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Measuring the status of lean manufacturing using AHP

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ABSTRACT : Even though many managers and academicians have cited lean manufacturing as a key competitive capability, efforts to measure and understand this complex construct continue. Consequently in this paper, we address the issue of lean manufacturing measurement, and then use these measures to better understand lean. A survey was carried to accomplish the status of lean manufacturing in the Indian manufacturing industry. Over more than 50 companies participated in this survey. Nine important elements i.e. elimination of waste ; continuous improvement; zero defects; just in time deliveries; pull of raw materials; multifunctional teams; decentralization; integration of functions and vertical information systems are identified to assess the lean manufacturing. Information on these elements is collected by using a specially designed and pre-tested survey instrument. A paired comparison of these elements has been carried out to find out their impact on lean manufacturing by drawing a position matrix by using analytical hierarchy process (AHP) modeling. The pair wise comparison was done by three experts to calculate the maximum value of Eigen vector. Along with scale development, establishing statistical relationships between lean manufacturing elements provides a better basis for measuring and creating a holistic understanding of this complex concept.

Keywords : Lean Manufacturing; Analytical Hierarchy Process (AHP); Elements; Manufacturing Industry.

I. INTRODUCTION

To stay close to the customers is essential for sustained growth and continuity of business. This forces all organizations to continue to evaluate customer needs and problems and take the best possible course of action to satisfy them. The need of the hour is to deliver high quality products through continuous improvements in product features, bring new products to the market, and make product changes faster and more manageable. Manufacturing organizations throughout the world are under great pressure to reduce time to market, reduce the cost, and meet the global quality standards, while coping with variety or customization pressures. Improving forecasting accuracy of the product demands, reduce costs, improve employee training, skills and education levels, improve information systems and networks and achieve manufacturing excellence through lean manufacturing is the hymn of survival and success. Minimizing wastage of resources and moving towards implementation of lean manufacturing have become key strategies to achieve cost cutting. The goal of Lean Manufacturing is to incorporate 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 top quality products in the most efficient and economical manner.

The first objective of this paper is to found the suitable measuring elements of lean manufacturing. The second and main objective is to examine the status of lean manufacturing in manufacturing industry. A brief description of the organization of the paper is presented below.

We define lean manufacturing and identify the contributing elements to each respectively. Formulate an Analytical Hierarchy Process (AHP) model to assess the weight of each element. Evaluate the status of lean manufacturing in manufacturing industry and analyze the data with SPSS 11.01 to find the correlation between various elements of lean manufacturing.

II. LITERATURE REVIEW

In the present dynamic business nature, leanness has undergone and still going a process of continuous and never ending evolution [1]. Since the introduction of the Toyota Production System, the lean concept has spread all over the world. The principle of lean manufacturing, of which process improvement is an important element was brought to the attention of the West by the publication of “The Machine that Changed the World” by Womack et al. [2]. This was followed by “Lean Thinking” [3] which was more practitioner focused. In addition, there have been many Japanese inspired books which focused on company’s specific production systems [4, 5]. On the other hand Bateman [6] relates process improvement with sustainability by identifying enablers associated with activities. Process improvement activities are a crucial tool for companies undergoing lean transformation and removing waste from their processes and he has suggested conducting more analytical study into what sustains the improvement made by these activities. There have also been a number of papers trying to identify what can be done to improve sustainability.

Boyer [7] stated the successful implementation of lean production rely on well-trained employees and other key to successful lean practice is worker empowerment, defined as giving workers more responsibility and control of the manufacturing process. This is because only employees can identify ways of improving the existing process or product [8]. Management that fails to embrace the implementation of lean process may interrupt the effort to improve business performance and identified management support and communications as important variables in a lean manufacturing implementation [9]. Maleyeff [10] presents the first known large-scale assessment of problems and opportunities in applying Lean principles to internal service systems. The review provides evidence that lean manufacturing is most fundamental and important key to survival. Although, isolated methods for assessing lean manufacturing have been developed, we provide a generic quantitative statistic flexible approach to measure lean manufacturing incorporate a number of technological elements in its design. Karlsson and Ahlstrom [11] principles of lean production forms the basis for measuring status of lean manufacturing in the present study.

