PRESENTING AN OPTIMAL LEAN MAINTENANCE STRATEGY USING FUZZY MADM

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ABSTRACT

Maintenance has a key role in cost reduction, reducing the idle time and increasing production cost, quality, efficiency and reliability of industrial equipment and therefore fulfillment of the organizational objectives. In this paper, development of a practical model to define an optimized effective maintenance strategy using lean approach based on the views of maintenance experts at nine production plants is investigated. In the developed model, based on the uncertainty observed in the maintenance field, fuzzy logic combining DEMATEL, entropy and TOPSIS methods is utilized. In this method, a model is presented based on relationships among Lean-Enablers of the maintenance process using fuzzy DEMATEL, weighting maintenance indicators using entropy, and criteria ranking using fuzzy TOPSIS.

Key Words:

Lean maintenance, MADM, Fuzzy TOPSIS, Fuzzy DEMATEL, Research paper

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INTRODUCTION

Every organization needs planned changes, which are controlled actions for organizational structure renewal, in a way that can be in harmony with the changeable conditions of environment and therefore achieve its new goals. This is difficult and sometimes costly, but these changes are important since they help the organization to accord with changes within the organization and environment which might threaten its existence [1]. The dynamism and perseverance of organizations depend on these changes and required flexibility in a relation to each operation based on the organization goals [2]. Furthermore, customer requirements are increasingly specific and change quickly. Customers still demand goods and services with high quality and low cost. Organizations must be able to respond to new, fast, continuous and unpredictable changes of environment and offer an appropriate verity of products and services in order to survive and compete. Only in these conditions, a business could reconstruct and reengineer itself in faced with changing demands. From the time of industrial revolution, production has changed a lot and had several mutations form manual production to lean and agile production. Maintenance concentrates on the repair and failure avoidance of the equipment. Most of the maintenance departments do not consider their activity as a way of waste elimination. In fact, a movement from active to proactive maintenance strategy in maintenance and management systems is carried more easily with a basic concentration on waste elimination. This is specifically true for the companies which are operated under a lean production system [3]. In nowadays business environment, factories often face challenges regarding demands for the increase of the profitability of the machineries, labor, and obsolete maintenance methods. The activities in the field of maintenance can take a significant portion of the production cost and bills of a factory. Non-plan stop related costs or above normal limit agreements in a production line can reduce the profit up to 30 to 40 percent. In addition, excessive stoppages can negatively affect the production time period or on-time delivery. Management's liability and accountability is totally vital for the success in creating changes in every business. Lean approach and its concepts can be extended to maintenance activities so that this approach can be a complement to the lean production in waste elimination of the production process [4]. In this paper, after identification of lean-enablers of maintenance process and analysis of these parameters in the improvement of the process criteria, we seek to define relations among maintenance components

in production performance. For the analysis of relations between leaning components of maintenance and maintenance criteria, due to uncertainty, fuzzy logic and a multi-criteria and combinative method of decision making using fuzzy DEMATEL, entropy and fuzzy TOPSIS is utilized.

LITERATUE REVIEW

Lean Production

The idea of lean production is based on the elimination of every kind of non-value added action. Lean production has principles such as: waste elimination, zero failure, multi-purpose teams, reduction of organizational hierarchies, team leadership, vertical information systems, continuous improvement, and pull systems. The term of lean production was coined by James Womack and his team in middle 90's during a research program called 'the machine that changed the world'. They define lean production approximately as a combination of the traditional production model of Ford and the model of techno-social systems in the Japanese production atmosphere. Lean approach is a managerial strategy to identify and eliminate MUDAs or waste sources to minimize costs and move towards profitability and organizational excellence. The approach was born from the continuous improvement and Kaizen idea and developed in form of lean production in Japanese factories and industries [3, 5].

Corrective Maintenance

This strategy is also known as failure based maintenance. In this approach, actions are applied only after failure and no intervening is occurred before a failure happens [6]. Corrective maintenance is an initial strategy which has emerged in industry [7].

Preventive Maintenance

This approach is based on reliability. In this method, equipment maintenance is performed during individual time periods based on a regular timing. In this policy, it is tried to reduce the number of sudden failures with the aid of special inspections and replacement of the components which have a high failure rate.

