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Performance Evaluation of Construction Project Using Multi Criteria Decision Making Methods

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Abstract— **In developing countries, where resources are limited, it is important to develop and study all available alternatives effectively and efficiently to improve project performance and in decision making. Performance evaluation techniques can help to find ways to improve solutions to the problems by providing a measured balance in cost, schedule, and quality via the performance evaluation of alternatives. This requires a motivated team of multi-disciplined professionals in cooperation with well-established project stakeholders who are stimulated and guided by the appropriate methods.Many quantitative methods have been developed to facilitate making rational decision making involving multi criteria. Most methods either ignore or barely include non-quantifiable factors. Analytical Hierarchy Process and Multi Attribute Utility Theory methods allow the inclusion of non-quantifiable parameters such as environmental, social and political criteria beside quantifiable cost-effective technical and economic factors. In this study, an attempt is made to evaluate different criteria and alternatives that are required for the enhancement of highway project performance. A highway project of Kandi – Shadnagar highway, in Andhra Pradesh, India is taken as case study. In this study two main processes have been followed. The first process is to identify the relevant highway performance criteria. Various criteria's are collected from respondents of construction projects by carrying questionnaire survey. The respondents will mark each criterion on a scale of 0-5 depending on his experience and priority. The second process is to determine value improvement and utility by applying Analytical Hierarchy Process, Multi Attribute Utility Theory and comparison between two methods have been done to evaluate the best alternative for enhancement of highway project performance.**

***Keywords*-Multi criteria decision making, Performance evaluation, Analytical hierarchy process, Multi attribute utility theory.**

I. Introduction

Public works sector programs such as highway construction and infrastructure projects include many different objectives and reflect the wishes of wide-ranging interests. One of the problems with the cost reduction studies for the public highway and infrastructure projects has been the tendency for studies to be a "cost cutting" tool instead of a value-enhancing tool. Since only study costs were reported at the conclusion of each study, there was no mechanism to weighting the value of the project costs that were cut against the project scope and project delivery components that accompanied these costs. The performance measurement application to a project plan can maximize function performance.

Decision making in the context of highway construction, therefore, involves the evaluation of a discrete set of alternatives while considering conflicting objectives. Even though it is essential to use techniques that include these multiple and conflicting objectives, decision making in the transportation sector is often performed with single-objective decision making methodologies such as cost-benefit analysis [1 & 2]. This paper illustrates how a Multi Criteria Decision Making technique, specifically Analytical Hierarchy Process (AHP) and Multi Attribute Utility Theory (MAUT) can be used to make decisions regarding highways and how these decisions would differ from the decisions reached through conventional single-objective techniques.

II. Methodology

The chapter presents an overview of the methodologies that will be used for the evaluation and measurement of construction project. In this study we will compare two multi criteria methods, Analytical Hierarchy Process (AHP) and Multi Attribute Utility Theory (MAUT). After collecting the questionnaire survey with project stakeholders, Relative rank index is used for ranking of criteria's [3] .Once the criteria's are ranked from top to bottom, AHP and MAUT will be applied [4]. This same procedure will be applied for measurement of performance for construction project.

A. Concept of Performance Measurement

The evolution of the concept of value has been a long one. In 1961, Miles published his Techniques of Value Analysis and Engineering, which laid forth the concept of function as an integral part of value. Miles codification of function as a component of value has had far reaching implications within the sphere of human industry. It spurred a new wave of thinking with respect to the value of goods and services. Miles defined value in terms of the relationship of function and cost. This was eloquently stated in his now famous axiom, "All cost is for function." of equal importance, he stressed that value is established by the users, or customers, needs and wants. This basic understanding of value is essential if we are going to set about improving it [5]. Building upon Miles theory of value, Carlos Fallon further refined these concepts. Fallon recognised that while function lay at the heart of value, it was the manner in which the function performed that allowed it to be quantified. Through his work, Fallon developed a methodology for quantifying performance, which he described using the word utility. Although Fallon credits numerous philosophers and economists, most notably Daniel Bernoulli and Jon Von Neumann, for developing the concept and mathematical approximations of utility, he appears to be the first to concisely define a practical method for its quantification. Utility, as Fallon describes it, is “the nonlinearity between performance, on the one hand, and the effect of performance, on the other. David De Marle, provides several simple equations to define value. The equation 1 is based upon Miles understanding of value.

$$V_{max} = F/C_{min} \quad (1)$$

The equation 2 is an expression of Fallon’s theory of value where the term utility is defined as the project of a need and the ability to satisfy that need.

