A MULTICRITERIA DECISION MAKING METHOD FOR EVALUATING ALTERNATIVE TRANSPORTATION PROJECTS

Konstantinos G. Zografos[1], Raul Driggs[2] and Stelios Zanakis[3]

[1]Athens University of Economics and Business
Department of Management Science and Marketing
76, Patission str., Athens 10434
Greece
[2]METRIC Engineering, Inc.
Miami, Florida 33186
U.S.A.
[3]Florida International University
Department of Decision Science and Information Systems
Miami, Florida 33199
U.S.A.

Abstract: A multicriteria decision making methodology is proposed for selecting among a set of transportation projects the most preferred alternative. The proposed methodology has the ability to deal with multiple and conflicting objectives, to consider both objectively and subjectively measured criteria, and to gauge the relative importance of individual responses in a non-homogenous panel of judges. The proposed methodology offers a simple and effective way to sensitize the value of each individual judge's decisions based on his/her self expressed knowledge, initial judgmental consistency, and perceived bias in his/her pattern of choices. The proposed method is illustrated through its application on a real-word decision making problem involving the selection of a preferred alternative for the construction of a major urban arterial street in Miami, Florida.

Keywords: Decision Making, Decision Support Systems, Decision Theory, Evaluation, Multiple Criteria, Trade Offs.

1. INTRODUCTION

The selection of alternative transportation projects is a discrete multiobjective decision making problem involving a non-homogeneous group of decision makers. Even though the alternative selection process has become much more democratic through the inclusion of public at the various stages (Yukubowsky, 1980) as well as more sensitive to non-economic issues (e.g. environmental and social concerns), it still largely exhibits many deficiencies that were prevalent 25 years ago. The failure of traditional methodologies to respond to the ever-changing complexity of transportation project evaluation requirements have been amply recognized (Cheslow, 1980; Giuliano 1985). There are five basic problem areas that are generally prevalent in the selection of alternative transportation projects, mainly: 1) the lack of clearly defined goals and objectives, 2) the absence of weights expressing compensatory tradeoffs between the conflicting objectives, 3) lack of sensitivity analysis, 4) criteria duplication, and 5) lack of alternative segmentation. These "problem areas" do not refer to methodological shortcomings of a particular technique but rather to recurring deficiencies that have virtually become "standard practice".

The objective of this paper, is to propose a multicriteria decision making framework that eliminates to a great extend the above stated deficiencies.

2. PROBLEM DEFINITION

The focus of this paper is the evaluation of alternative transportation plans, during the Project Development and Environment (PD&E) phase.

In very simplistic terms, the PD&E phase involves the preparation of the required engineering and environmental documentation for federal and state approval, and consequently funding of transportation projects. Figure 1 illustrates the 6 major activities involved in the transportation needs process.

