FUZZY APPROACH TO PROJECT DELIVERY SYSTEM SELECTION

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Abstract

Since variety of construction projects with their individual specifications could be handled through different procurement systems, selection of the most appropriate project delivery system is a vital step towards more efficient project execution. The appropriate selection of project delivery system may also ensure more competent management of the project. Its impacts are not only limited to the first stages of the project, as it could also influence pre-construction, construction and operational phases of the project. Among different approaches exerted for this purpose, none has taken uncertainty into account, despite the fact that during first stages of the project most of the selection factors are still uncertain and not clearly defined. This paper, hence, aims to provide a fuzzy insight into the project delivery system selection. Through this approach more tangible model of the evaluation process may be presented. Proposed fuzzy method is indeed a multi criteria decision making model, based on the group of criteria, assigned for the evaluation procedure. A case study is also conducted, based on the opinion of an invented group of the experts.

Keywords: Delivery Methods, Project Selection, Decision Making, Fuzzy Sets and Systems, Construction Industry

1. Introduction:

Diversity of construction projects -each with its own characteristics and requirements- resulted in assortment of project delivery systems. The success of the project depends significantly on adoption of these delivery systems which are pertinent to technical features of the project, and requirements of client and contractor. An average of 5% reduction in costs has been estimated through selection of an appropriate procurement method in construction project. Project delivery system defines roles and responsibilities of the parties involved in a project. They even establish an execution framework in terms of sequencing of design, procurement, and construction. The development phase of a capital project usually involves consideration of alternative project delivery systems, to determine which delivery system would be most suitable for the project. The number of different procurement systems in the construction industry has increased over the last decade. This point has resulted in the need to conduct a selection process for any specific project in a disciplined and systematic manner. Decision making for selection of project delivery

systems should be based on consideration of objective quantitative metrics applied in an analytical evaluation of alternatives. However, quantitative data required for analytical evaluation of alternatives are usually not available. Currently, therefore, delivery systems are in most cases selected based on non-quantitative approaches (Oyetunji 2001).

The structured decision-making process has several benefits over the holistic approach. The decision analysis process involves decomposition of the decision problem into smaller problems that the decision maker can focus on separately. The solutions to the smaller problems are aggregated using established techniques and an optimal course of action can then be easily evaluated. French _1983_ states "unguided human judgment is susceptible to many failings. In particular, a number of studies have shown that holistic assessments give weight to fewer value attributes than a guided multi-attribute approach." Generally, the structured process provides the decision maker with greater insights into the decision problem. A quantitative procedure based on sound analytical theory would greatly improve the quality of decision making overall.

Several analysis methods were considered for evaluating alternative project delivery systems for the purpose of identifying an optimal solution for any given project. Common analysis methods considered included genetic algorithms, statistical decision theory and variety of multi-criteria decision models. Since different factors are to be considered in selection of the appropriate project delivery systems, it should be considered as an MCDM problem.

Multi criteria decision models have recently grabbed great attention. These models are mainly divided into two main groups; Multi Objective Decision Models (MODM) which are mainly utilized in continuous decision spaces (especially mathematical programming with different objective functions) and Multi Alternative Decision Modeling (MADM) 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. Given that in early stages of the project development most of the parameters -considered in selection of appropriate project delivery system- are still indefinite and vaguely defined, application of fuzzy mathematics will be quite conducive. Furthermore all researches conducted so far has emphasized on uncertainty exists in the evaluation of procurement systems. This uncertainty, however, has never been taken into consideration. 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 procurement team especially due to the fact that in most cases evaluation process requires personal subjective assessment. Fuzzy set systems theory also avails to conversion of qualitative numbers into quantitative amounts. This approach is considered to be most appropriate in generating the numerical data, from non-numerical, qualitative variables for quantitative comparison of delivery systems.

Proposed method could support the procurement team especially due to the fact that in most cases evaluation process requires personal subjective assessment.

