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HYDRAULIC EXCAVATOR SELECTION USING IMPROVED QUALITY COMPARISON METHOD

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ABSTRACT

Quality comparison equipment selection is essentially an equipment ranking method developed by Cokorilo and Milicic in 1991. The concept of this method is based on three matrixes models which are namely called as the machine technical characteristic matrix, parameter machine matrix and corresponding machine matrix respectively. However, the researchers mentioned have ignored to take into consideration the uncertainty in parameter machine characteristic matrix. Therefore, in this paper as a tool to manage this uncertainty and to improve the matrix explained , the use of fuzzy triangular technique is sought and thus as a numerical example, an application of the technique is given for a selection of hydraulic excavator. In quality based equipment selection, the results obtained from the application presented that the magnitude of fuzzy triangular technique is remarkable.

Key Words : Machine technical characteristics, Parameter machine characteristics, Corresponding matrix, Fuzzy triangular technique

GELİŞTİRİLMİŞ KALİTE KARŞILAŞTIRMA METODUYLA HİDROLİK KAZICI MAKİNE SEÇİMİ

ÖZET

Kalite mukayeseli makine seçimi, 1991 yılında Cokorilo ve Milic tarafından geliştirilmiş makinelerin oranlamasına dayalı bir tekniktir. Metodun mantığı, makinenin teknik özelliklerini içeren matris, kuramsal makinelerin özelliklerini içeren parametre matrisi ve atama matrisi olarak bilinen üç matris model üzerine kuruludur. Ancak bu modeli ilk geliştiren araştırmacılar kurumsal parametre matrisindeki belirsizlikleri dikkate almayı ihmal etmişlerdir. Bundan dolayı bu makalede söz konusu matristeki belirsizliği dikkate almak ve tekrar düzenlenmek amacıyla, bulanık üçgensel sayılar yaklaşımının kullanımı araştırılmış ve tekniğin hidrolik kazıcı makinesi seçiminde bir de nümerik uygulaması yapılmıştır. Neticede elde edilen sonuçlar bulanık sayılar yaklaşımının son derece etkili bir yaklaşım olduğunu ortaya koymuştur.

Anahtar Kelimeler : Makine teknik karakteristikleri, Parametre makine karakteristikleri, Atama matrisi, Üçgensel bulanık teknik

1. INTRODUCTION

When making decision associated with mining equipment selection, many factors should be taken into account In particular, since an item of equipment suggested is technically not suitable for any specified job, it is of no more importance at what price it has been offered. Therefore, the technical characteristics such as capacity, design aspiration, working rmp, digging and dumping height, weight must be appropriate with other selection criteria. Until today the importance of technical characteristics in equipment selection is emphasised by many researchers but not deeply investigated . However, Cokorilo and Milicic in 1991 have developed a highly sophisticated method only taking into the technical characteristics of equipment and which will be easily to put into practice. In this method, comparing the technical characteristics of equipment alternatives on the quality basis chooses the most proper equipment and by using three matrixes called machine technical characteristics matrix, parameter machine characteristic matrix and corresponding parameter matrix this quality comparison has performed. However, in this method in setting up the parameter machine characteristic, the uncertainty is totally ignored and such an ignorance drives the decision-maker to make a wrong decision in selection process.

As known, some attributes of materials excavated such as geological, geomechanical and physical factors, and equipment such as weight, bucket capacity, digging and dumping height are the major factors contributing to the complexity of equipment selection. These factors can not be exactly matched for an item of equipment and furthermore, most of these factors cannot be defined by a single index. Therefore, all these cases indicate that selecting a proper item of equipment alternative is a triangular fuzzy problem. Hence in this paper, the method developed by these two authors is re-evaluated under uncertainty created by the characteristics of material excavated and equipment alternatives. In particular, in constructing the parameter machine characteristic matrix, the equipment technical characteristics are compared with the geological and geomechanical factors of material, weather and operational characteristics and fuzzy triangular technique is employed to handle the existing uncertainty.