$$Value = \frac{nxa}{c} \quad (2)$$

Finally, proposed a simple equation 3 for value that also captures the idea that user determines value.

$$Value = performance/price \quad (3)$$

The equation 4 suggested by Miles states that maximum value is achieved by providing the function for the lowest possible cost. The term “function” as it is commonly understood within the context of value studies, is defined as the means by which an expressed need or want is fulfilled. It would contend that when we discuss the concept of value, what we are really expressing is a relative measure of how well that need or want is being fulfilled relative to the cost to do so. The “how well” part really refers to the performance of the function rather than of the function itself.

$$V_f = P/C \quad (4)$$

In other words, the value of function is equal to its performance divided by its cost. There are two ways to improve value in a given cost. First is “adding desirable functions” and second is “improve the performance of the projects current functions.” The most cost-effective and reliable way to accomplish this is to focus more on the performance of the required project functions. The equation5 shows the relationships between value, performance, and cost with modification of traditional definition of value which include change F (function) to P (Performance).

$$V= P/C \quad (5)$$

Where, V is the value improvement, P is the performance, C is the cost. This study develops a process to measure the performance of a project. The following list of steps gives the detail of this process:

- Identify key project performance criteria.
- Determine the hierarchy/impact or weight of each criterion.
- Establish the baseline of the current project performance.
- Identify the change in performance of newly generated project alternatives.
- Measure the aggregate effect of alternative concepts relative to the baseline projects performance.
- Relate the performance measurements to project costs to determine the project-value improvement.

B. *Relative Rank Index*

The Relative Rank Index (RRI) technique is used for comparison between the importance levels of variables and derived from the likert scales which represent the level of importance of variables chosen by respondents which need to be transformed into a RRI that has a value of one or less [6]. A six point likert scale is used in this study. The RRI can be calculated using the equation:

$$RRI=11/ (nN)(\sum_{i=1}^{n} l_i x_i) \quad (6)$$

Where, RRI is the Relative Rank Index, n is the the maximum Likert scale, N is the total number of responses i : 1, 2….n, and l_i: Likert scale (l_1 is the least important and l_n is the most important), x_i: The frequency of the i’th response.

C. *Analytical Hierarchy Process*

Analytic Hierarchy Process (AHP) is a mathematical decision making technique that allows consideration of both qualitative and quantitative aspects of decisions. It provides one framework to reduce qualitative and quantitative complex constrains by formulating a series of one-on-one comparisons. Compared to other techniques like scoring techniques, AHP uses human judgment to compare alternatives of a designated criteria or sub-criteria [8&9]. It not only helps decision makers choose the best alternative, but also provides justifications for the choice. The process was developed in the 1970’s by Thomas Saaty. According to Saaty, the AHP relies on three fundamental assumptions deduced from the words of the technique [7]:

Analytic:

The decision alternatives are described analytically using number and logic. Different alternatives for a given criterion are reasoned independently and assigned numerical scores.

Hierarchy:

The score for a given criterion is calculated from its sub-criteria. That is, the criteria can be arranged in a hierarchy, and the numerical score at each level of the hierarchy can be calculated as a weighted sum of the lower level scores. At a given level, suitable scores can be calculated from only pair-wise comparisons.

Process:

In any real problem involving decision making, a process is required to gather information, negotiate and revise. AHP guides the decision maker to where more information and most important information are needed. The AHP also allows group decision making. Each member of the group provides separately his own judgments according to his experience, values and knowledge. If the group has achieved consensus on some judgment, only that judgment is registered. If during the process it is impossible to arrive at a consensus on a judgment, the group may use some voting technique, or may choose to take the "average" of the judgments, that is the geometric mean of the judgments. The group may decide to give all group members equal weight, or the group members could give them different weights that reflect their position in the project.

III. Performance Evaluation using Analytical Hierarchy Process

The technique developed to measure the performance of construction projects, includes the following steps and Figure.1 show the detail of this procedure:

- Define Criteria

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- Determine Hierarchy
- Establish Baseline
- Evaluate Alternatives
- Compare Concepts

A complete discussion of each of these steps is provided in the following sections. Figure 1. Shows the flow Chart of Analytical Hierarchy Process.

