Fuzzy Decision Support System for Application of Value Engineering in Construction Industry

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Abstract: *The use of Value Engineering (VE) methodology in construction industry has grown significantly, mainly in view of its extensive benefits. The main task in evaluation phase of VE workshop is to assess alternative ideas, proposed for each function. This phase of VE, hence, could be deemed as a Multi Criteria Decision Making (MCDM) problem. This paper presents a fuzzy decision support system (DSS) to be employed in evaluation phase of VE. The proposed multi alternative decision model may be recommended where alternatives' preferences ratios are different, and scores assigned to each alternative idea are uncertain. As use of VE has greater payoffs at the earlier stages of the construction projects, in which most of the criteria are still vague and not precisely defined, exploiting this DSS may result in more tangible model of decision making process and satisfactory outlook of VE studies in construction projects. A ranking methodology in a spreadsheet template is also provided to facilitate the ranking process. Performance of the proposed methodology is tested using a case example in the tunneling industry.*

Key Words: *Value Engineering – Fuzzy Set Theory – Evaluation Phase – Multi Criteria Decision Making - Tunneling*

Introduction

Value Engineering as Society of American Value Engineers (SAVE) defines is the systematic application of recognized techniques which identifies the functions of the product or service, establishes the worth of those functions, and provides the necessary functions to meet the required performance at the lowest overall cost [1]. Outstanding points which make VE different from other identical approaches are: "function analysis, creative attitude and improvements without any reduction in desired value"[1]. The methodology is well adopted in construction industry and its utilization was dramatically increased during recent decades, due to the fact that there has been always a great keenness on reducing projects life cycle cost and increasing cost effectiveness of projects. An established framework for fulfilling assigned tasks of the methodology has been defined as VE job plan. Various approaches have been used for this methodology so far, although the most common methodology is defined in five basic phases as follows [2]:

- Information phase: information acquisition, function analysis and selecting areas with poor value for detailed study

- Creative phase: generating ideas as an alternative for proposed functions

- Analytical phase: evaluation of ideas and selecting the most desirable ideas

- Development phase: developing prominent ideas and selection of the best idea

- Presentation phase: recommending a VE

change and improvement proposal in a most challenging format

Recently multi criteria decision models have grabbed great attention. These models are mainly divided into two main groups; Multi Objective Decision Making (MODM) models which are mainly utilized in continuous decision spaces (especially mathematical programming with different objective functions) and Multi Alternative Decision Making (MADM) models which mainly concentrates on discrete decision making spaces. In other words it could be stated that MODM models are mainly used for design but MADM models are rather used in selecting optimal alternatives [3].

In order to assess proposed ideas and select best alternative in analytical (evaluation) phase of the VE, which is in fact an MADM problem, variety of these models, as a case in point Analytical Hierarchy Process (AHP) have been exploited [1]. Given the fact that in early stages of the project development, where VE has the greatest payoffs [4], most of the parameters are still indefinite and vaguely defined, application of fuzzy mathematics will be quite conducive. In other words lack of decisive information in those stages may make the precise judgment impractical. In these cases fuzzy set theory may be employed to assist decision maker in making more realistic judgments. It could support the VE team especially due to the fact that in most cases evaluation process requires personal subjective assessment.

Concept of Fuzzy Sets Theory

As one can perceive from its name, fuzzy sets is a theory about uncertainty. Conventional sets mainly deal with sets which their membership is defined on a yes/no basis, while in fuzzy set theory; membership is not a precise phenomenon. This type of uncertainty is different from stochastic uncertainty which had been described through probability theory long time ago. Stochastic theory is concerned with uncertainty in likelihood of an event's occurrence but indistinctness in fuzzy sets theory is in description of characteristics of a phenomenon. This concept has been founded out by Prof. Lotfi A. Zadeh at 1965, as he believes that many systems for modeling reality are not successful due to precise inputs they required. Utilizing this theory in practical problems would make the models more consistent with reality. Therefore mathematical frameworks would be prepared in which all ambiguities could be examined as there is no fuzzy point regarding fuzzy sets theory.

