Final Report

Contract NAS1-14908, Task 9

TRANSPORTATION SYSTEMS EVALUATION METHODOLOGY DEVELOPMENT AND APPLICATIONS: PHASE III

Submitted to:

National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

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16. Abstract

A method is presented for use in evaluating new transportation systems or proposed changes in current systems. Four principal evaluation criteria are incorporated in the process: (1) Service Utilization, based on the operating performance characteristics as viewed by potential users; (2) Community Acceptance, reflecting decisions based on the perceived impacts of the system; (3) Technological Feasibility, estimating what is required to reduce the system to practice; (4) Financial Feasibility, predicting the ability of the concept to attract financial support. This report deals primarily with the first two criteria.

The method is based on a series of matrix multiplications in which the various matrices represent evaluations in a logical sequence of the various discrete steps in a management decision process. One or more new alternatives are compared with the current situation, and the result provides a numerical rating which determines the desirability of each alternative relative to the norm and to each other. The steps in the decision process are isolated so that contributions of each to the final result can be readily analyzed. The chief advantages of the method are its ability to protect against bias on the part of the evaluators and the fact that system parameters which are basically qualitative in nature can be easily included.

The method is described in detail and its use is illustrated by considering four different concepts for transatlantic air service.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. THE PROBLEM AND ITS ELEMENTS

A transportation system involves two major classes of components--the physical system and the human participants. The physical components include the vehicles, a place for loading and unloading the vehicles (terminal), and a set of paths over which the vehicle travels (way). The human involvement with this physical system occurs at several levels. The direct interactions are limited to the users and the operators. The users justify the existance of the system, while the operators supply the service, and, thus, must satisfy the interest of the users. In addition, there are several other groups of individuals who are vitally concerned with the system, and may have a major impact on its success, even though their relations to it are more indirect. These include: residents, whose community includes the system or parts of it; special interest groups, who are concerned with one or more aspects of the system; industries, who manufacture, supply and service the equipment and facilities; financial institutions, who provide funds required for implementation of the system; government regulators at all levels; and local, regional, and national officials who are confronted with the constituent needs which generate the impetus for the system, and who must often make decisions involving the committment of public support.

The success of a solution to a given transportation problem depends upon the decisions of all of these groups, each differing in their motivations, perceptions, and degree of involvement with regard to the system. The ultimate decision makers, contemplating a new or revised transportation system, must work in a setting in which the individual group decisions about any new concept are being made on the basis of a comparison with what currently exists. Furthermore, the transportation system will always be viewed in its entirety by these groups, i.e. as a total door-to-door system. Hence a failure in any part of the system can often cause the entire system to fail. In general, the ultimate decision should be made on the basis of a reliable set of quantitative information regarding four principal criteria which will form the basis for a final evaluation of probable success. The process is illustrated schematically in Figure 1.

The first criterion is that of the service utilization which might be anticipated. This is based on the acceptance of the operating performance characteristics as viewed by the potential users. The issues are how well does it meet basic needs, and how attractive is it in terms of such things as comfort, convenience, cost, dependability, etc.

The second criterion is that of community acceptance. This reflects group decisions based on the perceived impacts of each group in such areas as pollution, congestion, noise, energy consumption, land use, economic development, etc. It also reflects the relative power and influence of the diverse groups.

Next is the criterion of technological feasibility. Given a goal or set of specifications, can the system be built and operated? How long will it take? How much will it cost? Will it be worth the effort, or will alternative technological developments be likely to make this system obsolete in a relatively short time frame? These issues must be treated with the expert judgement of the scientists and engineers active in the appropriate research and development areas.

Finally, there is financial feasibility which depends upon the willingness of financial institutions to commit monetary resources to the system. How competitive will the system be in attracting capital investment? What benefits are likely as a result of the existance of the system? How much capital will be required? What form should the investment take? How well will it be protected by the potential for operating profit? Over what time period will the investment be required? These are judgements which must be made by the relevant community of financial experts.

As shown in Figure 1, each alternative concept must be evaluated relative to the existing situation according to these four criteria. It is interesting to note that the results for the first three criteria stand as independent evaluations. However, the financial feasibility is strongly dependent on the results of all the others. After the four criteria evaluations are obtained, they must be properly weighted as to their overall importance and then combined in reaching a final go or no-go decision. This is true for decisions in either the public or private sectors. These final weightings are heavily involved with local political factors or with corporate planning issues, and do not lend themselves readily to a universal approach. The individual criteria evaluations are fundamentally more general in nature with local issues being accomodated through the appropriate selection of the components and groups involved in each criterion.

Thus, it was the objective of the work reported herein to develop an appropriate set of methods and techniques to obtain reliable numerical outputs which characterize the four individual criteria evaluations in such a form that they are directly comparable by the ultimate decision maker. Actually, since the design, development and construction processes for implementing new transportation concepts is often long and expensive, the ultimate decision must be reached early in the process during the planning stage. This implies that the evaluations must be made on the basis of the probability of occurrence for a given result.

In selecting a method for determining reliable evaluations of the four individual decision criteria it is apparent that the following attributes are all important:

(1) Provide a framework for obtaining quantitative values for the criteria so that the relative degree of the improvement (positive or negative) of each proposed concept can be measured relative to the existing situation.

(2) Allow active participation of all groups of individuals involved in the system.

(3) Minimize time requirements imposed upon the participants.

(4) Properly weight the importance of the various interactions.

(5) Protect against bias of the evaluators.

(6) Perform all mathematical manipulations easily.

(7) Provide capability for quick response in sensitivity analysis.

Perhaps the one item in this list having the most fundamental significance is #(5). It is absolutely vital that the final decision makers have opinions which are objective and free from bias of all kinds. The bias, or preconception, problem is a major issue with regard to the first two evaluation criteria, viz. user and community acceptance. It is important to use a technique which will allow the evaluations to be made without requiring that the participants relate their impressions, values, and judgements to specific systems or concepts. On the other hand it is necessary that the final decision involves a firm understanding of the possible diversity of opinions held by the participating groups regarding broadly stated issues, motivations, or matters of policy.