III. RESEARCH METHODOLOGY

For measuring lean manufacturing, various elements contributing towards lean manufacturing (LM) are identified from the literature review. A paired comparison of these elements has been done by three experts to find out their weight by drawing position matrixes by using analytical hierarchy process (AHP). Further; questions have been framed related to these elements in a specially designed questionnaire to know the response of the manufacturing firms to these elements. Information lies also been collected through personnel discussions with persons at different levels in the company to know the level of LM. The survey was carried out in manufacturing industry of India. The methodology adopted includes the following :

(*a*) Design of a questionnaire covering various elements of LM and it's pre-testing.

(*b*) Collection of information by taking response in questionnaire and through personal visits.

(*c*) Analysis of information and assessing the status of LM in survey firms.

(*d*) Assessing the correlation analysis between various elements of LM.

A. Analytical hierarchy process (AHP)

The analytical hierarchy process has been used while finding lean manufacturing. Saaty [12, 13] describe and elaborate the process. Paired comparison is based on the idea that a complex issue can be effectively examined if it is hierarchically decomposed into its parts. The elements are compared with each other. Thus providing an opportunity for a pair-wise comparison for evolving the structure into a mxm reciprocal judgement matrix. In the matrix, one begins with an element on the left and compares how much more important it is than an element on top. When compared with itself, the ratio is one. When compared with another element, if it is more important than that element, an integer value as discussed below is used. If, however, it is less important, then reciprocal of the previous integer value is used. In either case reciprocal value is entered in the transpose position of the matrix. Thus only m(m-1)/2 judgements are considered where n is the total number. The respondent is to concentrate on only two elements at a time. A scale of 1 to 9 is used for giving judgement value according to the following guide lines :

= 1 if i and j are equally important,

= 3 if i is weakly more important than j

= 5 if i is strongly more important than j

= 7 if i is very strongly more important than j

= 9 if i is absolutely more important than j.

Values of 2, 4, 6 and 8 are used to compromise between two judgements.

The weightages of the features are obtained by calculating the Eigen Vector weights for the judgement matrix. An index of consistency is calculated to provide information on how serious is violations of numerical and transitive consistency. The results could be used to seek additional information and re-examine the data used in constructing the scale in order to improve consistency. Each entry in column j of pair wise comparison matrix is divided by the sum of the entries in column j. This yields normalized matrix A_w. Eigen vector 'c' is found out by dividing the sum of all the entries in rows i with 'm' no. elements of normalized matrix.

$$Aw = \begin{bmatrix} \frac{a_{11}}{\Sigma a_{i1}} & \frac{a_{11}}{\Sigma a_{i2}} & \cdots & \frac{a_{1m}}{\Sigma a_{im}} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \frac{a_{m1}}{\Sigma a_{i1}} & \frac{a_{m2}}{\Sigma a_{i2}} & \cdots & \frac{a_{mm}}{\Sigma a_{im}} \end{bmatrix}$$

$$c = \begin{bmatrix} c_1 \\ c_2 \\ \cdots \\ \cdots \\ c_m \end{bmatrix} = \begin{bmatrix} \dfrac{\frac{a_{11}}{\Sigma a_{i1}} + \frac{a_{12}}{\Sigma a_{i2}} + \cdots + \frac{a_{1m}}{\Sigma a_{im}}}{m} \\ \cdots \quad \cdots \quad \cdots \quad \cdots \\ \cdots \quad \cdots \quad \cdots \quad \cdots \\ \dfrac{\frac{a_{m1}}{\Sigma a_{i1}} + \frac{a_{m2}}{\Sigma a_{i2}} + \cdots + \frac{a_{mm}}{\Sigma a_{im}}}{m} \end{bmatrix}$$

It is necessary to check the consistency in the pair wise comparison matrix and the validation of the AHP. Compute AC in the following forms:

$$Ac = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1m} \\ a_{21} & a_{22} & \dots & a_{2m} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mm} \end{bmatrix} \times \begin{bmatrix} c_1 \\ c_2 \\ \dots \\ \dots \\ c_m \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ \dots \\ \dots \\ x_m \end{bmatrix}$$

The consistency index (CI) is computed as follows. Where m is the number of elements being compared and ?$_{max}$ is the largest Eigen value of the judgement matrix.

