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The Formulation of a model to establish the lean score through the lean attributes by eliminating major losses to improve lean performance

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Abstract–**Lean manufacturing concept is becoming a very important strategy for both academicians and practitioners in the recent times, and Japanese are using this practice for more than a decade. Although it was being adopted by many industries throughout the world, but due to lack of clear understanding of lean manufacturing practices, it is difficult to achieve the best performance and measurement through it. There are many papers, articles and research are available for lean techniques and tools, but very few will have a systematic focus on lean performance evaluation. In this present scenario, this paper describes an innovative approach for lean performance evaluation by using fuzzy membership functions and formulating a model to establish the lean score through the lean attributes by eliminating major losses. The model is dynamic, flexible and easy to use. It shows a systematic lean performance measurement by producing a final integrated unit less-score.**

Index Terms– **fuzzy membership values, FMECA, lean metrics,lean performance, lean score, Major losses,Maintenance,TPM.**

I. Introduction

Lean manufacturing tools and techniques are well knowingly popularized over the last two decades and bringing a remarkable changes in all the wings of the manufacturing systems. In this contrast, particularly managers are going ahead in productivity by eliminating wastes through lean manufacturing tools and techniques. In this contrast, cost, quality and just in time (JIT) delivery and continuous improvement are playing a vital role [1]–[3]. Now-a-days, more companies are going to implement lean manufacturing tools and techniques, to become alive in this competitive global market and collectively striving to give the best to the customers. Unfortunately, most of the companies are being failed to implement the best practices of lean, due to lack of clear understanding of lean and its principles. Generally it is difficult to manage lean without measuring its performance. A number of models and techniques were developed and discussed for the measurement of lean and its practices [4], [5] . Previously qualitative techniques such as surveys are used to measure lean performance level [5]–[8]. But the results obtained by the surveys vary from different individuals [9] . After that benchmarking a comparative tool for the measurement of lean was proposed by many authors [10], [11]. By adopting this methodology, it is somehow hard to find the similar benchmarking company with our manufacturing specifications. Sometimes accessing to benchmarking data is also uneven and impossible so our paper proposes the self benchmarking process would become a solution. The past few years have witnessed a tremendous growth in the number and variety of applications of fuzzy logic (FL).With the help of fuzzy logic, we can specify mapping rules in terms of words rather than numbers. Calculating with the words gives us imprecision and tolerance. The basic fundamental of fuzzy logic system was given by Bojadziev and Bojadziev [12]. Nakajima S [13] has given the basic definitions of TPM and its importance, merits and demerits, goals and objectives, and steps to be followed while implanting TPM. The main objective of TPM is to improve productivity and quality along with increased employee morale and job satisfaction. TPM is an innovative approach for the maintenance and optimization of equipment effectiveness, eliminates breakdowns and other operator related wastes through day to day activities involving total employee force. Malay niraj [14] has given the heuristic approach for the frequency of maintenance and type of maintenance required for a firm on the basis of criticality and severity of the factors responsible. In this paper he has differentiated the best practices of TPM, basing on the criticality. A quantitative model is suggested in this paper for measurement of lean performance, by using fuzzy membership functions. Current performance of the manufacturing firm are quantified and compared with benchmarking data derived from the historical data and lean performance score is calculated and given to the managers to do further improvements and enhance the best results by taking appropriate actions.

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II. Literature Review

In this section, the lean history and some lean performance measurements are reviewed.

A. History of lean manufacturing systems

The Japanese automaker, Toyota has introduced the concept of lean and lean manufacturing which has been thriving the global competitive market for decades. In 1988, Ohno introduced the Toyota production systems (TPS) and developed in this company to overcome the difficulties after world war II. This TPS was developed to survive in tough economic crisis when there are limited resources. Due to vast shortage of men, material and everything, the TPS is decided to eliminate wastes in the shop floor in order to achieve the manufacturing goals. Because of this policy in hard times, the Toyota was remained as a world class manufacturer for its high efficient production systems. Shortage of resources made this company as bench marking company to the world automakers. The word Lean was first introduced by MIT professors to interpret Toyotas production system that does away with mass production [15], [16]. Actually lean production system is described as the high efficient system which uses fewer amounts of resources and gives more products with best quality and competitive cost. Generally lean is defined by many authors in different ways. An operational system that maximizes value added, reduces essential support and eliminates wastes in all processes throughout the value stream by John Workman. Lean is a toolbox which is full of tools and techniques and selected correctly for the correct improvement is defined by havardell [17] . Lean is a system which reduces costs, added with continuous improvements and customer satisfaction in terms of Womack and Jones [18] . Now a days, the lean concepts and its tools are being implanted beyond the shop floors like lean implementation in administration [19] , supply chains [20], and service sectors.

