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A Conceptual Methodology for Transportation Projects Selection

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ABSTRACT

Selection of appropriate infrastructure transportation projects such as highways, plays an important role in promotion of transportation systems. Usually in evaluation of transportation projects, because of lack of information or due to long time and high expenditures needed for gathering information, different effective factors are ignored. Thus, in this research, regarding multi criteria nature of transportation projects selection and using fuzzy logic, an appropriate conceptual framework for ranking and selecting transportation projects is proposed. Also, unlike the previous researches, we've applied a fuzzy inference system (FIS) to account value of each project with respect to each criterion, in the proposed methodology. The FIS helps us to set rule-based systems for paying attention to expert's experience and professional knowledge in decision making. The proposed methodology is explained in detail through an applicable example. We've considered most common criteria including effect of transportation project on traffic flow, economical growth and environment beside budget constraint, in the descriptive example.

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1. Introduction

When evaluating transportation projects and determining which of them to carriy out, several criteria need to be considered in the decision. The criteria are not always the same. Common criteria for evaluation are effect of transportation projects on time savings, traffic and accident reduction, environmental aspects, operational and construction costs, regional economic development, land use issues, etc [1]. In previous researches [2,3,4,5,6,7,8,…], different techniques have been used for transportation projects selection including profile and checklist methods, cost and benefit analysis (CBA), mathematical programming models and multi objective approaches (ELECTRE, AHP, PROMETHEE, ….).

In most of these techniques, qualitative criteria which are difficult to measure or there isn't any information available about them, are ignored in the evaluation process. For example, in many selection processes environmental effects are omitted from direct consideration since they are difficult to measure quantitatively [9]. Also, these techniques can not deal effectively with the decision maker's preferences and knowledge. In fact, when the decision makers evaluate the weightings of criteria and the appropriateness of alternatives (transportation projects) versus criteria, they usually depend on their experience, professional knowledge and information that are difficult to define and describe exactly. In order to cope with these deficiencies with common techniques, in this research we've proposed a conceptual model for transportation projects selection, based on fuzzy theory and fuzzy inference systems. In the proposed model, after identification of projects and evaluation criteria, at first transportation projects are assessed versus the criteria.

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This process should be performed through FISs with if-then rule based systems. Then, an overall score is calculated for each project. Finally, a Knapsack Problem, in which coefficients of decision variables in the objective function are the scores earned from the previous stage, will be solved and most efficient projects will be selected. Also, different steps of the methodology are explained via an applicable example. Effect of transportation project on traffic volume and economical growth of the region that project will be built there and environmental aspects are three considered criteria in the example. The framework of this paper is arranged in five sections. In section two related literature is reviewed briefly. In section three the conceptual model for transportation projects selection is presented. In section four an applicable example is used to explain the proposed model and finally the paper concludes in section five.

2. Literature Review

In this section the previous related studies on transportation projects selection by categorizing them based on their evaluation procedure has been studied:

2.1. Multicriteria Approaches

The application of multicriteria approaches Including multi attribute decision making, multi objective models, multi attribute utility theory, etc, for transportation projects selection has recently increased. These techniques consider multiple objectives in the analysis. There are several researches in this area such as [2,9,10,11]. Different ranking based approaches (like AHP, ELECTRE and PROMETHEE) and optimization procedures are used in these researches. The main fault of these approaches is the need for exact data in order to get meaningful results. This need stands in contrast to the high level of uncertainty associated with transportation projects.

2.2. Fuzzy Multiobjective Approaches

Usually the process of transportation projects selection takes place under fuzzy environment and uncertainty. In order to cope with inexact information, fuzzy theory is accompanied with multi objective analysis in lots of researches [12,13,14,15,16].

3. Evaluation Methodology

In this part the objective is to see how we can select or rank transportation projects by evaluating their effect with respect to some criteria. Along these lines, a generic framework for evaluation and selection of transportation projects is developed here. The proposed methodology as illustrated in Figure 1, consists following steps:

Step one: Identification of a list of alternatives (transportation projects) and evaluation criteria.

Step two: Determination of the importance of considered criteria using a fuzzy linguistic variable ($\tilde{W}$).

