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FUZZY COMPOSITE PROGRAMMING FOR RANKING INFRASTRUCTURE PROJECTS

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ABSTRACT

Management of capital intensive infrastructure projects is a massive task involving high risk and uncertainty. Methods available to evaluate the project viability place too much emphasis on the hard factors leaving aside the so called soft factors like environmental, social, political etc. The paper develops a methodology using fuzzy composite programming to aid the decision makers evaluate and rank the projects taking into consideration not just the hard factors but the soft factors as well. The methodology is useful for evaluating alternatives where there are conflicting objectives, the objectives have different preferences (weights), and the value of each input variable is uncertain. The procedure is explained with the help of an example: selection of an appropriate public transportation system (Monorail or Rapid Bus Transit System) in Delhi.

Introduction

Countries across the globe are continuously engaged in planning and implementing large infrastructure projects. These projects are large complex projects which are highly capital intensive and are irreversible in nature. The management of these projects, particularly in developing countries, is most important for their economic growth and development. With the increasing popularity of privately financed, build and operated facilities in recent years, a systematic evaluation of investment options is needed, especially if these options are competing for the same capital resource. Governments, contracting organizations and developers tend to concentrate on establishing the financial and technical viability of a project through feasibility studies. Some of the methods generally used for the feasibility study are Net Present Value, Internal Rate of Return, Pay Back Period, Analytical Hierarchy Process, Score System, etc. A project is deemed economically feasible, if the expected revenue meets or exceeds an acceptable pre-determined level of return on the organization's initial investment. The estimation of values of investment parameters is undoubtedly crucial to the success of the feasibility study.

However, the methodology of project appraisal should assess the overall viability of a project for an organization (Lopes and Flavell 1998). A major reason why non-financial and non-technical aspects are not considered more fully during project appraisal is probably the lack of an analytical framework that would highlight the importance of those aspects and would provide guidelines on how to incorporate them into the appraisal. A review of the literature, however, showed that there is little research into the role played by the non-financial aspects of projects in the appraisal. In particular there is no comprehensive study of all those aspects or any published

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framework that a company might use to incorporate systematically all the various non-financial components in the appraisal process.

Therefore, there exists a need of a model for solving the problem of choosing the best alternative (or best course of action) or making a complete ranking of a finite set of alternatives. The problem involves decision making under conditions of risk and uncertainty. The decision has to be taken during the conceptual and the early design phase when the information available is not complete and the decision-making environment is governed by uncertainties. Thus, the value of each parameter affecting the decision is affected by a myriad of risks and uncertainties which are often difficult to quantify. In addition to the crucial uncertainty factor, the model should allow for the non-monetary factors to be considered in assessing the investment option. Non-monetary project aspects such as social, environmental, political and legal factors are deemed to be important.

In this paper, a multi-level, multi-objective, decision making methodology using fuzzy sets is developed to assist decision makers where there are conflicting objectives, the objectives have different preferences (weights), and the value of each input variable is uncertain. The method is explained with the help of a suitable example.

Development of Evaluation Method Using Fuzzy Composite Programming

Background

In project managements, there are situations in which several alternatives have to be compared and the 'best' one selected. If all alternatives could be evaluated on a linear scale, say monetary scale; then ranking and decision-making would be relatively simple. However, in practice, this is not the case. Usually, each alternative has several attributes or criteria or features. For example, risk assessment of specific regions is affected by ground motion, vulnerability of structures, importance of buildings, and secondary hazards such as liquefaction, landslide and ground rupture. If all these factors for one building are worse than those for the others, then the ordering is obvious. This is called Pareto preference. However, 'Pareto preference' does not always lead to ordering of alternatives with multi-attributes. For instance, if some factors for one building are worse than the corresponding factors for another building, but the rest are better, then one will have difficulty in ordering these two buildings based only on the Pareto preference.

Determination of Weights

Weighting coefficients are assessed to reflect the relative importance of each criterion. To calculate the weighting coefficients, the procedure developed by Saaty (1980), can be applied. Analytic hierarchy process (AHP) (Al Khalil 2002) is used to obtain the relative weight of each criteria in a group based on paired comparison of each. Pairwise comparison of alternatives is easier than assigning all the weights simultaneously. It is based on the idea that a complex issue can be effectively examined, if it is hierarchically decomposed into parts. To compare criterion i with criterion j, the decision maker assigns values a_{ij} from Table 1.

