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An approach for selecting the optimum and effective combinations of machines based on specific operations using fuzzy multi-criteria decision making model

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Abstract— In manufacturing systems, inputs are transformed into an output by gathering inputs in an optimal way to guide the manufacturer. Machining process plays a prominent role in industry, and thus, directly affects the efficiency of the manufacturing systems. Due to highly competitive global market, the organizations are now forced to focus more on increasing productivity while decreasing cost and time by right selection of the combination of machines. Proper selection of machines justifies labor saving, improved product quality and increased production rate with enhanced overall productivity. Evaluation and selection of a combination of machines is a complex decision-making problem involving multiple conflicting criteria. Due to different importance of the conflicting criterions, the multi-criteria decision-making methods are extremely useful in the selection process of the proper machining type. This study provides distinct systematic approaches in fuzzy environments to deal with the selection problem of proper combination of machines and proposes a decision support model for the guidance of decision makers to assess potentials of four distinct traditional machining processes, namely Lathe machine, Drill machine, Grinding machine and Milling machine, in the operational process of mild steel bar of length 6 inch and diameter 0.8mm. The required data for decision and weight matrices are obtained via a questionnaire to specialists, personal trials as well as by deep discussions with experts. . Finally, an application of the proposed model is also performed and the desired combination of machines is obtained.

Index Terms— Multiple criteria decision-making model, fuzzy logic, linguistic variables, fuzzy number, combination of machines, optimum.

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1 Introduction

OPTIMIZATION and decision making are important. In many industrial engineering problems, we must select a design, select parameters of a process or, in general, make a decision.

In practically all manufacturing decisions specifications of the system are often imperfectly known since the imprecise and subjective nature of information makes decision making rather complex and inconsistent. Fuzzy logic (Zadeh, 1965, 1996, 1997) is an analysis method purposefully developed to incorporate uncertainty into a decision model. Fuzzy logic allows for including imperfect information no matter the cause. In essence fuzzy logic allows for considering reasoning that is approximate rather than precise. There are key benefits to applying fuzzy tools. Fuzzy tools provide a simplified platform where the development and analysis of models require reduced development time than other approaches. As a result, fuzzy tools are easy to implement and modify. Nevertheless, despite their ''user-friendly' 'outlet, fuzzy tools have shown to perform just as or better than other soft approaches to decision making under uncertainties. These characteristics have made fuzzy logic and tools associated with its use to become quite popular in tackling manufacturing related challenges.

The methods of fuzzy multi-criteria decision-making have been developed due to the imprecision in assessing the relative importance of selection criteria and in estimating the performance of alternative strategies with respect to these criteria. The imprecision may derive from several respects: unquantifiable information, incomplete information, impossible obtainable information and partly from ignorance. To overcome this obstacle, the fuzzy sets theory was developed to improve the reliability of decision making process under uncertainty (Bellman and Zadeh, 1970).

For fuzzy multi-criteria decision making problem, the decision makers use linguistic values associated to their related linguistic variables to assess the importance of selection criteria and also to estimate the performance of each action plan with respect to these criteria for selection in the future implementation. This study will address as a practical example the problem of selecting optimum and effective machining sequence and machine, which consists in exploring various constraints and performance index.

To assess the importance of the various constraints and performance criteria, Fuzzy-Delphi method must be used, to have regard to the decision-making opinions from different sequence of machining to be performed, just to give a character of homogeneity and subsequent performance to the decision making process. The fuzzy concept was incorporated into the

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Delphi method by calculating the weighted average of the importance given to various criteria after its evaluation via questionnaire to specialists, personal trials as well as by deep discussions with experts.

2 Objectives

The objectives of the project are:

1. To determine the optimum combination of machines.
2. To determine the effective sequence of machining.
3. To reduce time and cost of machining.
4. To obtain the perfect combination of machine using Fuzzy-Delphi method.