Step three: Assessment of the value of the transportation projects, using FISs that results in an assessment of the fuzzy linguistic variable $\tilde{R}$. Step four: Defuzzifying of the fuzzy linguistic variables $\tilde{R}$, $\tilde{W}$. Step five: Calculating an overall score for each transportation project. Step six: Solving the Knapsack Problem (KP) and selecting the most efficient transportation projects.

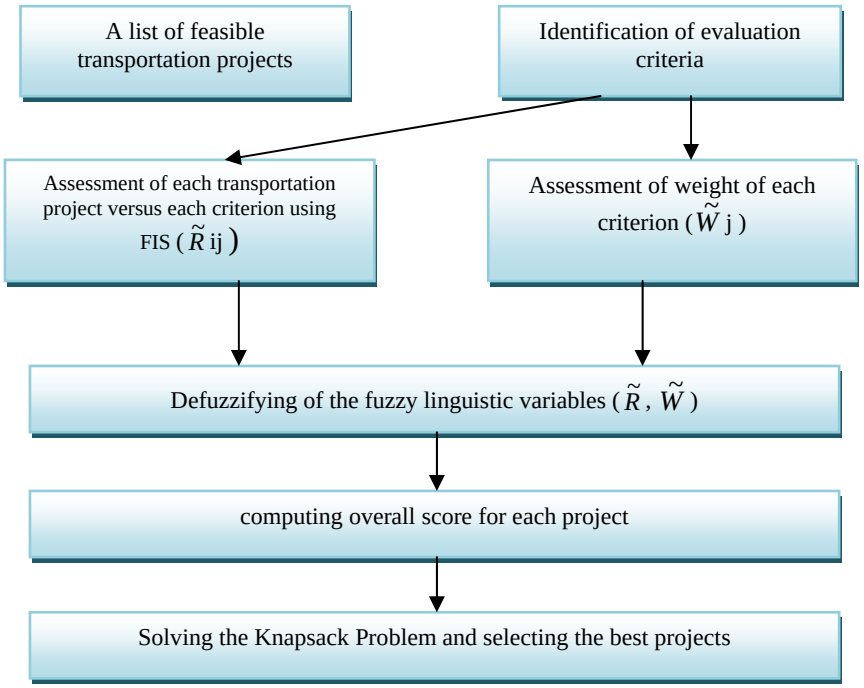

Fig. 1. Conceptual model for transportation projects evaluation

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According to the proposed model, after determination of transportation projects and evaluation criteria (step one), a weight denoting importance of each criterion should be estimated (step two). Different methods might be used in this step to assess the importance of each project, including Eigen vector, Entropy, Least squares errors, etc. But since it is easier to assess weights linguistically based on knowledge of experts at transportation planning, a linguistic model should be used for this fuzzy variable. Let $\tilde{W} = \{w_j, j = 1,...,n\}$ be a set of fuzzy numbers on the unit interval [0,1], denoting the weight (importance) of jth criterion (Cj).

Then in step three, the various transportation projects have to be assessed with respect to each criterion. In fact, The decision problem is composed of a matrix of 'm' transportation projects rated on a set of 'n' criteria. Let $\tilde{R}$ ={Rij , i=1,2,…, m, j=1,2,…, n} be a set of fuzzy number, also, on the interval [0,1], denoting the rating of the ith transportation projects with respect to jth criterion .

In this step, in order to pay attention to different required information for the evaluation process, which are ignored usually, usage of a FIS is suggested. A fuzzy inference system uses a collection of fuzzy membership functions and rules, instead of Boolean logic, for the reasoning process [17]. The main steps in designing fuzzy inference system is to recognize the input variables, to determine entity values to each input and output variable and to identify rules. These stages will be described in depth, in the next part.

The step four is to defuzzify the linguistic fuzzy variables $\tilde{W}$ and $\tilde{R}$ into numeric values. There are several difuzzification methods such as centroid, middle of the max and bisector that might be used for this step. After that in step five, we need a method for computing an overall score for each transportation project. Several MADM methods such as SAW, TOPSIS and AHP might be used for scoring projects.