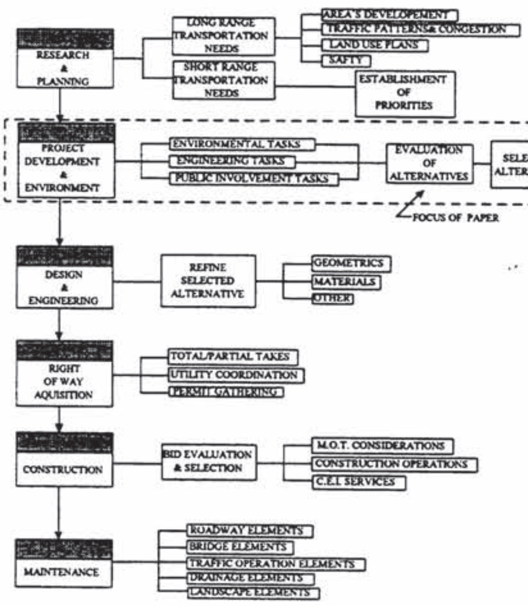

Fig. 1.Transportation needs process

The initial phase involves the identification of needs through both the long range planning element and the short range planning element; the long range element defines the policies and required improvements for the next 20 to 30 years, while the short term element identifies those projects most needed during the next 5 to 10 years. Within the short range phase, priorities are established for different projects based on various constraints such as immediate need, availability of funds, etc. Once a project has been selected and is funded, the so called PD&E phase begins. The PD&E phase is essentially comprised of three main types of activities: environmental, engineering and public involvement. Environmental activities include the preparation of various reports or documents dealing with the potential effect of the various alternatives under consideration on such issues as air and water quality, noise and vibration, threatened or endangered species, hazardous materials contamination impacts, etc. Engineering activities include the determination of the existing and future project traffic needs as well as gauging the effect of the alternatives on such issues as geometric and operational adequacy, access and safety impacts, multimodal features, etc. Public Involvement activities (such as public informational meetings, public hearings, etc.) insure that public officials, citizens and special interest groups are informed and involved in the development of the project. The development of an alternative evaluation methodology which combines the inputs from the three main types of activities is the focus of this paper.

There are five basic problem areas as it was mentioned in the previews section that are generally prevalent in the selection of transportation alternatives. Let us briefly described them:

a. Lack of clearly defined Goals and Objectives: Before attempting to solve any problem it is first necessary to understand the nature of the problem. The problem formulation process begins with the "needs statement" which basically portrays the difference between what is "wanted and what is available" (Cohen 1978). The ultimate goal is to eliminate or minimize the perceived need.

The lack of clear definition of goals and objectives might seem trivial at first, but it is a serious recurring problem that unnecessarily complicates the review and evaluation process.

b. Resolution of conflicting objectives: The evaluation of transportation alternatives is essentially a multi-objective problem. That makes clear that in order to ultimately choose the most preferred efficient alternative, a series of decisions involving conflicting objectives must be made.

c. Lack of Sensitivity Analysis: Since many decisions involved in the evaluation of transportation alternatives are subjective in nature, there is a substantial element of risk involved. A slight variation in the weight assignment of objectives/criteria or even in the assumed interest rate in economic analysis might result in a totally different recommended alternative. It is clear that the weight assigned to a particular criterion might depend entirely on the perspective of the evaluator. In order to reduce this inherent risk and to improve the quality of our decision-making abilities, a sensitivity analysis should be conducted. Unfortunately the use of sensitivity analysis is not prevalent at the PD&E stage; quite the contrary it is indeed rare.

d. Criteria Duplication: Another common problem is that of "duplication" in the evaluation of alternatives. "Duplication" is understood as the inclusion of related or non-independent variables in the evaluation criteria.

e. Lack of Alternative Segmentation: It is indeed rare to find a transportation alternative that is totally homogeneous in nature. Any urban corridor (or rural for that matter) is usually composed of a series of segments or sectors with widely different characteristics. These differing characteristics might entail distinct land uses, traffic patterns, environmental concerns, soil problems, geometric considerations, etc. It is thus clear that in order to select the "best" transportation alternative, the alternative must first be broken down into a series of homogeneous segments.

3.THE PROPOSED METHODOLOGY

To overcome the above stated deficiencies a new multicriteria decision making methodology is suggested. The proposed method is based on the Analytical Hierarchy Process (AHP) method (Saaty,1980). The AHP is a process of "systematic rationality ": it enables us to consider a problem as a whole and to study the simultaneous interaction of its components within a hierarchy" (Saaty,1980).

The AHP is based on three principles: 1) the principle of constructing hierarchies, 2) the principle of establishing priorities, and 3) the principle of logical consistency.

According to the method a complex decision making problem is decomposed hierarchically into its components. After the hierarchical decomposition of the problem has been completed, a matrix of pairwise comparisons, expressing the relative importance of the elements in a given level of the hierarchy with respect to the elements in the level immediately above it, is constructed, figure 2.

$$A = \begin{bmatrix} a_{11} & \cdots\cdots & a_{1k} & \cdots\cdots & a_{1n} \\ \cdot & & \cdot & & \cdot \\ a_{i1} & & a_{ik} & & a_{in} \\ \cdot & & \cdot & & \cdot \\ a_{n1} & \cdots\cdots & a_{nk} & \cdots\cdots & a_{nn} \end{bmatrix}$$

Fig. 2. Pairwise comparisons matrix.

