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An Integrated Fuzzy-based Multi Criteria Decision Making System to Selection of Lean Tool Performance: An Indian Automotive Parts Manufacturing Company Case Study

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Abstract

Selecting virtuous lean manufacturing tool is an essential requirement in competitive scenario due to vagueness and uncertainty in multi-criteria, multi-factor decision environment. Taking meticulous selection of lean tools value stream mapping, poka-yoke, single minute exchange of die, kaizen and 5S in specific multi factors leadership & management, financial capabilities, skill and expertise, organizational culture and manufacturing strategy. This case study is witnessed without weightage criteria and with weightage value stream mapping is best tool and appropriate lean tool in fuzzy based multi criteria decision making system using dominance matrix.

Keywords: Fuzzy, Lean Manufacturing, Multi Criteria Decision Making System

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1. Introduction

There are no secrets to success. It is the result of preparation, perfect selection, and learning from failure. Authentic selection of appropriate lean manufacturing tool suitable to manufacturing industries is the requirement of multi criteria decision making problem. The selection process depends on several qualitative factors. Lean manufacturing tool selection problem is governed by inadequate data, destitute knowledge and spurious input parameters. There is always a scope of optimization on the obtained results as these values are non- reflective of the real life scenario. In real world, the selection process comes across many uncertain factors, ambiguous and vague parameters while operating the lean tools in manufacturing industries. Apart from quantifying the vague factors, there is a need of a methodology which can estimate the quantity of equipment based on the quantum of work to be executed. Lean tools are grouped on the basis of affecting factors and are to be optimized for concluding the overall cost of the product. Here, complex multi dimensional problems with multi objective scenario arise where minimum budget, maximum staff index are achieved optimally.

A fuzzy-based multi-preference, multi-criterion, and multi-person decision-making heuristic has been developed to resolve the problem of such magnitude. In past many analytical and heuristic methods were developed for solving the optimization problem in manufacturing and service sector industries .Decision making for selection of an optimal lean tool is most important scientific, environmental and economic effort. The essence of the project head is to overcome uncertainty and to make correct and consistent choice. Lean manufacturing tool selection is an important aspect in the manufacturing industries to improve various activities in cluster environment. It is important when there are two or more alternatives, hence decision may be defined as a selection of an act, considered to be the best according to some pre designated standards from the available alternatives.

2. Past Work

In the context of discussion of proposed prioritization method for intuitionistic fuzzy preference, relations also discuss interval valued intuitionistic fuzzy AHP method for multi-criteria decision making problem (Jian Wu, 2013). Investigate fuzzy gen-

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eralized dalta rule with different back propagation algorithms and upon the desired problem in linguistic term (G. Bortlan, 1997). Explore the group preference aggregation procedure in AHP & violation social choice axiom (R. C. Vandehonert, 1998). Conduct the rank of site selection rating on basis of fuzzy and decision making-criteria (Gin-shuh liang, 1991). Explore fuzzy AHP and TOPSIS to evaluate best handling equipment selection among possible alternative (Abdolreza yazdani chamzini, 2014). Faisal (2014) contribution is based on among lean manufacturing principle and fuzzy bow-tie analysis access to find out risk factor and aggregate risk probability and also draw risk priority matrix on basis of failure mode and effect analysis.

3. Research Methodology

A systematic research methodology (Figure 1) is proposed in this study to select the most appropriate lean manufacturing tool. The targeted objectives of case study are:

- To identify set of criteria and numerous decision makers, each with their own set of viewpoints for set of alternative lean tools.
- To develop position matrices for the finite set of lean tools across the set of criteria.
- To aggregate the membership values using modified pessimistic aggregation.

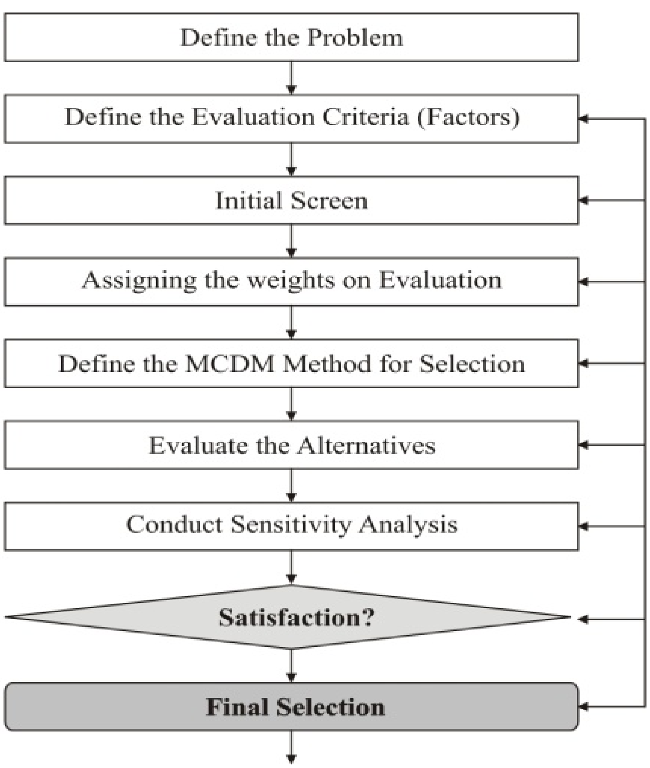

Figure 1. Research methodology.