Predictive (Condition Based) Maintenance (PdM)

Predictive maintenance compares the defined parameters for the performance of equipment with the defined engineering limits of those parameters. After performing required analysis, the approach identifies the problems which potentially cause failure and take necessary actions to eliminate those problems [8].

Reliability Centered Maintenance (RCM)

John Mowbray defines RMS as "a process used to determine which operations are necessary for maintaining physical properties at a certain level of efficiency (according to the views of their users) and preserving performance" [9].

Total Productive Maintenance (TPM)

Total productive maintenance is the foundation of lean maintenance and the way to optimization of reliability and effectiveness. The base of total productive maintenance is on collective activities and active maintenance and includes all levels of organization form top level managers to workshops. Total productive maintenance conducts the whole production system life cycle and provides a basis for consistent system with the aim of waste elimination. The goal of total productive maintenance is the elimination of all accidents, deficiencies and failures [8].

Lean Maintenance

Lean maintenance has been created in order to optimal performance and coordinating different maintenance concepts with approaches such as RCM, TPM and PM using value stream analysis. This maintenance strategy seeks identification and elimination of non-value added actions. Lean maintenance consists of three cores and one platform. The three main core of the lean maintenance are lean thinking, RCM and PCM. The platform is Computerized Maintenance Management System (CMMS) which is a base for data gathering and maintenance analysis. During the operation processes, different tools such as 5S and value stream map are utilized for improvement of processes (Fig.1) [10].

The main stages of lean maintenance design are shown in Figure 2.

First stage: concentration on infrastructures, second stage: concentration on accessibility level, third stage: concentration on functionality

MAINTENANCE INDICATORS

The relationship between maintenance and production is complicated. The problem arises when the goal is to measure the inputs and outputs of the maintenance process quantitatively [12]. Since maintenance plays a positive role in achieving of the strategic goals of an organization, the senior management of the organization understands the significance of added value of this process and its roles cost in reduction. In other words, weak maintenance, in addition to being an impediment to value creation, can destroy the strategies and capitals of company [13]. Leading indicators of the maintenance process monitor true performance of maintenance tasks to achieve desired results. These indicators measure and evaluate four tasks including work identification, work planning, work scheduling, and work execution. Lagging indicators of maintenance, are concern with measurement of the maintenance process via performance results and maintenance costs. Maintenance results can be summarized via reliability, availability and operability. (see fig. 3)

Application of Weighting and Multi Criteria Decision Making Techniques

Fuzzy DEMATEL

DEMATEL method is a technique for complicated problems. The technique was developed based upon graph theory to solve problems in an easy way. The shortfall of the DEMATEL method in decision making in uncertainty caused the development of the fuzzy DEMATEL. Fuzzy DEMATEL facilitate decision making under uncertainty using fuzzy linguistic variables. The technique can be utilized in different fields such as production, organizational management, information system and social sciences. In addition, the problem can solve difficulties that organizations face using collective decision making in fuzzy conditions this technique can properly analyze interrelations of the parameters.

Fuzzy Entropy

Entropy measures data in uncertain conditions. The method was primarily presented by Shanon [15].

Fuzzy TOPSIS

Fuzzy TOPSIS is method in which matrix elements or the indicator's weight are expressed in fuzzy form. In order to solve problems with fuzzy TOPSIS method, different techniques can be employed. One of the most common techniques has been introduced by Chen and Hoang [16].

METHODOLOGY

This study includes both fundamental and practical types of researching, since it seeks to investigate the relationship between indicators and present a model. The method of gathering data is using questionnaire. Identified indicators and key elements of lean maintenance were used in two different questionnaires. In the first questioner, the experts were asked to determine the effectiveness of each element of lean maintenance in the sense of paired comparison to each other; and denote if these elements are employed in their factories and in which level they are implemented if the answer is yes. The questioners are answered according to the following table (Table 1) by the experts [14].

triangular fuzzy numbers	Linguistic choices
(0.75 , 1,1)	**Very High**
(0.5 , 0.75 , 1)	**Medium High**
(0.25 , 0.5 , 0.75)	**Low**
(0 , 0.25 , 0.5)	**Very Low**
(0 , 0 , 0.25)	**No Effect**