B. Measurement of lean performance system

A little effort has made on the literature survey while reviewing lean performance measurement. Some of the previous review on the related area will be discussed now. For measuring the degree of leanness of manufacturing systems, Soriano-Meier and Forrester [12] has carried out a survey on 30 UK manufacturing firms. They depend upon the model developed by Karlsson and Ahlstrom [21] which shows the lean production principles. They identified the nine lean performance variables like Zero defects (ZD), Elimination Of Wastes (EW), Pull Of Materials (PULL), Continuous Improvement (CI), JIT deliveries, Multifunctional teams (MFT), Decentralization (DEC), Integration Of Functions (IF), and Vertical Information Systems(VIS). Wan [12] developed a mathematical model by using data envelopment analysis (DEA) to measure the performance of leanness of the firms. In this aspect he makes decisions by comparing his data with the benchmarks which was derived from the historical data. In his study he has taken only the time based performance of leanness and does not involve any other losses and wastes. Next is Bayou and Corvin [2], in his paper he has developed a systematic algorithm for measuring the lean degree of performance by using fuzzy systems as lean performance is measured in degree. Srinivasaraghavan and Allada [22] emphasized the basic properties for assessing the lean performance metrics. In another paper Farzad Behrouzi and Kuan Yew Wong [21] developed an innovative approach to measure the lean performance of manufacturing systems by using fuzzy membership functions. In this paper the author measured the lean score of a manufacturing unit by taking the best and worst performances of lean attributes and using their fuzzy membership values.

C. Basic concepts of fuzzy logic

Bojadziev and Bojadziev [12] has given the theory and basic concepts of fuzzy sets. Fuzzy models give the fuzzy sets to represent the non statistical, uncertain and linguistic values. Definition 1: a fuzzy set A is defined by a set of order pairs,given in eq. 1.

$$A = \{(x, \mu_A(x))|\ x \epsilon A, \mu_A(x) \epsilon\ [0\ 1]\} \tag{1}$$

Where A(x) is a function called membership function; A(x) specifies the grade or degree to which any element x in A belongs to the fuzzy set A. Definition 2: A membership function of a triangular fuzzy number is defined as eq.2.

$$\mu_{F(x_i)} = \begin{cases} 1 \\ 1 - (\ \frac{x_i - a}{b - a}\ ) \\ 0 \end{cases} \begin{cases} \text{if } x_i \leq a \\ \text{if } a < x_i < b \\ \text{if } x_i \geq b \end{cases} \tag{2}$$

III. The Proposed Measurement Model

In this section, we will propose

1) The measurement of the lean performance by using multi attributes of the manufacturing firm
2) We will classify the lean attributes into categories, basing on the severity of its worst performance rate and by FMECA method.
3) Basing on severity, lean attributes and TPM best practices are differentiated and implemented.
4) We will compare the results of the lean score, before and after implementation of the best practices of TPM and its suitable remedies.

A. Measurement of lean score

For the measurement of lean score firstly we have to get data from the manufacturing unit and we have to get a deep study about the firm. We have to concentrate on the performance of the each machine and each process of the manufacturing unit. We have to find out the losses of the plant. As we have studied earlier in the lean manufacturing about the lean nine variables. Actually lean manufacturing systems means giving more value to the customers. In this study, Elimination of wastes, Continuous improvement, Zero defects and JIT deliveries are identified as a most important lean performance attributes which draws more attention for studying of the firm. Each lean attribute is measured with respect to cost, quality and time based categories for the performance of waste elimination and deliveries has been taken for measurement of JIT. Continuous improvement has to be given to all levels of the categories which is shown in fig.1.

While measuring the performance of the each attribute, it is difficult to choose the number of metrics for the best results. In this context the author have taken two metrics for some attributes and three for some attributes and are tabulated below in table I and the metrics are numbered. As the number of metrics increases, the lean score obtained is that much sensitive.