3 Literature Review

Multiple criteria decision making (MCDM) is a modeling and methodological tool for dealing with complex engineering problems. Fuzzy set approaches are suitable to use when the modeling of human knowledge is necessary and when human evaluations are needed. Fuzzy set theory is recognized as an important problem modeling and solution technique. Fuzzy set theory has been studied extensively over the past 40 years. Most of the early interest in fuzzy set theory pertained to representing uncertainty in human cognitive processes. Fuzzy set theory is now applied to problems in engineering, business, medical and related health sciences, and the natural sciences. Over the years there have been successful applications and implementations of fuzzy set theory in MCDM. MCDM is one of the branches in which fuzzy set theory found a wide application area.

According to Moreno-Jimenez et al. (2005), the selection process consists in three main stages, namely modeling, evaluation and synthesis [1]. Thus, the first step consists in the construction of a hierarchy, the second incorporates the judgments that reflect the preferences of actors involved in the selection process and finally the third step provides the priorities after comparing the alternatives.

The Delphi method was designed as a group technique whose purpose was to obtain the most reliable consensus of experts' group opinions, by applying a series of intensive questionnaires with a control feedback of opinions (Jon Landeta, 2006)[3]. The evaluation of selection criteria is a problem of fuzzy decision-making within the fuzzy assessments and the opinions of several experts may be taken into account. The makers decisions judgments are often divergent due to some reasons that most often arise in fuzzy environments.

Over the time, there were published a series of articles and papers in the topic of decision making problem under uncertainty. Thus, starting with the bedside article of fuzzy logic, namely "Fuzzy sets", published by Zadeh in 1965, so far there is a wide range of publications in the method domain of fuzzy multi-criteria decision making (FMCDM), of which I will mention only the most current in their order of appearance: Yang and Chou (2005), Chang, Wang, and Wang (2006), Xu and Chen (2007), Yang et al. (2007), Yang and Hung (2007), Chou, Chang, and Shen (2008), Wang (2008), Yeh and Chang (2009), Hossein Alipour et al. (2010), Awasthi et al. (2010), Ye (2011) and Kaya and Kahraman (2011)[3]. The recent findings have extended the concept of FMCDM towards a fuzzy decision making-problem within a group, as it is mentioned by Chang et al. (2000), Cheng and Lin (2002), Chang and Wang (2006), Liu and Chen (2007), Yeh, Cheng, and Chi (2007), Chang, Wu, and Chen (2008), Ekel et al. (2009), Yeh and Chang (2009), Boroushakin and Malczewski (2010), Chen et al. (2011).

Cheng and Lin (2002) used the Delphi method to adjust the fuzzy assessments of each member of the decision group, assessments based on linguistic terms which are then converted into trapezoidal fuzzy numbers. These trapezoidal fuzzy numbers were used by Zeng et al. (2007) for capturing and converting the subjective judgments of decision-maker members [2]. The next step was then the operation with fuzzy numbers via fuzzy inference rules and operators of addition, subtraction, multiplication and division, so that finally to take place the defuzzification process through various methods such as max, average, centroid, singleton, and others [2].

4 Methodology

4.1 Procedure

Multi-criteria decision making (MCDM) is a branch of operation research models and a well known field of decision-making. These methods can handle both quantitative as well as qualitative criteria and analyze conflict in criteria and decision makers. Several classification and categorization exist but in general these methods can be divided into two categories: multi-objective decision-making (MODM) and multi-attribute decision-making (MADM).

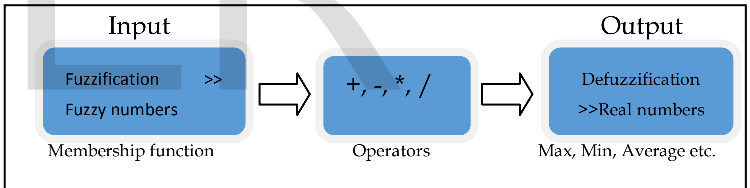

Fig. 1. A classical fuzzy system.

