541**	0.218
MF5	0.517**	0.343*	0.250	0.358**	0.243	0.206	0.562**	0.275*	0.503**	0.445**
MF6	0.317*	0.188	0.268	0.152	0.121	0.124	0.404**	0.175	0.496**	0.269
MF7	0.635**	0.424**	0.196	0.429**	0.317*	0.224	0.546**	0.121	0.475**	0.490**
MF	0.605**	0.521**	0.406**	0.543**	0.503**	0.470**	0.657**	0.397**	0.595**	0.658**

** Correlation is significant at $p \leq 0.01$ level * Correlation is significant at $p \leq 0.05$ level

The results of analysis illustrates that 'ability of machines to perform diverse set of operations' (MF1) is positively and significantly related with all parameters of lean manufacturing and entire lean manufacturing (LM). This shows that ability of machines to perform diverse set of operations' (MF1) contributes to all aspects of lean manufacturing. Machine setup or changeover (MF2) is also positively and significantly related with all parameters of LM and entire lean manufacturing except 'pull of raw materials' (LM5). This shows that 'machine setup or changeover' (MF2) is complementary in nature with all parameters of lean manufacturing except pull of raw material (LM5).

Time and effort needed to change the tools and operations (MF3) is positively and significantly related with 'elimination of waste' (LM1), 'multifunctional teams' (LM6), 'decentralization' (LM7), 'integration of functions' (LM8), 'vertical information system' (LM9) and with total lean manufacturing (LM). However, its relationship with ‘continuous improvement’ (LM2), ‘zero defects’ (LM3), ‘just in time deliveries’ (LM4) and ‘pull of raw materials’ (LM5) are not significant. It shows that ‘time and effort needed to change the tools and operations’ (MF3) contributes towards elimination of waste (LM1), multifunctional teams (LM6), decentralization (LM7), integration of functions (LM8) and vertical information system (LM9). It doesn’t significantly contribute towards continuous improvement (LM2), zero defects (LM3), just in time deliveries (LM4) and pull of raw materials (LM5) significantly.

Cost effectiveness of operations over machine change (MF4) is positively and significantly related with ‘elimination of waste’ (LM1), ‘decentralization’ (LM7) and ‘vertical information system’ (LM9). Its relationship with all other parameters of lean manufacturing is not significant. It depicts a very interesting fact that cost effectiveness of operations over machine change (MF4) contributes towards elimination of waste but doesn’t contribute toward continuous improvement (LM2), zero defects (LM3), just in time deliveries (LM4), pull of raw materials (LM5), multifunctional teams (LM6) and integration of functions (LM8).

Productivity effectiveness due to change of machine (MF5) is positively and significantly related with ‘elimination of waste’ (LM1), ‘continuous improvement’ (LM2), ‘just in time deliveries’ (LM4), ‘decentralization’ (LM7), ‘integration of functions’ (LM8), ‘vertical information systems’ (LM9) and entire lean manufacturing (LM). However, its relationship with ‘zero defects’ (LM3), ‘pull of raw materials’ (LM5) and ‘multifunctional teams’ (LM6) is not significant. It shows that productivity effectiveness due to change of machine (MF5) contributes towards lean manufacturing through elimination of waste, just in time deliveries, decentralization and improving the vertical information system.

Obsolescence rate of machines at introduction of new products (MF6) is positively and significantly related with ‘elimination of waste’ (LM1), ‘multifunctional teams’ (LM7) and ‘vertical information systems’ (LM9). However, its relationship with other parameters of lean manufacturing i.e. LM2, LM3, LM4, LM5, LM6, LM8 and total lean manufacturing (LM) is not significant. It indicates that obsolescence rate of machine at introduction of new products (MF6) contributes towards elimination of waste (LM1), multifunctional teams (LM7) and vertical information systems (LM9). It doesn’t much effect the continuous improvement (LM2), zero defects (LM3), just in time deliveries (LM4), pull of raw material (LM5), multifunctional teams (LM6) and integration of functions (LM8).

Reliability of machines over job change (MF7) is positively and significantly related with ‘elimination of waste’ (LM1), ‘continuous improvement’ (LM2), ‘just in time deliveries’ (LM4), ‘pull of raw materials’ (LM5) ‘decentralization’ (LM7), ‘vertical information systems’ (LM9) and entire lean manufacturing (LM). However, its relationship with ‘zero defects’ (LM3), ‘multifunctional teams’ (LM6) and ‘integration of functions’ (LM8) is not significant. This shows that reliability of machines over job change (MF7) contributes towards lean manufacturing through improvement in elimination of waste (LM1), continuous improvement (LM2), just in time deliveries (LM4), pull of raw materials (LM5), decentralization (LM7) and vertical information systems (LM9). It is indicated from the above analysis that MF is, in general, of a harmonizing nature with all parameters of lean manufacturing.

V. DISCUSSION

A. Multiple regression analysis

The purpose of analysis under this section has been to identify a set of variables which conjointly contribute significantly towards the criterion variable. Coefficients of multiple correlation and corresponding coefficients of multiple stepwise regressions are set up by taking various parameters of LM as the criterion variables and various parameters of MF as predictor variable.