Table 1. Linguistic choices and triangular fuzzy numbers of fuzzy DEMATEL

In the second questionnaire the experts are asked to determine the effect and importance of each effective element in relation to 4 groups of leading and lagging indicators by using Linguistic choices and triangular fuzzy numbers of fuzzy TOPSIS (Table 2), in order to have a lean maintenance process [6].

	triangular fuzzy numbers	Linguistic choices
Very low(VL)	(0 , 0 , 0.1)	**Very Low**
Low(L)	(0 , 0.1 , 0.3)	**Low**
Medium low(ML)	(0.1 , 0.3 , 0.5)	**Medium Low**
Medium(M)	(0.3 , 0.5 , 0.7)	**Medium**
Medium high(MH)	(0.5 , 0.7 , 0.9)	**Medium High**
High(H)	(0.7 , 0.9 , 1)	**High**
Very high(VH)	(0.9 , 1 , 1)	**Very High**

Table 2. Linguistic choices and triangular fuzzy numbers of fuzzy TOPSIS

To be confident about comprehensiveness of the views, the following indicators were assured: Correspondence of experts' experiences to maintenance, presence of experts form managerial occupations, senior and experienced maintenance employees and people from academia with related educations. The papers which use structural-interpretive method for the analysis of the results suggest a number of experts between four and fourteen. In this study, fourteen experts from nine different production plants field the questioners.

Data Analysis

Extracting useful results form a research requires employing precise and verified scientific methods. For this purpose, the following steps for analyzing data are used in this study.

First step: Extracting direct relation matrix of lean enablers of maintenance process from the answers from the first questionnaire which the fourteen experts have filled up.

Second step: To structuration the effect of each lean-enablers on the others and investigating the relationship and affecting/taking effect between them, the fuzzy DEMATEL technique is employed. Using this method, in respect to the relationship between elements of lean maintenance, gives the study a proper structure and provides the optimal model for strategy finding based on the lean maintenance. By extracting the affecting/taking effect indicators between the elements of lean maintenance, it is possible to evaluate the effect of these elements on each other in order to analyze the ranking of these elements based on the effectiveness of each one of them. 1-Normalizing the direct relation matrix 2- Producing total relation matrix 3- Producing cause and effect matrix 4- Producing dependence matrix 5- Determining the order of influencing the elements on each other 6- extracting the affecting/taking effect indicators of the lean maintenance, which represent the effecting and taking effect among indicators.

Third step: Extracting approximate agreement matrix of evaluation using the answers to the second questionnaire. In this questionnaire, the elements of lean maintenance are considered as choices and the leading and lagging indicators of maintenance are considered as criterion. The output of the second step, namely the affecting/taking effect between elements, is added to these indicators.

Forth step: Determining the weight of the indicators using Shanon entropy method. In this analysis the weight and importance of each group of leading and lagging indicators and the affecting/taking effect indicators of lean maintenance are determined.

Fifth step: Ranking and weighting the elements of lean maintenance using FTOPSIS technique. This technique is used for ranking and weighting because it is a compensatory method which compares the choices based on weight, normalized number and calculation of each criterion. In compensatory methods such as FTOPSIS, interchanging between the criteria is acceptable; therefore, the weak results of on criterion are compensated by the good results of other criteria. The compensatory methods present a more realistic picture compared to the non-compensatory methods which ignore the obtained solutions due to applied cut-offs on them. The steps of this method are: 1- producing normalized decision matrix 2- Calculating the weighted normalized matrix 3- Determining the ideal positive and negative point 4- Calculating the Euclidean distance of the ideal positive and negative solutions 5- Sorting. The obtained numbers are sorted discerningly so that the preferred solution is selected.

Sixth step: Presenting the model using the outputs of fuzzy DEMATEL and FTOPSIS where the dependency and ranking of their elements has been determined. The results of the field studies and trade analysis of lean maintenance elements and its indicators, provides the optimal model for express maintenance strategy with a lean approach.