We use the earned scores from the previous step for building a Knapsack Problem (KP). Let Si be the score of each project. These scores would be the coefficient of each transportation project in the objective function of the KP. The KP will be like bellow:

$$\begin{aligned} &Max \quad f(x) = \sum_{i=1}^{m} S_i X_i \\ &s.t: \\ &\sum_{i=1}^{m} NPV_i X_i \leqslant Budget \\ &X_i \in \{0,1\} \end{aligned} \tag{1}$$

In the KP, we have to select some of the projects that optimize the objective function. Several researches have been done on this problem [18,19,20,21,…]. The execution decision is expressed in a form of binary variables $X_{_}$ representing whether the ith project is selected for execution or not. NPV_1 is the net present value of both initial cost and yearly maintenance costs of ith project during its lifetime. The capacity constraint is given by the available budget (Budget) for the planning horizon. In order to pay attention to time value of the money NPV is used in this constraint. Finally, after solving the KP we'll be able to select the best projects for execution.

In the next part an applicable example is used to describe the proposed methodology in detail.

4. A Descriptive Example:

10 transportation project are supposed. Three generic and important evaluation criteria are considered including effect of project on traffic volume, economical growth (land use) and environmental aspects. Regarding the criteria and budget constraint, we want to select the best projects for execution. As mentioned before, here we've considered a fuzzy linguistic variable for the term 'weight'. Also, linguistic variables are defined for projects initial cost and yearly maintenance cost. linguistic terms of these linguistic variables are defined through trapezoidal and triangular fuzzy numbers. We used triangular and trapezoidal fuzzy numbers as membership functions for fuzzy linguistic variables, due to their popularity, wide-use and simplicity. Figures 2,3 and 4 represent the membership functions of the mentioned fuzzy variables. Other information related to the projects are listed in Table 1.

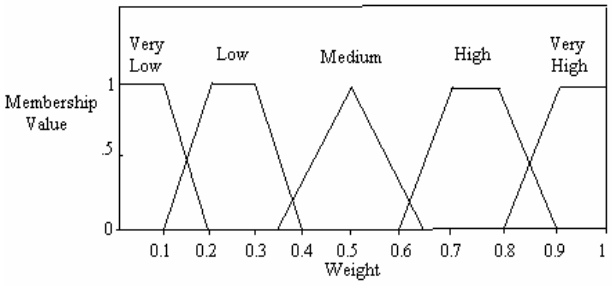

Fig. 2. Membership functions of linguistic variable "Weight"

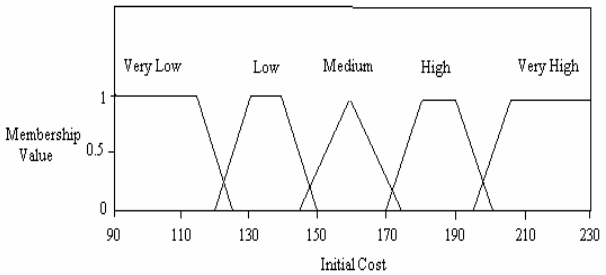

Fig. 3. Membership functions of linguistic variable "Initial Cost"

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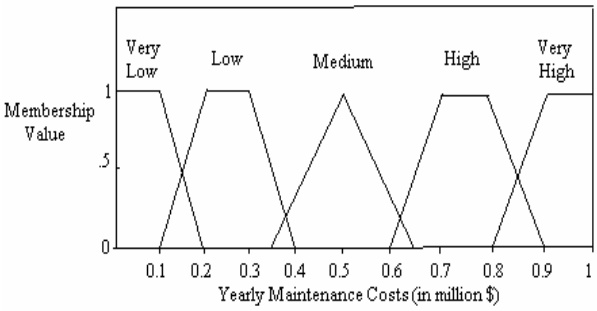

Fig. 4. Membership functions of linguistic variable "Maintenance cost"

Tab. 1. Transportation Projects Information

Project	Initial Cost	Main. Cost	Life Time
1	VH	L	20
2	M	L	30
3	M	M	20
4	H	L	25
5	VH	L	40
6	H	L	25
7	VH	VL	15
8	M	M	30
9	M	L	25
10	L	VL	20

In table 1, Life time and maintenance costs are in year. Also, initial and maintenance costs are in million $ and assume that available budget for the planning horizon is 1000 (in million $).