To achieve the objective of absence of bias in meeting the last two criteria, viz. technical and financial feasibility, may be much more difficult. It seems probable that a judgement on these matters cannot be obtained without exposing the evaluators to specific systems or concepts. However, in making these evaluations these individuals will be acting in a professional capacity and hence should be expected to be relatively objective and much less emotional than those involved in user and community acceptance. This should provide protection against bias, at least to the first order.

Many researchers have worked on the development of methodologies for decision analysis, and the literature is quite voluminous. Approaches to the problem vary from reasonable simplicity to extreme complexity. It has certainly never been established that the benefit to be derived bears any relationship to the complexity of the method used. Several years ago the authors became interested in an evaluation technique which may be called descriptively the Matrix Multiplication Method. It has the enviable property of being at the simplistic end of the methodological hierarchy, yet it appears to meet all of the seven attributes mentioned above. In addition it has two properties which should be of inherent value as well as of great convenience to the user.

First of all, the quantitative measures obtained from participating groups are produced directly by those groups and are not based upon a variety of interpretations by an analysis team, as is the case in many techniques. This is a very important point and represents another safeguard against bias, this time on the part of the analysts, thus improving the potential for the accuracy of the result.

Secondly, the technique as modified and extended for this work does not require that the participating groups have any direct knowledge of the specific systems under consideration. Instead, they are asked to provide quantitative measures for standard sets of interactions between lists of descriptors and the transportation activities involved in a large class of door to door transportation experiences. Then they are asked to place an importance value on each descriptor. Thus, once these matrices are developed and become stable, the system designer can proceed to evaluate system modifications and even new concepts for that class of systems without need for further interactions with the participating groups. This makes the method both a powerful and relatively inexpensive tool for the evaluation of transportation system concepts.

Because of these interesting characteristics, the Matrix Multiplication Method was adopted as the best way to provide assistance to the decision maker involved with assessing the potential of new transportation systems. This required many extensions and advances in the basic concepts. The method as developed is described in more detail in the next section. This is followed by a section which discusses some of the key elements and issues of the method. Finally, section IV illustrates the method by a simple application to transatlantic air travel. Since the overall research program was motivated by the desire to evaluate new concepts in air travel, the terminology relative to this field is used throughout. However, method is equally applicable to any mode.

The work reported herein has emphasized the first two tracks of Figure 1, i.e. Service Utilization and Community Acceptance. Although considerable thought has gone into tracks 3 and 4, and many observations and suggestions have been made concerning them throughout this report, it has not been possible within the bounds set by the resources available to the project to reduce them to practice. Furthermore, in Section II, in the interest of brevity the general method is illustrated for the Service Utilization track only, and the application in Secion IV is limited similarly.

II. GENERAL DESCRIPTION OF THE MATRIX MULTIPLICATION METHOD

System Activities

The initial steps in developing a model to aid decision making for transportation systems is to identify all of the components which must be represented in the model. To begin with, door-to-door travel can be thought of as a series of discrete activities, i.e. the specific things that the user does while making use of the system. This is illustrated schematically in Figure 2. For some particular types of trips not all stages are necessarily involved. For other types there may be duplication of individual activities. For example, the trunk sub-system may involve two stages with a transfer at a terminal interposed.

Each of the activities in Figure 2 may be examined in as much detail as desired. For example, one specific type of airport access may be thought of as consisting of the following activities:

(1) Make arrangements for the access (pre-trip planning)
(2) Leave point of origin
(3) Take vehicle (taxi, bus, private car) to limousine terminal
(4) Board limousine
(5) Limousine trip from terminal to airport
(6) Egress from limousine at the airport

The flow of activities in this example is quite similar to that shown in Figure 2. On the other hand a more detailed analysis of the aircraft flight, either connecting or trunk, might be structured as follows:

(1) Taxi to the runway
(2) Take-off
(3) Climb to altitude
(4) Cruise
(5) Descent and hold
(6) Final approach
(7) Landing
(8) Taxi to gate

Thus, in using the model, a set of activities must be formulated appropriate to the analysis being made.

Descriptors

The next component for the modeling process is a set of descriptors which will be used to characterize the activities. These are the success criteria depicted in Figure 1. For the service utilization evaluation they are called parameters. These are the characteristics or attributes of the transportation system which represent the impressions a person has of the system, obtained either indirectly or through experience with the use of the system. System impacts are the descriptors applicable to community acceptance. These represent the areas in which a transportation system could interact with the society and the environment in which it operates. Technological feasibility is evaluated on the basis of considering the research and development problem areas involved. Thus, these descriptors represent a reasonably standard set of R & D categories applicable in this case to air transport. Finally, the decision of the financial community for or against providing the financial resources required for the endeavor will be based on the attractiveness features of the investment opportunity.

A typical list of these four sets of descriptors which has been found to be useful in evaluating air transportation systems is shown in Table 1. These listings are general in nature and serve as guides to the analyst, who then has the responsibility for developing the set most appropriate to the particular situation under study.

Evaluator Groups

The next step is the selection of the groups of individuals who are to be used to make the judgements which are required for the evaluations. The key points in obtaining a useful opinion for the evaluation of a transportation system lie in utilizing persons who have a genuine need or concern in the area for which they are selected, and in grouping them properly according to their motivations. Individuals should not be involved in evaluating issues toward which they have no basic motivation. For example, the users of a transportation system are motivated by the need to transport something, and in selecting a particular concept to use they are motivated by the attractiveness of the options offered by the competing systems in meeting their needs. Operators, on the other hand, are motivated by the desire to make a profit or to perform a public service as the case may be. If both of these groups were asked to evaluate the importance of performance characteristics, then the results would not necessarily be expected to be similar--nor, in fact, should their quantitative judgements be averaged without appropriate weightings supplied by the analyst or decision maker. A similar difference in motivations would arise in community acceptance between a group of civic business leaders and a group of active environmentalists.