2. QUALITY COMPARISON METHOD

Originally, the quality comparison method based equipment technical characteristics has been developed and contributed by Cokorilo and Milicic 1991. As it is well known that equipment selection is one of the most critical process in a long-term mine planning. Although it is not an exact science and a general rule, a fruitful selection of mining equipment can be accomplished by the following three stages;

- Preselection based technical characteristics of equipment only
- Selection based production capacity and operating factors only
- Optimum selection based cost factors only

Cokorilo and Milicic (1991) as a preselection have developed a method which will be highly easy to put into practice and in the subsequent pages this method is explained in more detail. After a preselection, a selection based production capacity and operating factors must be considered and so the alternatives obtained from the preselection stage are reselected by considering operating factors at the mine site and production requirements. Since two past decade, many valuable papers relating to this stage have been already produced. As a final selection stage, in the optimum selection the most suitable equipment alternative is chosen by only considering the cost factors (Cebesoy, 1993).

As stated by Cokorilo and Milicic, the quality comparison method based mining equipment selection is typically a *mxn* type of matrix operation as follows;

$$A = \left(a_{ij}\right)_{m\times n} = \begin{bmatrix} a_{11}a_{12} & \cdots & a_{1j} & \cdots & a_{1n} \\ a_{21}a_{22} & \cdots & a_{2j} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{i1}a_{i2} & \cdots & a_{ij} & \cdots & a_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{m1}a_{m2} & \cdots & a_{mj} & \cdots & a_{mn} \end{bmatrix}$$

In this matrix, while each column contains the technical characteristics of an item of equipment, each row contains the equipment alternatives available. As noted earlier, this method consists of three matrixes called machine technical characteristics, parameter machine characteristics and corresponding parameter matrixes. Machine technical characteristics, as matrix A, are formed by the information obtained from technical literatures published by equipment manufacturer. As matrix E, the parameter machine characteristic matrix corresponding a machine, which theoretically exist is constructed by taking each element of the matrix A. While doing that, the first values in each column of matrix E are subjectively assigned and then these values are divided by each value in the columns of matrix A. However, the point to be considered here is that the first values allocated to matrix E are serious uncertainty sources and this can be an important lack of this method.

In parameter machine characteristics matrix, representative values in which they are the highest values in each column of this matrix, are selected as follows,

$$E = (b1, b2,...., bj,......, bn),$$
$$b = \max(a_{1j}, a_{2j},........, a_{ij},.......... a_{mj})$$

Using the representative values a corresponding parameter matrix (Q) is formed by using the following equation,

$$qij = \frac{bj}{aij},\ i = 1,2,........, m;\ j = 1, 2,...........n \qquad (1)$$

Hence, qij ≥ 1 for every i = 1,2...m and for every j = 1,2...n and the corresponding matrix is formed as follows;

$$Q = \left(q_{ij}\right)_{m\times n} = \begin{bmatrix} q_{11}q_{12} & \cdots & q_{1j} & \cdots & q_{1n} \\ q_{21}q_{22} & \cdots & q_{2j} & \cdots & q_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ q_{i1}q_{i2} & \cdots & q_{ij} & \cdots & q_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ q_{m1}q_{m2} & \cdots & q_{mj} & \cdots & q_{mn} \end{bmatrix}$$

From the corresponding parameter matrix, an average squared difference corresponding equipment alternatives in relation to the representative machine is calculated as follows,

$$Ri = \sqrt{\frac{(q_{i1}-1)^2 + (q_{i2}-1)^2 + ... + (q_{in}-1)^2}{n}} = 1, 2, 3....m \quad (2)$$

The smaller value of R_i indicates the better equipment satisfying the attributes of the representative equipment. Hence, the existence of uncertainties in the parameter machine matrix is an important drawback of this method. Therefore, one efficient way of overcoming this drawback lies in the triangular fuzzy method.