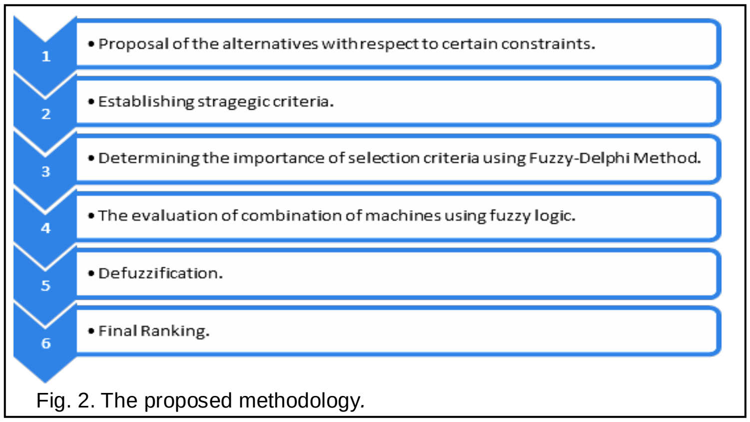

Fig. 2. The proposed methodology.

The implementation of the proposed methodology involves going through five main stages, as described in figure 2. As it can be seen within the algorithm above, the first step in the proposal of the alternatives which often may have more elements in common with respect to certain constraints. It follows then to establish the strategic criteria. Stage 3 consists of determining the importance of the selection criteria of the machines by using Fuzzy-Delphi method. In stage 4 takes place the estimation and evaluation of the performance of combinations of machines with respect to each constraint, by experts in this case, using fuzzy sets. In the phase 5 takes place the defuzzification process of the aggregate scores obtained by multiplying operation of the results from steps 3 and 4 within the fuzzy method of multi-criteria decision making. In the last stage, takes place the final ranking of the machines, so finally to be chosen for effective combination, with the highest obtained score.

4.2 A Brief Introduction to Fuzzy Set Theory

Fuzzy logic starts with the concept of a fuzzy`` set. A *fuzzy set* is a set without a crisp, clearly defined boundary. It can contain elements with only a partial degree of membership [7]. To understand what a fuzzy set is, first consider the definition of a *classical set*. A classical set is a container that wholly includes or wholly excludes any given element

This type of set is called a classical set because it has been around for a long time. It was Aristotle who first formulated the Law of the Excluded Middle, which says X must either be in set A or in set not-A [7]. Another version of this law is:

"Of any subject, one thing must be either asserted or denied."

Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalued logic [7]. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree.

The only condition a membership function must really satisfy is that it must vary between 0 and 1. The function itself can be an arbitrary curve whose shape we can define as a function that suits us from the point of view of simplicity, convenience, speed, and efficiency.

A classical set might be expressed as [6]

$$A = \{x \mid x > 6\} \quad (1)$$

A fuzzy set is an extension of a classical set. If X is the universe of discourse and its elements are denoted by x, then a fuzzy set A in X is defined as a set of ordered pairs [6].

$$A = \{x, \mu A(x) \mid x X\}$$

μA(x) is called the membership function (or MF) of x in A. The membership function maps each element of X to a membership value between 0 and 1.

A fuzzy number is defined as a convex and normal fuzzy set defined on R whose membership function is continuous. The most widely used fuzzy numbers are the triangular and trapezoidal fuzzy numbers, mainly due to their simplicity and ease of application in modeling and interpretation (Petroni and Rizzi, 2002). A triangular fuzzy number (a_i, b_i, c_i) is a fuzzy number whose membership function μi(x) is defined by the following expressions:

$$\mu_i(x) = \begin{cases} 0, if\ x < a_i \\ \frac{x-a_i}{b_i-a_i}, if\ a_i \le x \le b_i \\ \frac{x-b_i}{b_i-c_i}, if\ b_i \le x \le c_i \\ 0, if\ x > c_i \end{cases} \quad (2)$$