In forming interest groups it may be desirable or necessary to address the problem at more than one level in a hierarchy. Again using the service utilization track as an example, the three principal user subgroups by motivation would be those whose trips were employer funded, those traveling on personal business, and those traveling for pleasure. However, under each of these it might be advantageous to further subdivide by sex, age, education level, etc.

A listing of the principal user groups at the first level in the hierarchy is shown in Table 2.

Concepts

Finally, that which is being evaluated must be considered as a major system component. The matrix multiplication model is so structured that it compares any number of new concepts with a norm. In most cases the norm can be a description of what is currently available, but if a rare situation arises for which no service of any kind exists, then a norm can be constructed on the basis of analogies with other areas, or on the basis of any logic which the analyst can justify.

The new concepts can be entirely new approaches to meeting the need, or alterations of one form or another in the current service. By designing the model to compare these new concepts with the norm, allowance is made for the fact that the proposed changes can be either better or worse than what now exists.

Engineering Analysis

The general structure of the matrix multiplication method as applied to any of the four group evaluations is described schematically in Figures 3 and 4. The starting point is an engineering analysis of each new concept, performed by the study analysis team. This takes each descriptor, one at a time, and produces an engineering estimate of the change in that descriptor relative to the norm for every activity in each of the new concepts under consideration. Thus, there is a concept/activity engineering design matrix for each descriptor, k, such than an entry in the matrix, R_{ijk}, measures the extent to which there is a change in the activity, j, due to concept, i, when evaluated from the perspective of descriptor, k.

The actual entries can be either numerical or short statement of fact, whichever is most appropriate in describing the level or state of the descriptor. For example, the descriptor time for the performance of the airport access activity in each concept can be estimated in minutes; however, it may be necessary to describe amenities by such statements as "none," or "beverage service provided," or "background music supplied," etc. Whenever possible an attempt should be made to express the design specifications in numerical terms, as these are the easiest to handle in succeeding steps.

Transformation to Subjective Judgements

At this point the evaluators must be introduced into the process. The need is to transform the impersonal engineering design estimates of changes in the descriptors into an interpretation of the significance of these changes by individuals properly motivated toward each decision criterion. This is especially important in the service utilization and community acceptance tracks. As indicated earlier, in the technical and financial feasibility tracks the work will be done by professionals and the transforms to subjective judgements may not be necessary. In these cases, if this step is omitted then the professionals should be given the scenarios for all the concepts involved and they should construct a set of numerical entries for the concept/activity matrix which reflects their best collective judgements.

Returning to the first two tracks of Figure 1, the need for this transformation is fundamental and addresses the appraisals which are made by the evaluators in reaching their ultimate decisions. For example, in the service utilization track, does a reduction of $x in cost have as much significance as an increase of y minutes of required time for the trip? Another point is that the value of a certain amount of increase or decrease in a descriptor is judged relative to the level of the descriptor to which the change applies. Hence a savings of $20 might be judged very important if the original cost was $40, whereas it would not be nearly as significant if the original cost had been $200.

A typical transformation function is shown in Figure 5. This is for the case of the cost of a long distance air trip. The ordinate is a numerical scale of 1 to 20. The abscissa, which represents the descriptor under study, is located at the ordinate value of 10. The cost of the norm concept is plotted on the abscissa as a constrained point through which all value curves must pass (in this case a value of $400). The evaluators then consider other abscissa points. For those values less than \$400 they assign an ordinate choice between 10 and 20 signifying their impression of how much improvement in cost has been made. Conversely, for cost values greater than \$400, an ordinate less than ten will be assigned. Thus, in general for all descriptors an assigned value greater than 10 signifies an improvement in the physical performance of that descriptor, and a value less than 10, a degredation in the opinion of the evaluator.

Figure 5 also illustrates the fact that the values obtained will depend upon the motivation of the evaluators. As can be seen, cost is much less important to the business (employer funded) traveler than to the other two groups. The shape of the curves will vary as the location of the norm value shifts on the abscissa. The curves must be generated by direct interactions between the analysis team and the evaluator groups. The questions presented to these groups do not mention the particular concepts involved but simply request a judgement on the basis of a scale from 10-20 of the value of an x% decrease in cost of a trip originally costing y dollars. This is repeated through ranges of combinations of x and y. A similar procedure applies to increases in cost where the scale is now 1-10. The curves represent the averages obtained from all evaluators in a particular sub-group.

When this transformation process is applied to the engineering design matrices for the service utilization track the result is shown in Figure 6. There are now three sets of concept/activity matrices, one set for each motivational group, l, of evaluators, where the entries, $(R_{ijk})_l$, are now numerical values on the scale of 1-20, rather than statements of engineering specifications.

Activity/Descriptor Matrix

Returning now to Figure 4, the next input required for the process is a measure of the extent to which each group of evaluators judges each descriptor to be involved with each activity relative to the total trip. A typical question put to the evaluator in the service utilization track would be: In a door-to-door trip by air of 500 miles how much of the total trip time (parameter) is normally consumed in airport access (activity)? This approach is repeated for each activity in combination with all parameters. In obtaining these values, it may be necessary to sometimes define the question in more detail, e.g. trip originates in a large city and ends in a large city. However, it should never be necessary to disclose the scenario by which the activity takes place. The result of this exercise with the evaluators will be a single matrix of activity/descriptor for each group of evaluators used. The entries in each matrix, $(K_{jk})_l$, represents a numerical evaluation of the contribution of activity, j, to the overall value of descriptor, k, for the overall trip, as judged by group, l.

Again, the evaluators should be the groups selected as being appropriate to the particular decision criterion involved. Continuing the previous example of service utilization of air transportation, the groups would be the same as used for the transformation functions, i.e. business, personal business, and pleasure. In scoring the matrix elements the evaluators are asked to distribute a certain number of points for each parameter, usually 10 or some multiple thereof, among all the activities so as to reflect the relative contribution of that activity to the total value of that parameter for the entire trip. This rule assures that no parameter will receive a scoring bias over any other, thus providing numerical significance to the relative values of the products of matrices as they are taken.