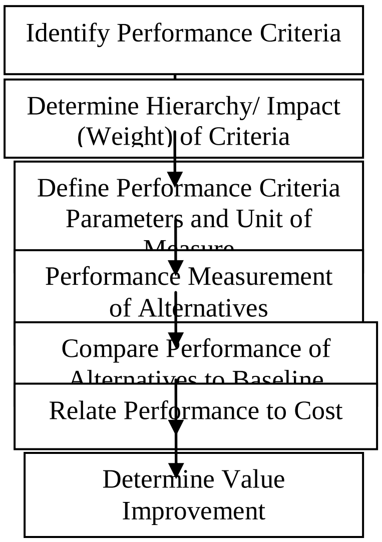

Figure 1. Flow Chart of Analytical Hierarchy Process

IV. CASE STUDY

The geographic locations of the project are at 18° 20'N Latitude, 78° 26'E Longitude and 16° 32'N Latitude, 78° 26'E Longitude, respectively. The project is widening and strengthening of Kandi – Shadnagar highway, in Andhra Pradesh, India. The project road starts at km 0+165, at Kandi on NH-9 and ends at cumulative chainage of km 68+400 at Shadnagar on NH-7. Cumulative length of the project road is 68.235 km, covering medak- rangareddy- mahabubnagar. These are evaluated on performance criteria such as Highway Safety, Traffic Operations, Geotechnical Issues, Construction Impacts to the Community, Environmental Impacts, Accessibility (Local Access), Project Schedule. Data obtained from the authorities reveal that about 17 km stretch at shankarpally is the most critical section of the stretch as the highway traffic is entering the town. To study and analyze the performance of the present project four concepts are considered and evaluated the performance of each of the concept. The concepts are described below.

- Existing original condition: 2- lane road as it is before
- Alternative 1: 4-laning of existing alignment without bypass
- Alternative 2: Repair works with both sides 1.5m extension
- Alternative 3: 4-laning of existing alignment with bypass road

(12 m bypass on left side of existing road)

A. Application of Analytical Hierarchy Process

Performances are evaluated for the above proposed concepts, at shankarpally using Analytical Hierarchy Process.

Defining Performance Criteria:

The criteria which were presented in Table 4.2 in the previous chapter, which are considered for the performance evaluation process are given below. The following gives the brief definition of selected criteria to evaluate the proposed concepts

- **Highway Safety**: How does the concept rate with regard to its compliance with established highway safety standards?
- **Traffic Operations**: How does the concept rate with regard to the project's overall design speeds and level of service?
- **Geotechnical Issues**: How does the concept rate with regard to the subsurface soil, rock and water conditions?
- **Construction Impacts**: How does the concept rate with regard to noise, vibration, dust, detours and traffic delays during construction?
- **Environmental Impacts**: How does the concept rate with regard to its effect on the environment including wetlands and wildlife?
- **Local Access**: How does the concept rate with regard to access between the main line and local arterials?
- **Project Schedule**: How does the concept rate with regard to the overall project schedule including design and construction?

Hierarchy of Performance Criteria:

Once the projects performance criteria are established, the next step is to determine their relative importance in relation to each other. This is accomplished through the use of an evaluative tool termed in this study as the "Performance Criteria Matrix". This matrix compared the performance criteria in pairs, asking the question: 'Which one is more important to the project?' If criterion "A" is more important than criterion "B", enter the intensity of importance value using the Saaty's 1-9 scale in the intersection box. If criterion "B" is more important than criterion "A", enter the reciprocal value of intensity of importance from the pair wise comparison scale in the intersection box. Continued for all pairs until matrix is completed. When all pairs are discussed, the numbers of "votes" for each are totaled and percentages have been calculated.

Measure Performance of Alternatives:

The last step in the process completes the Performance Rating Matrix that was initially begun to develop the performance ratings for the original concept. The performance ratings developed for the alternative concepts are entered into the Performance Rating Matrix-Overall Performance is completed. The value index have been calculated by dividing the total performance by the total project construction cost, and the difference between the value indices of the original and the alternatives is expressed as a “%Value Improvement.

Table1 Performance Rating Matrix-Overall Performance

Concept	Total performance	Totalcost ($ million)	Value index (P/C)	%value improve ment
Original	227.14	0	-	-
Alter-1	407.05	100	4.070	-
Alter-2	347.02	80	4.337	6.56
Alter-3	722.17	140	5.158	18.93

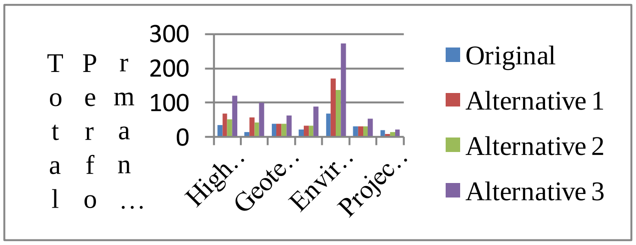

Figure 2. Total Performance of Concepts Corresponding to each Criterion

B.Application of Multi Attribute Utility Theory

Performances are evaluated for the above proposed concepts, at shankarpally using Multi Attribute Utility Theory [9].