Suppose the importance of each criterion is estimated like bellow:

Effect on traffic volume: Very High (VH)

Effect on economical growth: Medium (M)

Environmental effects: High (H)

According to the proposed methodology, the step three is to assess each project regarding each criterion. In this study, the fuzzy logic toolbox of the MATLAB 7.6 (R2008a) is used to develop the fuzzy inference system for evaluation process. Following parts are devoted to explain how to perform the step three of the methodology.

4.1.Input and Output Variables

As mentioned before, we've considered three important and generic criterion for the evaluation process. For each criterion we have to develop a FIS.

The first one is the effect of transportation project on traffic flow reduction of the region under study. If the project is built in a region with high traffic volume and also, accessibility to the new project with regard to distance and path is high, then the project will help to reduce traffic flow of the region.

Thus, effect of transportation project on traffic flow reduction depends on these two efficient and qualitative factors (traffic volume and accessibility) which are considered as input variables to the related FIS.

The next criterion is the effect of transportation project on economical growth of the region under study. Putting it differently, this criterion concentrates on effects of transportation project on land use issues. Two important input variables are considered here, too. One of them is the effect of transportation project on promotion of people welfare through more accessibility to shopping and hiking centers.

The other important factor is the effect of transportation project on easily accessibility to occupation and work centers. Finally, the last criterion is environmental effects of each transportation project. Two kind of important environmental effects are historical monuments destruction and green spaces destruction.

The more destruction, the less valuable transportation project. Thus, amount of destruction of historical monuments and green spaces are two input variables for the considerd FIS. The output of the FISs is the fuzzy linguistic variable ‘‘Rate’’. It represents how precious each project is, regarding each criterion. The linguistic terms of the introduced input and output variables are shown in Figures 5 and 6. Using a scale from 0 to 10, we can assess the input variables. Then, these inputs are fuzzified using membership functions. Table 2, shows the input values for each project. The next step in constructing FISs is to make relation among input and output variables through rule base definition.

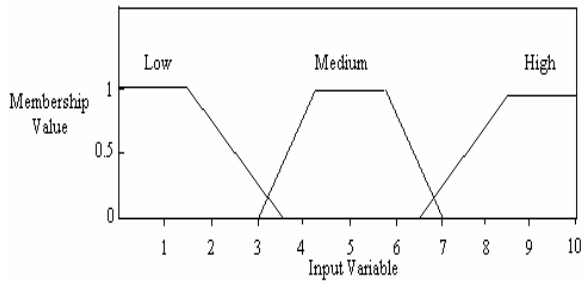

Fig. 5. Membership functions of Input Variables

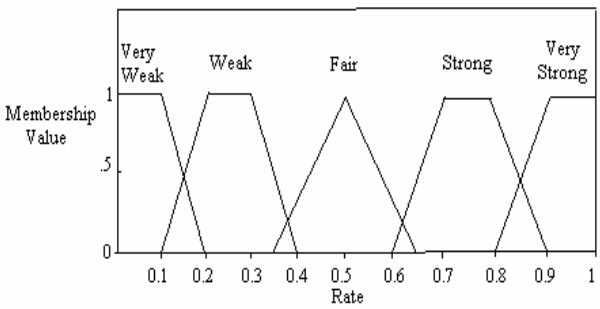

Fig. 6. Membership functions of Output Variable

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Tab. 2. Assessment of Input Variables

	Inputs of the first criterion		Inputs of the second criterion		Inputs of the third criterion	
Projects	**Traffic Volume**	**Accessibility**	**Welfare**	**Occupation**	**Monument**	**Green space**
1	8	5	3	8	1	4
2	3	7	6	4	7	3
3	5	6	8	3	5	5
4	7	8	2	5	1	2
5	4	7	5	3	4	3
6	6	2	7	3	2	4
7	8	8	6	4	1	2
8	5	3	4	8	3	1
9	8	6	5	8	2	2
10	5	8	8	4	1	7

4.2. Rule Base

The behavior of a fuzzy system is characterized by a set of linguistic rules which constitutes a rule base. A linguistic fuzzy rule is of the form of the following example [3]:

If x1 is A1 and x2 is A2 and . . . and xn is An; then y is B;

where x1 and x2 and … and xn are input variables, A1 and A2 and … An are input linguistic terms represented by fuzzy sets, y is an output variable and B is an output linguistic term represented by fuzzy sets [3]. The antecedent (the rule's premise) describes to what degree the rule is applied, while the consequent assigns a membership function to the output variable [7]. Moreover, every rule has a weight (a number between 0 and 1) which assigns the importance of each rule. Here in our analysis we have assumed identical weight for the rules.