Table 1: Pair-wise comparison scale for AHP preferences (Saaty, 1980)

Level of Importance	Definition
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Very strong or demonstrated importance
9	Absolute Importance
2, 4, 6, 8	Intermediate values between adjacent scale values

He then proceeds as follows:

1. If $a_{ij} = \tau$, then $a_{ji} = (1/\tau)$, where $\tau \neq 0$ and $i \neq j$.
2. If i = j, then $a_{ij} = a_{ji} = 1$.
3. Construct matrix $A = (a_{ij} \backslash i = 1,....., m; j = 1,....., m)$.

For example, if criterion 1 is strongly preferred to criterion 3, then $a_{13} = 5$ and $a_{31} = 1/5$. Saaty (1980) suggested that the eigen vector corresponding to the maximum eigen value of matrix A provides a good estimate for the weighting factors. The eigen value problem is solved by:

$$A \cdot W = \phi_{max} \cdot W \qquad \text{.............(1)}$$

where ϕ_{max} = a scalar corresponding to the maximum eigen value; and the unit eigen vector W corresponding to ϕ_{max} gives the preference weights.

Computation of Priority Vector

A priority vector (PV) can be defined as a simple normalised eigen vector corresponding to greatest non-zero eigen value of a square decision matrix. In fact, it is a column matrix of order m by 1 and whose elements/components add to unity. The square decision matrix on its analysis gives a way to determine qualitatively the relative importance of various attributes in a problem situation. After obtaining the decision matrix, it is suitably analyzed to compute the vector of priorities or priority vector (PV). In terms of matrix algebra, the decision matrix analysis consists of determining the "principle vector" (eigen vector) of the matrix and then normalising it to 1.0 or 100% to obtain the Priority Vector (PV).

Methodology of Evaluation

A fuzzy-composite programming method is applied to formulate a methodology for the relative weighting mechanism of the input variables and the logical aggregating tool of evaluating the results. The fuzzy-composite programming method has been used as a useful tool to solve decision-making problems where there are conflicting objectives, the objectives have varying degrees of importance, and values of input variables are uncertain. This is a multi-level, multi-objective programming method using fuzzy sets to represent the uncertainty in input variables.

Hence, the problem of evaluation of alternatives reduces to that of a problem of multi-criteria decision making where there are conflicting objectives, the objectives have different weights and the value of each input variable is uncertain. The methodology organizes a problem into the following sequential format: (1) Define basic criteria; (2) Group basic criteria into progressively fewer, more general groups; and (3) Evaluate and rank the various alternatives.

Composite Procedure

The composite procedure involves a step-by-step regrouping of a set of various basic criteria to form a single criterion (Bogardi and Bardossy 1983). For example, the five basic criteria in level 1 as shown in Figure 1 are selected as critical. The set of first three basic criteria can be grouped into soft factor which is an element of the subset of second level criteria. The final composite (rank) criterion can be formed by composing the second level criteria such as soft

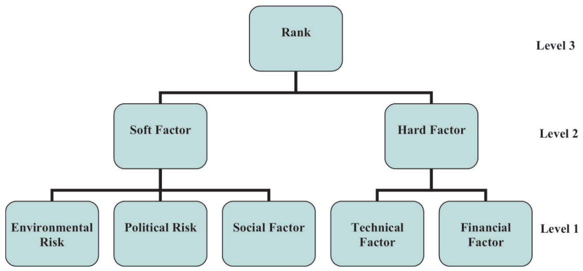

Figure 1: Example of Composite Procedure

factor and hard factor.

Trade-off Analysis Using Fuzzy Values

The values of the basic criteria for the evaluation process are estimated as fuzzy values to characterize their uncertainty. The fuzzy values are numbers that belong to a given set (interval) with a degree of membership. To evaluate the various alternatives under uncertainty, let $Z_i(x)$ be a fuzzy value of the *i*th basic criterion, and let its membership function $\mu[Z_i(x)]$ be a trapezoid (Figure 2), where x is one element of the discrete set of alternatives. As shown in Figure 2, $Z_{i,h}(x)$ is the interval value of the *i*th basic criterion at the membership degree h (i.e., a $\leq_{i,h}(x)$ $\leq$ b).