2. 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 defined as follows:

$$\mu_s(x) = 0 \longrightarrow n \notin s$$

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

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

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

$$\mu_s(x) = 1 \longrightarrow x_i \in s$$

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 [5].

3. Definition of the Project Delivery System selection Problem:

3.1 Selection of evaluation criteria and their weights

Selection criteria are closely linked with project objectives, both tangibles, such as time and cost and intangibles such as feasibility. The selection factors that are relevant to the decision making problem were determined through reviewing previous studies and then selecting those criteria that are relevant to Iran. Consequently following factors are deemed in the study:

1. Project Duration
2. Cost Certainty

3. Flexibility Against Changes
4. Project Quality
5. Risk Avoidance
6. Single Source of Responsibility
7. Price Competition
8. Complexity
9. Safety Related Issues

Corresponding weights calculated with the means of analytic hierarchical process (AHP) model is presented in Table 1.

Criteria	Weights	Balancing Factor
Project Duration	0.327	1
Cost Certainty	0.032	1
Flexibility Against Changes	0.073	1
Project Quality	0.173	1
Risk Avoidance	0.069	1
Single Source of Responsibility	0.158	1
Price Competition	0.035	1
Complexity	0.110	1
Safety Related Issues	0.024	1

Table (1): Criteria weights and Balancing factors

3.2 Determination of procurement options

The boom of construction industry in Iran in the last twenty years has resulted in a great demand for infra-structure development. This has brought about an increase in projects size, design complexities, and construction difficulties. However, the development cycle has been shortened to reduce the overall cost of development. The traditional approach of Design – Bid – Build can no longer meet clients' requirements, and various procurement options have been developed to satisfy needs of the industry. Project delivery alternatives, shown below, selected for evaluation and selection of the most appropriate procurement system:

1. Design – Bid – Build
2. Design – Build
3. Construction Management

4. Selection of the Project Delivery System Utilizing Fuzzy Set Theory:

Structure of the Fuzzy Decision Support System (DSS) is illustrated in figure (1). Proposed DSS is adapted from the model developed by Lee, Y. et al. (1991) for dredged material management. The model comprises three main sectors. At first assigned scores are converted into the fuzzy set. Thereafter scores for each alternative system would be aggregated at aggregation module. Finally alternative systems 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, its membership function will be $\mu[Z_i(x)]$ as denoted in figure (2) with a trapezoid membership function. Membership

degree for each value would be assigned based on the expert's judgment. 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.
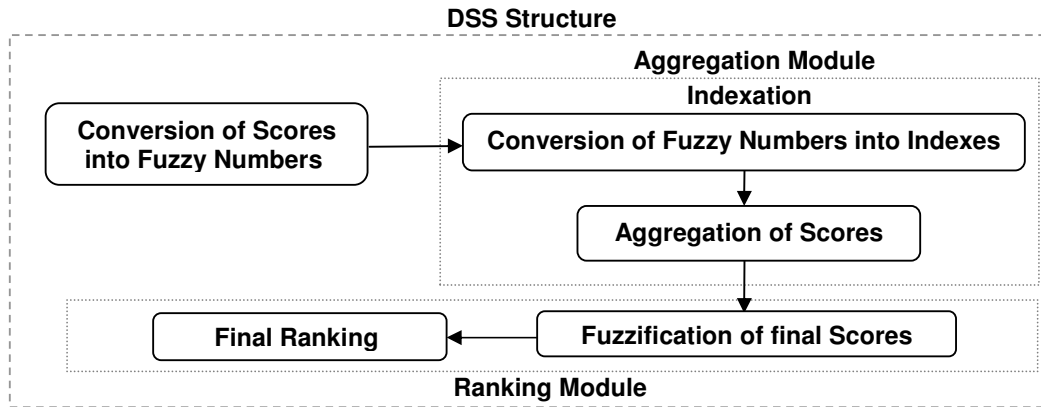
DSS Structure