3. TRIANGULAR FUZZY NUMBER METHOD

Uncertainty can be considered, as the lack of adequate information to make a decision and human beings are highly skilled in dealing with uncertainty. The first thing to be considered in an uncertainty event is to quantify the factors causing the uncertainty and vagueness in human thoughts. For that purposes, a number of techniques have been developed to manage uncertainty. These include classical probability, Bayesian theory based on classical sets, Hartly theory, Shannon theory based on probability, Dempster-Shafter theory and Zadeh's fuzzy set theory. However, form among these techniques, this paper will only involve the fuzzy set theory. Fuzzy set theory originally developed by Zadeh (1968) has been successfully employed in many engineering projects dealing with uncertainty. Theory is primarily concerned with quantifying the vagueness in human thoughts and perception. In much way fuzzy set theory differs from the classical set or crisp set theory. In crisp set theory objects are either included or excluded from a set or in other way an object is a member of the crisp set or not. However, in fuzzy set theory, the objects are described in such a way so as to permit a gradual transition from being a member of a set to a non member. Each object contains a degree of membership ranging from zero to one where zero signifies nonmembership, one indicates full membership and values in between describe the degrees of partial membership. In order to better highlight the difference between two sets, as a simple example, a selection of hydraulic excavator may be given by comparing the breakout force with digging resistance of a material having 10 kN of digging resistance. In real life, it is very difficult to find an excavator which has an ideal breakout force exactly meeting the digging resistance of a given material and so, a proper selection with a crisp set is usually impossible or very difficult. However, in fuzzy set, the ideal breakout forces change in ranging of possible values and a continuos fuzzy number can be assigned for the breakout forces of candidate excavators, however the decision maker always prefer to discrete values rather than continuos. Hence, to excavate this material, the breakout forces of candidate excavators must be higher than digging resistance or at least equal to digging resistance and thus some alternatives will naturally be eliminated, others will be ranked in order of suitability. In fuzzy theory, either suitability or elimination is measured by the degrees of membership assigned to the breakout forces between 0 and 1. The degrees of membership is represented by a function, commonly known as a membership function and theoretically membership function can take various shapes and forms. One of the most widely used forms is fuzzy number and as a special case of fuzzy number, triangular fuzzy number (TFN) is more frequently used among others fuzzy numbers.

The triangular fuzzy number with three parameters, each representing the linguistic variable associated with a degree of membership of either 0 or 1 is shown to be easily implemented and a triangular fuzzy number can be designated as P = (a, b, c). It is graphically depicted in Figure 1 (Chui and Chan, 1994). The parameters a, b and c respectively denote the smallest possible value, the most promising value and the largest possible value that describe a fuzzy event.

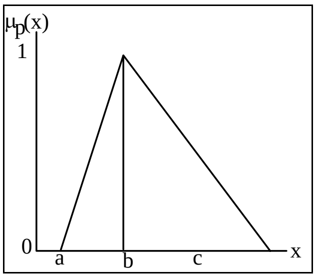

Figure 1. A triangular fuzzy number (After Chui and Chan, 1994)

The membership function of a triangular fuzzy number is defined as follows

$$\begin{aligned} \mu_p(x) &= 0 && x<a \\ &= (x-a)/(b-a) && a \le x \le b \\ &= (c-x)/(c-b) && b \le x \le c \\ &= 0 && x > c \end{aligned}$$

For each value of x increasing from a to b, its corresponding degree of membership linearly increases from 0 to 1. While x increases from b to c, its corresponding degree of membership linearly decreases from to 1 to 0. The membership function is a mapping from any given x to its corresponding degree of membership.

As mentioned earlier, in constructing the parameter machine characteristics matrix, a single value for each technical factor in each column is subjectively assigned and the parameter machine characteristics matrix is constructed by dividing these values to the values existed in the each column of the machine technical characteristics matrix. Hence the highest values in the column of the parameter machine characteristics matrix are selected as representative values. However, in forming the parameter machine characteristics matrix, the estimation and assignment of a best single value is very difficult. This is because the geological and geomachenical factors of the material excavated and other factors such as working site characteristics, which can not be certainly matched with the specifications of equipment, selected. As a result, the parameter machine characteristics are mainly governed by these factors so that this matrix must be constructed by using the range of values rather than a single value. For example, estimating true volume of a bucket (assume that it may be between 10 and 12 cubic meter or approximately 12 cubic meter or more or less 12 cubic meter), lies in between two extremes value. As an another example, say that the digging resistance of overburden is more or less 12kN, thus the crowd and breakout forces of equipment alternatives considered cannot be precisely matched with this value. In both examples, those words such as “more or less”, “between”, and “approximately” are the important sources of uncertainty and in practice the quantification of such these linguistic terms are easily managed by using the fuzzy triangular number method.