As stated above central concept of Fuzzy Sets Theory is its membership function which represents numerically the degree to which a member belongs to a set. By considering S as a classic set whose members are x_i, usually membership of this set is as follows:

$$x_i \in s \tag{1}$$

Membership function of this set $\mu_s(x)$ would be also defined as:

$$\begin{cases} \mu_s(x_i) = 1 \longrightarrow x_i \in S \\ \\ \mu_s(x_i) = 0 \longrightarrow x_i \notin S \end{cases} \tag{2}$$

Accordingly a distinct border between members and nonmembers of the set is defined. In many actual cases, however, these boundaries are not clearly defined. In that cases membership function could be explained as follows:

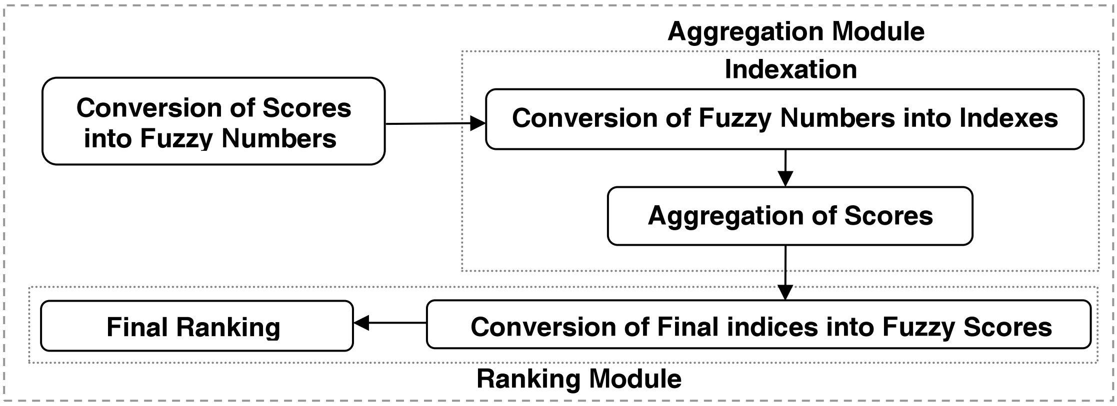

Fig.1 Fuzzy System DSS Structure

- $\mu_s(x)=0 \rightarrow n \notin s$

- The value of $\mu_s(x)$ is close to zero $\rightarrow$ n_i is weakly member of S

- The value of $\mu_s(x)$ is between zero and one $\rightarrow$ n_i is to some degree member of S

- The value of $\mu_s(x)$ is close to one $\rightarrow$ n_i is strongly member of S

- $\mu_s(x)=1 \rightarrow x_i \in s$

In order to eliminate complexity of assigning a certain boundary, fuzzy set theory introduces vagueness on boundaries. Many critics states difficulties in accurate assigning of membership degree as a weak point of fuzzy set theory, but as Prof. Zadeh pointed out it is not in keeping with the spirit of the fuzzy-set approach to be too concerned about the precision of these numbers. This is sufficient that the number representing degree of membership seems intuitively reasonable.

Fuzzy Decision Support System for Analytical Phase of VE

As mentioned above after selection of a function for in-depth study, alternative ideas for that function would be presented. Assessment of the proposed ideas is chief process in the third phase of VE workshop so as to appoint the best choice among alternative ideas. Structure of the Fuzzy Decision Support System (DSS), proposed for this process, is illustrated in figure (1). The model comprises three main sectors. At first scores assigned to each alternative idea against each evaluation criterion are converted into a fuzzy set. Thereafter, fuzzy sets related to each alternative idea, based on different criteria, would be aggregated at aggregation module. Finally alternative ideas are ranked based on the acquired final scores at aggregation module, which are fuzzy numbers.

If $Z_i(x)$ is assumed as a fuzzy value for i^{th} alternative against x^{th} criterion, its membership function will be $\mu[Z_i(x)]$ as denoted in figure (2) with a trapezoid membership function. This fuzzy set contains opinions of VE team members. Membership degree for each value would be assigned based on the expert's judgment. That is, scores assigned by each member of the team to an alternative idea in view of an evaluation criterion is considered as a fuzzy set,

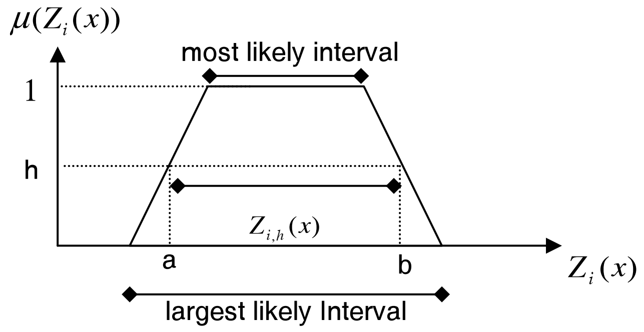

Fig.2 Fuzzy score of xth alternative against ith criterion

indicating score of that alternative. Boundaries of this fuzzy set would be assigned based on experts' opinion. As it is shown in figure (2), $Z_{i,h}(x)$ is an interval in which membership degrees are higher than h. This interval, which has been assigned based on h likely interval, is a sub-set of the fuzzy set and has been introduced based on level-cut concept. One of these intervals $Z_{i,1}(x)$ is the most likely interval, where the membership degrees are one. Moreover $Z_{i,0}(x)$ is largest likely interval and if any of $Z_i(x)$ fall out of this interval its membership degree would be zero.