Let be (a_1, a_2, a_3) and (b_1, b_2, b_3) two fuzzy triangular numbers. Then, the basic operations between them are as follows:

$$(a+b) = (a_1+b_1,\ a_2+b_2,\ a_3+b_3) \quad \text{for addition} \quad (3)$$

And,

$$(a\times b) = (a_1\times b_1,\ a_2\times b_2,\ a_3\times b_3) \quad \text{for multiplication} \quad (4)$$

Similarly, a trapezoidal fuzzy number $a = (a_1, a_2, a_3, a_4)$, $a_1 \le a_2 \le a_3 \le a_4$, has the following membership function, illustrated also in figure 3:

$$\mu_a(x) = \begin{cases} 0, if\ x < a_1 \\ \frac{x-a_1}{a_2-a_1}, if\ a_1 \le x \le a_2 \\ \frac{x-a_4}{a_3-a_4}, if\ a_3 \le x \le a_4 \\ 0, if\ x > a_4 \end{cases} \quad (5)$$

Let consider another trapezoidal fuzzy number $b = (b_1, b_2, b_3, b_4)$. Then the basic operations with trapezoidal fuzzy numbers are described as follows:

$$(a+b) = (a_1+b_1,\ a_2+b_2,\ a_3+b_3,\ a_4+b_4) \quad \text{for addition} \quad (6)$$

And,

$$(a \times b) = (a_1\times b_1,\ a_2\times b_2,\ a_3\times b_3,\ a_4\times b_4) \quad \text{for multiplication} \quad (7)$$

It is easy to see from the figure that if a2 = a3 it is resulting the transformation of trapezoidal fuzzy number into a fuzzy triangular number, thus,

$a = (a_1, a_2, a_3, a_4)$, becomes $a = (a_1, a_2, a_3)$, as it can be seen in figure 4.

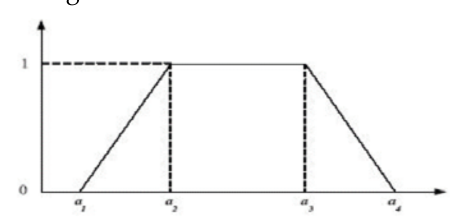

Fig. 3. The membership function of trapezoidal fuzzy numbers.

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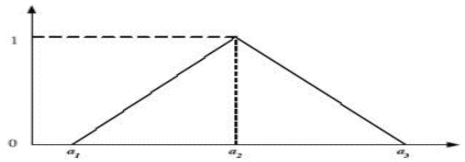

Fig. 4. The membership function of triangular fuzzy numbers

For modeling and representation of decision-makers views in relation with the evaluation of importance of the selection criteria and with the estimation of the performance of each machine along with their combination with respect to the constraints and also for the final selection of the combination, we shall take the following steps:

- Proposal of the alternatives with respect to certain constraints.
- Establishing strategic criteria based on the weight of the constraints.
- Determining the importance of selection criteria using Fuzzy-Delphi Method.
- The evaluation of combination of machines using fuzzy logic.
- Defuzzification of the crisp numbers into real numbers.
- Final Ranking of the combination.

The Fuzzy-Delphi method is a methodology in which the decision makers subjective judgments are transformed in easy manipulated data using fuzzy sets. To start, we will focus on identifying the alternative plans or strategies for sustainable development which by the opinion of the decision makers will be part from the selection process. Let noted their number by n where j = 1, . . . , n. The next step is to establish the strategic selection criteria and assess their importance which representing the directions that a good sustainable development plan needs to meet. Let us note by lci the importance of criterion i, where i = 1, . . . ,m. It should be noted that each member of the management decision makers has a certain weight in decisional process (denote the weight by p), taking into account his position in the hierarchy and his experience. In our case, we consider that the sum of weights of each decider member is equal to 1. If the number of decision makers is k, then:

$$P_1+P_2+ \cdots\cdots +P_k = 1 \quad (8)$$

The opinion makers on the importance of each criterion are expressed by a linguistic value which is then converted into a trapezoidal fuzzy number. Thus, let us note the assessment of the importance of criterion i evaluated by the decision maker k with lc_{ik}. Therefore, the final fuzzy value of the importance of criterion i, it will be weighted as follows, taking into account the opinion of each decision maker [4]:

$$lci = lc_{i1}\times P_1 + lc_{i2}\times P_2 + \cdots\cdots + lc_{ik}\times P_k \quad (9)$$