RESULTS AND DISCUSSION

In this study nine elements were identified as factors which by their appropriate implementation, the maintenance process would be lean and optimized. These elements are: purchase and storing spare parts based on lean approach, training and education, CBM, RCM, AM, PM and CM. In the first step, using data from questionnaire related to fuzzy DEMATEL and table of linguistic choices and triangular fuzzy numbers in fuzzy DEMATEL method, the effect of each element of lean maintenance is determined by experts. Equation (1) shows the expert's view about the effect of factor *i* over factor *j*.

$$\breve{O} = (l_{ij}, m_{ij}, u_{ij}) \quad (1)$$

For every $i=j$, the corresponding number is set to zero. For every expert, a 9x9 matrix with fuzzy elements in form of Equation (2) is defined.

$$\widetilde{OP} = \begin{bmatrix} P \\ \tilde{O}_{ij} \end{bmatrix} \quad (2)$$

The number of experts is fourteen and the values are the simple average of expert`s views in which $\breve{O}$ is triangular fuzzy dimensions [14]. The decision matrix of direct relation intensity for lean maintenance enablers calculated and then With the execution of fuzzy DEMATEL, the affecting/taking effect indicators are extracted as shown in Table 3.

Element	Affecting			Taking Effect		
Lean Spare	2/43	4/35	2/39	9/17	18/3	36/7
5S	2/94	5/26	3/48	11/7	23/4	46/7
CMMS	3/11	5/51	3/87	12/5	25	49/9
Training	2/98	5/3	3/48	11/8	23/5	47/1
CBM	2/9	5/14	3/28	11/3	22/7	45/3
RCM	2/93	5/3	3/64	11/9	23/8	47/5
AM	2/52	4/47	2/69	9/68	19/4	38/7
PM	1/91	3/38	1/67	6/96	13/9	27/9
CM	1/91	3/38	1/67	6/69	13/9	27/9

Table 3. Value of affecting/taking effect indicators

In the second step, the weight of the maintenance indicators is calculated using Shanon entropy (Table 4). This method used separately in upper, middle and lower limits in order to calculated the fuzzy weights of maintenance indicators. The affecting/taking effect and efficiency indicators of the maintenance costs are considered negative indicators. The other indicators are considered positive.

Fuzzy Weight			Indicator	Fuzzy Weight			Indicator
0/1	0/1	0/2	**Measures of Equipment Performance**	0/1	0/3	0/2	**Work Identification**
0/0	0/0	0/0	**Affecting**	0/1	0/1	0/2	**Work Planning**
0/4	0/2	0/0	**Measures of Cost Performance**	0/1	0/1	0/2	**Work Scheduling**
0/0	0/0	0/0	**Taking Effect**	0/1	0/1	0/2	**Work Execution**

Table 4. Weight of maintenance indicators calculated by Shanon entropy

In the third step, the lean criteria are calculated and ranked via fuzzy TOPSIS using the average value of the data from second questionnaire (Table 5). In this questionnaire, experts determine the effect of each maintenance element on the improvement of maintenance indicators using linguistic data related to Table 2.

Lean-Enabler Element	Similarity index	Similarity index (Value)	Weight
PM	cc1	0/82	%16
RCM	cc2	0/77	%15
CMMS	cc3	0/67	%13
5S	cc4	0/62	%12
Lean Spare	cc5	0/57	%11
AM	cc6	0/53	%10
Training	cc7	0/44	%9
CBM	cc8	0/39	%8
CM	cc9	0/37	%7

Table 5. Ranking of lean maintenance elements

According the analysis above, it is observed that PM, RCM, CMMS, 5S, and purchase and storing of spare parts using lean approach are the most important elements for the optimization of maintenance process. These five elements constitute %67 of the lean maintenance process. Using the outputs of the fuzzy DEMATEL and FTOPSIS in which element dependency and ranking are defined, and also the results of field studies and analysis of the relation between

elements of lean maintenance and trend of maintenance indicators, optimal model for strategy making process of lean maintenance is presented (fig. 4). In this ascending model, it is observed that the primary and effective infrastructures for planning optimal maintenance operations are three elements: RCM, CMMS, and training and education. These elements are necessary for the appropriate execution of each other as well as basic elements for achievement of the planned goal of maintenance process. In the next step, for achievement of other goals of maintenance, other elements of the lean maintenance are considered.