- To identify an optimal lean tool using dominance matrix approach by introducing tolerance limit and weightages for each criteria.
- Conduct sensitivity analysis

To achieve objectives of research methodology the following approach consists of steps defining the problem.

Step 1: Define the problem

The collected data is the basis on which the appropriate multi criteria decision making (MCDM) technique is identified and utilized to solve the problem. The characteristics of the problem such as identifying the number of alternatives, tolerance limit, attributes, weights and constraints are addressed here.

Step 2: Define the evaluation criteria

The evaluation criteria are in terms of qualitative factors. The criteria are identified based on applicability and computational complexity. The defined evaluation criteria will be used as the attributes of an MCDM formulation and is the input data of decision matrix for selection method.

Step 3: Initial screen

In the initial screening, the infeasible alternatives and criteria are eliminated and is shown in Figure 2.

Alternatives represent the different choices of action available with the decision makers. Usually, the set of alternatives is assumed to be finite, ranging from several to hundreds. They are supposed to be screened, prioritized and eventually ranked. The alternatives which possess unacceptable and infeasible attribute values are eliminated in the screening process. The conjunctive method is employed to remove the unacceptable alternatives. Any alternative which has an attribute value worse than the cut off values will be eliminated. The cut off values given by the decision makers play a key role in eliminating the alternatives.

Step 4: Assign weights on evaluation criteria

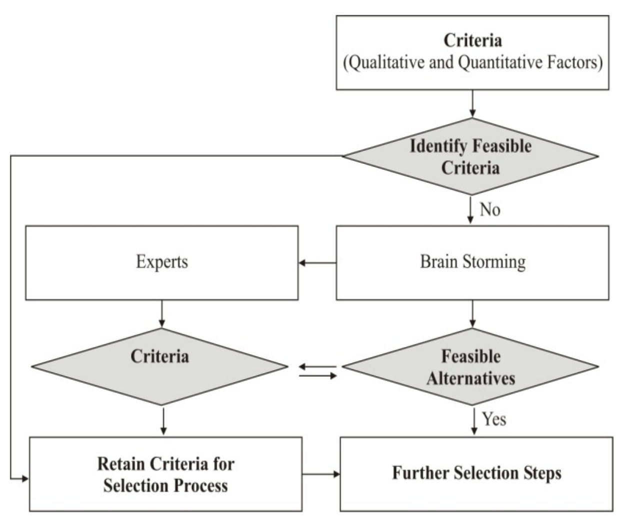

Figure 2. Initial screening process.

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Criteria represent the different dimensions from which the alternatives can be viewed. If the numbers of criteria are large in some cases, it may be arranged in a hierarchical manner. Some criteria may be major criteria and each major criterion may be associated with several sub-criteria. Similarly, "each sub-criterion may be associated with several sub-sub-criteria and so on.

After the initial screening is complete, the decision maker's preference information on the evaluation criteria is defined. This will reflect which criterion is more important to the decision maker (DM). Relative weights are assigned to each evaluation criterion to describe the DM's preference information, the weights must be carefully considered based on the DM's preferences and experiences, subjective scale between 0.0 to 1.0 is used with calibration that 0.0 stands for extremely unimportant while 1.0 represents extremely important.

The normalized matrix a_{ij} is represented in Eq. 1.1

Where N is the number of alternatives and M is the number of criteria, and a_{ij} is the membership value of i^{th} alternative (i = 1 to n) in terms of the j^{th} criterion (j = 1 to m).

$$a_{ij} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1N} \\ a_{21} & a_{22} & a_{22} & \cdots & a_{2N} \\ . & & & & \\ . & & & & \\ a_{M1} & a_{M2} & a_{M3} & \cdots & a_{MN} \end{bmatrix} \quad (1.1)$$

Each membership value is raised to the power equivalent to the relative weight (W_j) of the corresponding criterion. In general, for realistic comparison, the exponential value of weights are considered, Here, each weight value is exponential to given membership values. The total weighted membership values are to be placed in the position matrix for evaluation.

Therefore, the weighted position matrix 'x ' for a_{ij} is represented as in eq. 1.2

$X = [a_{ij} w_j]$

Where 'x' indicates weighted position matrix,

'a_{ij}' indicates normalized matrix,

And 'w_j ' indicates weight assigned.