Multiple regression analysis is a method of analyzing the collective and separate contribution of two or more independent variables ‘X’ to the variation of dependent variables ‘Y’. The square of multiple correlations (R^2) is called the coefficient of determination, shows the proportion of variance of the criterion accounted for by different predictors. A stepwise multiple regression analysis enables to know the most relevant variables which account for maximum variance in the criterion from the total set of variables.

B. Multiple regression of machine flexibility parameters towards lean manufacturing

A stepwise multiple regression analysis is carried out taking each parameter of LM as criterion variable and MF parameters as predictive variables to analyze the collective and separate contribution of two or more MF parameters as independent variables to the variation of each LM parameters as dependent variable.

Table 10 shows various parameters of machine flexibility as predictive variables used in the study, multiple R of the selected variables with the criterion variable i.e. elimination of waste, and the value of R^2, the conjoint contribution of all the selected variables taken together towards the criterion variable. Further to test the significance of value of R^2, F values are also calculated. Out of the seven variables of machine flexibility only four variables 'ability of machines to perform diverse set of operations' (MF1), 'time and effort needed to change the tools and operations' (MF3), 'cost effectiveness of operations over machine change' (MF4) and 'reliability of machines over job change' (MF7) have emerged to be significant predictors of elimination of waste (LM1). Conjoint predictive value of these machine flexibility parameters for elimination of waste is 51.1% (R^2 = 0.511). It is inferred that 51.1% of whatever leads to increase in elimination of waste can be attributed to MF1, MF3, MF4 and MF7. The remaining 48.9% of elimination of waste is attributed to other factors. Thus it is the ability of machines to perform diverse set of operations with minimum time and effort needed to change the tools and operations along with the cost effectiveness of operations and reliability of machines over job change which contribute towards elimination of waste to achieve lean manufacturing.

Out of seven, only one parameter of machine flexibility 'ability of machines to perform diverse set of operations' (MF1) has emerged to be the potential predictor for increase in continuous improvement to achieve lean manufacturing. The value of R^2 is 0.370. The analysis depicts that the 37.0% of whatever leads to increase in continuous improvement is attributable to ability of machines to perform diverse set of operations (MF1) and the remaining 63.0% is attributed to other factors.

Table 10: Multiple Regression Analysis

Criterion Variable	Variables Selected	Multiple R	R^2	dF	F Value
Elimination of waste (LM1)	MF1	0.419	0.176	50	10.655
	MF1, MF3	0.525	0.275	49	09.311
	MF1, MF3, MF4	0.674	0.455	48	13.349
	MF1, MF3, MF4, MF7	0.715	0.511	47	12.279
Continuous improvement (LM2)	MF1	0.608	0.370	50	29.393
Zero defects (LM3)	MF1	0.412	0.170	50	10.208
	MF1, MF2	0.492	0.242	49	07.819
Just in time deliveries (LM4)	MF1	0.708	0.501	50	50.165
Pull of raw materials (LM5)	MF1	0.754	0.568	50	65.863
	MF1, MF6	0.776	0.602	49	37.097
Multifunctional teams (LM6)	MF1	0.694	0.481	50	46.392
Decentralization (LM7)	MF1	0.532	0.283	50	19.744
	MF1, MF4	0.590	0.348	49	13.058
	MF1, MF4, MF5	0.645	0.416	48	11.417
Integration of functions (LM8)	MF1	0.487	0.237	50	15.523
Vertical information systems (LM9)	MF1	0.318	0.101	50	05.636
	MF1, MF2	0.417	0.174	49	05.169
	MF1, MF2, MF3	0.553	0.305	48	07.030
	MF1, MF2, MF3, MF4	0.654	0.428	47	08.787
Lean manufacturing (LM)	MF1	0.727	0.528	50	56.037

Two variables 'ability of machines to perform diverse set of operations' (MF1) and 'machine setup or changeover' (MF2) contribute significantly towards achieving zero defects (LM3). The value of R^2 which is 0.242, illustrates that 24.2% of whatever leads to achieve zero defects is attributable to these two parameters of machine flexibility.

Only one parameter of machine flexibility 'ability of machines to perform diverse set of operations' (MF1) is significantly contributed towards 'just in time deliveries' (LM4). The value 0.501 of R^2 illustrates that

50.1% of whatever leads to achieve just in time deliveries is attributable to ability of machines to perform diverse set of operations (MF1) and remaining 49.9% is attributed to other factors. Thus ability of machines to perform diverse set of operations has emerged as the main parameter of machine flexibility to be focused on for just in time deliveries to achieve lean manufacturing.

Out of all the seven variables of machine flexibility only two variables MF1 and MF6 have emerged to be significant predictors of pull of raw materials (LM5). Conjoint predictive value of these MF parameters for pull of raw materials is 60.2% (R^2 = 0.602). It is inferred that 60.2% of whatever leads to increase in pull of raw materials can be attributed to 'ability of machines to perform diverse set of operations' (MF1) and 'obsolescence rate of machines at introduction of new products' (MF6) for achieving lean manufacturing. The remaining 39.8% of pull of raw materials is attributed to other factors.