The resulted pairwise comparisons matrix is positive and reciprocal (i.e., $a_{ij}>0$ and $a_{ij}=1/a_{ji}$). Finally the selection of the most preferred alternative is made based on the values of the priority vector of the lowest level of hierarchy.

One of the major advantages of AHP is the capability to identify errors in judgment and evaluate the consistency of the evaluators by calculating an index called *Consistency Ratio C.R.* The calculation of C.R. is described by the following equation:

$$C.R. = \frac{C.I}{R.I.}$$

equation 1

where:

$$C.I. = \frac{\lambda_{max} - n}{n - 1}$$

C.I. = consistency index
λ_{max}= maximum eigenvalue of matrix A
n= matrix dimension
R.I.= Random Index computed as follows: For each size of matrix n, random matrices were generated and their mean C.I. value called R.I. was computed

AHP has the ability to deal with multiple and conflicting objectives, to consider both objectively and subjectively measured criteria. In addition the proposed methodology has the ability to gauge the relative importance (weight) of individual responses in a non-homogeneous panel of judges.

The weight assignment to the response of each individual member of the panel is estimated on the basis of the following equation :

$$W_{i(k)} = K_A \frac{(1 - IR_{i(k)})}{\sum_{i=1}^{n}(1 - IR_{i(k)})} + K_B \frac{\sum_{c=1}^{n} SR_{i(c)k}}{\sum_{i=1}^{n}\sum_{c=1}^{n} SR_{i(c)k}} + K_C \frac{BR_i}{\sum_{i=1}^{n} BR_i}$$

equation 2

where:

$W_{i(k)}$ = resulting weight assigned to judge (i) in decision area (k).

K_A = empirically determined factor expressing the relative importance of the consistency element in the overall judgmental weight.

K_B = empirically determined factor indicative of the relative importance of the expressed judge knowledge (self rating) in the overall judgmental weight.

K_C = empirically determined factor indicative of the relative importance of the personal balance in the overall judgmental weight.

$IR_{i(k)}$ = inconsistency ratio of judge (i) in a particular decision area (k) determined through the application of the AHP technique.

$\sum SR_{i(c)k}$=sum of self ratings of judge (i) for all components (c) in a particular decision area k. Each self rating varies from a maximum of 5.0 for self proclaimed expert knowledge to 1 for minimal knowledge.

BR_i = personal balance ratio of judge (i). Personal

balance refers to the flexibility in using both rational and intuitive behavior in a complementary, rather than in a contrasting way.
Equation 2 states that the resulting relative weight assigned to a particular judge is dependent on his/her judgmental consistency, his/her self expressed knowledge of the topic in question as well as his/her personal balance when faced with strategic situations. The relative importance of these three elements in the overall weight determination is expressed through the use of three empirically determined factors ($K_A + K_B + K_C$). It is clear then, that since these three factors are expressing the relative importance of one versus each other, their sum must equal 1(equation 3).

$$K_A + K_B + K_C = 1$$

equation 3

A brief explanation of each of three main components in equation 2 follows:
a) Inconsistency: The AHP (Saaty, 1980) provides a way to estimate judgmental consistency, through the use of the inconsistency ratio IR. An inconsistency ratio of 0.10 or less is considered acceptable. The idea being that the validity of judgmental results can be improved through the reduction of the inconsistency ratio. It should be noted that even though the "consistency element" expressed in equation 2 is based on the initial inconsistency ratio obtained from the application of AHP, this in no way precludes the fact that additional chances could be given to the individual judges to further reduce their initially obtained inconsistencies. According to equation 2, the initial inconsistency ratio for a judge (i) in a particular decision element (k) will be subtracted from 1 and divided by the corresponding sum of the results obtained for all the judges in the panel (normalized).

b) Knowledge of the topic area: Another key factor in the determination of $W_{i(k)}$ involves the consideration of a judge's familiarity or knowledge concerning the topic in question. It is inherently clear that a person can be perfectly consistent in his/her judgments, but may lack enough knowledge about the topic to compromise the validity of his/her judgments. Substantial amount of previous research (Brown, Cochran and Dalkey, (1969, 1970)) indicates a clear relationship between group self-rating and accuracy.