Table 2 Payoff Matrix

Concept	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Original	20	30	90	80	90	50	80
Alter-1	75	70	40	30	60	80	40
Alter-2	40	50	60	50	80	60	65
Alter-3	80	70	40	40	70	80	60
Min	20	30	40	30	60	50	40
Max	80	70	90	80	90	80	80
Range	60	40	50	50	30	30	40

Ranking of Scaling Constants:

The scaling constants of the criteria are to be ranked based on their priority. The response is so, value of k_5 is greater than k_1 to k_4, k_6 and k_7, where k_1 to k_7 are scaling constants corresponding to criteria C_1 to C_7. The procedure is repeated to rank the remaining criteria. The ranking of criteria based on the response from decision maker is given as:

$k_5 > k_1 > k_4 > k_2 > k_6 > k_3 > k_7$.

Determination of Indifference Points and Derivation of Multi Attribute Utility Function:

To establish the actual magnitude of the scaling constants, concept of indifference curve (contours of equal utility) is used. The pair of indifference values obtained from the decision maker for (C_5, C_1), (C_5, C_4), (C_5, C_2), (C_5, C_6), (C_5, C_3), (C_5, C_7) are 76, 75, 65, 70, 70, 75 respectively.

(C_5,C_1)

(worst) (best) (y) (worst)

$$[1 + kk5.u5(C5)][1 + kk1.u1(C1)] = [1 + kk5.u5(C'5)][1 + kk1.u1(C'1)] \quad (7)$$

Where C'_5 and C'_1 are indifference points for criteria C_5 and C_6 respectively.

(C_1 = best, C_5 = worst) (C_1 = worst, C_5 = y)

u_1(best) = 1 u_5(worst) = 0 u_1(worst) = 0 u_5(y) = ?

The pair of indifference points (equal utility) for the above case are (80, 60), (20,y) where y = 76. Assuming linear utility function for intermediate values between best and worst combinations, for criteria C_1 u_1(best) = u_1(80) = 1, C_5 u_5(worst) = u_5(60) = 0, u_5(76) = ? For u_5 (76) it is linearly interpolated as

$$u5(76) = 0 + (1-0) \times \frac{(76-60)}{(80-60)}$$

= 0.8

Substituting the values in equation(7)

$$(1 + kk5\,X\,0)(1 + kk1\,X\,1) =$$
$$[1 + kk5\,X\,u5(y)](1 + kk1\,X\,0)$$

$k_1 = 0.8k_5$

Similarly, (C_5, C4), the pair of indifference points (equal utility) for the above case are (80, 60), (30,y) where y = 75. u_5 (75) =0.75, k_4 = 0.75k_5; (C_5, C2), the pair of indifference points (equal utility) for the above case are (70, 60), (30,y) where y =65. u_5 (65) =0.5, k_2 = 0.5k_5; (C_5, C6). The pair of indifference points (equal utility) for the above case are (80, 60), (50,y) where y = 70. u_5 (70) =0.5, k_6 = 0.5k_5; (C_5, C3); the pair of indifference points (equal utility) for the above case are (90, 60), (40,y) where y = 70. u_5(70)=0.34, k_3 = 0.34k_5; (C_5, C7) , the pair of indifference points (equal utility) for the above case are (80, 60), (40,y) where y = 75. u_5 (75) =0.75, k_7 = 0.75k_5. Equating the utility values of lottery A* and B* for two highly ranked criterion results in

$$k5 = p'(k5 + k1 + kk5k1) \quad (8)$$

A probability value (p’) 0.65 is given by the decision maker, all the criteria are set at their best levels, equation 5.2 then becomes

$$k5 = \frac{-0.327}{k}$$

$$1 + k = (1 + kk_1)(1 + kk_2)(1 + kk_3)(1 + kk_4)(1 + kk_5)(1 + kk_6)(1 + kk_7) \quad (9)$$

Substituting the relationships in equation 9 and simplifying the equation yields the value of k as -0.824 and corresponding scaling constants for the criteria 1 to 7 are 0.3174, 0.1984, 0.1349, 0.2976, 0.3968, 0.1984 and 0.2976 respectively presented in Table 3. It is observed that summation of scaling constants for all the criteria are 1.8411. Since this value is greater than 1, usage of multiplicative form of equation is taken as valid. It is observed that the negative value of k represents the risk aversive nature of the decision maker with reference to the present problem.