The First Matrix Multiplication

At this point the first matrix multiplication takes place. It is performed independently by each group, and for each group the concept/activity matrix is multiplied by the activity/descriptor matrix according to the multiplication rule:

$$(R^*_{ik})_l = (R_{ijk})_l \times (K_{jm})_l \times \delta_{km}$$

where

δ_{km} = 0, if k $\neq$ m, and = 1, if k = m. (the Kronecker Delta Function). The product $(R^*_{ik})_l$ represents the contribution of concept, i, to the improvement in descriptor, k, for the overall door-to-door trip as viewed by the evaluator group, l.

The process is illustrated in Figure 7 for the service utilization track.

The Descriptor/Group Matrix

The next step is to obtain another input. As shown in Figure 4, what is required this time is a judgement by each group of evaluators as to the relative importance of each descriptor to them in reaching their decisions concerning the particular issue at stake in the track under consideration. Again, the evaluators are asked to distribute a certain number of points (e.g., 10) among the various descriptors. The matrix can be written as:

V_{kl} -- the value of the descriptor, k, to group, l.

The Second Matrix Multiplication

This multiplication is illustrated in Figure 8 for the service utilizaton track. It takes place according to the multiplication rule:

$$I_{il} = R^*_{ikl} \times V_{kp} \times \delta_{lp}$$

where again δ_{lp} is the Kronecker Delta Function

$$\delta_{lp} = 0, \text{ if } p \neq 1, \text{ and } = 1, \text{ if } p = 1.$$

In general each element of the product matrix, I_{il}, represents the capability of concept, i, for achieving the objectives of the particular track being evaluated as viewed by each group of evaluators used. For example, in the service utilization track I_{il} would represent the capability of concept, i, for improving the attractiveness of the system to the user group, l. Actually, the numerical value for concept, i, should be compared with that for the norm concept to see if concept, i, represents an improvement or is less attractive than the norm. Similarly, in the technological feasibility track I_{il} would be the degree of ease in solving the technological problems in the opinion of expert group, l.

In a sense this second product is one of the key results of the analysis. The decision makers now have a measure of how each group of evaluators views the various concepts. In many cases decisions can be made on the basis of the information contained in this matrix. However, the process can be taken formally a step further as shown below.

The Group/Rank Matrix

This is a single column matrix to be scored by the decision makers and their advisors. It ranks the importance of the judgements of each of the groups in reaching the final decision. Again, to preserve the numerical relationships between the values obtained in the products, a fixed number of points should be distributed among the groups. The entry selected should represent a consensus opinion reached by the decision team in discussion. Each element may be denoted as W_l. It is interesting to note that in the case of the service utilization track, this estimate is essentially one of market share.

The Third Matrix Multiplication

This produces a final Figure of Merit, F_i, for each concept for each evaluation track according to the rule:

$$F_i = I_{il} \times W_l$$

The decision makers now have an overall appreciation of the ability of each concept to achieve the objectives of each particular track, based upon the value judgements rendered by each group most concerned with the issues in that track, and upon the opinion of the decision makers of the relative importance of these group value judgements. In summary, the extent to which each concept might be expected to improve patronage over the current concept will be shown; the concept which is most acceptable to the community will be identified; and the potential for successful reduction to practice and for implementation of each concept will be estimated. This last multiplication is illustrated in Figure 9.

It remains to combine these results into a final decision. This could be handled formally in another matrix multiplication in which the decision makers prepare a single column matrix expressing the importance of each track to the final decision. However, it is felt that at this stage such an approach might be an oversimplification. The issues involved here contain many political and institutional factors which are difficult to combine formally, and so the decision probably would be best made on the basis of the general consensus of those responsible.

III. COMMENTS CONCERNING THE MATRIX MULTIPLICATION METHOD

General Advantages and Disadvantages

The matrix approach to solving transportation systems problems has several advantages and some drawbacks. The purpose of this section is to discuss the value of these advantages, and apprise the potential user of the drawbacks. In comparing the various techniques available for evaluating the relative strengths of new concepts, the liteature can generally be classified into three major methods. These methods are: pure economic models, cost-benefit models, and ranking/weighting models. The matrix method falls into the latter category. The two major strengths of the matrix method are the major weaknesses of all the others. First, it is the only method that is capable of accounting for parameters of the system which are basically qualitative in nature (e.g., safety, convenience, etc.). Both economic and cost-benefit models require a monetary evaluation for all items being considered in a new concept. It is easily shown that many parameters associated with transportation concepts cannot be quantified in monetary terms with any reliability. The matrix method gives us a way to incorporate these values.

The second major strength is the ability to protect against bias on the part of the evaluators. In most other methods the bias of the analyst comes through because of the inherent approach. It can be seen that with the method proposed here the bias of the analyst is removed by using different groups for different functions. The technologist is only asked to evaluate the system from an engineering perspective. User groups and interest groups of various kinds are only asked for perceptions that they are qualified to judge. The decision makers are only asked the importance of various factors in their decision process. Except for the technologists and the analyst performing the evaluation, no one needs to know the identity of the specific systems under consideration.

We believe that this method is far superior from the standpoint of eleiminating bias.

An additional benefit derived from the use of the matrix method is the ability to gain information at intermediate steps in the analysis process. It is possible, with the proper construction of the method, to obtain information on various parameters and activities as a subset of the entire concept. In this way one can isolate a particular problem area rather than judge the whole concept. In addition, the perceptions of various groups can be isolated in order to examine their likes and dislikes.

Last, but certainly not least, is the ability to incorporate many groups in the decision process when using this method. It is through this mechanism of multi-group participation that one can hope to identify early in the design process potential problem areas that may be overlooked by any one specialty group. The use of three tracks of evaluation, the user track, the impact track, and the financial track further opens the problem to many groups.

One of the major concerns in a matrix technique is that the final results do not represent an interval scale. That is, the relative magnitudes of the final rankings do not imply percentage change, but rather only a relative position. Two concepts whose relative magnitudes in the final analysis are 100 and 200 are not necessarily twice (or half) as good as the other. However, it is clear that the concept with the superior rating is the best concept.