Since the use of self-ratings has proven to be an effective way of measuring accuracy (even among non-homogeneous groups), it will be used as the second key element in equation 2. In order to obtain the self-rating element, questionnaires are distributed among the judges asking them to rate themselves regarding their knowledge of the topic in question. The use of a semantically anchored five point scale ranging from "minimal knowledge" = 1 to "expert knowledge" = 5 is proposed. Again in order to normalize the results, each individual self-rating is divided by the corresponding sum of the results obtained for all the judges in the panel.

c) Personal balance: A substantial amount of research has already been accomplished (Henderson and Nutt, 1980; Haley and Stampf, 1989; Mullen and Stumpf, 1987; Stumpf and Dunbar, 1991) indicating that individuals with different personality-type exhibit cognitive styles that are associated with specific biases in the pattern of choices they make. Moreover, the desirability of a balanced or flexible approach to managerial problems have been previously documented by Taggard and Valenzi (1990) and Simon (1987) among others.

Two potential "instruments" to measure the personality-types/personal balance of the individual judges composing the panel were investigated; the Myers-Briggs Type Indicator (MBTI) (Myers, 1962) and the Human Informational Processing (HIP) Metaphor (H.I.P.S.,Inc.1991). MBTI relies on Jung's personality-theory typology while the HIP Metaphor is based on neurophysiology. Quantitative interpretation of the MBTI scores is not recommended (Myers, 1962) since according to the authors they were designed to show the direction of a preference rather than its intensity.

On the other hand, the HIP metaphor approach does offer significant opportunities towards the development of a personal balance ratio. This is partly due to the fact that the HIP Survey is not structured in a restrictive forced-choice format (as is MBTI's) but rather it offers a choice between six distinct levels of usage (i.e. 1) never, 2) once in a while, 3) sometimes 4) quite often, 5) frequently if not always, 6) always). These adverbial anchors of frequency are much more indicative of an over or under reliance in a certain way of behaving and thus an effective measure of "personal balance".

d) As previously explained these three factors (K_A, K_B & K_C) are intended to express the relative importance of the consistency, knowledge and personal balance elements in the context of the overall judgmental weight. Are all three elements equally important, or is one more important than the other? A sensitivity analysis should be conducted varying the relative values of all factors to gauge the overall net effect. As an initial step to the "calibration" procedure, the judges themselves could be asked to rate the individual importance of the three elements. The median value of their results could be used as the initial value.

4.METHODOLOGICAL STEPS

Figure 3 illustrates the various steps required for the application of the proposed methodology.

A brief explanation of each step follows:

Step 1. Determination of Project Type and General Project Characteristics.

Step 2. Establishment of Hierarchical Breakdown of Phase I Goals and Objectives. One essential step in the alternative selection process entails the identification of the goals and objectives that the project strives to attain. The overall goal reflects the desired end state that is to be achieved. Since objectives are indicative of general and specific concerns, they should be structured in a hierarchical arrangement.

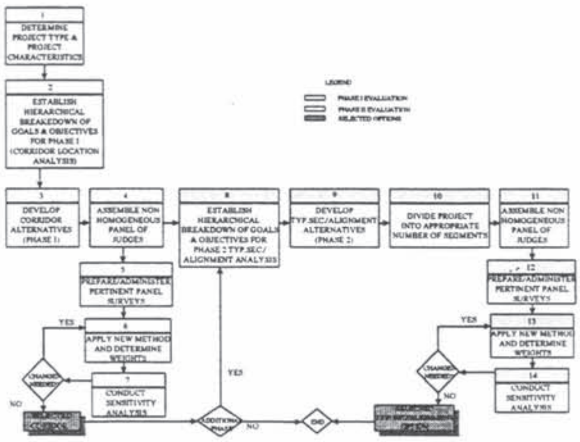

Fig. 3.The Proposed Methodological Framework

Step 3. Development of Corridor Alternatives (Phase I). The proper development of the corridor alternatives is an essential element in insuring that the best possible transportation option is ultimately chosen.