Table 3 Scaling Constants

Concept	K	k_1	k_2	k_3	k_4	k_5	k_6	k_7
Original	-0.824	0.317	0.198	0.134	0.297	0.396	0.198	0.297
Alter-1	-0.824	0.317	0.198	0.134	0.297	0.396	0.198	0.297
Alter-2	-0.824	0.317	0.198	0.134	0.297	0.396	0.198	0.297
Alter-3	-0.824	0.317	0.198	0.134	0.297	0.396	0.198	0.297

Table 4 Utility Values for each Criteria

Concept	u_1	u_2	u_3	u_4	u_5	u_6	u_7
Original	0.9000	1.0000	0.0000	0.0000	0.0000	1.0000	0.600
Alter-1	0.0000	0.0000	0.2000	1.0000	1.0000	0.0000	1.000
Alter-2	0.3333	0.5000	0.4000	0.4000	0.6667	0.3333	0.700
Alter-3	1.0000	1.0000	0.5000	0.8000	0.3333	1.0000	0.500

$$u(concept) = \left[\frac{\sum(1 + kk1u1(C1)) - 1}{k}\right] \quad (10)$$

Substituting the utility values, scaling constants and overall scaling constant of each concept in equation 5 and simplifying yields the overall utility values presented in Table 5.

Table 5 Utility Values for Concepts

Original	0.6598
Alternative 1	0.7587
Alternative 2	0.6767
Alternative 3	0.8415

IV Results and Discussion

In AHP, the total performance of concepts for all the criteria is found to be 227.14, 407.05, 347.02 and 722.17 respectively. Table 1 presents the Performance Rating Matrix-Overall Performance; it is observed that having not provided the cost of original concept i.e., baseline project, the percentage improvement of original and alternative 1 could not be calculated. Alternative 2 provides 6.56% value improvement with total cost of 80 million dollars and total performance of 347.02. While alternative 3 provides 18.93% value improvement with total cost of 140 million dollars and total performance of 722.17. Total Performance of Concepts Corresponding to each Criterion, it is observed that alternative 3 has the highest total performance of 722.17 and highest percentage value improvement of 18.93 compared to other concepts. By choosing alternative 3 i.e., 4-laning of existing alignment with bypass road, the value of the project will be improved by 18.93% with corresponding total performance of 722.17.

In MAUT, Table 4 presents the scaling constants it is observed that negative value of overall scaling constant (k) represent the nature of decision maker to be risk aversive. From Table 5, it is found that concepts provide utility values of 0.6598, 0.7587, 0.6767, and 0.8415 respectively. Alternative 3 has the highest utility of 0.8415 compared to other concepts. By choosing alternative 3 i.e., 4-laning of existing alignment with bypass road, the utility of the project is 0.8415. The comparison between AHP and MAUT has been done, it is found from the results that, in AHP having not provided the cost of original concept i.e., baseline project, the percentage improvement of original concept and next concept cannot be calculated. For AHP having more than eight criteria is certainly feasible, a larger number tends to make the process more cumbersome to facilitate. Whereas MAUT can be consider certainly larger number of criteria that makes the process more efficient and workable. The results depends purely on the expertise of the decision maker, the judgment should be done properly to get the optimal solution. However, choosing alternative 3 i.e., 4-laning of existing alignment with bypass road at shankarpally by adopting Multi Attribute Utility Theory decision making method gives the better solution.

V. Conclusions

Based on the results, it is observed that the performance evaluation improves the probability of delivering a project that serves with optimal project value. The Relative Rank Index (RRI) values of different criteria are obtained from all the respondent opinions and A4: Highway Safety is assigned the highest importance. B3: Hydraulic Issues is assigned least importance. From the study it is found that, alternative 3 provides 18.93% value improvement when compared to other alternatives by using AHP. The attitude of the decision maker is risk aversive as evident from negative value of overall scaling constant. The MAUT method alternative 3 provides highest utility value when compare to other alternatives. The comparison between AHP and MAUT, it is found from the results that MAUT can consider certainly larger number of criteria that makes the process more efficient and workable decision making method to improve the performance of the project. The uses of performance evaluation have proven to be benefit to construction project. These benefits are achieved by the collaboration of the construction team and the utilization of AHP and MAUT methods for the improvement of project performance.

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