Thus, the weighted position matrix is shown in Eq. 1.3

$$X = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1N} \\ a_{21} & a_{22} & a_{22} & \cdots & a_{2N} \\ . & & & & \\ . & & & & \\ a_{M1} & a_{M2} & a_{M3} & \cdots & a_{MN} \end{bmatrix} * \begin{bmatrix} w_1 & w_1 & w_1 & \cdots & w_N \\ w_2 & w_2 & w_2 & \cdots & w_N \\ . & & & & \\ . & & & & \\ w_N & w_N & w_N & \cdots & w_N \end{bmatrix} \quad (1.2)$$

Where * represents exponential form of weights. Therefore weighted position matrix

$$X = \begin{bmatrix} a_{11}w_1 & a_{12}w_1 & a_{13}w_1 & \cdots & a_{1N}w_N \\ a_{21}w_2 & a_{22}w_2 & a_{22}w_2 & \cdots & a_{2N}w_N \\ . & & & & \\ . & & & & \\ a_{M1}w_N & a_{M2}w_N & a_{M3}w_N & \cdots & a_{MN}w_N \end{bmatrix} \quad (1.3)$$

Step 5: Define the MCDM method for selection

The Dominance Matrix (DM) is chosen to select the most suitable alternative considering its simplicity. Basically, the DM provides dominance of each alternative to others.

Dominance method for decision making is characterized by a set of alternatives, set of criteria and numerous decision makers, each with their own set of viewpoints. This process can be represented in a matrix form and is known as the evaluation matrix. In judging the finite set of lean manufacturing tools (A_1, A_2,.........A_N) across a set of factors (F_1, F_2, ..., F_M) one can assign a value for each factors and for each lean manufacturing tool. Since one evaluation matrix would not adequately define the evaluation of all decision makers, a series of matrices is developed over a range of positions. Since the evaluation is based on subjective interpretations, there is no choice but to tolerate some level of imprecision and ambiguity.

An inherent property of dominance matrices is that they are additive. Therefore, if the features in an aggregate matrix are subdivided into *k* sets and a dominance matrix is calculated for each set, then the complete dominance matrix for the entire aggregate matrix is simply the matrix sum of the *k* dominance matrices. The difference between the column sums and the row sums of the dominance matrix gives the dominance relation between the alternatives. This dominance relation is normalized with respect to the most inferior alternative as the datum for ease of reference and expressed as a dominance vector of dimension *N*.

The opinion of the expert can be easily expressed in matrix format. A decision matrix A is an $(M \times N)$ matrix in which element a_{ij} indicates the performance of alternative A_i when it is evaluated in terms of decision criterion C_j, (for i =1,2,3, ..., M, and j = 1,2,3, ..., N). In order to display the dominance structure between all possible pairs of lean manufacturing tools, an N × N matrix, called the Dominance Matrix (D) is constructed. The element d_{ij} is the number of factors for which the membership value of lean tool 'J' is greater than that of lean tool i'. The dimensionality N is equal to the number of lean tools under consideration. It is also assumed that the decision maker has determined the weights of relative performance of the decision criteria (denoted as W_j, for j = 1,2,3, ..., N). The weighted matrix is as shown in Table 1.

Step 6: Evaluation of the Alternatives

The concept of membership plays a central role in this application. Membership is defined over a range from *0* (low) to 1

Table 1. Weighted matrix

Factor ⟶ ↓ Alt.	F_1	F_2	F_3	F_4	…..	F_N	Weights
A_1	a_{11}	a_{12}	a_{13}	a_{14}	…	a_{1N}	w_1
A_2	a_{21}	a_{22}	a_{23}	a_{24}	…	a_{2N}	w_2
A_3	a_{31}	a_{32}	a_{33}	a_{34}	…	a_{3N}	w_3
.	.	.	.	.	.		
.	.	.	.	.	.		
A_M	a_{M1}	a_{M2}	a_{N3}	a_{N4}	…	a_{MN}	w_N

(high) against some qualitative scale. By convention, *low* represents the least desirable end of the scale and *high* represents the most desirable end of the scale.

The membership value of *1.0* is treated as complete satisfaction of needs associated with a qualitative feature and the membership value of *0.0* as complete dissatisfaction. Intermediate values can be assigned depending on the degree of satisfaction.

In order to define a basis on which an alternative can be considered superior to another, the concept of dominance is invoked. A lean tool is said to dominate another lean tool for a given feature if and only if its aggregate membership value is greater than that of the other lean tool. A lean tool is said to be superior to a second lean tool if it dominates the second lean tool in more features than the number of features in which the second dominates the first.