Now the author wants to bring the relation between each metric. So now he tries to calculate the performance of each

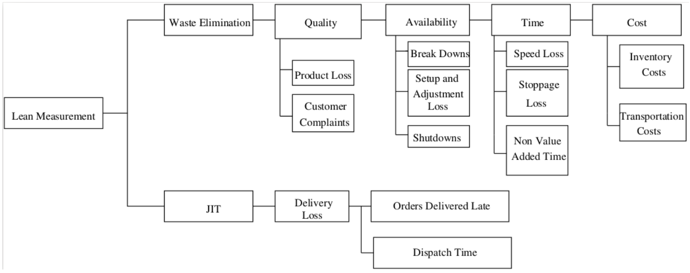

Fig. 1: Classification of lean metrics

Lean Attribute	Performance Category	Metrics (M)	Description
WASTE ELIMINATION	Quality Loss	1	Product Loss
		2	Number of customer complaints
	Availability Loss	3	Breakdowns
		4	Set up and Adjustment Loss
		5	Shutdowns
	Time Loss	6	Speed Loss
		7	Stoppage Loss
		8	Non Value Added Time
	Cost Loss	9	Annual Inventory Costs
		10	Annual Transportation Costs
JIT	Delivery Loss	11	Orders Delivered Late
		12	Dispatch Time

TABLE I: lean performance metrics

Metric	Formulation
Product Loss	$M_1 = \frac{Numberofstartuprejects+Numberofproductionrejects}{Totalnumberofproducts} \times 100$
Number of customer complaints	$M_2 = \frac{Numberofcustomercomplaints}{Totalnumberofcomplaints} \times 100$
Breakdowns	$M_3 = \frac{Breakdowntime}{Plannedproductiontime} \times 100$
Set up and Adjustment Loss	$M_4 = \frac{Timetakenforsetupandadjustmentloss}{Plannedproductiontime} \times 100$
Shutdowns	$M_5 = \frac{Numberofshutdowns}{Totalplannedshutdowns} \times 100$
Speed Loss	$M_6 = \frac{Actualproduction}{Desiredproduction} \times 100$
Stoppage Loss	$M_7 = \frac{Minorstoppagetime}{Operatingtime} \times 100$
Non Value Added Time	$M_8 = \frac{Idletime+Interferencetime+Linebalancingloss}{operatingtime} \times 100$
Annual Inventory Costs	$M_9 = \frac{Annualinventorycost}{Totalannualsales} \times 100$
Annual Transportation Costs	$M_{10} = \frac{Totalannualsales}{totalannualsales} \times 100$
Orders Delivered Late	$M_{11} = \frac{Ordersdeliveredlate}{Totaldeliveries} \times 100$
Dispatch Time	$M_{12} = Averagetotalnumberofdaysfromordersreceivedtodelivery$

TABLE II: Performance metrics and their indexes

metric and finally to get the unique lean score. Here the author implemented some formulaes for calculation which are tabulated below in table II.

Now we have to set the fuzzy area and membership functions for each performance metric by taking two values as point A and point B. Point A represent the best performance and point B represents the worst performance of the given metric. So by using those, we can fuzzify the metrics and can bring the fuzzy membership values to each metric, where the continuous improvement is given to all the metrics. Graphically, triangular areas are obtained to show the fuzzy areas and the membership values for the each metric can be obtained from Bojadziev and Bojadziev as eq.3 [12].

$$\mu_{F(M_i)} = \begin{cases} 1 \\ 1-(\frac{M_i - a}{b-a}) \\ 0 \end{cases} \begin{cases} \text{if } M_i \leq a \\ \text{if } a < M_i < b \\ \text{if } M_i \geq b \end{cases} \quad (3)$$

From the fuzzy set areas the author says that the point A is fixed its all values to zero, as it indicates the best performance of all metrics and the values at A must be reduced as much as low he can. At point B the worst performance has to be noted at that period. Fixing the points A and B is arbitrary and can be changed to different values by the manufacturers analyst. Now, it is time to calculate the lean score by taking average of all the performance metrics membership values. This score will be used as for lean evaluation the firm and used for the better improvement in the particular areas of the manufacturing unit. Lean performance score can be calculated as eq. 4 from Farzad Behrouzi and kuan Yew Wong [21].

$$LEANSCORE = (\sum_{i=1}^{12} \frac{\mu_F(M_i)}{12}) \times 100 \quad (4)$$

B. Classification of lean attributes

From the above relation, we can measure the performance of an individual firm. In the same way, the author had a survey around 30 industries in India, and obtained different lean scores for various industries. Basing on the lean score data of a particular industries, the author tries to differentiate the lean score s into different zones and they are tabulated below in table III.