Conversion of Scores into Indexes

Since different criteria, with different characteristics and units, are going to be integrated; $Z_{i,h}(x)$ as a score assigned to each idea regarding every criterion should be converted into an index. This index is in fact a ratio and is comparable for variety of criteria. Subsequently final decision would be made based on aggregation of opinions considering all criteria. For that reason, considering (BES Z_i) and (WOR Z_i) respectively as best and worst values $Z_{i,h}(x)$ could be converted into $S_{i,h}(x)$ index as follows:

1. If BES Z_i > WOR Z_i then:

$$S_{i,h}(x) = \begin{cases} 1 & Z_{i,h}(x) \geq BESZ_i \\ \dfrac{\left(Z_{i,h}(x) - WORZ_i\right)}{\left(BESZ_i - WORZ_i\right)} & WORZ_i < Z_{i,h}(x) < BESZ_i \\ 0 & Z_{i,h}(x) \leq WORZ_i \end{cases} \tag{3}$$

2. If WOR Z_i > BES Z_i then:

$$S_{i,h}(x) = \begin{cases} 1 & Z_{i,h}(x) \leq BESZ_i \\ \dfrac{\left(Z_{i,h}(x) - WORZ_i\right)}{\left(BESZ_i - WORZ_i\right)} & BESZ_i < Z_{i,h}(x) < WORZ_i \\ 0 & Z_{i,h}(x) \geq WORZ_i \end{cases} \tag{4}$$

Consequently $Z_{i,h}(x)$, as a fuzzy function, is converted to $S_{i,h}(x)$ and related trapezoid diagram is transformed to the following diagram [figure (3)]. Two conditions have been considered above, due to the reason that usually characteristics are assessed in two directions. That is, regarding some criteria like workability, durability, aesthetic, etc., getting greater score is equal to being more appropriate, so first equation would be assigned to these types of criteria.

In contrast concerning some criteria like time

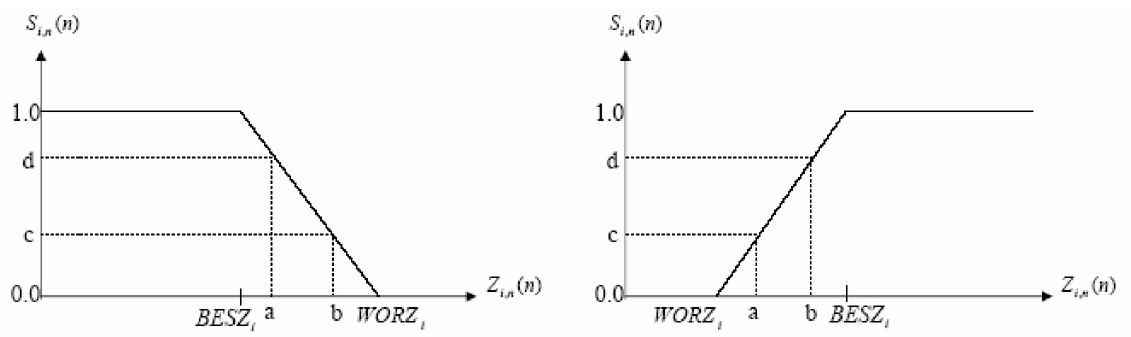

Fig.3 Transferring fuzzy values to index value

consumption or cost, getting greater score means less acceptability, therefore second equation would be assigned for these types of criteria. Subsequently impact of the scoring direction is crossed out and results from all criteria could be summed up.

Aggregation of Scores Regarding Each Alternative Idea

For summing up all the scores and obtaining final score concerning each alternative idea, based on all evaluation criteria, following equation could be exploited:

$$I_h(x) = \left\{ \sum_{i=1}^{n} W_i \left(S_{i,h}(x) \right) P \right\}^{\frac{1}{p}} \tag{5}$$

Where n= the number of criteria; $S_{i,h}(x)$ = Index for i^{th} criterion with h level of acceptance; w_i = Related weight of each criterion($\sum w_i$=1); P = Balancing factor and $I_k(x)$= Final index for each criterion with h level of acceptance.