4. FACTORS CAUSING UNCERTAINTY AND AFFECTING TECHNICAL CHARACTERISTICS OF EQUIPMENT

In early, it is mentioned that technical characteristics of equipment cannot precisely meet the geological factors and geomechanical factors of material and other factors at the mining site. Hence the selection of a proper item of equipment totally satisfying all factors is very difficult task and there always are some uncertainties. In particular due to the following factors shown in Table 1, the uncertainty is more apparent in selecting a right item of equipment.

Table 1. Factors Causing Uncertainty in Equipment Selection

Material factors	Operational Factors	Weather Factors
Digging resistance Stickiness Abrasivity	Bench height Berm bearing capacity Road condition	Altitude Humidity Dust Temperature

There are strong relations between the factors shown in Table 1 and the technical characteristics of equipment, particularly hydraulic excavators, for example the digging resistance, stickiness and abrasivity of the material excavated affects the bucket size, breakout force, crowd force, digging depth and loading condition of hydraulic excavator. In practice, for an easy digging, breakout force of an item of excavator to be selected must overcome the digging resistance of the material. Digging resistance varies and depends on many factors such as the intact strength, competence, mineral constituents and bulk density of the material and so, to some degree, a digging resistance measured always contains the uncertainty due to these factors. The stickiness and abrasivity are obvious obstacles to measure true capacity of production or to find true volume of bucket size of the excavator. Therefore available bucket sizes absolutely change in a number of range. Bench height affects the cutting height, digging depth of excavators and bench height for a good loading is little higher or equal to the cut height of the excavator. On the other hand, the constructed bench height at the mine site deteriorates with the passage of time due to the blasting problems and so to keep the same bench height within a time is very difficult The bearing capacity of berm is also an important factor for the weight of hydraulic excavators against sinking and so the berm bearing capacity must be higher than the weight of hydraulic excavators. The road condition affects the speed of hydraulic excavators which will be moved from one excavating point to other excavating point The dump height of hydraulic excavators is controlled by trucks used in haulage so that the optimum dump height of excavators is at least equal or little higher than the height of truck.

The weather conditions particularly affect the engine power of the hydraulic excavators.

In order to manage uncertainty existing between the excavator technical characteristics and the material, operational and weather factors, the following membership functions seen in Figure 2 are depicted. As shown, in the first membership function, the most promising value (b) is equal distance to the smallest and largest values (a and c), in the next function, the most promising value is equal to the smallest value but the largest value is two size larger from the most promising value, in the third function the largest value is equal to the most promising value but the smallest value is two size smaller from the most promising value, in the fourth and fifth functions the most promising values are located in changing distances from the both values. In each function, the predicate unit (PU) plays a key role in handling the uncertainty and this unit changes the shape of the membership function. If the decision maker has perfect information about the future or possible equipment technical characteristics, the PU is equal to 0 and as the predicate unit increases from 0, the decision maker is less certain about future (Chui et all., 1995). As a defuzification strategy, to find the relative weights of the smallest, promising and largest fuzzy numbers estimated by a PU, the following dominance equation developed by Kaufman and Gupta will be employed.

Dominance equation = (a+2b+c) / 4 (3)

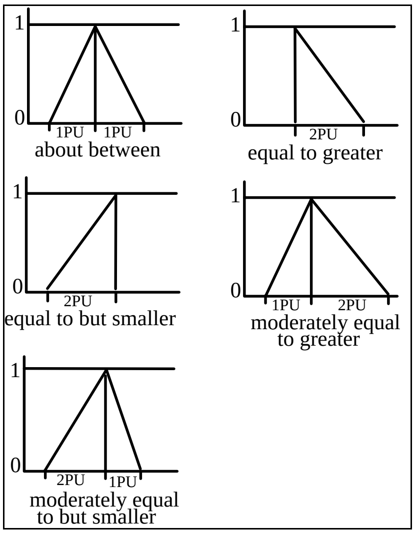

Figure 2. Triangular fuzzy membership functions

5. AN EXAMPLE

A hydraulic excavator having a bucket size of changing around 3 and 10 cu-yd will be purchased to handle the overburden over a lignite seam and for that purpose, as shown in Table 2.