If the j^{th} column is summed, the total number of dominances of lean tool j over all other lean tools is obtained. Similarly, if the i^{th} row is summed, the number of times that the i^{th} lean tool is dominated by all other lean tools is obtained. The sums of columns and rows can be compared and from this one can see that most favourable outcomes have higher column sums and lower row sums.

The method with the highest column sum and lowest column sum is recommended as the most appropriate alternative under consideration.

Step 7: Conduct sensitivity analysis

Sensitivity analysis is performed on the MCDM method selection algorithm in order to analyze its robustness with respect to parameter variations, such as the variation of DM's preference information and the input data (Evangelos Triantaphyllou and Alfonso Sanchez 1997).

Assessment of dominance is quite sensitive to errors in the data of the position matrix. They are potentially changed by the addition or removal of even a single option to or from the set under consideration. To avoid such sensitive errors, sensitivity analysis is carried out, for the effective use and implementation of qualitative factors. A tolerance limit of (± 0.03) is considered in the decision making process of dominance matrix.

For example, if membership value assigned to one alternative is 0.75 and the membership value of another alternative is 0.77 so, according to dominance criteria concerned, domination of 0.77 over 0.75 can't be considered because the difference between these two membership values is 0.02 which is falling under the limit of tolerance ± 0.03.

The objective of a typical sensitivity analysis of an MCDM problem is to find out when the input data (i.e., the a_{ij} and w_j values) is changed into new values, the ranking of the alternatives will change. Above said statement can be explained in detail by taking min-max criteria. By applying min-max criteria the entire rankings may change for example from the Table 14, modified pessimistic aggregated matrix max. member ship value 0.543 of factor F3 corresponding to alternative A4 is maximum and membership value of 0.175 corresponding to alternative A3 is minimum, so as per min-max criteria, rankings of alternatives will be as A3 stands in first position and A4 stands in last position (Liberling 1981), whereas per assigning weightages to criteria, the positions are entirely different. To avoid such ambiguity and lacunas, sensitivity analysis is to be carried out to select the best alternative among available alternatives.

The available lean manufacturing tools are kaizen, value stream mapping, 5S, single minute exchange of die and poka-yoke. The collected data is in the form of qualitative factors. The objective is to identify the optimum lean manufacturing tool using Artificial Intelligence Approach.

3.1 Ranking of Alternatives

The Lean manufacturing is to be ranked based on the qualitative criteria. A questionnaire has been prepared to evaluate the lean manufacturing tools against these alternatives. The questionnaire was circulated to lean manufacturing implementing industries experts in Maruti Suzuki, HVCC, Sumi-Motherson, Tata Moters & Sundram Fasteners to have their opinions in terms of membership values and questionnaire is given in Appendix 1. Membership values examined by experts is from Table 2 to 11.

The questionnaire deals with qualitative criteria such as leadership & management, financial capability, skills and expertise, organisational culture and manufacturing strategies in lean environment. An interview with the lean manufacturing

Table 2. Position matrix of an expert no.1

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5
1.	(F1)	0.75	0.85	0.75	0.7	0.75
2.	(F2)	0.6	0.7	0.3	0.7	0.5
3.	(F3)	0.5	0.7	0.5	0.7	0.75
4.	(F4)	0.7	0.7	0.75	0.6	0.75
5.	(F5)	0.7	0.8	0.2	0.7	0.7

Table 3. Position matrix of an expert no.2

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5
1.	(F1)	0.10	0.20	0.10	0.10	0.10
2.	(F2)	0.05	0.10	0.05	0.25	0.10
3.	(F3)	0.10	0.20	0.10	0.50	0.10
4.	(F4)	0.10	0.20	0.50	0.10	0.10
5.	(F5)	0.10	0.30	0.15	0.30	0.15

Table 4. Position matrix of an expert no.3

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5
1.	(F1)	0.85	0.80	0.75	0.50	0.80
2.	(F2)	0.85	0.80	0.70	0.65	0.80
3.	(F3)	0.60	0.80	0.60	0.80	0.90
4.	(F4)	0.90	0.80	0.75	0.60	0.85
5.	(F5)	0.75	0.60	0.75	0.60	0.85

Table 5. Position matrix of an expert no.4

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5
1.	(F1)	0.70	0.60	0.65	0.65	0.70
2.	(F2)	0.65	0.55	0.40	0.70	0.45
3.	(F3)	0.65	0.55	0.45	0.70	0.65
4.	(F4)	0.65	0.55	0.70	0.65	0.65
5.	(F5)	0.70	0.75	0.25	0.70	0.60

Table 6. Position matrix of an expert no.5

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5
1.	(F1)	0.20	0.30	0.20	0.15	0.20
2.	(F2)	0.10	0.10	0.10	0.30	0.20
3.	(F3)	0.15	0.30	0.15	0.60	0.20
4.	(F4)	0.15	0.30	0.50	0.15	0.20
5.	(F5)	0.15	0.30	0.20	0.40	0.15