Lean Score	Severity
0 <= 25	Super critical
25 >= 40	Critical
40 >= 60	Less critical
60 >= 100	Safe performance

TABLE III: Severity zones based on lean score

Basing on the data of the industrial survey, the author categorized the lean performance metrics under the lean severity zones which are tabulated in Table IV. Basing on the

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severity of the lean metrics, the author suggests the required maintenance practice and frequency of maintenance required from Malay Niraj [14].

Super Critical	Critical	Less Critical	Safe Performance
Breakdowns	Shutdowns	Non value added time	Annual inventory loss
Setup and adjustment loss	Speed loss	Late delivery	Dispatch time
Stoppage loss	Product loss	Customer complaints	
		Annual transportation cost	

TABLE IV: Classification of lean metrics based on severity

Severity	Maintenance Practice	Frequency of Maintenance
Super Critical	TBM & CBM both	Daily or Twice a day.
Critical	CBM	Daily or Twice a Week
Less Critical	CBM or Breakdown Maintenance	Monthly or fortnightly
Safe Performance	Breakdown Maintenance	At the time of failure

TABLE V: Classification of TPM best practices based on severity

IV. Illustrated Example

For the sake of better understanding of the proposed measurement model, an example is presented here. Let us consider a manufacturing unit and its data has been collected and its performance metrics has been calculated and tabulated in table VI as per our proposed measurement model below. Obviously from the data the final lean score (30 out of 100) which obtained was not that much satisfactory. Further it needs a lot of improvement in its lean performance metrics. From the table it is seen that the performance metrics M_2, M_{11} are out of the fuzzy areas and their respective membership values are equals to zero. This means, there is a lot of chance for the better improvements. Similarly metrics M_1, M_3 , M_4, M_6, and M_7 are categorized as major six big losses of the manufacturing systems. A little change in these performance results in a huge variation of the lean score. These metrics need more concentration and better improvements. In the same way, metrics M_8, M_9, M_{10}, and M_{12} are having very poor performance and needs more improvement in their processes. In this study the weights of all performance metrics is same but individually different by depending on their importance. The author suggests that for future work contains some more metrics and can get more sensitive lean performance score.

A. Graphical data of lean performance values

Here as the author already discussed about the triangular fuzzy membership values for the lean performance values

Metric	Hypothetical Performance Data	Point A	Point B	Membership value
Product Loss	2.41%	0	4%	0.39
Number of customer complaints	5%	0	4%	0
Breakdowns	4.1%	0	6%	0.31
Set up and Adjustment Loss	6.09%	0	8%	0.23
Shutdowns	1%	0	2%	0.5
Speed Loss	0.87%	0	2%	0.56
Stoppage Loss	4.13%	0	7%	0.41
Non Value Added Time	9%	0	14%	0.35
Annual Inventory Costs	7%	0	10%	0.3
Annual Transportation Costs	3%	0	5%	0.4
Orders Delivered Late	6%	0	2%	0
Dispatch Time	12%	0	14%	0.14
LEAN SCORE	30			

TABLE VI: Hypothetical data and its lean score

of the firm. In this context, he had given the graphical representation of the lean performance value of the individual lean metrics before implementation of the TPM best practices. He had made this pictorial view with the initial data shown in the figures 2,3,4.

V. Results

In this paper, initially the author concentrates on the two important variables of leanness and next he extracts the corresponding metrics and finally brings a relation between them by using fuzzy membership functions in order to find out the unique lean score of the manufacturing unit. The same process is adopted among 30 industries in Jamshedpur and got their individual lean scores. Basing on the data, he categorized the lean score into different severity zones. Basing on the severity, he differentiated the lean metrics and best practices of TPM. Following his study, he adopted the best practices of TPM and frequency of maintenance at an appropriate period of time, and he once again calculated the lean score which gives a tremendous increment in his results which are tabulated below in table VII.