Table 2. Machine Technical Characteristics Matrix (A)

Make	Model	Bucket Size cu yd	Engine (HP)	Weight (lbs) x 1000	Breakout Force (lbs) x 1000	Crowd Force (lbs) x 1000	Speed (mph)	Cut Height (ft)	Digging Depth (ft)	Dump Height (ft)
Caterpillar	245	4.5	300	150.8	99.1	87.37	1.5	32	4.5	24.5
Demag	H-71	5.5	330	169.5	88.2	92.6	1.0	31.9	9.4	21.8
Demag	H-121	7	675	270.4	103.6	108	1.6	37.3	13	26.3
Demag	H-185	10.5	1000	430	165	161	1.6	45	11	40
Demag	H-65	5.6	399	154.3	68.5	83.6	1.4	30	9.2	29
Hitachi	UH-20	3.5	300	114	66	66	2.5	31	13.1	23
Hitachi	UH-30	5	400	161	83	78.3	1.3	37.2	16.0	27.3
Koehring	116-FS	6	464	195.6	84	70	1.9	30.6	10.1	28.4
Liebherr	R-982	3.5	360	169.3	70.2	65.9	1.5	29.5	9.7	31.6
Liebherr	R-991	10	688	361.6	121.6	130.4	1.3	46.7	15.0	36.9
O&K	RH-40	4	493	187.8	72.8	72.8	1.5	36.1	13.1	30.4
O&K	RH-75	6	714	284.3	122	94	1.3	39.4	9.7	32.2
O&K	RH-90C	8	892	348.2	167.5	167.5	1.5	40	10.0	31
Poclain	300-CK	4	309	127.6	49.3	71.7	1.8	28.9	7.9	24.3
Poclain	400-CK	4.5	410	165	98.6	99.88	1.8	33.2	7.6	27.6
Poclain	600-CK	7	607	265	136.2	153.4	1.6	36.9	7.4	31.3
Poclain	1000-CK	9	883	425	175	207.4	1.1	40	9.2	33.5
BR YT	X42TF	3.9	263	220	79.4	79.4	1.3	28.3	13.8	14.8

18 hydraulic excavators are considered to be suitable for a given this job. Hence the following specifications present the overburden, operational and weather factors which play a key role in selecting the most suitable excavator.

- Type of overburden excavated : clay, gravel and sandstone
- Conditions of overburden : moist and wet
- Thickness of overburden : varies between 15 m and 20 m
- Digging resistance : varies in accordance with the excavating point and is classified as medium and hard
- Stickiness : moderate and medium

- Suggested bench height : approximately around 10 - 15 m
- Working altitude : varies between 1450 m - 1500 m
- Humidity : no present and temperature: -20 C

Due to the uncertainty created by these factors, the technical characteristics of the excavators alternatives can be evaluated by a fuzzy environment as seen in Table 3. From Table 2 and 3, the parameter machine characteristic matrix in Table 4 is constructed together with the triangular fuzzy numbers. Then by using the equation (1), the defuzzified parameter machine characteristic matrix from Table 4 is formed and as representative values, the highest values in each column in Table 5 are selected as follows;

E = (1.73, 1.93, 2.03, 1.50, 1.13, 2.73, 1.00, 3.10, 2.03)

With these representative values, the defuzzified corresponding parameter matrix (Q) is constructed in Table 6 and using equation (2) and Table 6, the average square differences (Ri) values are calculated in Table 7.

Table 3. Technical Characteristics With Triangular Fuzzy Numbers

Technical Characteristics	Linguistic Factors	Fuzzy Environment	Predicate Unit	Promising Value
Available bucket sizes	Medium digging	About between	3	6 cu yd
Engine Power	High altitude	Equal to greater	10	500 HP
Weights	Moderate ground	Equal to but smaller	20	250 (lbsx1000)
Breakout force	Medium digging	Moderately equal to greater	25	75 (lbsx1000)
Crowd force	Hard digging	Moderately equal to greater	25	75 (lbsx1000)
Speed	Medium rolling resistance and traction	Equal to greater	0.50	1.8 (mph)
Cut height	High cutting height	Moderately equal but smaller	8	30 (ft)
Digging height	Medium height	About between	4	33 (ft)
Digging depth	High consolidated and frozen ground	Moderately equal to greater	2	13 (ft)