Since the units of the basic criteria are different (such as technical factors not being expressed in units at all while the cost is in Rupees), thus making it difficult to compare them directly, the actual value of each basic criterion $[Z_{i,h}(x)]$ should be transformed into an index (Paek et al. 1992). Using the best value ($BESZ_i$) of Z_i and the worst value ($WORZ_i$) of Z_i for the

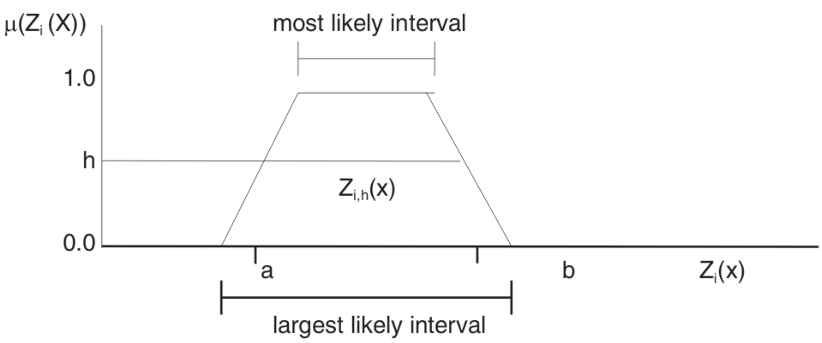

Figure 2: Fuzzy Estimate of *i*th Basic Criterion

*i*th basic criterion, the actual value $Z_{i,h}(x)$ can be transformed into an index value $S_{i,h}(x)$ as shown below.

If $BESZ_i > WORZ_i$, then

$S_{i,h}(x)$ =

$$\begin{bmatrix} 1, & Z_{i,h}(x) \geq BESZ_i \\ Z_{i,h}(x) - WORZ_i]/(BESZ_i - WORZ_i), & WORZ_i < Z_{i,h}(x) < BESZ_i \\ 0, & Z_{i,h}(x) \leq WORZ_i \end{bmatrix} \quad ....(2)$$

If $BESZ_i < WORZ_i$, then

$$S_{i,h}(x) = \begin{cases} 1, & Z_{i,h}(x) \geq BESZ_i \\ [Z_{i,h}(x) - WORZ_i]/(BESZ_i - WORZ_i), & BESZ_i < Z_{i,h}(x) < WORZ_i \\ 0, & Z_{i,h}(x) \leq WORZ_i \end{cases} \qquad \text{...............(3)}$$

For example, in selecting an alternative, the less the construction cost, the better the choice. Because the best value (lowest cost) is less than the worst value (highest cost), equation (3), i.e. ($BESZ_i < WORZ_i$) should be used to calculate the index value for the criterion of cost. As another example, the bigger the net floor area, the better the choice. In this case, (2), i.e. ($BESZ_i > WORZ_i$) should be used to obtain the index value for the net floor area. To calculate the index value of the *i*th basic criterion, one should therefore select either equation (2) or (3) according to the characteristic of the *i*th basic criterion.

Next, index values, $L_{i,h}(x)$, for second-level composite criteria can be calculated by using the index values of basic criteria, or

$$L_{j,h}(x) = \{\sum_{i=1}^{n_j} W_{i,j} \, [S_{i,h,j}(x)]\} \qquad \text{...............(4)}$$

where n_j = the number of elements in the second-level group j; $S_{i,h,j}$ = the index value for the *i*th basic criterion in the second-level group j of basic criteria; and $w_{i,j}$ = the weight reflecting the importance of each of basic criteria in group j ($\Sigma W_{i,j} = 1$).

The final composite index value $L_n(x)$ can be obtained by combining the index values of the two last level criteria :

$$L_n(x) = \{w_1[L_{1,h}(x)] + w_2[L_{2,h}(x)]\} \qquad \textbf{...............(5)}$$

where $L_{1,h}(x)$ = the index value for the first criterion (technical factor) in the final group (system); $L_{2,h}(x)$ = the index value for the second criterion (cost) in the final group; and w_1 and w_2 = the weights representing the relative importance between the two criteria in the final group.