Another concern is the manner in which numbers are combined. The current approach is to use a simple matrix multiplication to arrive at the final values. This approach has some intuitive value attached to it. However, the process is by no means limited to this approach. Weighted multiplication is also possible giving each row and each column a different weighting factor dependent on the psychological mechanism with which humans combine the information.

At the present time there seems to be no compelling reason to go to anything more complicated than what is being used.

A large amount of data is required to form the value judgement curves and group ratings of the importance of parameters. However, it should be emphasized that new data are not necessarily required each time the process is used. This is because of the unique property which does not require knowledge of the concepts by these groups. A given set of data can be obtained for each class of trip and this will remain valid over a period of time dependent only on the general change in world or national conditions or in human values and standards. The stability of the data set can be checked every two or three years with a relatively small sample. The trip classifications to which a data set should be applicable are very broad. They need to define only the type of city in which the trip originates (large, medium, or small), and the trip distance interval (>2000 miles, 1000-2000 miles, 500-1000 miles, <500 miles) together with any specific defining features such as transoceanic, special season, regularly scheduled service vs. charter, etc.

Special Features

The method has several special features which can be adapted to meet the needs of the analyst. First, if preferred, it can be applied using a probabalistic approach. That is to say that each entry in the value matrices can be expressed as a distribution of the probabilities for finding that entry to be a particular number relative to the NORM. Whether or not such an approach is required depends upon the spread in the data obtained when surveying the participating groups. Our experience to date has indicated that in most instances the use of an average of the responses is adequate.

The computations involved are all straightforward, albeit cumbersome, particularly if distribution functions are used. However, they are easily handled by computer with a minimal effort in programming required since most of the steps can be made standard. The ease with which the process can be adapted to computers also makes it relatively simple to analyze the impacts of the various steps involved in producing the final result. In other words, programs for conducting sensitivity analyses at each step throughout the process are not difficult to write.

Along a similar line, the analyst can employ the method in a simulation mode to expore the effect on the final results which might occur as value structures change with time. Global-type scenarios can be prepared which reflect changing consumer attitudes, economic or political conditions, etc., and modifications to the value matrices postulated as possible responses to these changing conditions. Repeated calculations will then indicate the overall implications of these changes. It should be noted that no direct contact with the evaluation groups is necessary for this kind of planning exercise.

Analytical Representation

It is interesting to note that the entire evaluation procedure can be handled analytically should this approach be preferred. An analytical expression which can be operated upon in accordance with the normal principles of calculus can often provide quick insights into the effects of changes in any of the variables. This is an important and useful tool. An analytical approach also provides an advantage in being able to easily display results graphically for enhanced perception. Unfortunately, in the present case the general problem is multidimensional with more than three dimensions. Thus it is difficult to present visual representations of maximal or minimal solutions in general. However, this type of display is possible if the problem is partitioned in various ways so that changes in only one or two variables are considered at a time. By repeating this process for various combinations of variables a good representation of the relationships between the variables and their effects on the final results can be obtained.

The analytical expression for the process can be developed as follows. The first term represents the elements of the Concept-Activity matrices. There are one group of these, one for each trip purpose. Each group contains a complete set of k matrices, each matrix representing the scoring relative to one of the k parameters. Thus, this term is written as:

$$S_{ijkl} \tag{1}$$

where: S = value of the subjective user judgement of the extent to which the concept i improves the activity j relative to the parameter k as compared with the NORM

i = index for concepts

j = index for activities

k = index for parameters

l = index for trip purpose.

The second term required represents the elements of the Activity-Parameter matrices. There could be one such matrix for each group, 1, if so desired, or a single matrix could be used for all groups. The term is written as:

$$A_{jn} \tag{2}$$

where: A = relative contribution of activity j to the total value of parameter n for the entire trip

j = index for activities

n = index for parameters.

The next step is to form the product of S and A. This multiplication involves combining the extent to which each concept improves each activity with the contribution which that activity makes to a given parameter, and then summing such terms over all activities for that parameter. The procedure is then repeated for each parameter. The product must be taken in such a way that physical integrity is assured; i.e. it does not make sense to multiply the improvement concept 1 makes to activity 1 with regard to parameter 1 by the relative contribution of activity 1 to, say, parameter 3 or 4; it only makes physical sense if the relative contribution of activity 1 to parameter 1 is used. The proper multiplicative rule is assured by inserting the Kronecker Delta Function in the process.

Forming the first multiplication process from (1), (2), and the Kronecker Delta Function, the following expression is obtained:

$$C_{inl} = \sum_{j=1}^{N_a} S_{ijkl} A_{jn} \delta_{kn} \tag{3}$$

where: C = improvement in parameter n due to concept i from the perspective of trip purpose 1

δ = Kronecker Delta Function
= 1, if k = n
= 0, if k ≠ n

i = index for concepts

j = index for activities

k = provisional index for parameters

n = index for parameters

l = index for trip purpose

N_a = number of activities defined for the system.

There are now 1 groups of the C_{in} matrix, and the specific activities are no longer explicitly involved in the final matrices of the evaluation process.

A typical element, e.g. C_{111}, in the matrix for trip purpose 1 is written as

$$C_{111} = S_{1111}A_{11} + S_{1211}A_{21} + S_{1311}A_{31} + \dots + S_{1N_a11}A_{N_a1}$$

The next step is to define a matrix, the elements of which represent the value placed upon each parameter n by each of the trip purpose groups in making their decisions regarding how to make a trip. This Parameter-Group matrix is written as:

$$I_{nm} \tag{4}$$

where: I = importance of parameter n to group m when making a decision about how to implement a planned trip

n = index for parameters

m = index for groups.