$$CI = \frac{(\lambda_{max} - m)}{(m - 1)}$$

$$\lambda_{max} = \frac{1}{m}\ \frac{\Sigma i\text{thentryin } AC}{i\text{thentry in } C}$$

$$= \frac{1\Sigma X_i}{mC_i}$$

Consistency ratio *CR* can be calculated by dividing *Cl* by the random consistency number for the same size matrix.

$$CR = \frac{CI}{RI}$$

Find the maximum Eigen value, consistency index *CI*, consistency ratio *CR*, and normalized values for each criterion alternative. If the maximum Eigen value, *CI*, and *CR* are satisfactory, then decision is taken based on the normalized values; else the procedure is repeated till these values lie in a desired range consistency ratio *CR* can be obtained. The value of *CR* should be around 10% or less to be acceptable. In some cases a maximum value may be tolerated. If *CR* is not within this range, participants should study the problem and revise their judgement.

B. Scale development

Precise scale development is a time-consuming attempt, which is also evidenced by the fact that between 1989 and 1996, Hensley [14] could find only six studies in the operations management literature that utilized and described a formalized, complete scale development process using questionnaire data. A questionnaire was specially designed to collect information on various elements of LM. Seven point likert-type scales were used. The scales ranged from “strongly disagree” to “strongly agree”, with a middle anchor point of “neither agree nor disagree” [15]. The questionnaire, thus made, was pre-tested on a random sample of twelve industries chosen covering every region, size and products of the industries to be surveyed. Questionnaire reliability testing is done with the SPSS 11.01 software. Acceptable value of reliability coefficient (a =0.9119) is achieved [16]. To ensure the effectiveness and relevance of the questions to the industry, the suggestions given by senior executives from industry and academicians were incorporated. Prior to finalizing the instrument, a through review of all the survey items was undertaken and changes were made. Status of lean manufacturing was found out from the levels of different elements implementation on 0-1 scale. The value of various elements have been worked out from the raw scores collected from the response of the questionnaire using the following formula.

Theoretical Value of Element,

$$S_E = \frac{\Sigma Sai}{nSm} \qquad ...(1)$$

Where Sai is the actual score of i^{th} question of element, which is further equal to

$$\Sigma \text{Sai} = S_1 + S_2 + ... + S_n \qquad ...(2)$$

Si is the score of a company in a question

(*i* varies from 1 to 7)

n is the number of questions in element, and

Sm is the maximum possible score of a question *i.e.*, 7.

The actual element value has been worked out from the calculated weights of the elements using AHP and the theoretical value of the various elements calculated in eq. 1 using the following equation :

Element actual value,

$$S_V = S_E \times W_X \qquad ...(3)$$

Where W_X is the weight and S_E is the theoretical value of the X^{th} element.

Lean Manufacturing,

$$\text{LM} = \Sigma S_{Va} + S_{Vb} + ... + S_{Vi} \qquad ...(4)$$

C. Data collection

Engineering manufacturing industries of northern India were considered. The engineering industry produces a wide range of products like tractors, machine tools, cycles, auto parts, pressure vessels, presses, electrical and construction machinery, plant and machinery for cement; paper and sugar, and a large number of other industrial and consumer goods. A list was prepared by referring to the directories of industries. A total of 186 industries were selected. The survey instrument was mailed to all 186 organizations in the sample frame along with a write-up on the objective of the survey and its usefulness for the industries. In spite of all the efforts total of 52 completed survey instruments were received. Survey provides a satisfactory response rate of 27.96% comparing with other empirical research [16, 17, 18] and considered acceptable in operations management survey research [19]. The survey sample consists of the desired mix of medium and large firms [17]. Thus, the objective of creating a sample of medium and large firms was accomplished. Out of the responding firms, 34 were from private sector and 18 were from public sector. Analyzing it from scale-wise, the response from large scale firms is 37.03% and from medium scale, it is 24.24%.

IV. MEASUREMENT OF LEAN MANUFACTURING

Lean manufacturing is aimed at the elimination of waste in every area of production including customer relations, product design, supplier networks and factory management. The goal of Lean Manufacturing is to incorporate 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 top quality products in the most efficient and economical manner. Soriano-Meier and Forrester [20] described the principles to measure the degree of leanness in manufacturing firms whereas Ohno [4] describes lean manufacturing as a management philosophy focusing on reduction of the seven manufacturing related wastes. Lean Manufacturing has been found out for each company from the response to the questions framed on the following elements:

(*a*) Elimination of waste.