Only one parameters of MF, ability of machines to perform diverse set of operations (MF1) has emerged to be significant predictor of multifunctional teams (LM6). Predictive value of this machine flexibility parameter for multifunctional teams is 48.1% (R^2 = 0.481). It is inferred that 48.1% of whatever leads to promote multifunctional teams can be attributed to MF1 to achieve lean manufacturing. The remaining 51.9% of multifunctional teams is attributed to other factors.

Three parameters of machine flexibility 'ability of machines to perform diverse set of operations' (MF1), 'cost effectiveness of operations over machine change' (MF4) and 'productivity effectiveness due to change of machines' (MF5) have emerged to be significant predictors of decentralization (LM7). Conjoint predictive value of these machine flexibility parameters for decentralization is 41.6% (R^2 = 0.416). It is inferred that 41.6% of whatever leads to encourage decentralization can be attributed to MF1, MF4 and MF5 to achieve lean manufacturing. The remaining 58.4% of decentralization is attributed to other factors.

Only ability of machines to perform diverse set of operations (MF1) has emerged to be significant predictor of integration of functions (LM8). Predictive value of this machine flexibility parameter for integration of functions is 23.7% (R^2 = 0.237). It is inferred that 23.7% of whatever leads to increase in integration of functions can be attributed to MF1 to achieve lean manufacturing. The remaining 76.3% of integration of functions is attributed to other factors.

Four parameters of machine flexibility 'ability of machines to perform diverse set of operations' (MF1), 'machine setup or changeover' (MF2), 'time and effort needed to change the tools and operations' (MF3) and 'cost effectiveness of operations over machine change' (MF4) have emerged to be significant predictors of vertical information systems (LM9). Conjoint predictive value of these machine flexibility parameters for vertical information systems is 42.8% (R^2 = 0.428). It is inferred that 42.8% of whatever leads to encourage vertical information systems can be credited to MF1, MF2, MF3 and MF4 to achieve lean manufacturing. The remaining 57.2% of vertical information systems is credited to other factors.

Only one parameter of machine flexibility i.e. ability of machines to perform diverse set of operations (MF1) has emerged to be significant predictor of entire lean manufacturing. Predictive value of this machine flexibility parameter for lean manufacturing is 52.8% (R^2=0.528). Thus ability of machines to perform diverse set of operations (MF1) has emerged to be the sole major contributor of lean manufacturing with a contribution of 0.528.

VI. CONCLUSIONS

In MF, the most important factor as per expert opinion is ability of machines to perform diverse set of operations. This has been supported by the correlation analysis where it is seen that this parameter contributes (0.805) maximum to the effective MF. However a look at the average score of the industry in parameters of MF reveals that the highest score has not got by this aspect rather another parameter, 'reliability of machines over job change'. Ability of machines to perform diverse set of operations has the least standard deviation (0.0963), showing that the unit to unit variation in this aspect is quite low. This indicates that most of the manufacturing industries are focusing on this parameter with top priority.

Having ability and reliability of machines to perform diverse set of operations is important but equally important are machine setups or changeover and cost effectiveness of operations over machine change. Low scores in these aspects point towards lack of awareness of the changeover cost effectiveness of machine operations. Overall score of MF in the manufacturing industry is not all that bad with many units above a reasonably good score of 0.80. But the matter of concern is large variation in the score of the companies which is evident from the fact that many organizations have a score less than 0.60. Lack of direction is another flaw found in the strategy adopted by the industry.

As per the rating given by experts through AHP process ‘elimination of waste’ has emerged to be the most important aspect of lean manufacturing. The same has been depicted by the correlation analysis. The analysis of the response of the survey shows that the industry has realized it and is paying attention to elimination of waste. This is indicated by the highest score of this aspect among all parameters of lean manufacturing. Overall scores of industrial units in lean manufacturing depict that the situation is reasonably good with many organizations receiving a score above 0.70. However, higher value of standard deviation (0.1599) in case of ‘integration of functions’ LM8 points out large variations within the surveyed units with regard to this aspect. Depicting that in some companies’ integration of functions is done regularly while in others it is not.

An important conclusion of the correlation analysis is that aability of machines to perform diverse set of operations has a positive and significant relationship with all other parameters of machine flexibility except cost effectiveness of operations over machine change. This shows that although more than one machine can perform a job but the efficiency of machines for various jobs is different and hence it may not be cost effective. Interrelationship of lean manufacturing parameters shows that all parameters complement each other except the relationship between ‘elimination of waste’ and ‘integration of functions’. It can be concluded that presently waste elimination is not an integrated effort among various functions. Rather it is the result of individual efforts made by various functions. Correlation analysis between overall MF and lean manufacturing depict that MF contributes towards all aspects of lean manufacturing including, elimination of waste, continuous improvement, achieving zero defects, just in time, pull system, multifunctional teams, decentralization, integration of functions and vertical information systems.

From the results of multiple regressions analysis between the parameters of MF and those of lean manufacturing it can be concluded that only one parameter of MF mainly contribute to overall lean manufacturing. This parameter is ‘ability of machines to perform diverse set of operations’ and inferred 52.8% alone to achieve lean manufacturing.

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