In order to weigh criteria to compare their importance, different methods may be utilized such as AHP (Analytical Hierarchy Process) introduced by Prof. Saaty and on which one acquires weights from eigenvectors corresponding to maximum eigenvalues of the comparison matrix. However weighing methods based on linguistic scales which are quicker could be also exploited, although these methods are not as accurate as AHP.

The balancing factor P ($P \geqq 1$) is a factor which shows importance of deviation magnitude between a criterion value and the best criterion for that value and would be proposed for a group of criteria. Therefore if P=1 then all deviations will get equal weight, and if P=2 each deviation will get weight in proportion to its scale. In general $P \geqq 3$ would be used for limiting criteria [6].

Furthermore if each criterion comprises other criteria, this equation could be extended for lower levels and then final result would be acquired by adding up results of each level. Consequently evaluation process could be followed up in different levels so as to obtain final score regarding each alternative [7].

Preparing Proposed Alternative Ideas for Ranking

After acquiring final index for each alternative, membership function of a fuzzy set $\mu[I_i(n)]$ will be figured out utilizing equation (6). The membership function is a piecewise linear function, in which $I(x)$ is

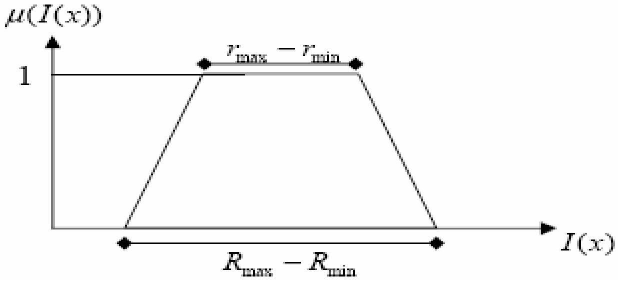

Fig.4 Membership function of the final score regarding each alternative

member of the fuzzy set associated with final score of the x^{th} alternative. This could be performed by calculating $I_{h=0}(x)$, and $I_{h=1}(x)$ whose levels of acceptance are zero and one respectively.

$$\mu[I(x)] = \begin{cases} 1 & r_{min} \le I(x) \le r_{max} \\ \dfrac{I_{(x)} - R_{min}}{r_{min} - R_{min}} & R_{min} \le I(x) < r_{min} \\ \dfrac{I_{(x)} - R_{max}}{r_{max} - R_{max}} & r_{max} < I(x) \le R_{max} \\ 0 & otherwise \end{cases} \tag{6}$$

r_{min} and r_{max} = lowest and highest value of $I_{h=1}(x)$ for final index respectively

R_{min} and R_{max} = lowest and highest value of $I_{h=0}(x)$ for final index respectively

$I_{h=0}(x)$ and $I_{h=1}(x)$ are resulted from $Z_{i,h=0}(x)$ and $Z_{i,h=1}(x)$ correspondingly [figure (4)]. If n alternative ideas have been considered for ranking, there will be n fuzzy sets as $[I_{(n)}|n=1,2,...,n]$, whose membership functions will be resulted from equation (6).

Final Ranking of Alternative Ideas

As numbers which are assigned to each alternative are fuzzy, ranking them is unlikely to be done by conventional straightforward ranking methods. Therefore a fuzzy ranking method is required to fulfill the objective. According to Chen and Hwang opinion, variety of the ranking methods which are proposed for fuzzy MCDM's, can be categorized into four groups [8]:

1. Utilizing preferences ratio, by applying techniques such as degree of optimality, hamming distance, α-cut and comparison function.
2. Fuzzy mean and spread by applying probability distribution.

3. Fuzzy scoring which involves techniques such as proportional optimal, left right scores, centroid index and area management.

4. Utilizing linguistic expression.

The method chosen for this purpose is developed by Chen (1985) through applying minimizing and maximizing sets [9]. The maximizing set M is a fuzzy subset with membership function of μ_M, defined as follows:

$$\mu_M(I) = \begin{cases} (I - I_{min})/(I_{max} - I_{min}) & I_{min} \le I \le I_{max} \\ 0 & otherwise \end{cases} \tag{7}$$