The linguistic rules are listed bellow and supposed so that they are generic and applicable in different real situations.

Rules related to the first criterion:

1- If Traffic Volume is High and accessibility is Low then TRate is Fair.
2- If Traffic Volume is High and accessibility is Medium then TRate is Strong.
3- If Traffic Volume is High and accessibility is High then TRate is Very Strong.
4- If Traffic Volume is Medium and accessibility is Low then TRate is Weak.
5- If Traffic Volume is Medium and accessibility is Medium then TRate is Fair.
6- If Traffic Volume is Medium and accessibility is High then TRate is Strong.
7- If Traffic Volume is Low and accessibility is Low then TRate is Very Weak .
8- If Traffic Volume is Low and accessibility is Medium then TRate is Weak.
9- If Traffic Volume is Low and accessibility is High then TRate is Fair.

We have to mention, by statement "If Traffic Volume is High and accessibility is Low then TRate is Fair", we mean, if traffic flow of the region around the project is high and accessibility to the transportation project is low (because of path or distance) then rate of transportation project will be Fair. Other rules have the same way of deduction.

Rules related to the second criterion:

1- If welfare is High and Occupation is Low then LRate is Fair.
2- If welfare is High and Occupation is Medium then LRate is Strong
3- If welfare is High and Occupation is High then LRate is Very Strong.
4- If welfare is Medium and Occupation is Low then LRate is Weak.
5- If welfare is Medium and Occupation is Medium then LRate is Fair.
6- If welfare is Medium and Occupation is High then LRate is Strong.
7- If welfare is Low and Occupation is Low then LRate is Very Weak.
8- If welfare is Low and Occupation is Medium then LRate is Weak.
9- If welfare is Low and Occupation is High then LRate is Fair.

By the statement "If welfare is High and Occupation is Low then LRate is Fair", we mean if execution of the project has high effect on accessibility of the people to shopping or hiking centers and also, the effect of project on accessibility to occupation and work centers is low, then rate of the project will be fair. Other rules have the same way of deduction.

Rules related to the third criterion:

1. If Monument is High and Greenspace is Low then ERate is Weak.
2- If Monument is High and Greenspace is Medium then ERate is Very Weak.
3- If Monument is High and Greenspace is High then ERate is Very Weak.
4- If Monument is Medium and Greenspace is Low then ERate is Strong.
5- If Monument is Medium and Greenspace is Medium then ERate is Weak.
6- If Monument is Medium and Greenspace is High then ERate is Very Weak.
7- If Monument is Low and Greenspace is Low then ERate is Very Strong.

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8- If Monument is Low and Greenspace is Medium then ERate is Strong.

9- If Monument is Low and Greenspace is High then ERate is Weak.

By the statement "If Monument is High and Greenspace is Low then ERate is Weak", we mean if execution of the project will lead to high destruction of historical monuments and also, the effect of the project on greenspace destruction is low, then rate of project will be weak. Other rules have the same way of deduction.

4.3. Aggregating all of the Outputs

Next, the fuzzy operators such as AND or OR are applied across the rules. After testing all the rules in the FIS, the outputs have to be summed up according to a method such as Mamdani or Sugeno method. These two types of inference systems vary somewhat in the way outputs are determined. Since the main feature of Mamdanitype fuzzy inference systems is that the rules are explained in linguistic variables, and as a consequence it is more compatible with the reasoning process of human operators [19], here a Mamdani-type fuzzy rule-based system is exploited. In a Mamdani-type fuzzy system the premises and the consequences of the if-then rules are linguistic variables associated with fuzzy concepts.

The step four of the methodology is to defuzzify the linguistic fuzzy variables, i.e."Weight" and "Rate", into numeric values. In the defuzzification process, the output fuzzy set resulted from the fuzzy inference mechanism is mapped to a crisp value. There are different methods for defuzzification such as centroid, bisector, middle of maximum (the average of the maximum value of the output set), largest of maximum, and smallest of maximum [18]. Perhaps the most popular defuzzification method is the centroid method, which returns the center of area under the curve. This method is used in our analysis. Table 3, shows cost parameters before and after defuzzifing. The last column of this table shows net present value of both initial and maintenance costs. In the calculation interest rate is assumed to be 10%.