From the table it is observed that the quality has a very little improvement, as it is very nearer to the 100% percent and coming to the availability there is an around 3 % improvement in a short time. Coming to the performance of the machines, there is an improvement of around 4% and in cost 2% and a huge improvement in the delivery up to 6%. So by seeing the above, it resolves clearly that there is a marginal increment in the lean score after implementation of the TPM best

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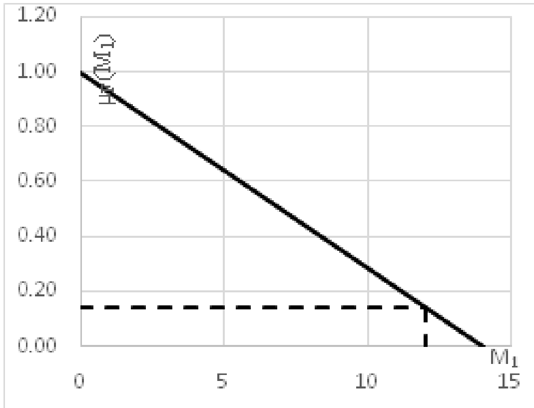

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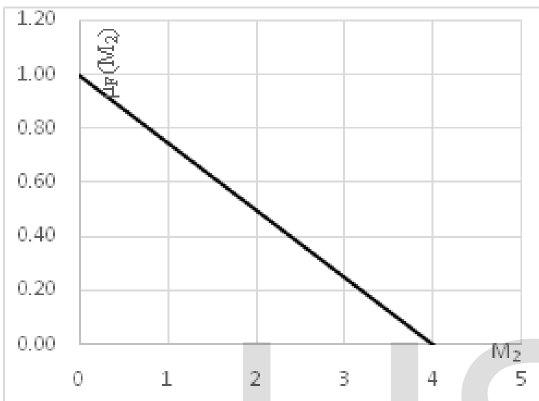

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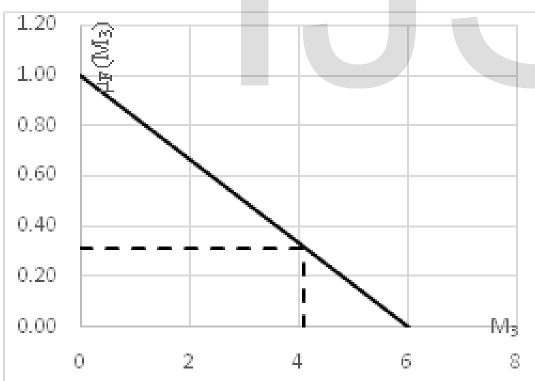

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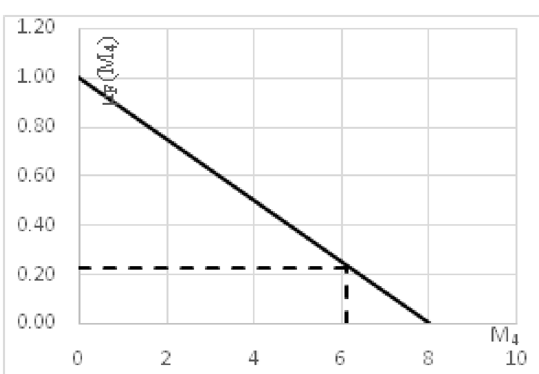
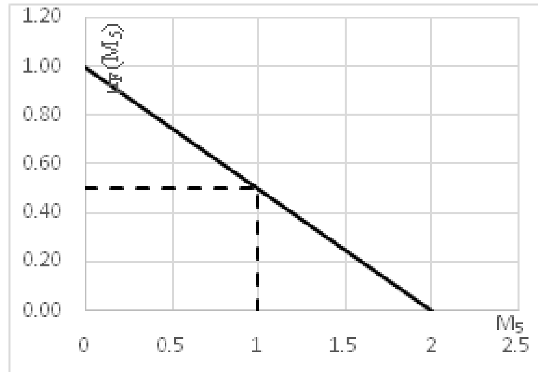


(d)

Fig. 2: Graphical representation of fuzzy membership values for lean attributes M_1, M_2, M_3, M_4.