$$I_{min} = \min(\min\ I_{h=0}(x)) \quad \text{for } x = 1, \ldots, n \tag{8}$$

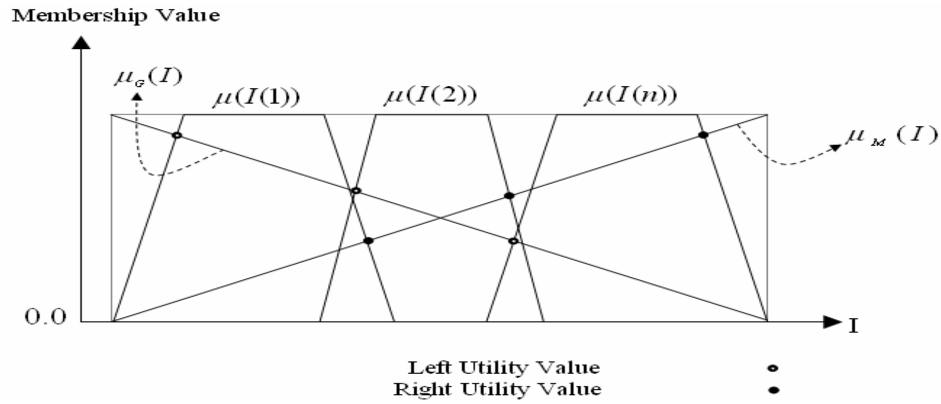

Fig.5 Idea's final score functions with related utility functions

$$I_{\max} = \max(\max\ I_{h=0}(x)) \quad \text{for } x = 1, \ldots, n \tag{9}$$

Therefore right utility value $U_R(x)$ for x^{th} alternative would be determined as:

$$U_R(x) = \max\left(\min\ (\mu_M(I(x)\ ,\ \mu(I(x))\right) \tag{10}$$

In the same way minimizing set G is also introduced as a fuzzy subset with membership function of μ_G:

$$\mu_G(I) = \begin{cases} \left(I - I_{\max}\right) / \left(I_{\min} - I_{\max}\right) & I_{\min} \le I \le I_{\max} \\ 0 & otherwise \end{cases} \tag{11}$$

And then left utility value $U_L(x)$ for alternative idea x would be determined as follows:

$$U_L(x) = \max(\min(\mu_G(L)\ ,\ \mu(I(x))) \tag{12}$$

Consequently total utility or ranking value for proposal x is:

$$U_{(x)} = \frac{\left(U_R(x) + 1 - U_L(x)\right)}{2} \tag{13}$$

The alternative with the best total utility value would be presented as the best option, thus all alternatives would be sorted based on their total utility values[figure (5)].

Exploiting Method in Tunneling Industry

Application of Value Engineering in tunneling industry is very limited. One reason behind not extensively utilizing the methodology is restricted room for maneuver regarding techniques to be applied. Other reasons could be rationalized by the rather modest size of the industry and it's confinement in terms of equipments, monetary size of the projects and even experts or companies involved. Therefore a case study promoted for utilization of VE in tunneling, so as to encourage more VE studies to be conducted in tunneling projects.

Lining forms one of the main elements in tunneling with different functionalities; which may depend on the project objectives. The basic function of lining is stabilization of surroundings, but other purposes such as water permeability, reducing surface roughness for water tunnels could be considered as secondary functions. In some cases these secondary functions may be served as primary function. Alternatives

Table (1) Criteria weights, Balancing factors, Best and Worst Values

Criteria	Worst Value	Best Value	Weights	Balancing Factor
cost	3200(€/m)	1500(€/m)	0.3	2
time	50(month)	30(month)	0.1	2
method effectiveness	1	10	0.2	2
execution risk	1	10	0.1	2
durability	1	10	0.2	2
water tightness	10	1	0.1	2

Table (2) Scoring and final results

	unlined tunnel		shotcrete		in-situ concrete		concrete segment		steel arch+ wiremesh	
	least likely interval	most likely interval	least likely interval	most likely interval	least likely interval	most likely interval	least likely interval	most likely interval	least likely interval	most likely interval
cost (€/m)	1800-2000	1875-1900	2060-2250	2100-2175	2250-2370	2320-2350	2800-3100	2900-3000	2125-2270	2180-2200
time (month)	30-32	31	35-37	36	48-50	49	33-36	35	39-42	40
method effectiveness	5-9	6-8	4-6	5	6-8	7	7-8	7	6-8	7
execution risk	1-3	2	4-7	5-6	7-8	7	8-9	8	2-5	3-4
durability	1-2	1	7-8	7	7-8	8	8-10	9	6-8	7
water tightness	7-10	9	5-8	7	2-3	3	2-4	3	8-10	9
Left Utility Value	0.996839729		0.320409497		0.231962066		0.149518717		0.665510597	
Right Utility Value	0.350862607		0.738576628		0.880909635		0.950458315		0.545954438	
Total Utility Value	0.177011439		0.709083565		0.824473785		0.900469799		0.440221921	

proposed to fulfill this function comprises unlined tunnels, shot-crete along with rock bolts support, in-situ concrete, concrete pre-cast segmental lining and also utilizing steel arches plus wire-mesh which is mainly employed in mining industry.