Also, after defuzzifing and normalizing the weights of criteria we have Table 4. Table 5, shows output of the FISs, after defuzzifying. In fact these values are assessment of each project versus each criterion.

Tab. 3. Difuzzifing Projects costs

After Deffuzifying		Before Deffuzifying		
NPV	**Main. Cost**	**Initial Cost**	**Main. Cost**	**Initial Cost**	**Project**
220.1285	0.25	218	L	VH	1
162.3568	0.25	160	L	M	2
164.257	0.5	160	M	M	3
187.2693	0.25	185	L	H	4
220.4448	0.25	218	L	VH	5
187.2693	0.25	185	L	H	6
218.5705	0.075	218	VL	VH	7
164.7135	0.5	160	M	M	8
162.2693	0.25	160	L	M	9
135.6386	0.075	135	VL	L	10

Tab. 4. Calculating Weights of Criteria

Normalized Weights	Weights (After Defuzzifing)	Weights (Before Defuzzifing)	Criteria
0.43	0.925	Very High	Effect on traffic volume
0.23	0.5	Medium	Effect on economical growth
0.34	0.75	High	Environmental effects

Tab. 5. Defuzzified output of FISs

Environmental effects	**Effect on economical growth**	**Effect on traffic volume**	**Project**
0.75	0.5	0.75	1
0.25	0.5	0.5	2
0.25	0.5	0.5	3
0.92	0.25	0.91	4
0.75	0.25	0.75	5
0.75	0.5	0.25	6
0.92	0.5	0.92	7
0.91	0.75	0.25	8
0.92	0.75	0.75	9
0.25	0.75	0.75	10

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To perform the step five of the proposed methodology, We selected the SAW method due to its simplicity and popularity to practitioners. According to this method the score of each criterion is calculated as:

$$S_i = \sum_{j=1}^{n} \mu_i = W_j$$

These scores are shown in Table 6:

Tab. 6. Scores of the Projects

10	9	8	7	6	5	4	3	2	1	**Project**
0.58	0.8078	0.5894	0.8234	0.4775	0.635	0.7616	0.415	0.415	0.6925	**Score**

Finally the KP is built on like bellow:

MAX

Z=.6925x1+.415x2+.415x3+.7616x4+.635x5+.4775x6 +.8234x7+.5894x8+.8078x9+.58x10

S.t:

220.1285x1+162.3568x2+164.257x3+187.2693x4+ 220.4448x5+187.2693x6+218.5705x7+164.7135x8+ 162.2693x9+135.6386x10 ≤ 1000

Xi, i=1,2,3, …, 10 ∈ {0,1}.

Using GAMS software, MIP solver, this KP is solved. The optimal solution of this problem is:

$$x'_1 = 1, x'_2 = 0, x'_3 = 0, x'_4 = 1, x'_5 = 0, x'_6 = 0, x'_7 = 1, x^{\bullet}_8 = 1, x^{\bullet}_9 = 1, x^{\bullet}_{10} = 0,$$

$$Optimal\,objective: Z^* = 3.675$$

This means we should select projects number one, four, seven, eight and nine for execution.

5. Conclusion

Selection of the most efficient transportation project is an important decision in the field of urban transportation planning. While previous approaches ignore experts experience and different effective factors due to lack of information or qualitative features in the evaluation process, in this research an appropriate conceptual methodology is developed. In order to pay attention to vague parameters and the knowledge of transportation experts, usage of fuzzy inference systems with imprecise linguistic If-Then rules is suggested in the methodology. Applying the methodology we'll be able to manage and use organizational knowledge and experience to create a knowledge base of experts professional knowledge which could be used for training and future decisions. An applicable example was used to describe the proposed methodology.

For further studies, it could be a good idea to add some other useful techniques to the methodology. For instance, in the situation that there is no access to experts we could implement neural network on the proposed fuzzy inference system, in order to use the learning and prediction capability of neural network to improve the fuzzy rules and fuzzy system intelligence.

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