Table 7. Position matrix of an expert no.6

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5
1.	(F1)	0.70	0.75	0.70	0.60	0.70
2.	(F2)	0.55	0.70	0.35	0.60	0.45
3.	(F3)	0.45	0.70	0.45	0.60	0.70
4.	(F4)	0.60	0.60	0.70	0.50	0.70
5.	(F5)	0.60	0.80	0.10	0.65	0.60

Table 8. Position matrix of an expert no.7

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5
1.	(F1)	0.30	0.35	0.20	0.35	0.20
2.	(F2)	0.15	0.15	0.10	0.30	0.20
3.	(F3)	0.25	0.25	0.10	0.50	0.15
4.	(F4)	0.15	0.25	0.45	0.10	0.15
5.	(F5)	0.10	0.40	0.40	0.30	0.20

Table 9. Position matrix of an expert no.8

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5
1.	(F1)	0.50	0.55	0.50	0.45	0.50
2.	(F2)	0.35	0.40	0.20	0.45	0.40
3.	(F3)	0.30	0.35	0.25	0.45	0.35
4.	(F4)	0.45	0.35	0.30	0.40	0.35
5.	(F5)	0.45	0.40	0.05	0.45	0.30

Table 10. Position matrix of an expert no.9

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5
1.	(F1)	0.80	0.90	0.85	0.80	0.85
2.	(F2)	0.65	0.75	0.40	0.80	0.55
3.	(F3)	0.60	0.75	0.60	0.75	0.60
4.	(F4)	0.75	0.75	0.80	0.75	0.60
5.	(F5)	0.75	0.85	0.30	0.70	0.65

Table 11. Position matrix of an expert no.10

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5
1.	(F1)	0.70	0.90	0.80	0.40	0.85
2.	(F2)	0.70	0.90	0.75	0.55	0.85
3.	(F3)	0.50	0.90	0.55	0.75	0.80
4.	(F4)	0.85	0.80	0.60	0.50	0.80
5.	(F5)	0.65	0.70	0.60	0.50	0.70

strategies experts was also conducted to collect data for evaluating the "qualitative criteria" affecting the lean tools manufacturing selection. A correspondence between the qualitative factors and the available lean tools was made explicit, and a numerical scale between 0.0 and 1.0 was established. A value of 0.5 indicates a neutral effect while a value of 1.0 is defined as complete satisfaction.

To assess the impact of qualitative and quantitative factors, the following lean manufacturing implementing firms are approached and their membership values are placed in different matrices.

In response to the questionnaire, each expert is given his degree of belief about the Lean manufacturing tools in terms of 0 - 1 with respect to the criteria. The transformed results of the questionnaire are tabulated in position matrices for each expert and are as follows.

For example, the membership value of 'A_{41}' in mean aggregated Table 12 is obtained as follows, here '41' indicates 4th row of 1st column of above matrix which is formed by using the following equation.

$$\mu_{ij} = \frac{1}{k}\sum_{i=1}^{k}\mu_{ij}^{1} \tag{1.4}$$

Here, μ_{ij} =Mean aggregated membership value.

K = number of position matrices.

i = row

j = column.

And, the procedure for obtaining the above value is as follows.

A_{41}=[$a_{41}{}^{1}$+$a_{41}{}^{2}$+.........................$a_{41}{}^{10}$]/10.

A_{41} = Mean aggregated membership value = 0.53

$a_{41}{}^{1}$, $a_{41}{}^{2}$,.......................$a_{41}{}^{10}$ are the membership values .of factor against each alternative from the position matrices of the experts from the Table 2 to 11

Now A_{41} is calculated as shown below.

A41={[0.90+0.10+0.70+0.65+0.15+0.60+0.15+0.45+0.75+0.85] /10} =0.53

And is tabulated in the mean aggregated matrix Table 12 at 4th row of 1st column. Remaining membership values are also calculated in same manner and are positioned in the Table 12 of mean aggregated matrix as shown above.

After identifying the mean aggregated values, the pessimistic aggregated matrix should be formed to minimize the risk of taking the values of memberships given by all the experts from the different companies for each factor against each alternative. To form pessimistic aggregated matrix, minimum membership value of each factor against each alternative from all the position matrices is taken and formed in a matrix shape as shown in the Table 13. For example membership value of 'A_{54}' of pessimistic aggregated matrix is obtained as follows: here '54' indicates 5th row of 4th column of pessimistic aggregated matrix which can be calculated by using the following equation 1.5

$$\begin{aligned} \mu_{ij} &= \mu_{ij}^{1} + \mu_{ij}^{2} + \ldots\ldots\ldots\ldots\ldots\ldots\mu_{ij}^{k} \\ &= \min\left(\mu_{ij}^{1},\ \mu_{ij}^{2},\ldots\ldots\ldots\ldots\ldots\ldots\mu_{ij}^{k}\right) \end{aligned} \tag{1.5}$$

Here μ_{ij} = Membership value.