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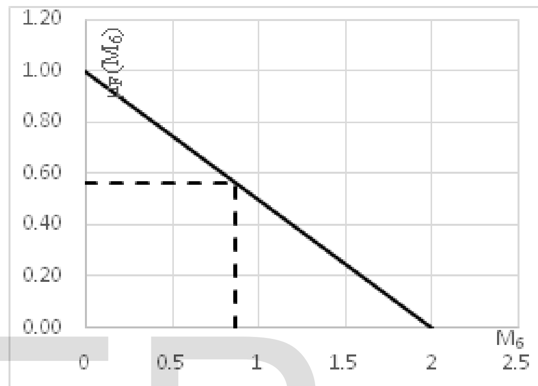

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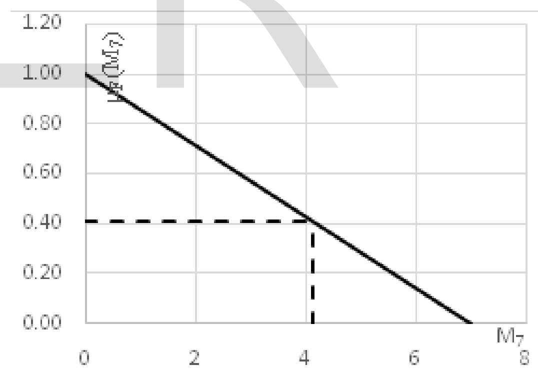

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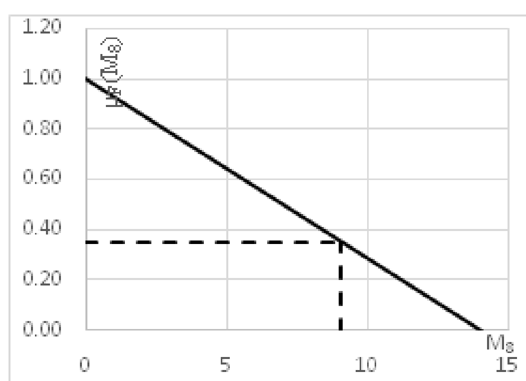

(d)

Fig. 3: Graphical representation of fuzzy membership values for lean attributes M_5, M_6, M_7, M_8.

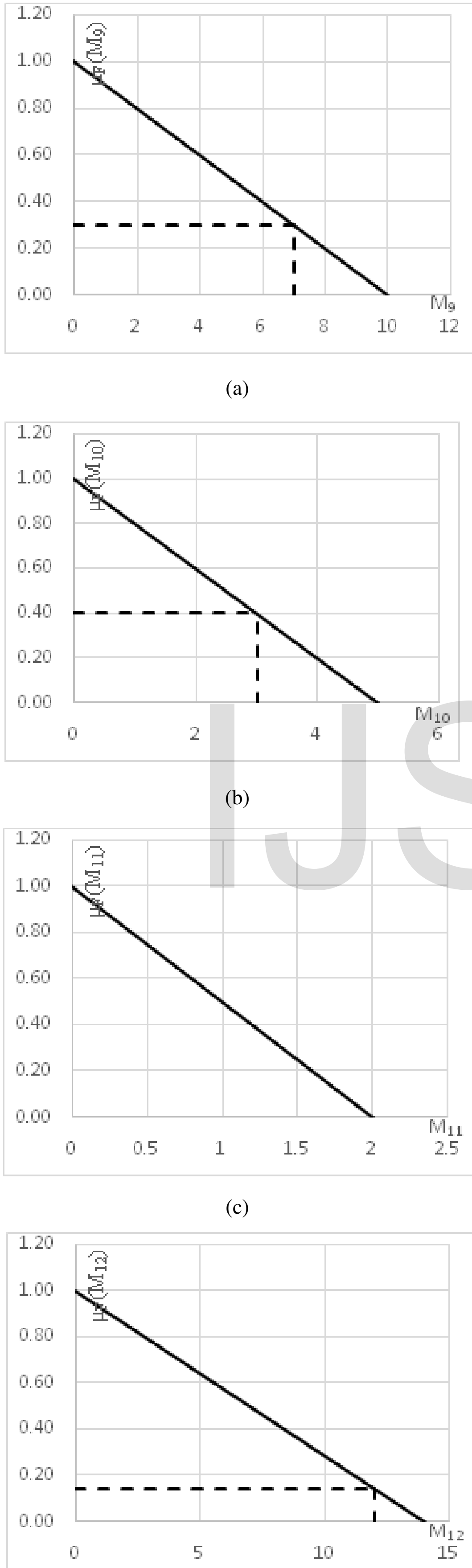

Fig. 4: Graphical representation of fuzzy membership values for lean attributes $M_9, M_{10}, M_{11}, M_{12}$.

practices and adopting suitable remedies. Now he graphically showed the results of various lean metrics before and after implementation of his study in Figure.5.