CONCLUSION

The presented model is a practical one which can be employed in different factories and production lines to optimize the maintenance process. It is observed that each element of the lean maintenance should be given a different value; and also for budgeting of the operation, importance and weight of the elements should be considered. For execution of these elements in order to achieving of maintenance goals, the starting point must be the mentioned infrastructures, and then other elements are utilized. For the future studies based on the presented methodology of research, Analytical Network Process could be replaced with the TOPSIS method, or statistical analysis of Fisher's exact test and logistic regression can be used instead of multi criteria decision making, and the results could be compared with those presented in this paper.

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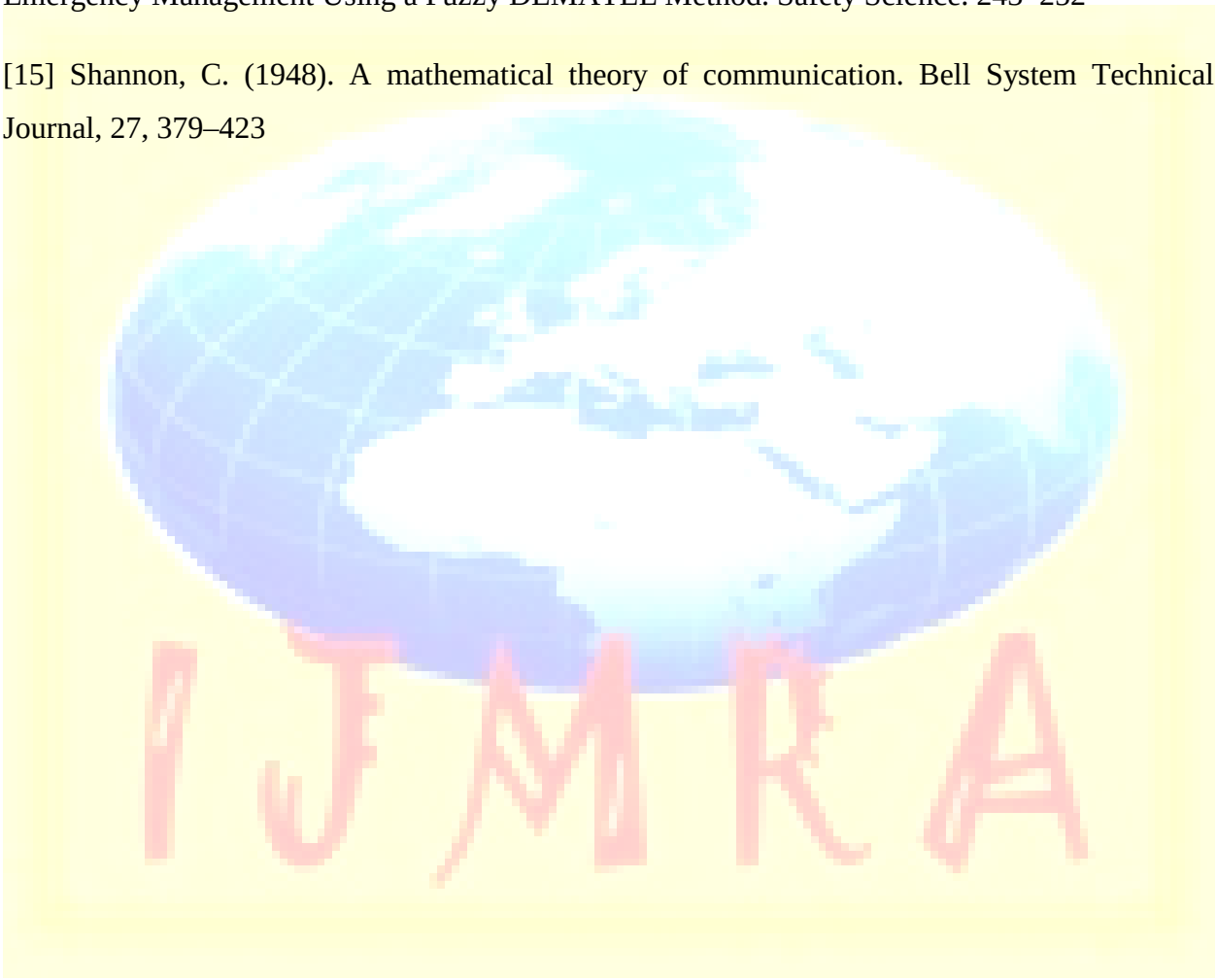