In μ_{ij}^{1}, μ_{ij}^{2}, ...μ_{ij}^{k}

I & j are row and column respectively, and

1, 2 ...k, indicates the number of matrices formed.

Minimum value among all the values of each criterion is taken and formed as single matrix shown in table no …., and

A_{54}= 0.30 is calculated as shown below.

A_{54} = min. of [$a_{54}{}^{1}$, $a_{54}{}^{2}$,...................., $a_{54}{}^{10}$] are the minimum membership values of criteria against alternatives.

A_{54}=min[0.60,0.30.0.70,0.70,0.40,0.65,0.30,0.45,0.70,0.50] = 0.30.

So, minimum value is '0.30' among all the membership values and is positioned in the matrix, in 5th row of 4th column of the matrix, and remaining minimum membership values for all the criteria against alternatives are tabulated as pessimistic aggregated matrix as shown in Table 13. Here A1,A2,A3,A4,A5 is taken as Kaizen, Value stream mapping,5 S, single minute exchange of die, Poka –Yoke and Factors F1,F2,F3,F4 and F5 is as leadership & management, financial capabilities, skill and expertise, organizational culture and manufacturing strategy.

These membership values of the experts are combined in a single matrix using modified pessimistic aggregation for each criterion against the alternatives since pessimistic aggregation attempts to minimize the risk, while the modified pessimistic aggregation may prove to be useful to have a spectrum of polarized opinions of the experts. The final aggregated membership values are from modified pessimistic aggregation, which is an average of arithmetic mean and pessimistic aggregation. Table 14 is the modified pessimistic aggregation table for the position matrices of various experts. These values are obtained by taking

Table 12. Mean aggregation of all position matrix

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5
1.	(F1)	0.56	0.62	0.55	0.47	0.565
2.	(F2)	0.465	0.51	0.33	0.53	0.45
3.	(F3)	0.41	0.55	0.375	0.635	0.52
4.	(F4)	0.53	0.53	0.605	0.305	0.515
5.	(F5)	0.495	0.59	0.3	0.53	0.49

Table 13. Pessimistic aggregation matrix

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5
1.	(F1)	0.10	0.20	0.10	0.10	0.10
2.	(F2)	0.05	0.10	0.05	0.25	0.10
3.	(F3)	0.10	0.20	0.10	0.45	0.10
4.	(F4)	0.10	0.20	0.30	0.10	0.10
5.	(F5)	0.10	0.30	0.05	0.30	0.15

Table 14. Modified pessimistic aggregation matrix

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5
1.	(F1)	0.33	0.41	0.325	0.285	0.332
2.	(F2)	0.258	0.308	0.193	0.39	0.275
3.	(F3)	0.255	0.375	0.238	0.543	0.31
4.	(F4)	0.315	0.365	0.453	0.203	0.308
5.	(F5)	0.298	0.445	0.175	0.415	0.32

different membership values for the factors affecting lean manufacturing tool selection by experts.

For example membership value of 'A34' of modified pessimistic aggregation is obtained by using the following equation.

$$\mu_{ij} = \frac{1}{2}\begin{Bmatrix} \mu_{ij}^{1} \cap \mu_{ij}^{2} \ldots\ldots\ldots\ldots \mu_{ij}^{k} \\ + \frac{1}{k}\sum \mu_{ij}^{1} \end{Bmatrix} \qquad (1.6)$$

And the procedure for obtaining the above membership value is as follows:

A_{34} = Average of every membership value of criteria against alternative of mean aggregated matrix and pessimistic aggregated matrix.

So, $A_{34} = \{[a_{34}^{ma} + a_{34}^{pa}\}/2]$, here a_{34}^{pa} are membership values of criteria against alternative of 3rd row of 4th column of mean aggregated matrix and pessimistic aggregated matrix respectively.

Here ma = mean aggregation

pa = pessimistic aggregation

So, $A_{34} = \{ (0.635 + 0.45] /2 \}$

$A_{34} = 0.543$ and is tabulated in the modified pessimistic aggregated matrix Table 4, remaining aggregated membership values are also calculated in the same manner and are positioned in the above table.

3.2 Comparison of Alternatives

The basis on which alternatives are ranked is based on Dominance Matrix. An alternative is said to dominate another alternative for any given feature if its aggregate membership values are greater than that of the other alternative. An alternative is defined to be superior to a second alternative if it dominates the second alternative in more features than the number of features in which the second dominates the first.