Table 4. Parameter Machine Characteristic Matrix (E)

Make	Model	Bucket Size (cu yd)	Engine (HP)	Weight (lbs) x 1000	Breakout Force (lbs) x 1000	Crowd Force (lbs) x 1000	Speed (mph)	Cut Height (ft)	Digging Depth (ft)	Dump Height (ft)
Trian. Fuzzy	Numbers	3 6 9	500 500 520	210 250 250	50 75 100	50 75 100	1.8 1.8 2.8	14 30 38	9 13 21	26 30 34
Caterpillar	245	0.7 1.3 2.0	1.7 1.7 1.8	1.4 1.7 1.7	0.5 0.8 1.0	0.6 0.9 1.1	1.2 1.2 1.9	0.4 0.9 1.2	2.0 2.9 4.6	1.1 1.2 1.4
Demag	H-71	0.6 1.1 1.6	1.5 1.5 1.6	1.2 1.5 1.5	0.6 0.9 1.1	0.5 0.8 1.1	1.8 1.8 2.8	0.4 0.9 1.2	0.9 1.4 2.2	1.2 1.4 1.6
Demag	H-121	0.4 0.9 1.3	0.7 0.7 0.8	0.8 0.9 0.9	0.5 0.7 0.9	0.5 0.7 0.9	1.1 1.1 1.8	0.4 0.8 1.0	0.7 1.0 1.6	1.0 1.1 1.3
Demag	H-185	0.3 0.6 0.9	0.5 0.5 0.6	0.5 0.6 0.6	0.3 0.5 0.6	0.3 0.5 0.6	1.1 1.1 1.3	0.3 0.7 0.8	0.8 1.2 1.9	0.6 0.8 0.9
Demag	H-65	0.5 1.1 1.6	1.3 1.3 1.4	1.4 1.6 1.6	0.7 1.1 1.4	0.6 0.9 1.2	1.3 1.3 2.0	0.5 1.0 1.3	0.9 1.4 2.3	0.9 1.0 1.2
Hitachi	UH-20	0.9 1.7 2.6	1.7 1.7 1.8	1.8 2.1 2.1	0.8 1.1 1.5	0.8 1.1 1.5	0.7 0.7 1.1	0.5 0.9 1.2	0.7 1.0 1.6	1.1 1.3 1.5
Hitachi	UH-30	0.6 1.2 1.8	1.2 1.2 1.3	1.3 1.6 1.6	0.6 0.9 1.2	0.6 0.9 1.3	1.4 1.4 2.2	0.4 0.8 1.0	0.6 0.8 1.3	0.9 1.1 1.3
Koehring	116-FS	0.5 1.0 1.5	1.0 1.0 1.1	1.1 1.3 1.3	0.6 0.9 1.2	0.7 1.1 1.4	0.9 0.9 1.5	0.5 0.9 1.2	0.9 1.3 2.1	0.9 1.1 1.2
Liebherr	R-982	0.9 1.7 2.6	1.3 1.3 1.4	1.2 1.5 1.5	0.7 1.1 1.4	0.8 1.1 1.5	1.2 1.2 1.9	0.5 1.0 1.3	0.9 1.3 2.2	0.8 1.0 1.1
Liebherr	R-991	0.3 0.6 0.9	0.7 0.7 0.8	0.6 0.7 0.7	0.4 0.6 0.8	0.4 0.6 0.8	1.4 1.4 2.2	0.3 0.6 0.8	0.6 0.9 1.4	0.7 0.8 0.9
O&K	RH-40	0.8 1.5 2.3	1.0 1.0 1.1	1.1 1.3 1.3	0.7 1.0 1.4	0.7 1.0 1.4	1.2 1.2 1.9	0.4 0.8 1.1	0.7 0.9 1.6	0.8 1.0 1.1
O&K	RH-75	0.5 1.0 1.5	0.7 0.7 0.8	0.7 0.9 0.9	0.4 0.6 0.8	0.5 0.8 1.1	1.4 1.4 2.1	0.4 0.8 0.9	0.9 1.3 2.2	0.8 0.9 1.1
O&K	RH-90C	0.4 0.8 1.1	0.5 0.5 0.6	0.6 0.7 0.7	0.3 0.4 0.6	0.3 0.4 0.6	1.2 2.1 1.9	0.4 0.8 0.9	0.9 1.3 2.1	0.8 1.0 1.1
Poclain	300-CK	0.8 1.5 2.3	1.6 1.6 1.7	1.6 2.0 2.0	1.0 1.5 2.0	0.7 1.1 1.4	1.0 1.0 1.6	0.5 1.0 1.3	1.1 1.6 2.6	1.1 1.2 1.4
Poclain	400-CK	0.7 1.3 2.0	1.2 1.2 1.3	1.3 1.5 1.5	0.5 0.8 1.0	0.5 0.8 1.0	1.0 1.0 1.6	0.4 0.9 1.1	1.2 1.7 2.8	0.9 1.1 1.2
Poclain	600-CK	0.4 0.9 1.3	0.8 0.8 0.9	0.8 1.0 1.0	0.4 0.6 0.7	0.3 0.5 0.7	1.1 1.1 1.8	0.4 0.8 1.1	1.2 1.8 2.8	0.8 0.9 1.1
Poclain	1000-CK	0.3 0.7 1.0	0.5 0.5 0.6	0.5 0.6 0.6	0.3 0.4 0.6	0.2 0.4 0.5	1.6 1.6 2.5	0.4 0.8 0.9	0.9 1.4 2.3	0.8 0.9 1.0
BR YT	X42TF	0.8 1.5 2.3	1.9 1.9 2.0	0.9 1.1 1.1	0.6 0.9 1.3	0.6 0.9 1.3	1.4 1.4 2.2	0.5 1.1 1.3	0.7 0.9 1.5	1.8 2.0 2.3