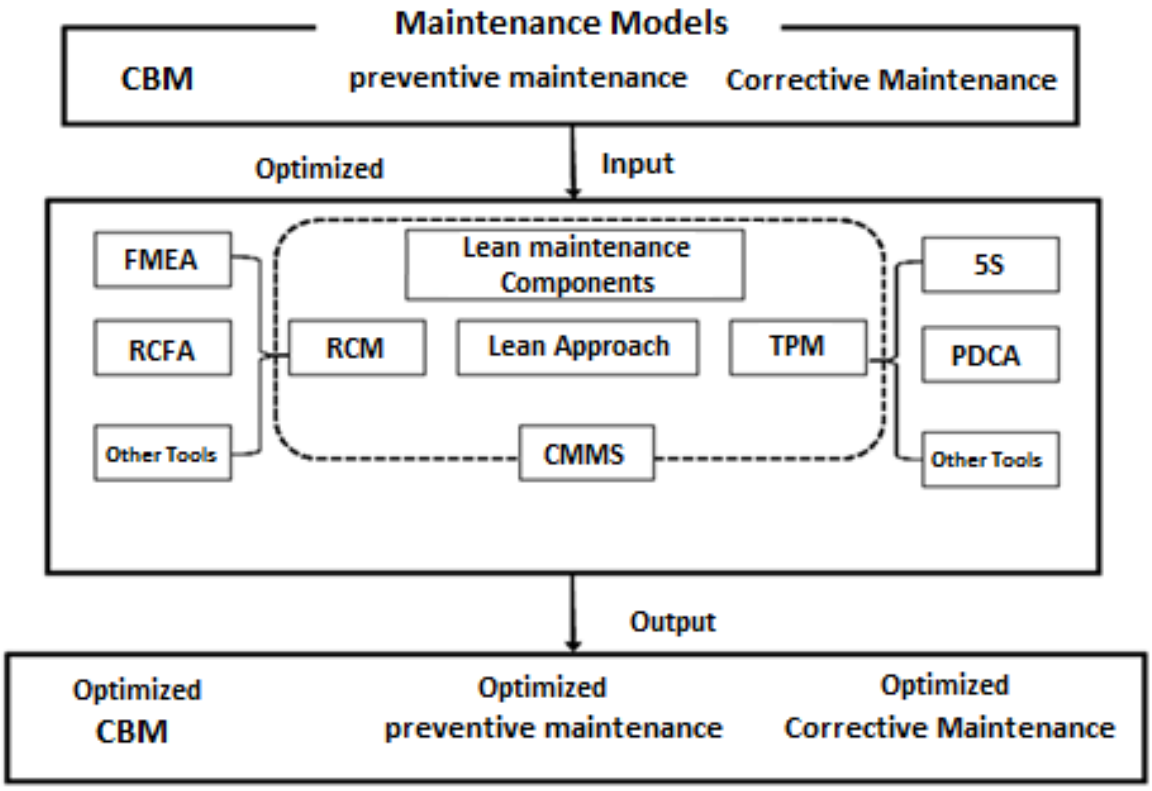

Figure 1. Lean maintenance Model

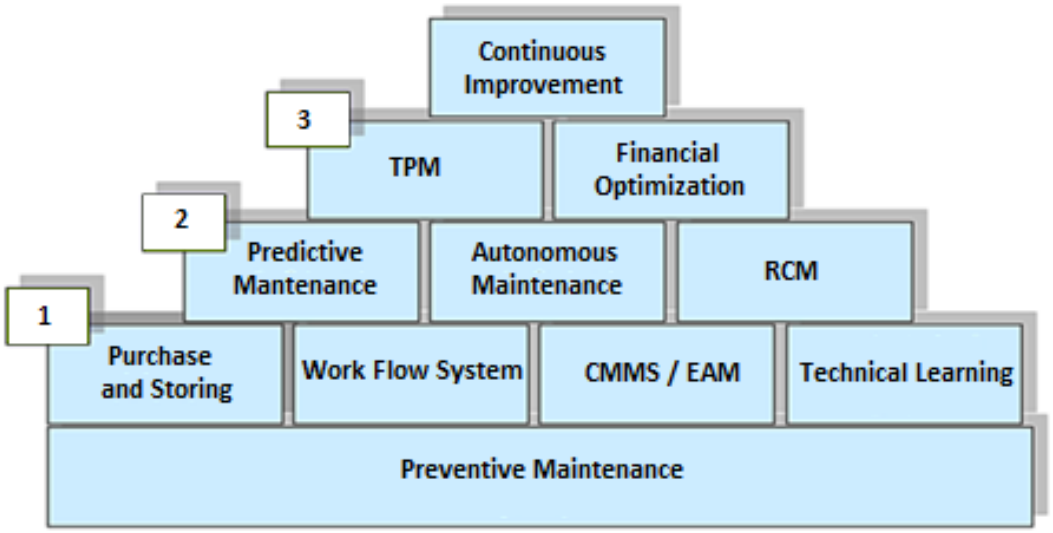