The process is now ready for the second multiplication which combines the improvement in each parameter brought about by each concept with the importance of each parameter in the decision process. The resulting equation must again preserve physical integrity by combining only those terms pertaining to the same group, and so the use of the Kronecker Delta Function is again necessary. The expression is:

$$P_{il} = \sum_{n=1}^{N_p} C_{iml} I_{nm} \delta_{lm} \tag{5}$$

where: P = overall value of concept i relative to the NORM as viewed by group l

δ = Kronecker Delta Function
= 1, if l = m
= 0, if l ≠ m

i = index for concepts

l = index for trip purpose groups

n = index for parameters

m = provisional index for trip purpose groups

N_p = number of parameters defined for the system

A typical element in the P matrix is:

$$P_{11} = C_{111}I_{11} + C_{121}I_{21} + C_{131}I_{31} + \dots + C_{1N_p1}I_{N_p1}$$

Equation (5) is a derived equation which can be written in its basic terms by substituting for C_{inl} from equation (3).

$$P_{il} = \sum_{n=1}^{N_p} \sum_{j=1}^{N_a} S_{ijkl} A_{jn} I_{nm} \delta_{kn} \delta_{lm} \qquad (6)$$

In this representation, the typical element P_{11} can be written as

$$P_{11} = S_{1111}A_{11}I_{11} + S_{1211}A_{21}I_{11} + S_{1311}A_{31}I_{11} + \cdots + S_{1N_a11}A_{N_a1}I_{11}$$

$$+ S_{1121}A_{12}I_{21} + S_{1221}A_{22}I_{21} + \cdots + S_{1N_a21}A_{N_a2}I_{21} + \cdots$$

The next step is to define a matrix which records the estimates of various market analysts as to the market share represented by each of the trip purpose groups. This is expressed as:

$$M_{lq} \qquad (7)$$

where: M = market share of trip purpose group as estimated by forecaster type q

l = index for trip purpose group

q = index for market analyst type.

This leads to the next multiplication in the sequence which yields:

$$O_{iq} = \sum_{l=1}^{N_g} P_{il} M_{lq} \qquad (8)$$

where O = market value of concept i as expressed by market analyst type q

i = index for concepts

q = index for market analyst type

l = index for trip purpose groups

N_g = number of trip purpose groups.

Equation (8) can be combined with equation (6) to yield:

$$O_{iq} = \sum_{l=1}^{N_g} \sum_{n=1}^{N_p} \sum_{j=1}^{N_a} S_{ijkl} A_{jn} I_{nm} M_{lq} \delta_{kn} \delta_{ln} \qquad (9)$$

where all symbols have been previously defined.

In essence, both equations (6) and (9) represent two forms of an evaluation of the competing concepts which represent very useful information to the systems analyst. Usually a final decision can be made after a careful study of these matrices. However, the formal process can be taken one step further by having the system analyst (or analysis team) form a weight vector which places a value on the relative opinions of the market forecasts. This vector is denoted as W_q.

A final multiplication is now possible which yields a concept ranking vector, F_i, given by:

$$F_i = \sum_{q=1}^{N_m} O_{iq} W_q \qquad (10)$$

where: F = final relative rank of concept i

i = index for concepts

q = index for market analysis types

N_m = number of market analysts involved.

The final analytical expression is obtained by combining (10) with (9).

$$F_i = \sum_{q=1}^{N_m} \sum_{l=1}^{N_g} \sum_{n=1}^{N_p} \sum_{j=1}^{N_a} S_{ijkl} A_{jn} I_{nm} M_{lq} W_q \delta_{kn} \delta_{lm} \qquad (11)$$

Concept ranking vector

Importance of opinions vector

Market share opinions matrix

Importance of parameters by trip purpose matrix

Extent to which each activity contributes to overall value of parameter matrix

Improvement of activity by concept relative to parameter as viewed by trip purpose - sets of matrices

An expression for the change in the Concept Ranking vector can be written as:

$$\Delta F_i = \sum_q \sum_l \sum_n \sum_j \{(\Delta S_{ijkl})A_{jn}I_{nm}M_{lq}W_q\delta_{kn}\delta_{lm} + S_{ijkl}(\Delta A_{jn})$$

$$\times I_{nm}M_{lq}W_q\delta_{kn}\delta_{lm} + S_{ijkl}A_{jn}(\Delta I_{nm})M_{lq}W_q\delta_{kn}\delta_{lm}$$

$$+ S_{ijkl}A_{jn}I_{nm}(\Delta M_{lq})W_q\delta_{kn}\delta_{lm} + S_{ijkl}A_{jn}I_{nm}M_{lq}(\Delta W_q)\delta_{kn}\delta_{lm}\}$$

Hence, the effect on the final ranking caused by a change in any one term can be obtained by a partial process in which all other factors are held constant. For example, a change in F due to a change in ranking the importance of parameters is:

$$\Delta F_i = \sum_q \sum_l \sum_n \sum_j S_{ijkl}A_{jn}(\Delta I_{nm})M_{lq}W_q\delta_{kn}\delta_{lm}$$

Typical Matrix Multiplication Detail

To aid the reader interested in using the matrix multiplication method for the analysis of a system, Appendix A has been included to illustrate the details of the process. In this exercise both the user evaluation and the sytem input tracks are considered. In order to maintain as much simplicity as possible without sacrificing the purpose of illustrating the details of composition of each term, specific activities and parameters have been selected to keep the matrix size at a maximum of 3 x 3. Also, only a single user group is considered. These simplifications should not detract from the purpose of the illustration.

IV. APLICATION OF THE MATRIX MULTIPLICATION METHOD--AN EXAMPLE

In order to illustrate the use of the Matrix Multiplication Method to evaluate air transportation system options, a problem in comparing four different New York to London transatlantic services was analyzed. The selection of this particular problem seemed appropriate since three existing services offer quite different features both in equipment and service characteristics. To this was added a fourth service based on a new concept not yet operational which offered changes in several of the variables. A standard 747 service, as exemplified by a regular Pan Am flight, was selected as the norm. The other two existing services were the British Airways Concorde and the Laker Skytrain. The future service was based on the current planning for a U.S. supersonic transport which is referred to as the SCAR concept. While this concept is hypothetical at this time, its general design features are known.

The exercise begins with a description of the four operating scenarios from which the data must be extracted to provide a basis for estimating the numerical values which go in each cell of the concept-activity and activity-parameter matrices. The scenarios are based on data available in mid 1979. Several features of all of the services have changed since that time, but the earlier data were preferred for the example since they gave values which emphasized the unique features of each new service as it was introduced.