Step 4. Assemble Non-Homogeneous Panel of Judges (Phase I). This task entails the formation of the panel of judges or evaluators that will directly assign the relative importance to every element in our multi-objective decision.

Step 5. Prepare/Administer Pertinent Panel Surveys (Phase I). Since the members of the panel of judges normally have different backgrounds, degrees of expertise, judgmental abilities, etc., these differences must be gauged through the application of a series of surveys.

Step 6. Apply Proposed Method and Determine Weights (Phase I). For the completion of Phase I primarily is used the standard AHP procedures for weight assignment. In addition, it should be noted that even though only the initial value obtained for the inconsistency ratios are used in the computation of the "consistency element", this does not preclude the evaluator from changing the original values in order to improve his/her consistency.

Step 7. Conduct Sensitivity Analysis (Phase I). The use of sensitivity analysis is an essential ingredient in improving the quality of our decision making abilities. It is important that all decision makers become aware of the implications of potential variance in their judgmental inputs, and the resulting change in the overall results.

In order to determine how sensitive the changes in the judgmental factors are in the determination of the final outcome, Alexander's 'A' indicator will also be used. This indicator developed by Alexander & Beimborn (1987).

Step 8. Establishment of Hierarchical Breakdown of Phase II Goals and Objectives. As a result of the previous step, a recommended corridor has been chosen, so now we can concentrate our attention in the evaluation of various typical sections/alignment combinations. As was the case for the Phase I objectives, some items might not be pertinent for specific project and thus should be deleted. In addition, the potential inter-relationship between the various objectives should again be explored to avoid the inclusion of non-independent items in the evaluation process (Driggs, 1993).

The proposed evaluation methodology promotes the clear definition of goals and objectives by listing up to 147 different criteria normally encountered in transportation projects. The criteria duplication issue is addressed through the provision of useful guidelines intended to identify pairs of non independent criteria.

Step9. Develop Typical Section/Alignment Alternatives (Phase II). Preparation of general guidelines involved in the development of the typical section/alignment alternatives as long as more specific guidelines concerning lane, shoulder and other part of the roadway requirements.

Step 10. Divide Project into Appropriate Number of Segments. If the corridor that was selected during the Phase I evaluation exhibits distinct characteristics (e.g., traffic, land use) along its length, it must then be segmented to address the specific needs of each segment.

Step 11. Assemble Non-Homogeneous Panel of Judges (Phase II). This step is essentially identical to Step 4 except that it relates to the Phase II evaluation, rather than to Phase I. Ideally, the same panel members assembled in Step 4 would again participate in this task, thereby facilitating (due to their previous experience) the completion of all of the subsequent steps. However, since the entire participation of the previous panel members might not be possible due to time constraints, previous commitments, etc..

Step 12. Prepare/Administer Pertinent Panel Surveys (Phase II). If the selected panel member for this evaluation phase are the same ones than for the previous phase, only the completion of the self rating survey would be required. As previously stated, this survey would establish each individual's claimed self knowledge regarding each of the evaluation topics in question.

*Step 13.*Apply Proposed Method and Determine Weights (Phase II).

*Step 14.*Conduct Sensitivity Analysis (Phase II). Essentially this step is similar to Step 7 previously conducted for Phase I.

5.CONCLUDING REMARKS

The proposed methodology was applied to select the most preferred alternative for the construction of a major urban arterial street in Miami, Florida. The proposed project extends from N.W. 57th Avenue to N.W. 27th Avenue, an approximate distance of three miles. There were four alternatives corridors to be evaluated.