Table 5. Defuzzified Parameter Machine Characteristic Matrix (E)

Make	Model	Bucket Size (cu yd)	Engine (HP)	Weight (lbs) x 1000	Breakout Force (lbs) x 1000	Crowd Force (lbs) x 1000	Speed (mph)	Cut Height (ft)	Digging Depth (ft)	Dump Height (ft)
Caterpillar	245	1.33	1.73	1.63	0.77	0.88	1.38	0.85	3.10	1.23
Demag	H-71	1.10	1.53	1.43	0.87	0.80	2.05	0.85	1.48	1.40
Demag	H-121	0.88	0.73	0.88	0.70	0.70	1.28	0.75	1.08	1.13
Demag	H-185	0.60	0.53	0.58	0.47	0.48	1.16	0.63	1.28	0.78
Demag	H-65	1.08	1.33	1.55	1.07	0.90	1.48	0.95	1.50	1.03
Hitachi	UH-20	1.73	1.73	2.03	1.13	1.13	0.80	0.88	1.08	1.30
qwertHitachi	UH-30	1.20	1.23	1.53	0.90	0.93	1.60	0.75	0.88	1.10
Koehring	116-FS	1.00	1.03	1.23	0.90	1.07	1.05	0.88	1.40	1.08
Liebherr	R-982	1.73	1.33	1.43	1.08	1.13	1.38	0.95	1.43	0.98
Liebherr	R-991	0.60	0.73	0.68	0.60	0.60	1.60	0.58	0.95	0.80
O&K	RH-40	1.53	1.03	1.25	1.03	1.03	1.38	0.78	1.03	0.98
O&K	RH-75	1.00	0.73	0.85	0.60	0.80	1.58	0.73	1.43	0.93

O&K	RH-90C	0.78	0.53	0.68	0.43	0.43	2.73	0.73	1.40	0.98
Poclain	300-CK	1.53	1.63	1.90	1.50	1.08	1.15	0.95	1.73	1.23
Poclain	400-CK	1.33	1.23	1.45	0.78	0.78	1.16	0.83	1.85	1.08
Poclain	600-CK	0.88	0.83	0.95	0.58	0.50	1.28	0.78	1.90	0.93
Poclain	1000-CK	0.68	0.53	0.58	0.43	0.38	1.83	0.73	1.50	0.90
BR YT	X42TF	1.53	1.93	1.05	0.93	0.93	1.60	1.00	1.00	2.03

Table 6. Defuzzified Corresponding Parameter Matrix (Q)