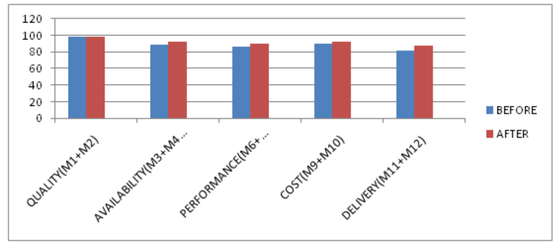

Fig. 5: Comparison of lean performance metrics

Based on his study, he formulated some suitable remedies to the corresponding lean metrics, which are very much useful in improving individual metric at faster rate by following the beneath table VIII.

Metric	Hypothetical Performance Data	Point A	Point B	Membership value
Product Loss	1.8%	0	4%	0.55
Number of customer complaints	3%	0	4%	0
Breakdowns	3.02%	0	6%	0.49
Set up and Adjustment Loss	4.03%	0	8%	0.50
Shutdowns	1%	0	2%	0.5
Speed Loss	0.62%	0	2%	0.69
Stoppage Loss	3.01%	0	7%	0.57
Non Value Added Time	6.4%	0	14%	0.54
Annual Inventory Costs	5.7%	0	10%	0.43
Annual Transportation Costs	2%	0	5%	0.6
Orders Delivered Late	4.7%	0	2%	0
Dispatch Time	7.3%	0	14%	0.47

TABLE VII: Hypothetical data and lean score after implementation of formula

VI. Conclusion

By using the fuzzy membership values, this study has given the steps to a performance measurement method to measure the lean performance of the manufacturing systems. Waste elimination and JIT deliveries are considered as the most important lean attributes for the improvement of the industry. Cost, quality and time are regarded as surrogates for the waste elimination and delivery is taken as surrogate for JIT deliveries and corresponding metrics have been taken for each surrogate and finally calculated the lean score before and after implementation of TPM best practices and following suitable remedies at a particular instant of time, which will be used for the managers and the high level superiors to work more to get more efficient plant. The results were compared and shown graphically. The most salient parameters like product loss, customer complaints and dispatch time loss has improved by 0.61%, 2% and 4.7% at a short period of time. In order to achieve a more sensitive and accurate lean score, more attributes have to be considered.

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TABLE VIII: Lean attributes and its remedies

S.No	Metric	Remedies
1.	Product loss	1) We must not send the raw material during warm up stage of the machine. 2) Thorough check is needed for machine, before starting it.
2.	Customer complaints	1) Quality is to be maintained up to customer satisfaction. 2) Proper advertisements are needed to reach all types of peoples.
3.	Breakdowns	1) Proper regular maintenance and lubrication is needed. 2) Alternative machines are used for heavy duty machines 3) Technical operator is needed for tool adjustments in sensitive machining operations. 4) Proper coolant is needed.
4.	Setup and adjustments	1) Proper set up time programs are to be given to the machines. 2) Operator shortage must be eliminated. 3) Setup time, changeover time must be reduced by allocating skilled operators.
5.	Shutdowns	1) Regular checking and maintenance is needed. 2) Setting up of secondary machines. 3) Shutdown time has to be reduced by fixing skilled operators
6.	Speed loss	1) Overload must be eliminated. 2) Proper lubrication is encouraged to avoid rough running, wear and tear of machine. 3) Adopting sequencing and scheduling methodology
7.	Stoppage loss	1) Finished goods have to be taken from its path after completion of its process at that instant. 2) Skilled or technical operator is suggested more. 3) Cleaning of machines and its environment is recommended.
8.	Non value added time	1) To maximum extent rework should be eliminated. 2) Management has to take immediate actions when required. 3) Motivation to the workers has to be given in time to time. 4) Following sequencing and scheduling rules
9.	Annual inventory cost	1) It should be minimized by using various techniques like JIT AND KANBAN systems.
10.	Annual transportation cost	1) It should be reduced by using techniques like Kanban system, group technology.
11.	Late Delivery	1) Communication gap is to be minimized. 2) Data transfer has to be fastened.
12.	Dispatch time	1) Good communication must be developed. 2) Proper mediators have to be maintained for faster delivery of the product. 3) By adopting Early due date (EDD) rule

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