Figure (1): DSS Structure of Fuzzy System

One of these intervals $Z_{i,1}(x)$ is the most likely interval, where 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.
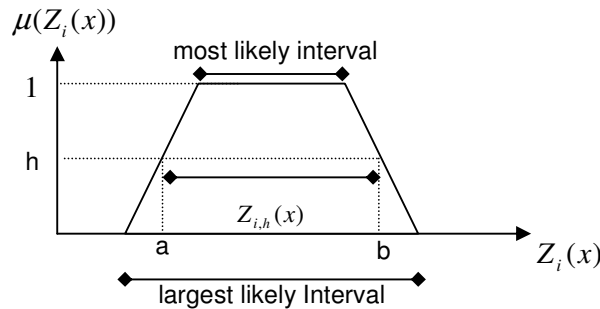

Figure (2): Fuzzy score of xth alternative against i^{th} criterion

5. Conversion of Scores into Indexes:

Since different criteria, with different characteristics and units, are going to be integrated; $Z_{i,h}(x)$ as score assigned to each system 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 and 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:

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

2. If $WOR Z_i > BES Z_i$ then:

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

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 diagrams (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.
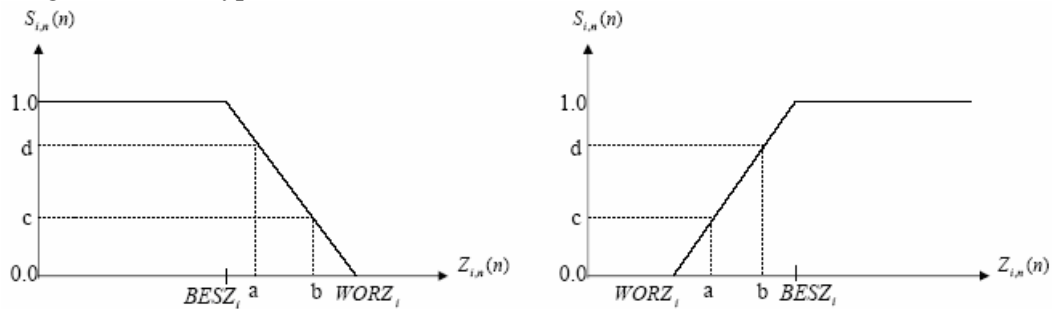

Figure (3): Transferring fuzzy values to index value

In contrast concerning some criteria such as time 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.

6. Aggregation of Scores Regarding Each Alternative System:

For summing up all the scores and obtaining final score concerning each proposal following equation could be exploited:

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

Where n= the number of criteria; $S_{i,h}$ = Index for i^{th} criterion with h level of acceptance; w_i = Related weight of each criterion $\left(\left(\sum w_i = 1\right)\right)$; P= balancing factor and $I_h(x)$ = 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, 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 $P(P \geq 1))$ is a factor which shows importance of deviation magnitude between a criterion value and the best criterion for that value. This factor would be proposed for a group of criteria. Therefore if P=1, all deviations will get equal weight. If P=2 each deviation will get weight in proportion to its scale. In general $P \geq 3$ would be used for limiting criteria [6].
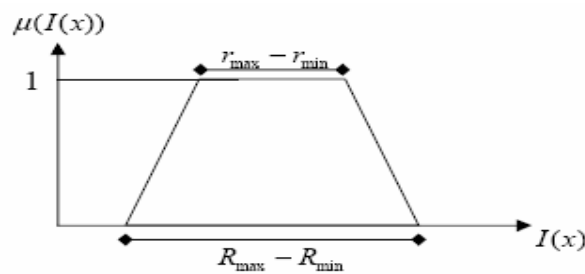

Figure (4): Membership function of the final score regarding each alternative

Furthermore if each criterion comprises other criteria, this equation could be extended for lower levels and then final result would be reached 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].

7. Preparing Proposed Alternative System 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 member of the fuzzy set associated with final score of the xth 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.

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

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. If n alternative systems have been considered for ranking, there will be n fuzzy sets as $\lfloor I_{(n)} \mid n = 1,2,....,n \rfloor$, whose membership functions will be figured out through equation (6).