Ranking Alternatives

As the first step of determining the ranking of the various alternatives, let L(x) be the fuzzy number representing the final composite criterion (system) of proposal x. With the help of two index values, $L_{h=1}(x)$ and $L_{h=0}(x)$, the membership function, $\mu[L(x)]$, of the fuzzy number L(x) can be approximately calculated from the piecewise linear function as shown in Figure 3 where r_{min} and r_{max} = lower, and upper-bound values, respectively, of the index value $L_{h=1}(x)$ of the final composite system obtained by using $Z_{i,h=1}(x)$; and R_{min} and R_{max} = lower and upper-bound values, respectively, of the index value $L_{h=0}(x)$ of the final composite system calculated by using $Z_{i,h=0}(x)$.

If there are n alternatives, there are n fuzzy numbers [L(x),x = 1,...,n]. The ranking of these n fuzzy numbers, which corresponds to the ranking of alternatives, can be determined by applying a ranking method such as the four point average criteria (Ross 1988). Ross (1988) has listed twelve criteria and pointed out that, it is impossible to establish a universal theory which can fit the behaviour of various decision-makers. However, what is important is that the criterion, once identified and established, should be followed throughout the whole process with consistency.

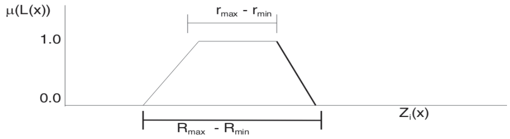

Figure 3: Membership Function of Fuzzy Number L(x)

Application (Ranking of Infrastructure Projects)

With the phenomenal growth in vehicular trips per day and the unavailability of adequate public transport systems in Delhi, more and more people are adopting the personalized mode of transport with its resultant consequences. The future looks even more ominous, as a RITES study (Anon 2005, EPCA 2006) clearly shows how the intra-city vehicular trips per day in Delhi will grow. According to the study, between 2001 and 2021, the population of Delhi is estimated to grow from 13.8 million to 23 million. In the same period the intracity vehicular trips per day are estimated to grow from 12 to 24.7 million. Adding about 15 per cent inter-city trips, the total trips to be catered to by 2021 will be about 28.7 million per day. Assuming that 80 per cent of these trips should desirably be carried by public transport, the total number of vehicular trips to be catered to by public transport by 2021 is 23 million. According to this report, the present bus services, Metro Rail and the Integrated Rail-cum-Bus transit (IRBT) system if implemented as planned together are estimated to carry about 15 million trips out of the total 24 million vehicular trips per day by 2021. Accordingly 9 million trips per day must be additionally catered to by other modes of public transport. It thus becomes imperative that augmentation of public transport takes place in tandem with the growing vehicular trips in the city. The new modes of transport considered by the authorities are the Monorail and the Rapid Bus Transit System.

Both the systems could provide a system with sufficient capacity and speed to improve mass transit rider ship. Mono-rail would require large capital subsidies for operations, construction or for the procurement of rolling stock where as the advantage of mono rail would be that it will minimize land acquisition which could be the biggest disadvantage of BRT system as land acquisition decision being mostly political can delay the project considerably (ITDP 2005).

The travel time may also be more in the BRT system because of more signals on crossings. BRT can provide effective mass transit system in lesser project duration at a reasonable fare price but it may increase air pollution, more traffic fatalities and injuries and increase land value in the corridor. As such the problem of selecting the infrastructure project is that of fuzzy multi criteria decision making.

For evaluating the best option, the five basic criteria shown in Figure 1 are selected as critical. The first three criteria are grouped into one second level criterion (Soft factor) and rest two is grouped into another second level criterion (Hard factor). The two second level criteria are grouped into one rank criterion in the third level. Table 2 contains the data about the basic criteria of each alternative as per the author's opinion. However, in practice actual data from the experts will be taken for further analysis. The best and worst values for the 5 basic criteria are also given in Table 2.