(*b*) Continuous improvement.

(*c*) Zero defects.

(*d*) Just in time deliveries.

(*e*) Pull of raw materials.

(*f*) Multifunctional teams.

(*g*) Decentralization.

(*h*) Integration of functions.

(*i*) Vertical information systems.

Although various elements, as listed above, contribute towards lean manufacturing yet their contribution cannot be assumed equal. Weights of some elements are more than the others. To determine their relative weights, AHP has been employed. Each element has been compared with other elements pair wise. The comparison has been carried out by experts chosen for the purpose. The weight of each element towards lean manufacturing has been determined by calculating an eigenvector and normalizing it. Table 1 depicts the weight of different elements judged by experts using AHP. The value of lean manufacturing of the surveyed firms is found on 0 to 1 scale. Figure 1 shows a histogram presenting the range of lean manufacturing in the surveyed firms.

Table 1 : Weight of various elements of lean manufacturing.

Elements	Expert	Expert II	Expert III	Mean Weight
a	0.3365	0.3588	0.3593	0.3515
b	0.0434	0.0462	0.0461	0.0453
c	0.0892	0.0999	0.0999	0.0963
d	0.1780	0.2045	0.2044	0.1956
e	0.0434	0.0462	0.0999	0.0632
f	0.1780	0.0999	0.0999	0.1259
g	0.0212	0.0223	0.0222	0.0219
h	0.0891	0.0999	0.0461	0.0784
i	0.0212	0.0223	0.0222	0.0219

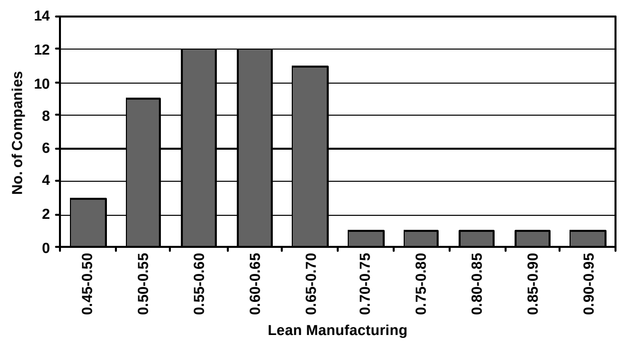

Fig. 1. Range of lean manufacturing in surveyed companies.

V. RELATIONSHIP STRENGTH OF LEAN MANUFACTURING ELEMENTS

Pearson coefficient of correlation (r) has been worked out with SPSS 11.01 between the various elements of lean manufacturing as shown in Fig. 2. Pearson coefficient of correlation illustrates the strength of relationship among them. To assess the strength of various elements of lean manufacturing (LM) over one another, interrelationship of various elements and with total LM has been found out. The values of coefficients of correlation between various elements are shown in Table 2. Total 90 correlations were found out, out of which 88 came to be significant. Further, 80 of these correlations are significant at a level of p d" 0.01 and 8 at a level of p d" 0.05. Elimination of waste (*a*) is positively and significantly related (b with r = 0.498), (c with r = 0.378), (d with r = 0.544), (g with r = 0.442), (i with r =0.635) and with total LM (r = 0.699) at p d" 0.01 level. It is also positively and significantly related (e with r = 0.347) and (f with r = 0.285) at p d" 0.05 level.

Continuous improvement (*b*) has a positive and significant relation with all other elements of LM and with total LM at p d" 0.01 level with a minimum value of r = 0.498 for (a) and maximum value of r = 0.861 for total LM. Zero defects (c) is also has a positive and significant relation with all other elements of LM and with total LM at p d" 0.01 level. Whereas value of correlation ranges from 0.378 to 0.741.

Just in time deliveries (d) is positively and significantly related with (a), (b), (c), (e), (f), (g), (h), (i) and also with LM at p d" 0.01 level with r = 0.544, 0.797, 0.632, 0.778, 0.731, 0.599, 0.659, 0.422 and 0.922 respectively. Pull of raw materials (e) is positively and significantly related (b with r = 0.704), (c with r = 0.592), (d with r = 0.778), (f with r = 0.809), (g with r = 0.511), (h with r =0.495) and with total LM (r = 0.797) at p d” 0.01 level. It is also positively and significantly related (a with r = 0.347) and (i with r = 0.285) at p d” 0.05 level.