For each constraint it will be given a subjective estimation expressed also this time by linguistic values which through the process of fuzzification it will be turn in trapezoidal fuzzy numbers. Suppose that the value of fuzzy numbers on the horizontal axis when we represent the membership functions of the trapezoidal fuzzy numbers not exceed the limit of 10, as can be seen in figure 5. As we can see, each linguistic value that summarizes the subjective assessment and estimation of the human factor decision maker can be converted into trapezoidal fuzzy numbers, as follows in table 1:

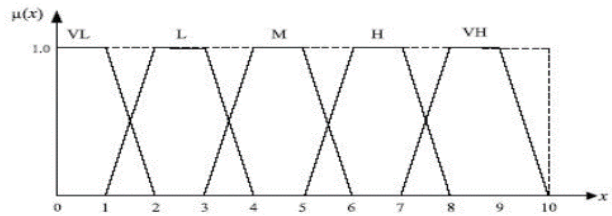

Fig. 5. The membership function of trapezoidal fuzzy numbers

TABLE 1
THE TRAPEZOIDAL FUZZY NUMBERS RELATED TO THE ASSESSMENT OF THE IMPORTANCE OF THE STRATEGIC CRITERIA AND TO THE ESTIMATION OF THE PERFORMANCE OF SUSTAINABLE DEVELOPMENT PLANS WITH RESPECT TO THE TACTICAL SUB CRITERIA

Linguistic Variable	Trapezoidal fuzzy numbers
Very Low (VL)	(0, 0, 1, 2)
Low (L)	(1, 2, 3, 4)
Moderate (M)	(3, 4, 5, 6)
High (H)	(5, 6, 7, 8)
Very High (VH)	(7, 8, 9, 10)

Regarding to the performance estimation of each machine combination and to the importance evaluation of the strategic criteria or constraints, the perceptions of decision makers are therefore converted from linguistic values as ″Very low (VL)″, ″Low (L)″, ″ Moderate (M)″, ″ High (H)″, or ″ Very high (VH)″ into trapezoidal fuzzy numbers.

Following the review by the ATO and lab assistants of Mechanical machine shop as well as the professionals of different engineering workshops, we shall determine the average scores with respect to these sub criteria in order to calculate the strategic criterion score that encompasses these sub criteria. Thus, having 3 trapezoidal fuzzy numbers, for example [4],

$a = (a_1, a_2, a_3, a_4)$, b = (b_1, b_2, b_3, b_4) and c = (c_1, c_2, c_3, c_4) the average will be:

$$\text{Average } (a, b, c) = [(a_1+b_1+c_1)/3, (a_2+b_{2+}c_2)/3, (a_3+b_3+c_3)/3] \quad (10)$$

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All values resulting from this operations, trapezoidal fuzzy numbers in this case, will be implemented into a matrix denoted by E_{ij} which represents the performance estimation of the plan j with respect to criterion i , where j = 1, . . . , n and i = 1, . . . ,m.