Table 2: Basic Criteria Values for Two Different Alternatives

Basic Criterion	Alternative 1		Alternative 2		Best Values	Worst Values
	Least Likely Interval	Most Likely Interval	Least Likely Interval	Most Likely Interval		
Environmental Risk	50-200	100-150	200-400	250-350	50	400
Political Risk	50-200	100-175	200-350	250-300	50	350
Social Factors	200-400	250-300	50-200	100-150	400	50
Technical Factor	150-200	160-180	200-300	220-270	300	150
Financial Factor	150-250	180-220	125-225	145-205	125	250

* Though the capital cost in case of monorail will be much higher but that will be compensated by the high land acquisition cost in case of the rapid bus transit system. Thus, there will not be too much difference in the finances of the two alternatives.

Calculation of Index Values

First Level Index Values: The index values are obtained for all the five criteria using equations (2) and (3) and the calculated value are shown in Table 3.

Criterion	Alternative 1 (Monorail)		Alternative 2 (Rapid Bus Transit System)	
	Least Likely Interval	Most Likely Interval	Least Likely Interval	Most Likely Interval
Environmental Risk	1-0.571	0.857-0.714	0.571-0	0.428-0.142
Political Risk	1-0.5	0.833-0.583	0.5-0	0.333-0.166
Social Factors	0.428-1	0.571-0.714	0-0.428	0.142-0.285
Technical Factor	0-0.333	6.666-0.2	0.333-1	0.466-0.8
Financial Factor	0.8-0	0.56-0.24	1-0.2	0.84-0.36

Table 3: Index Values of Basic Criteria

Second Level Index Values: The index values $L_{ih}(x)$ for second level composite criteria are obtained by using the index values of basic criteria arrived as in Table 3 and the weights of basic criteria obtained from the priority vector after getting the decision matrix from the experts. The weights for various criteria are shown in Table 4. The second level index values are given in Table 5.

Table 4: Weights for Various Criteria

Criteria	Weights	Remarks
Environmental Risk	0.5	Refer to Figure 1 to identify the level of each criterion and the group to which each criterion belongs
Political Risk	0.3	
Social Factors	0.2	
Technical Factor	0.25	
Financial Factor	0.75	
Soft Factor	0.4	
Hard Factor	0.6	

Table 5: Index Values of Second Level Criteria

Criterion	Alternative 1 (Monorail)		Alternative 2 (Rapid Bus Transit System)	
	Least Likely Interval	Most Likely Interval	Least Likely Interval	Most Likely Interval
Soft Factors	0.885-0.635	0.792-0.675	0.435-8.571	0.342-0.178
Hard Factors	0.6-8.333	0.436-0.23	0.833-0.4	0.746-0.47

The composite fuzzy value of each alternative is given in Table 6.

Table 6: Composite Fuzzy Values for the Two Alternatives

Criterion	Alternative 1 (Monorail)		Alternative 2 (Rapid Bus Transit System)	
	Least Likely Interval	Most Likely Interval	Least Likely Interval	Most Likely Interval
Rank	0.714-0.304	0.579-0.408	0.674-0.274	0.585-0.353

Ranking the Alternatives

The ranking of alternatives is made by using the four point average criterion. The average numerical grade is given by

G = ¼ [Sum of Most Likely Intervals + Sum of Least Likely Intervals]

Table 7: Defuzzified Result

Alternative	Order Value
Alternative 1 (Monorail)	0.501
Alternative 2 (Rapid Bus Transit System)	0.471

Since, the order value of the first alternative as given in Table 7 is greater than the order value of the second alternative, therefore, the monorail alternative is preferred to the rapid bus transit alternative.

Conclusions

The management of projects, particularly in developing countries, is most important for its economic growth and development. At the initial planning stage of a major infrastructure project initiative, there are problems of ambiguity and uncertainty. Large-scale development projects are inherently risky, owing to the possibility of unforeseen or unrecognized changes in the project environment which will cause the outcome to deviate from expectation. Changes in the socioeconomic and political environment can invalidate the original project definition. The original estimates of project costs and schedule can quickly be found to be unrealistic.

The high level of uncertainty results in a large number of alternatives being thrown up in front of the owner/ government. And the owner/ government have no way to select the best alternative out of the ones available. The paper has developed a fuzzy based system to rank the various alternatives based on multi-level, multi-objective decision making methodology. The above approach can also include intangible factors. The system has been explained through a case study of selection of an appropriate public transportation system in Delhi to cater the rapidly increasing traffic. According to the system, monorail is considered to be a better option as compared to the Rapid bus transit system.

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