Make	Model	Bucket Size (cu yd)	Engine (HP)	Weight (lbs) x 1000	Breakout Force (lbs) x 1000	Crowd Force (lbs) x 1000	Speed (mph)	Cut Height (ft)	Digging Depth (ft)	Dump Height (ft)
Caterpillar	245	1.30	1.12	1.25	1.95	1.28	1.98	1.18	1.00	1.65
Demag	H-71	1.57	1.26	1.42	1.72	1.41	1.33	1.18	2.09	1.45
Demag	H-121	1.97	2.64	2.31	2.14	1.61	2.13	1.33	2.87	1.80
Demag	H-185	2.88	3.64	2.30	3.19	2.35	2.35	1.59	2.42	2.60
Demag	H-65	1.61	1.45	1.31	1.40	1.26	1.84	1.05	2.07	1.97
Hitachi	UH-20	1.00	1.12	1.00	1.33	1.00	3.41	1.14	2.87	1.56
Hitachi	UH-30	1.44	1.60	1.33	1.67	1.22	1.71	1.33	3.52	1.85
Koehring	116-FS	1.73	1.87	1.65	1.67	1.06	2.60	1.14	2.21	1.88
Liebherr	R-982	1.00	1.45	1.42	1.39	1.00	1.98	1.05	2.17	2.07
Liebherr	R-991	2.88	2.64	2.99	2.50	1.88	1.71	1.72	3.26	2.53
O&K	RH-40	1.13	1.87	1.63	1.46	1.09	1.98	1.28	3.01	2.07
O&K	RH-75	1.73	2.64	2.39	2.50	1.41	1.73	1.37	2.17	2.18
O&K	RH-90C	2.22	3.64	2.99	3.49	2.63	1.00	1.37	2.21	2.07
Poclain	300-CK	1.13	1.18	1.07	1.00	1.05	2.37	1.05	1.79	1.65
Poclain	400-CK	1.30	1.60	1.40	1.92	1.45	2.35	1.20	1.68	1.88
Poclain	600-CK	1.97	2.32	2.14	2.57	2.26	2.13	1.28	1.63	2.18
Poclain	1000-CK	2.54	3.64	3.50	3.49	2.97	1.49	1.37	2.07	2.26
BR YT	X42TF	1.13	1.00	1.93	1.61	1.22	1.71	1.00	3.10	1.00

Table 7. Average Squared Difference Values

Make and Model	Ri Values
Caterpillar 245	0.5337
Demag H-71	0.4226
Demag H-121	1.1804
Demag H-185	1.6852
Demag H-65	0.9405
Hitachi UH-20	1.0414
Hitachi UH-30	0.9914
Kohering 116-FS	0.8808
Liebherr R-982	0.6673
Liebherr R-991	1.5520
O&K RH-40	0.9198
O&K RH-75	1.1057
O&K RH-90C	1.6337
Poclain 300-CK	0.5757
Poclain 400-CK	0.7271
Poclain 600-CK	1.1146
Poclain 1000-CK	1.7883
BR YT X42TF	0.8310

As seen in Table 7, the most proper item of equipment is Demag H-71 which has the smallest Ri value and the other first three alternatives can be given according to the order of their suitability as follows:

- Caterpillar 245
- Poclain 300-CK
- Liebherr R-982

6. CONCLUSION

As preselection, the quality comparison is a robust method, which will be to put into practice. However, the existence of uncertainty in selection process confines the capabilities of method and so in order to make this method more powerful, the use of fuzzy triangular technique in this paper is suggested as a way. Furthermore equipment selection problem is of course very difficult task and in particular the natural factors make a proper selection difficult and to a considerable extent, equipment alternatives available do not totally satisfy these natural conditions. As a result, some technical characteristics of equipment alternatives must be accepted within a range of values optimising almost all natural factors. Within this range of values, some values are more superior than others and their membership grade are more close to 1 or the most promising fuzzy triangular value and some values are less important and their membership grade are more close t 0 or the smallest or the largest fuzzy triangular value. Hence, in this paper, with five fuzzy triangular membership functions, hydraulic excavator selection has explained and the findings obtained shows that if the quality comparison method is more improved by using the triangular fuzzy method, more accurate results can be captured.

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