In many cases there may be alternatives which are very close to each other on the basis of the dominance matrix. In these situations the magnitude of the dominances which is the difference in the membership values in the aggregate matrix can be examined. Because of the uncertainty or fuzziness of the information contained in the aggregate matrix entries, it is useful to establish a tolerance limit. That is if the membership value of a second alternative is outside the specified limit, then dominance exists; while if it is within the limit, the alternatives can be considered equivalent with respect to that feature. This range is set arbitrarily (± 0.03). A higher value of this may result in losing too much information thereby causing imprecise decision leading to distortion in the criteria for the decision making.

3.3 Dominance Matrix Structure

In order to display the dominance structure between all possible pairs of lean manufacturing tools, a *N by N* matrix, called the Dominance Matrix (D) is constructed. The element d_{ij} is the number of features for which the membership value of lean manufacturing tool j is greater than that of lean manufacturing tool i. For example in modified pessimistic aggregation as shown in Table 14, the element X_{12} indicates that how many times criteria of alternative 2 dominates criteria of alternative 1 and is tabulated in Dominance Matrix at X_{12}.

The dimensionality N is equal to the number of lean manufacturing tools under consideration. If the j^{th} column is summed, the total i number of dominances of lean manufacturing tools j^{th} over all, other lean tools are obtained. Similarly, if the i^{th} row is summed number of times j^{th} lean tool is dominated by all, other lean manufacturing tools are obtained. The sum of columns and rows can be compared and it can be seen that most favourable outcomes have higher column sums and lower row sums.

An inherent properly of dominance matrices is that they are additive. Therefore, if the features in an aggregate matrix are subdivided into 'k' sets and a dominance matrix is calculated for each set, then the complete dominance matrix for the entire aggregate matrix is simply the matrix sum of the *k* dominance matrices. The difference between the column sums and the row sums of the dominance matrix gives the dominance relation between the alternatives. This dominance relation is normalized with respect to the most inferior alternative as the datum for ease of reference is expressed as a dominance vector of dimension *N*. The dominance of alternatives for the modified pessimistic aggregation is given in Table15 and is as follows:

Table 15. Dominance Matrix of the modified pessimistic aggregation

	A1	A2	A3	A4	A5
F1	_	5	1	3	3
F2	0	_	1	2	0
F3	4	4	_	3	4
F4	2	3	2	_	2
F5	1	5	1	3	_

Based on the above dominance matrix, the best alternative is identified as follows:

- Sum up all the column and row values
- Choose the column with highest value and lowest row totals to select the best lean manufacturing tool
- If two alternative column sums are same, choose the alternative with minimum row sum
- If sums of columns and rows are same, choose an alternative arbitrarily
- To choose the next best, delete the values of the best lean tool and repeat the procedure.

The alternatives are ranked with above methodology and is in Table 16

Ranking of lean manufacturing tools
A2[17,3] 2.A5[9,5] 3.A4[6,4]
4. A1[4,1] 5.A3[1,0]

In the Table 16 highest column sum is 17 and lowest row sum is 3 for the alternative A2. Therefore, using Dominance Matrix, the alternative A2 is the best alternative and corresponding to value stream mapping. To choose the next best, the values of these alternatives values are removed and the procedure is repeated. Using the dominance matrix 'poka-yoke', single minute exchange of die, kaizen, and 5S are ranked respectively.

Lacuna in the present system

In the process given above certain drawbacks are there which are mentioned below.

- All qualitative factors are given equal importance
- Important factors are overlooked
- Some inferior factors are ranked equally with other factors

To overcome such lacunas, concept of weightage (0.0 to 1.0) given by experts has been introduced.

Table 16. Dominance Matrix Analyses

	A1	A2	A3	A4	A5	Row Sum			
F1	_	5	1	3	3	12	7	4	1
F2	0	_	1	2	0	3	1	0	0
F3	4	4	_	3	4	15	11	7	3
F4	2	3	2	_	2	9	6	4	2
F5	1	5	1	3	_	10	5	2	1
Column Sum	7	17	5	11	9				
	7	14	4	9	9				
	6	10	3	6	7				
	4	5	2	3	4				

3.4 Assigning the Weights on Evaluation Criteria

The membership values given for quantitative factors are of equal importance. To overcome certain drawbacks given by different experts, before evaluating the alternatives weightages for each factor have been introduced to get accuracy in selecting optimum alternative among available alternatives. Satty's multi criteria decision algorithm are assigned for weightages and are tabulated in Table 17.

After identifying the weightages to be assigned to the membership values of features of available alternatives from the experts, these weightages are assigned exponentially to all the factors in Table 14 that is placed in the Table 18.