Cost, construction time, effectiveness (technical know-how of the executor, availability of the equipment and current state restrictions), water tightness, execution risks regarding likely hazardous of incidents and durability could be taken into account as main criteria for evaluation of ideas proposed for the under studied function. Weights and extreme values regarding these criteria are presented in Table (1), according to the experts' opinion. Regarding some criteria such as cost and time, actual amounts are considered for ranking. Experts' opinions on alternative ratings were collected and classified as fuzzy sets. For this purpose two scores around average of the assigned scores of each alternative idea for every criterion were considered as boundaries of least likely interval. Subsequently smallest and greatest scores of this set were assigned as borders of most likely interval. Thus fuzzy sets regarding assigned score of each alternative for every criterion are perceivable considering Table (2) and Figure (2). Following transfer of all scores into fuzzy sets format, these scores were converted to index values employing Eq. 3 and 4.

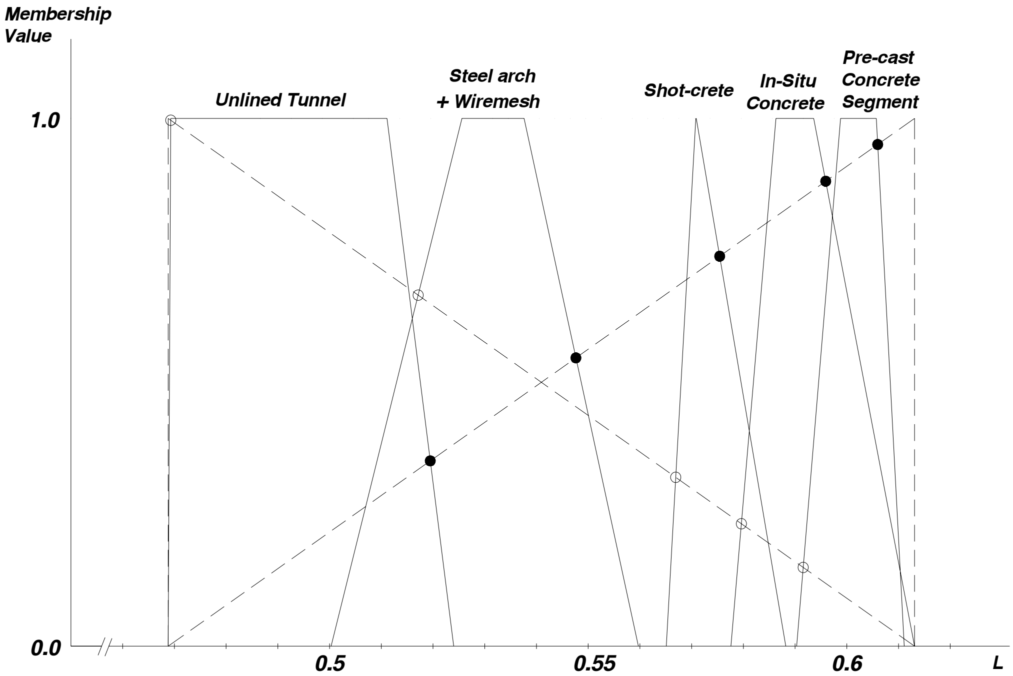

Fig.6 final idea's score regarding lining water tunnel

Thereafter aggregation process to achieve one fuzzy score regarding each alternative idea would be determined (Eq. 5), considering weights, Best and Worst values and balancing factor presented at table 1. By attaining most and least likely intervals for final score, utility values regarding each alternative were calculated based on Eq. 6 – Eq.13. Results are shown in Table (2) and Figure (6) membership function of one criterion as an example is denoted in Figures (7-12). In order to assist the VE team, a spreadsheet program for entire ranking process is also provided. Therefore based on the assessment of the VE team, concrete pre-cast segment was proposed as the best alternative. It should be emphasized that availability of appropriate technological capabilities may affect evaluation result through impact on score values of factors, hence modifying final selected alternative. In addition functionality of tunnel will affect evaluation process, for instance the assessment of the VE team regarding water tunnel and transportation tunnel are rather diverse.