4.3 The Final Ranking and the Selection of the Best Plan

The fuzzy weights describing the importance of each selection criteria will be implemented as a matrix with 1 row and m columns [4], as follows:

$$lci = (lc1\ lc2 \ldots lcm) \quad (11)$$

To establish the final performance of each combination of machine, the above matrix lc will be multiplied with each machine rating E_{ij}, j = 1, . . . , n, i = 1, . . . ,m,[4] as follows (we note the performance of each plan by (P_j) [4]:

$$P_j = l_c \times E_{ij} \quad (12)$$

For each Pj constraints will therefore result an aggregate fuzzy score, displayed as a trapezoidal fuzzy number [4]:

$$S(p_j) = (x_1, x_2, x_3, x_4), \quad j = 1, \ldots, n. \quad (13)$$

For the final ranking and for the selection of the optimum and effective machine, the fuzzy numbers do not allow an objective and fair assessment. Thus, is required their transformation in crisp, real numbers, through the defuzzification process and using the centroid method [4], as follows:

$$D(p_j) = [(x_1+x_2+x_3+x_4)/4], \quad j = 1, \ldots, n. \quad (14)$$

Following the hierarchy of all scores resulted D(P_i) from defuzzification process, the machine with the highest score will be selected for obtaining the right sequence and combination.

4.4 Layout of machines in a shop

Machines can be placed in any manner in a workshop. The analysis of selection of the effective combination and sequence of machines is dependent on the layout. Here, the calculations are based on considering the following layout:

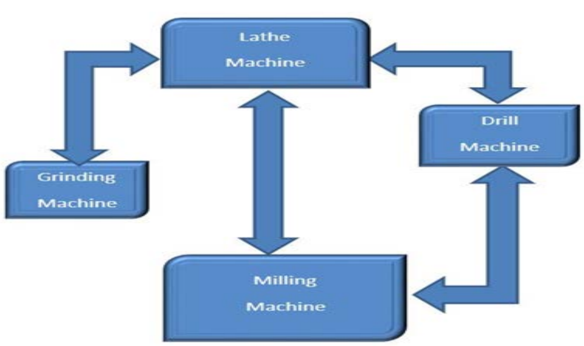

Fig. 5. Layout of a Machine shop (according to hypothesis)

4.5 Establishing strategic criteria based on the weight of the constraints

This case study has been done on a cylindrical mild steel bar of length 6 inch bar and diameter of 0.8 mm. Various data and readings has been taken with respect to the requisite operations on the basis of some constraints. The constraints and their associated weights are:

TABLE 2
VARIOUS CONSTRAINTS WITH THEIR ASSOCIATED WEIGHTS

1. Optimum Cost (D1)	**P1 = 0.20**
2. Accuracy (D2)	P2 = 0.40
3. Machine distance (D3)	P3 = 0.10
4. Machine Availability (D4)	P4 = 0.15
5. Setup time (D5)	P5 = 0.05
6. Operation time (D6)	P6 = 0.10

Here we have to perform four operations namely turning, facing, drilling, thread cutting. These operations can be machined in various combinations of machines. The machines taken for the case study are lathe machine, drill machine, grinding machine, milling machine. Each operation can be performed by several machines such as facing can be done on both lathe machine and grinding machine. Likewise for drilling, lathe machine and drill machine can be used. Similarly for thread cutting operation, both lathe machine and milling machine can be used. But turning is only done in lathe machine. We are to selection the optimum and effective combination of machines (as per the sequence of operations) which may be as follows:

1. Lathe, lathe, lathe, lathe.
2. Lathe, grinding, lathe, lathe.
3. Lathe, lathe, drill, lathe.
4. Lathe, Lathe, lathe, milling.
5. Lathe, lathe, drill, milling.
6. Lathe, grinding, lathe, milling.
7. Lathe, grinding, drill, lathe.
8. Lathe, grinding, drill, milling.

The machines have been given specific weights on the basis of various criterions such as safety, human health, cutting speed, simplicity of operation, cutting at any spot, process control, usability/flexibility, and material removal rate etc.