A panel of 18 professionals representing the Florida Department of Transportation and two private consulting firms involved in PD&E were used to evaluate the proposed alternatives.

The evaluation was performed in two phases. At the first Phase (Phase I) the most preferred alternative corridor was selected. An hierarchical breakdown of objectives in three levels was used for solving the evaluation problem at the first Phase.

At the first level four broad objectives were used. These were 1) Cost, 2) Regional/Local Transportation service, 3) Socio/Economics Impacts and 4) Environmental Impacts. As we get down to lower levels of hierarchy the number of objectives increases. Thus, at the second level 17 objectives were used, while at the third level the number of objectives became 48.

After the selection of the most preferred corridor (Phase I), the second Phase of the method proceeds with the selection of the most preferred section/alignment alternative. Like in Phase I, in Phase II an hierarchical breakdown of objectives was used. The second Phase hierarchical breakdown consists of four levels, i.e. the three levels used in Phase I, and a fourth level covering 38 criteria.

The application of the proposed methodology demonstrated that the method can provide essential decision support for analyzing complex decision making problems, and that the cooperation of the experts involved in the panel constitutes a necessary prerequisite for the success of the method.

REFERENCES

Alexander, E.R. and Beimborn, E.A, (1987). Sensitivity Analysis of Multiple-Choice Decision Methods for Transportation. *Transportation Research Record* **1124**, pp. 36-42.

Brown, B., Cohran,S., and Dalkey, N. (1969). The Delphi Method II: Structure of Experiments. *The Rand Corporation RM-5957-PR.*

Cheslow, M.D. (1980). Issues in the evaluation of metropolitan transportation alternatives: Transportation system analysis and planning. *Transportation Research Record*, **751**,1-8.

Cohen, H.S., Stowers, J.R., and Petersillia, M.P. (1978). Evaluation Urban Transportation System Alternatives Prepared for the U.S. Department of Transportation, Office of Assistant Secretary for Policy and International Affairs as Report #DOT-P-78-44. System Design Concepts, Inc. Washington D.C.

Driggs, R. (1994). A Multicriteria Decision Making Approach for Evaluating Alternative Transportation Plans, Ph.D. thesis, University of Miami.

Giuliano, G. (1985). A Multi-criteria Method for Transportation Investment Planning. *Transportation Research Record*, vol. **19-A**, No 1, pp.29-41.

Haley, U.C.V., and Stumpf, S.A.(1989). Cognitive Trails in Strategic Decision Making: Linking Theories of Personalities and Cognition. *Journal of Management Studies*, **26** (5), pp. 477-497.

Henderson, J.C., and Nutt, P.C. (1980). The Influence of Decision Style on Decision-Making Behavior. *Management Science*, Vol. **26**, pp. 371-386.

Human Information Processing Systems, Inc.(1991). *Management Style Inventory Survey*, H.I.P.S., Miami, Florida.

Mullen, T.P., and Stumpf, S.A.(1987). The Effect of Management. Styles on Strategic Planning. *Journal of Business Strategy*, vol. **7**, pp. 60-75.

Myers, I.B. (1962). The Myers-Briggs Type Indicator. *Consulting Psychologists Press*, Palo Alto, California.

Saaty, T.L. (1980). The Analytical Hierarchy Process: Planning Priority Setting, Resource Allocation. McGraw-Hill, N.Y.

Simon, H.A. (1987): Making Management Decisions: The Role of Intuition and Emotion, Academy of Management *Executive*, Vol. **1**, pp. 57-64.

Stumpf, S.A., and Dunbar, R.L.M.(1991). Effects of Personality Type on Choices Made in Strategic Decision Situations. *Decision Sciences*, Vol. **22**, pp. 1047-1072.

Taggart, W. and E. Valenzi, (1990). Assessing Rational and Intuitive Styles: A Human Information Processing Metaphor, *Journal of Management Studies*, Vol. **27**, pp.149-172.

Yukubowsky, R. (1980). Effective Cittizen Participation: Public Search for Democratic Efficiency. *Transportation Research Record* **742**, pp. 88-93