Conclusion

VE utilization gains widespread favor in construction industry. However evaluation of alternative ideas remained as a bottleneck, owing to the fact that different disciplines ranging from designers to contractors are participating in Value Engineering workshops. In this study a multi alternative fuzzy DSS is provided to assist multi disciplinary VE team in selection of the best ideas, proposed for under studied function. As stated above this model could be used when objectives have varying degree of importance, objectives are conflicting and values are still uncertain [5], as there is so in VE. Since utilizing VE has more potential of saving at earlier stages of the project and considering more indefiniteness in those stages, introducing fuzzy sets theory into VE

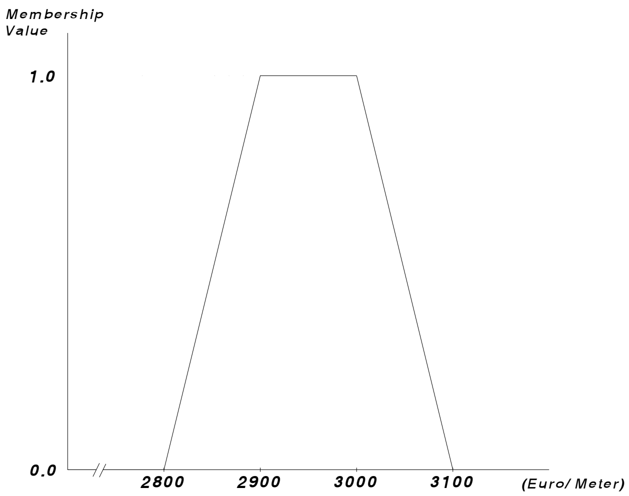

Fig.7 fuzzy set score of cost (criterion) for concrete segment (alternative idea)

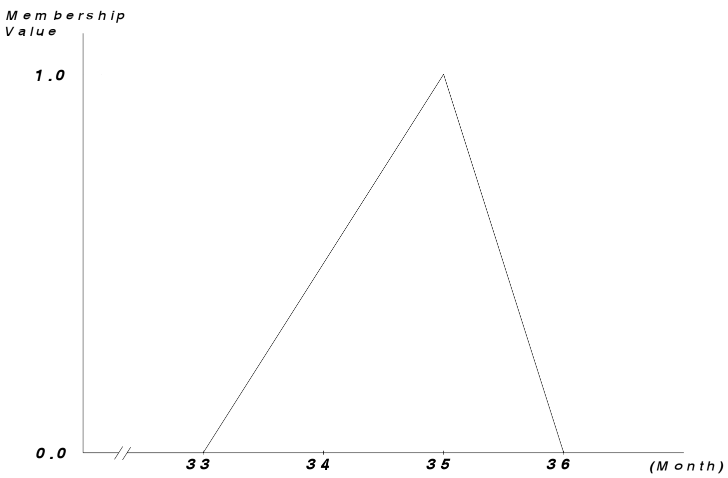

Fig.8 fuzzy set score of time (criterion) for concrete segment (alternative idea)

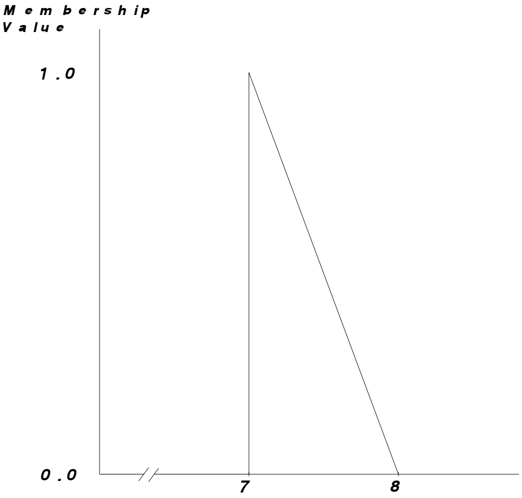

Fig.9 fuzzy set score of method effectiveness (criterion) for concrete segment (alternative idea)