The alternatives are ranked according to previous methodology, given in Table 19

Ranking of factor with weighted values is as follows:

1.A2[9,1] 2.A4[8,6] 3.A5[3,0]
4.A1[2,0] 5.A3[0,0]

Table 17. Weightages of Factors

Factor	F1	F2	F3	F4	F5
Weights	0.474	0.144	0.13	0.202	0.05

Table 18. Weighted aggregated table

S.No.	Alternatives/ Factors	A1	A2	A3	A4	A5	Weight
1.	(F1)	0.59	0.66	0.59	0.55	0.59	0.474
2.	(F2)	0.82	0.84	0.79	0.87	0.83	0.144
3.	(F3)	0.84	0.88	0.83	0.92	0.86	0.13
4.	(F4)	0.79	0.82	0.85	0.73	0.79	0.202
5.	(F5)	0.94	0.96	0.92	0.96	0.94	0.05

Table 19. Weighted dominance matrix analyses

	A1	A2	A3	A4	A5	Row Sum			
F1	_	2	1	2	0	5	3	0	0
F2	0	_	0	1	0	1	0	0	0
F3	0	4	_	3	1	8	4	0	0
F4	2	2	2	_	2	8	6	2	0
F5	0	1	0	3	_	4	1	0	0
Column Sum	2	9	3	9	3				
	2	8	3	8	3				
	2	6	3	6	3				
	2	4	2	2	2				

4. Results and Discussion

Due to diverse needs of automotive industries, various lean manufacturing tools are available for implementation in process such as kaizen, value stream mapping, poka-yoke, SMED and 5S.The selection of appropriate lean manufacturing tool plays a vital role for removal of non added values. Based on the available data and lean manufacturing tools information, the important factors are identified and optimum lean tool is selected. The factors applied are numerous, subjective and difficult to quantify. The expert's subjective knowledge is converted into numerical measure and is used to select the alternatives.

Since the membership values are very close to many features, alternatives are affected for comparison. Because of uncertainty of fuzziness of information contained in aggregate matrix entire tolerance limit was established. That is, if a membership value of a second alternative is outside the specific limit then dominance exists while if it is within the limit the alternative can be considered equivalent with respect to that feature within the range of ±0.03.

Since some inferior factors rank equally with other factors to avoid this lacunas concept of weightage between 0.0 to 1.0 was introduced and the alternative are ranked based on weightages. The alternative are selected without weightages and with weightages in the selection process using Dominance Matrix. The ranking of lean manufacturing tools is as follows

Without weights 1.A2[17,3] 2.A5[9,5] 3.A4[6,4] 4.A1[4,1] 5.A3[1,0]

With weights 1.A2[9,1] 2.A4[8,6] 3.A5[3,0] 4.A1[2,0] 5.A3[0,0]

Here ranking of lean manufacturing tools A2, A5, A4, A1 and A3 respectively are without weights and A2 corresponds to value stream mapping, A5 corresponds to poka-yoke, A4 corresponds to single minute exchange of die, A1 corresponds to Kaizen and A3 corresponds to 5S lean manufacturing tool.

After introducing the weightages the position of alternative A4, A5 has been changed as A2, A4, A5, A1 and A3 respectively. This indicates the importance of weightages and reflects in selection and ranking of alternatives.

5. Conclusion

Optimum selection of lean manufacturing tools for automotive industries depends on qualitative factor decision making criteria and identifies an organized set of factor for the selection of lean manufacturing tool based on artificial intelligence approach .The major findings identified are listed as below:

1. Amongt the identified lean manufacturing tools value stream mapping tool with supporting values 17 and 3, poka-yoke , single minute exchange of die, kaizen, and 5S are ranked with supporting values [9,5],[6,4,],[4,1],[1,0] respectively.
2. Taking the weightages value stream mapping was also identified as best lean manufacturing tools with supporting value of 9 and 1 for weightages value of 0.474,0.144,0.13,0.202,0.05 respectively for F1,F2,F3,F4 and F5 factors respectively.
3. The linguistic variables are converted into numerical measure for decision making.
4. Because of uncertainty or fuzziness of the information in aggregate matrix entries a tolerance limit of ±0.03 was established.
5. The range was set arbitrarily and a higher value of this results in losing too much information thereby causing imprecise decision leading to distortion in the criteria for the decision making.
6. Artificial Intelligence approach provides several valuable aspects for representing and appropriately manipulating qualitative and linguistic information in a wide range of lean manufacturing tool selection activity and their associated complexities encountered in lean tool selection scenario.
7. In the traditional analysis a difference of opinion, bias or prejudice, that may be present can pose problems affecting the particular decision making process whereas artificial intelligence approach incorporates qualitative factor and non value added factor can be easily eliminated.
8. Uncertain data in terms of linguistic variable was incorporated for solving multiple attribute problems in fuzzy environment.
9. The fuzzy dominance method is considered relevant criteria for fuzzy multiple attribute decision making along with weights. Thus selection results derived from fuzzy multiple attribute decision making methods are comparatively more significant than those obtained by other decision making methods.

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