Each step in the evaluation process will be described as it takes place. The computations were done on a computer, and whenever appropriate the actual computer printouts are used to illustrate the process. In order to simplify the presentation all activities were grouped into two types:

(a) the flight portion of the trip (designated: air);

(b) the non-flight portion of the trip (designated: non-air).

Step 1. Scenario Descriptions

These are presented separately for the air and non-air portions of the trip.

A. Air Trip

Concept 1. NORM: Pan American

Pan American World Airways uses two versions of the Boeing 747 for its New York to London Service. The regular 747 can carry 30 passengers first class and 375 coach; the 747 SP will accomodate 42 first class passengers and 222 coach. First class passengers may request sleeperettes. Both versions of the 747 are four engine jets with a pressurized cabin. Coach seating is eleven abreast (3/5/3) with two aisles. There are two lounges. First class seating has two seats on each side of a wide aisle. Flight time is about 6 hours and 40 minutes from New York to London, and about 7 hours and 35 minutes from London to New York. The aircraft cruise speed is 625 miles per hour.

Pan Am has three flights a day from New York to London, leaving at 1000, 1900 and 2030. Arrival times in London are 2140, 640 and 830 respectively. The latter two flights are overnight flights, arriving in London the next day. On all Pan Am flights both a dinner and breakfast are served. Fares are $865 one way for first class and $312 one way for low season coach. Peak season coach fare is $369 one way. Various economy or budget fares are also available, subject to sufficiently advanced booking and stays of specified durations. A daylight standby fare is also available at $160 one way during the peak season and $149 off-peak.

There are also three flights from London to New York each day with departures from London at 1100, 1330 and 1800. The corresponding New York arrivals are 1335, 1605, and 2035--all on the same day.

Concept 2. British Airways Concorde

British Airways flies the Concorde supersonic transport two round trips daily between New York and London. The Concorde travels at a cruise speed of 1350 miles per hour in the supersonic mode at an altitude of 52,000 to 60,000 feet. Cabin pressure is maintained at the equivalent of 5,500 feet, and there is no variation during the flight. Seating is four abreast with one aisle. There are 100 seats and all are first class. Fare is $944 one way.

Departures for London are at 1015 and 1215 with arrivals at 1900 and 2100. Return flights leave London at 930 and 1115 and arrive in New York at 829 and 1014 respectively. The main portions of all flights occur in daylight and arrive on the same day local time as departure. Actual fight time is about 3½ hours.

The Concorde underwent over 5000 hours of test and endurance flying prior to going into commercial service. It is billed as the safest jet ever built, and is clearly the most thoroughly tested one.

Concept 3. The Laker Skytrain

Laker Airways Skytrain service flies twice daily in each direction between New York's Kennedy Airport and London's Gatwick Airport. Flights leave New York at 2000 and 2355, arriving in London at 745 and 1140 the next morning. The return flights leave Gatwick at 1415 and 1830 and arrive at JFK at 1700 and 2115 the same day. The New York to London flight requires 6 hours and 45 minutes, while London-New York requires 7 hours and 45 minutes. The aircraft cruise speed is about 600 mph. Laker uses the McDonnell-Douglas DC-10 passenger jet. The aircraft is a three engine jet with pressurized cabin. Seating is eight abreast in a 2/4/2 configuration with two aisles and a capacity of 345 passengers.

Laker's standard service involves no reservations. Tickets may be purchased on a first come-first served basis starting six hours before the departure time for a flight. Fares are $149 one way during September, the shoulder season, slightly more in summer and less in winter. Meals and drinks may be purchased, and it is necessary to sign up for meals at the time the ticket is purchased.

Concept 4. SCAR Supersonic Aircraft

The proposed U.S. supersonic transport, SCAR, will have a passenger capacity similar to the 747. However, it will operate at a speed higher than the Concorde and require only 2½ hours for the New York-London flight. Its larger capacity and improved performance provides economic operation at a fare about equal to the first class fare now charged by Pan Am which is about $100 cheaper than the Concorde.

The cabin seating will be in the tourist configuration, but will not be cramped or crowded. On-board services and amenities are assumed to be about the same as Pan Am's tourist class.

B. Non-Air Portions of the Trip

This is concerned with activities such as reservations, airport access and egress, ticketing, etc. First, the scenarios for the ground connections to and from the particular airports used are described and then additional information about the impacts which the various services have upon the evaluation parameters is provided.

With regard to the non-air portions of the trip, it is assumed that the circumstances pertaining to SCAR will be identical with those of the Pan Am NORM; i.e. it will use the same airports with similar access provisions and reservation/ticketing procedures.

1. Ground Connections

The general problem under evaluation calls for a door to door trip originating somewhere in downtown or midtown Manhattan and terminating somewhere in the central districts of London.

New York

All four services depart from the John F. Kennedy International Airport (JFK) in Queens. JFK is 15 miles (24.1 km) from midtown Manhattan, and the trip usually takes about 75 minutes. Ninety (90) minutes is more likely between 1600 and 2000. Connections to JFK are conveniently made from Manhattan by bus, departing from the East Side Airlines Terminal (37th St. and 1st Ave.). At this terminal one may obtain flight information, purchase tickets, and weigh baggage. The bus fare to JFK is $4.00. Taxi service to JFK costs at least $17.00 and increases during periods of heavy traffic. Personal auto may also be used. Parking is available at the airport. Short term rates are $1.00 for the 1st hour and $.50 each additional hour; long term is $3.00 for the 1st 24 hours and $1.50 for each additional 12 hours. A free bus service is provided from the long term lot to the terminal every ten minutes from 600 to 100 and every 30 minutes from 100 to 600. Helicopter and air taxi service are available from specific points in the city. Subway service does not run directly to the airport.