Figure 2. Stages of lean maintenance design

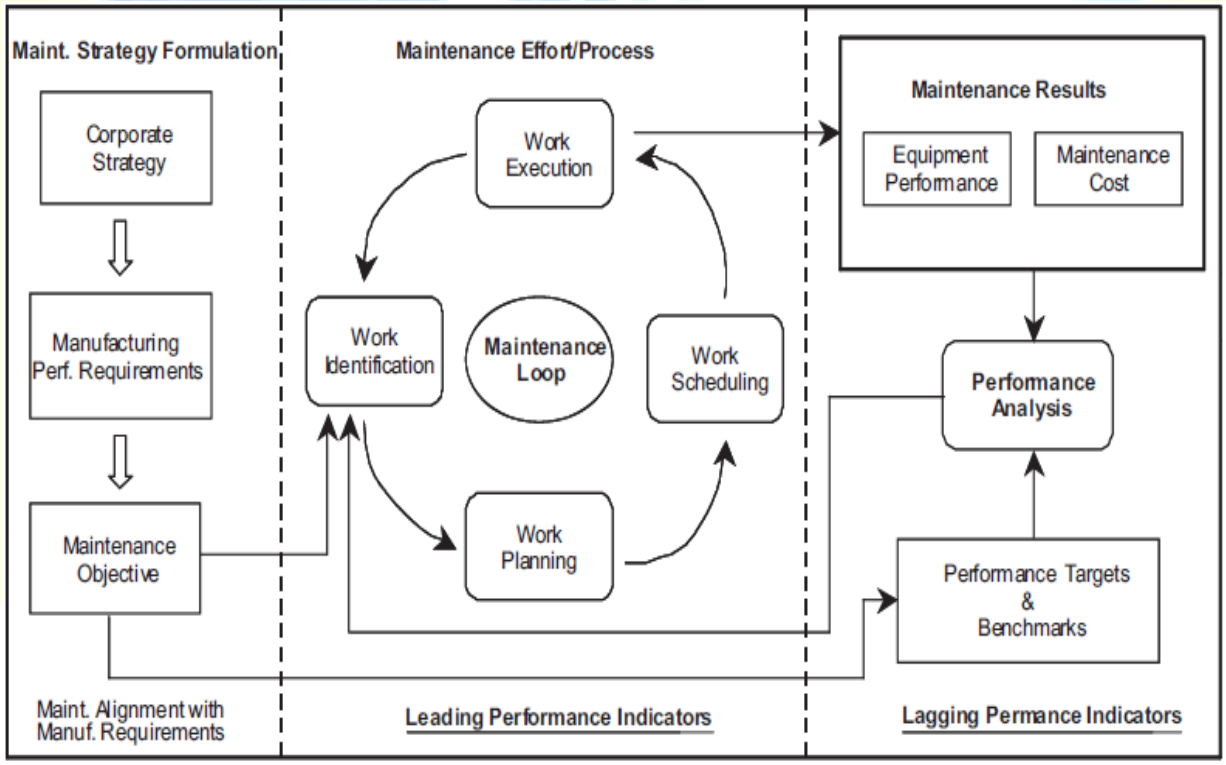

Figure 3. Maintenance Indicators