Multifunctional teams (f) is positively and significantly related (b with r = 0.740), (c with r = 0.625), (d with r = 0.731), (e with r = 0.809), (g with r = 0.573), (h with r =0.662) and with total LM (r = 0.820) at p d” 0.01 level. It is also positively and significantly related (a with r = 0.285) and (i with r = 0.297) at p d” 0.05 level.

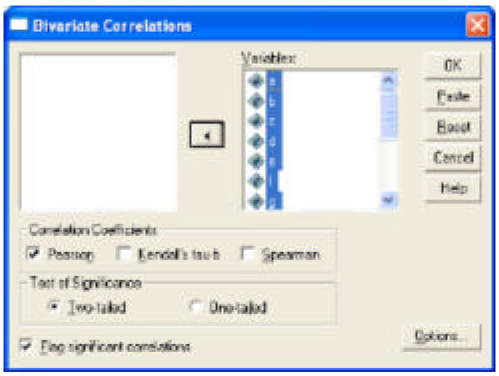

Fig. 2. Pearson correlation window.

Decentralization (g) has a positive and significant relation with all other elements of LM and with total LM at p d” 0.01 level. Whereas value of correlation ranges from 0.412 to 0.680. Integration of functions (h) is positively and significantly related (b with r = 0.574), (c with r = 0.526), (d with r = 0.659), (e with r = 0.495), (f with r = 0.662), (g with r =0.518), (i with r = 0.414) and with total LM (r = 0.712) at p d” 0.01 level.

Vertical information systems (i) is positively and significantly related (a with r = 0.635), (b with r = 0.503), (c with r = 0.535), (d with r = 0.422), (g with r = 0.679), (h with r = 0.414) and with total lean manufacturing (r = 0.598) at p d” 0.01 level. It is also positively and significantly related (e with r = 0.285) and (f with r = 0.297) at p d” 0.05 level.

Total LM is positively and significantly related with its all elements i.e. (a), (b), (c), (d), (e), (f), (g), (h) and (i) at p d” 0.01 level with r = 0.699, 0.861, 0.741, 0.922, 0.797, 0.820, 0.680, 0.712 and 0.598 respectively.

Table 2 : Coefficient of correlation between various elements of lean manufacturing.

Element	a	b	c	d	e	f	g	h	i	LM
a	1	0.498**	0.378**	0.544**	0.347*	0.285*	0.442**	0.252	0.635**	0.699**
b	0.498**	1	0.763**	0.797**	0.704**	0.740**	0.634**	0.574**	0.503**	0.861**
c	0.378**	0.763**	1	0.632**	0.592**	0.625**	0.412**	0.526**	0.535**	0.741**
d	0.544**	0.797**	0.632**	1	0.778**	0.731**	0.599**	0.659**	0.422**	0.922**
e	0.347*	0.704**	0.592**	0.778**	1	0.809**	0.511**	0.495**	0.285*	0.797**
f	0.285*	0.740**	0.625**	0.731**	0.809**	1	0.573**	0.662**	0.297*	0.820**
g	0.442**	0.634**	0.412**	0.599**	0.511**	0.573**	1	0.518**	0.679**	0.680**
h	0.252	0.574**	0.526**	0.659**	0.495**	0.662**	0.518**	1	0.414**	0.712**
i	0.635**	0.503**	0.535**	0.422**	0.285*	0.297*	0.679**	0.414**	1	0.598**
LM	0.699**	0.861**	0.741**	0.922**	0.797**	0.820**	0.680**	0.712**	0.598**	1

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

VI. CONCLUSION

This paper presents a generic and flexible methodology framework to assess the status of lean manufacturing in manufacturing sector. We identify the most relevant elements which contribute toward lean manufacturing. All the coefficients of correlation are positive and significant, proves the feasibility and reliability of the elements identified for measuring lean manufacturing.

In this paper we establish a hierarchy of the various elements of lean manufacturing using the AHP. This hierarchy depicts the importance of various elements on the basis of their contributed weights toward implementation of lean manufacturing. Elimination of wastes has maximum impact (35.15 %) and integration of functions and vertical information system having least impact of 2.19 % each whereas all other elements have in between. This hierarchy will help to decide future strategy to implement lean manufacturing in manufacturing industry.

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