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The associated weights of the machines evaluated on a scale of 1–10 by specialists and experts in this field. So, the weights are:

TABLE 3
DETERMINING THE IMPORTANCE OF SELECTION CRITERIA USING FUZZY-DELPHI METHOD

Machine	Weights (E)
Lathe machine (M1)	9
Drill machine (M2)	8
Grinding machine (M3)	6
Milling machine (M4)	8

4.6 The evaluation of combination of machines using fuzzy logic:

After establishing the framework of expression of the decision making process and of the working methodology, in the following we will see which is the importance of the machine combination, from processing the views using fuzzy logic by equation (9), as can be seen from table 2.

TABLE 4
FOR TURNING OPERATION

	D1	P1 = 0.20	D2	P2 = 0.40	D3	P3 = 0.10	D4	P4 = 0.15	D5	P5 = 0.05	D6	P6 = 0.10	*lc*
M1	H	(5, 6, 7, 8)	VH	(7, 8, 9, 10)	H	(5,6,7,8)	VH	(7,8,9, 10)	M	(3,4,5,6)	M	(3,4,5,6)	(5.8,6.8,7.8,8.8)
M2	-	-	-	-	-	-	-	-	-	-	-	-	-
M3	-	-	-	-	-	-	-	-	-	-	-	-	-
M4	-	-	-	-	-	-	-	-	-	-	-	-	-

Now, *lc*= {(5.8,6.8,7.8,8.8)}
According to equation (12) and (13),

$$S(M1) = lc \times E_1 = (52.2,61.2,70.2,79.2)$$

For the final ranking and for selection of the best plan, the fuzzy numbers as are shown do not allow an objective and fair assessment. Therefore, we need to transform them in real, crisp numbers, by the centroid defuzzification method, according to equation (14), as follows:

$$D(M1) = 65.7$$

TABLE 5
FOR FACING OPERATION

	D1	P1 = 0.20	D2	P2 = 0.40	D3	P3 = 0.10	D4	P4 = 0.15	D5	P5 = 0.05	D6	P6 = 0.10	*lc*
M1	L	(1, 2, 3, 4)	VH	(7, 8, 9, 10)	M	(3,4,5, 6)	H	(5, 6, 7, 8)	VL	(0,0,1,2)	H	(5,6,7,8)	(4.55,5.5,6.5,7.5)
M2	-	-	-	-	-	-	-	-	-	-	-	-	-
M3	VH	(7, 8, 9, 10)	VL	(0, 0, 1, 2)	VL	(0, 0, 1, 2)	M	(3, 4, 5, 6)	M	(3,4,5,6)	L	(1,2,3,4)	(2.1,2.6,3.6,4.6)
M4	-	-	-	-	-	-	-	-	-	-	-	-	-

Now, $lc \times E_1$ = {(4.55,5.5,6.5,7.5), (2.1,2.6,3.6,4.6)}
According to equation (12) and (13),

$$S(M1) = lc \times E_1 = (40.95,49.9,58.9,67.9)$$
$$S(M3) = lc \times E_3 = (14.4,17.4,24,30)$$

For the final ranking and for selection of the best plan, the fuzzy numbers as are shown do not allow an objective and fair assessment. Therefore, we need to transform them in real, crisp numbers, by the centroid defuzzification method, according to equation (14), as follows:

$$D(M1) = 54.3125$$
$$D(M3) = 19.35$$

Hence, M1 i.e. lathe machine is selected over grinding machine.

TABLE 6
FOR DRILLING OPERATION

	D1	P1 = 0.20	D2	P2 = 0.40	D3	P3 = 0.10	D4	P4 = 0.15	D5	P5 = 0.05	D6	P6 = 0.10	*lc*
M1	L	(1, 2, 3, 4)	H	(5,6,7,8)	L	(1,2,3,4)	M	(3, 4, 5, 6)	H	(5,6,7,8)	L	(1,2,3,4)	(3.1,4.1,5.1,6.1)
M2	H	(5,6,7,8)	H	(5,6,7, 8)	VL	(0,0,1,2)	H	(5, 6, 7, 8)	M	(3,4,5,6)	H	(5,6,7,8)	(4.4,5.3,6.3,7.3)
M3	-	-	-	-	-	-	-	-	-	-	-	-	-
M4	-	-	-	-	-	-	-	-	-	-	-	-	-