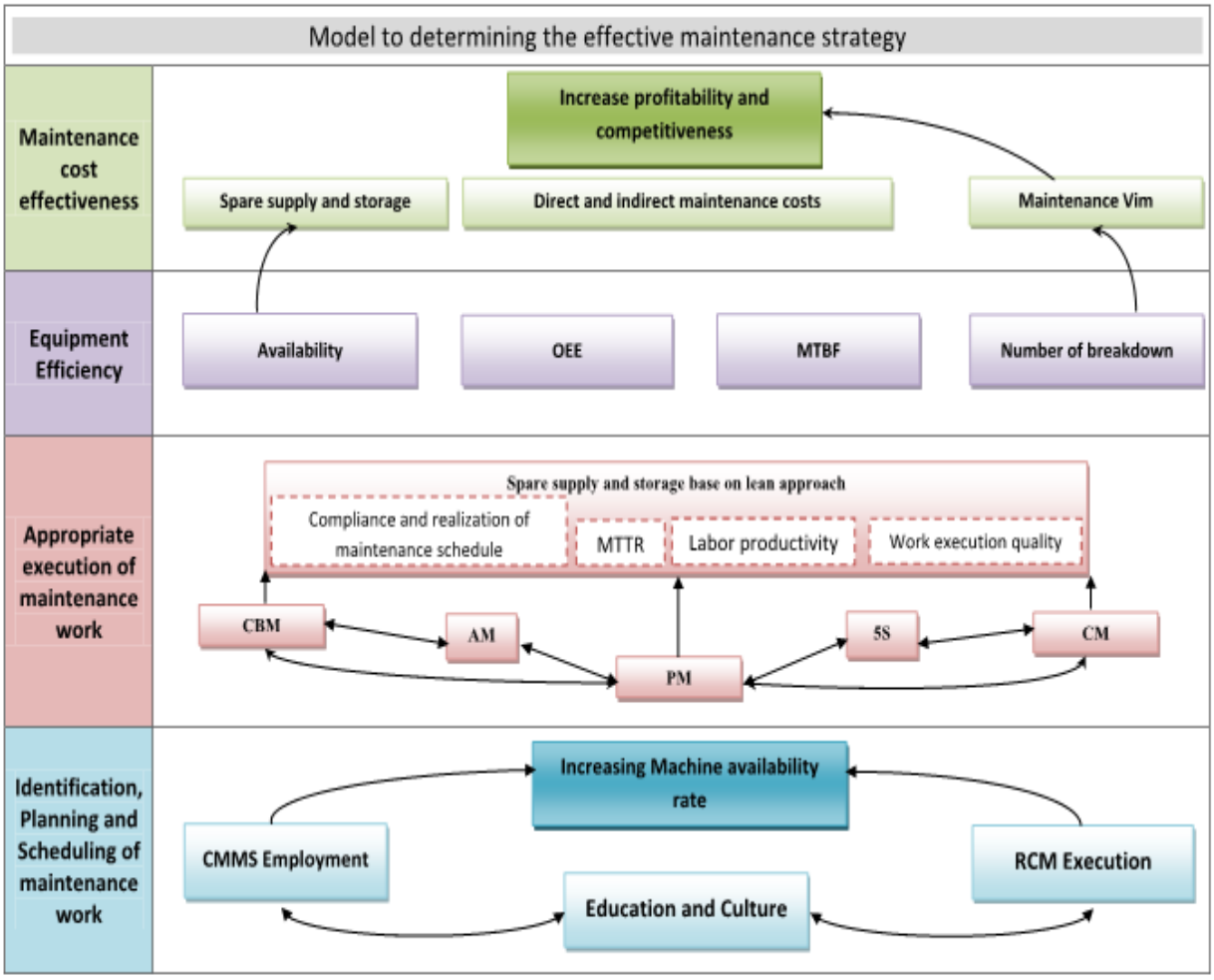

Figure 4. Model of optimal maintenance strategy using lean approach