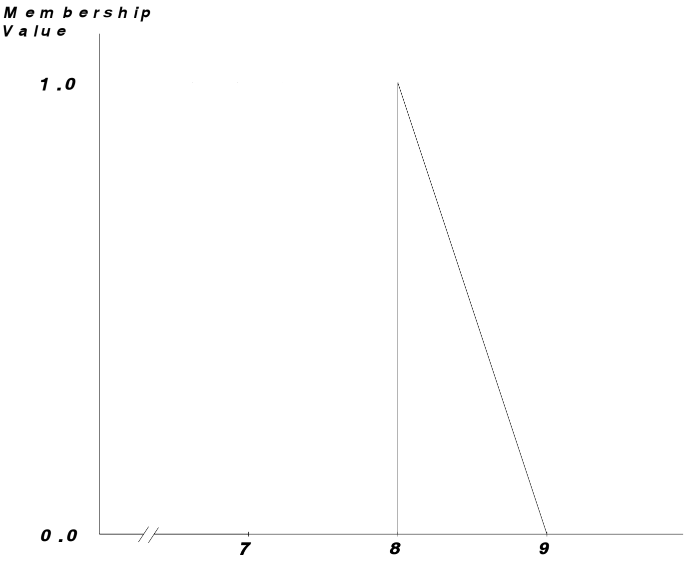

Fig.10 fuzzy set score of execution risk (criterion) for concrete segment (alternative idea)

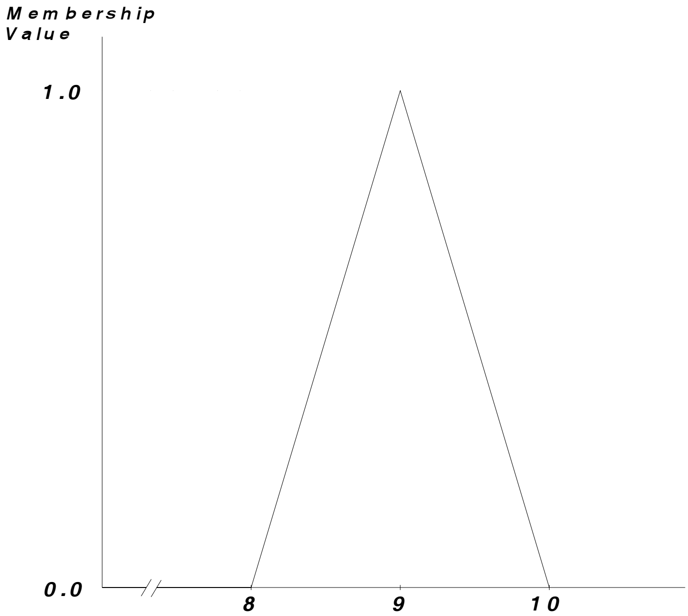

Fig.11. fuzzy set score of durability (criterion) for concrete segment (alternative idea)

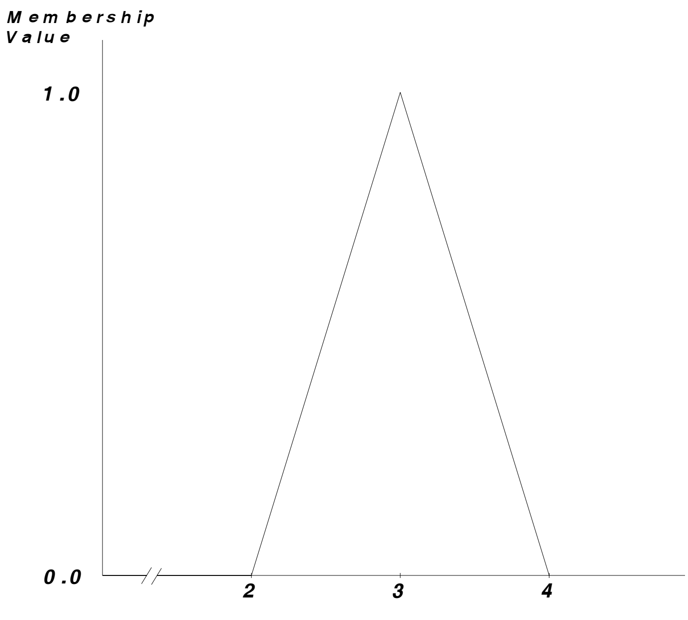

Fig.12. fuzzy set score of water tightness (criterion) for concrete segment (alternative idea)

could benefit decision makers to make more tangible and realistic conclusions. As stated the model is also capable of solving problems in endless depth (problems which are related to the criteria in several layers). It should be taken into account that in spite of superficial complexity, the model is rather practical and straightforward and there is no contradiction with the simplicity desired by VE. Indeed model is following simple routines and along with the computer base program (like provided spreadsheet program) it could be utilized at VE workshops in order to achieve more reliable results. However more simplification could encourage more value engineers to utilize it. Another advantage could be explained as it's flexibility regarding range of the scoring values, as intervals between Worth and Best values would be assigned at the first step. Subsequently experts' opinion in evaluation process could be even actual values, e.g. actual cost of the project.

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