Now, *lc*= { (3.1,4.1,5.1,6.1) , (4.4,5.3,6.3,7.3)}
According to equation (12) and (13),

$$S(M1) = lc \times E_1 = (27.9,36.9,45.9,54.9)$$
$$S(M2) = lc \times E_2 = (35.2,42.4,50.4,58.4)$$

For the final ranking and for selection of the best plan, the fuzzy numbers as are shown do not allow an objective and fair assessment. Therefore, we need to transform them in real, crisp numbers, by the centroid defuzzification method, according to equation (14), as follows:

$$D(M1) = 41.4$$
$$D(M2) = 46.6$$

Hence, M2 i.e. drill machine is selected over lathe machine.

TABLE 7

For Thread Cutting Operation

	D1	P1 = 0.20	D2	P2 = 0.40	D3	P3 = 0.10	D4	P4 = 0.15	D5	P5 = 0.05	D6	P6 = 0.10	lc
M1	M	(3, 4, 5, 6)	H	(5, 6, 7, 8)	H	(5,6,7,8)	VH	(7, 8, 9,10)	H	(5,6,7,8)	H	(5,6,7,8)	(4.9,5.9,6.9,7.9)
M2	-	-	-	-	-	-	-	-	-	-	-	-	-
M3	-	-	-	-	-	-	-	-	-	-	-	-	-
M4	VL	(1, 2, 3, 4)	VH	(7, 8, 9,10)	L	(1,2,3,4)	M	(3, 4, 5, 6)	VL	(0,0,1,2)	L	(1,2,3,4)	(3.6,4.6,5.6,6.6)

Now, $lc \times E_1$ = { (4.9,5.9,6.9,7.9) , (3.6,4.6,5.6,6.6)}
According to equation (12) and (13),

$$S(M1) = lc \times E_1 = (44.1,53.1,62.1,71.1)$$
$$S(M4) = lc \times E_4 = (28.8,36.8,44.8,52.8)$$

For the final ranking and for selection of the best plan, the fuzzy numbers as are shown do not allow an objective and fair assessment. Therefore, we need to transform them in real, crisp numbers, by the centroid defuzzification method, according to equation (14), as follows:

$$D(M1) = 57.6$$
$$D(M4) = 40.8$$

Hence, M1 i.e. lathe machine is selected over milling machine.

Therefore, the desired combination is lathe, lathe, drill, lathe.

5 Result & Discussion

5.1 Result

Proper combinations and sequences of machines should be done for all manufacturing process for optimization. Based on the various constraints with their associated weights, layout of machine shop (assumed), simplicity of operation and associated weights of the machines (1-10), we have found the optimized and proper sequence of machines.

The obtained combination and sequence of machines is Lathe, Lathe, Drill, Lathe.

5.2 Discussion

Here in this project work we have made all the possible combinations of those four machines. We have done all the four operation (Turning, Facing, Drilling, Thead cutting) on a cylindrical mild steel bar along with those proposed machine combination. For gaining this proper combination and sequence of machine we have done those operations in various combinations and sequences. We have got the associated weights of the machines (1-10) by specialists and experts in this field. Various data and readings has been taken with respect to the requisite operations on the basis of constraints.

6 Conclusion

Fuzzy set theory allows the complexity of real life issues to be included within the confines and rigors of the mathematical model. The proposed approach is used to solve the combinations and sequence of machines problems to improve the manufacturing systems to optimize their operations by the optimizations of various constraints such as cost, time and operational complexity. The proposed methodology can be successfully applied for the purposes of pursuing a course of action in terms of developing combination and sequence of machines decision problem which have a significant effect on optimization. By using Fuzzy-Delphi method, we have established the importance of the strategic criteria of selection and every rating of the constraints and machines had a greater or lesser influence in the total weight of the decision.

7 References

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