8. Final Ranking of Alternative System:

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:

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

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

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

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

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

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

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

And then left utility value $U_L(x)$ for alternative system 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:

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

The alternative with best total utility value would be presented as the best option, thus all alternatives would be sorted based on their total utility values.
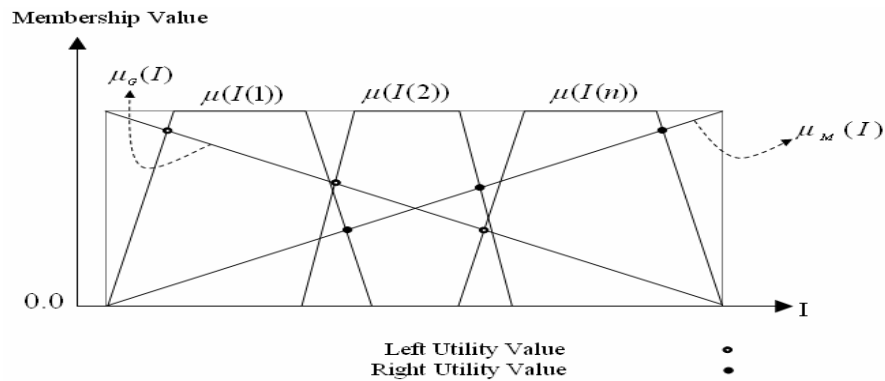

Figure (5): final idea's score functions with related utility functions

9. Practical Assessment Based on the Proposed Model:

A group consisting five experts is considered to carry out a case study, through application of the proposed model. A spread sheet program is also provided in order to help evaluation team during selection process, based on the assessment criteria and methodology proposed in this study. Brief outcome of the assessment is presented at Table 2.

		Project Duration	Cost Certainty	Flexibility Against Changes	Project Quality	Risk Avoidance	Single Source of Responsibility	Price Competition	Complexity	Safety Related Issues	Left Utility Value	Left Utility Value	Left Utility Value
DBB	least likely interval	48-53	79-88	57-64	67-74	72-79	72-81	70-92	52-87	48-70	0.6491	0.4933	0.4221
	most likely interval	50-51	82-86	60-61	68-71	73-75	74-77	83-86	60-73	52-61			
DB	least likely interval	74-95	57-80	61-70	47-66	53-80	44-70	58-80	51-67	61-97	0.5711	0.8038	0.6164
	most likely interval	84-87	60-76	64-68	52-58	65-76	54-62	65-72	57-63	76-83			
CM	least likely interval	64-87	57-72	52-77	57-67	45-79	41-60	64-90	50-78	60-84	0.617	0.7238	0.5534
	most likely interval	72-73	65	64-71	60-62	58-76	47-52	71-74	54-64	75-78			

Table (2): Scoring and final results

As it could be understood from the table, Design-Build option is evaluated as the best alternative for project procurement system. It should be emphasized that this evaluation is made base on the proposed case. In different situation the outcome of the assessment could vary, simply based on the actual requirements and restraints.

10. Conclusion:

In this study a multi alternative fuzzy decision support system (DSS) is exerted to assist the client in construction project delivery system selection. As stated above the model suited situations where criteria have varying degree of importance, criteria are conflicting and values are still uncertain. Since the project delivery system should be performed at the earlier stages of the project and considering more indefiniteness in those stages, introducing fuzzy sets theory could benefit decision makers to make more tangible and realistic evaluation. It should be taken into account that in spite of superficial complexity, the model is rather practical and straightforward. Indeed model is following simple

routines, and along with the computer base program (like provided spreadsheet program) it could be utilized in order to achieve more reliable assessment of the procurement systems. More simplifications, however, could encourage more procurement teams to utilize it. Another advantage may be enumerated as flexibility regarding range of the scoring values, as intervals between Worst and Best values are assigned at the first step of the assessment. The outcome of the case study indicated that public client in the studied project has selected Design-Build method as the most appropriate delivery system for the proposed project.

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