Passengers for British Airways and Pan Am go directly to JFK to catch their flights, or originate their trip at the East Side terminal, whichever is most convenient. The Laker service requires passengers to buy their tickets at a Queens office (9524 Queens Blvd., Rego Park, Queens). Tickets go on sale six hours before departure time on the day of the flight, and will be sold up to 30 minutes before departure. There are often long lines at the ticket counter. Only cash or traveller's checks are accepted as payment. A small waiting lounge is provided.

Local access from Manhattan to the address on Queens Blvd. can be made by auto, but no parking facilities are provided. Access by bus is possible via regular city routes, and taxi service represents the only other mode of access, with fare running on the order of $12-$15. Travel time can be as much as 75 to 85 minutes from Manhattan.

Upon purchasing a ticket at the Queens office, baggage is checked and the passenger waits. Baggage allowances are 44 pounds checked and six pounds carry-on. No porter service is available. Bus service is supplied by Laker to JFK, or a personal auto or taxi may be used if one prefers not to wait. Travel time is approximately 15 minutes. Passengers then move through security checks at the United Airlines Terminal and are immediately boarded onto the aircraft. Most delays occur at the Queens ticket office.

London

All services except Laker use Heathrow Airport. Laker uses Gatwick Airport as its access point to London.

Heathrow Airport is about 15 miles (24.1 km) west of London. Ground transportation into London takes about 35 minutes. Several modes of travel are available: subway, taxi, bus, rental cars, and personal vehicles. The tube (underground) connects Heathrow Central, an access point at a terminal convenient to all airlines, to the center of London's West End. There is a tube connection at the international terminal. This newly opened route is served by modern comfortable trains designed especially for airport service with special luggage racks in the cars. The trip takes less than 40 minutes, and the fare from Heathrow to Picadilly Circus is $1.60. About 25% of the passengers arriving at Heathrow use the tube to go into London, and about 20% of the departing passengers arrive at Heathrow by underground. Once into London, the subway may be used to connect to all parts of the city.

British Airways has a special bus service from Heathrow to the British Airways town terminal near Victoria Station. The fee is $2.00. Taxis into London cost about $12.00 plus tip (20%), but can deliver the traveler directly to any point. Car rental costs depend upon the size and make of the car and the duration of the contract.

Gatwick Airport is 27 miles (43.3 km) south of London. All Laker flights come and go from Gatwick. Travel into London is by rail, taxi, rental car, or personal vehicle. Travel time is about 45 minutes. Trains leave Gatwick every 15 minutes for London, and connect with Victoria Station. The fare is $3.87. The British rail system connects directly to the front of the Gatwick terminal building.

For getting about London, the traveler should be aware that the London transport services stop running at midnight on weekdays and 2330 on Sundays.

2. Factors Influencing the Parameters

Time

For international flights there are many activities which involve about the same amount of time on all airlines. However, these four carriers operate with different emphasis on time and embody different assumptions about the value of time for their passengers. The greatest discrepancy between them is for the air trip itself; Pan Am and Laker require nearly seven hours for the trip from New York to London, Concorde takes only 3½ hours and SCAR will do it in 2½ hours.

Both Pan Am and British Airways take reservations by phone, through travel agent or in person. Tickets may be mailed or picked up from a travel agent or at the airport. Payment can be either cash or credit card. Concorde reservations are handled on the phone by specially trained sales agents.

The Laker service does not involve reservations. Tickets go on sale six hours before a flight and if not sold out they will be available up to 30 minutes before departure. Tickets are sold only at an office in Queens. Thus, potential passengers must travel to this office, wait to buy tickets and then travel to JFK. Depending on the season, demand and passenger apprehension, up to 6 hours may be lost in buying the ticket and getting to the flight.

Pan Am and British Airways ask passengers to arrive at the terminal 60 minutes before departure time, but Concorde passengers may check in up to 12 minutes before departure. Pan Am suggests than an additional 15 minutes be allowed if the passenger must pick up a ticket. Baggage may be checked at the terminal door for ticketed passengers. Otherwise, bags must be checked at the airline desk. Seat assignments and boarding passes are also issued at the desk.

British Airways has special facilities for check-in, baggage, and boarding for their Concorde passengers. Check-in takes about two or three minutes.

Upon arrival in London, all passengers pass through immigration and customs. For Pan Am deplaning requires about eight minutes, and baggage is available in 15 minutes. British Airways again provides special facilities and personal service for the Concorde passengers. They emphasize the fast delivery of baggage. The actual immigration and customs process requires an average of about 30 minutes for either Laker or Pan Am. However, Concorde flights are scheduled to arrive at Heathrow during off-peak hours so that moving through immigration and customs is quick and easy. In addition, only 100 Concord passengers must be processed, while 200-300 passengers arrive at one time on the other airlines.

British Airways is geared throughout to minimizing travel and processing time for their passengers. They see their users as "people for whom time really does mean money," and they aim to reduce overall travel time by a factor of two. Concorde passengers receive priority service throughout their trip. Special ticketing, handling, departure and arrival services are provided, e.g. an executive jet or helicopter can be obtained to provide a direct connection to other cities in the United Kingdom.

The scheduling of the various flights implies different activity patterns for their passengers. For Concorde flights, the passenger is likely to leave from his or her business, while most Pan Am and Laker flights make this less likely.

Convenience

Both Pan Am and British Airways take reservations--by phone, in person, or through a travel agent. Both allow payment by cash or by credit card. The Laker service does not involve reservations, and tickets must be bought the day of the flight at one location only. Only cash or travelers checks are accepted in payment.

Pan Am has the usual service facilities at the airport for ticketing, baggage handling, seat assignment and issuing of boarding passes. British Airways has special, exclusive facilities for their Concorde passengers. They are deluxe in all aspects. For Laker, check-in or ticketing is accomplished at their Queens Blvd. station. Following a bus ride to the airport, passengers are screened and boarded through United Airlines facilities. No parking facilities are provided at the Queens Blvd. office.

Safety

All three transatlantic services have good safety records. Objectively there is very little difference between them. However, Laker does fly DC-10's and, although Laker has had no accidents or major mishaps, this aircraft is currently percieved as having "safety problems" by many air travelers.

Dependability

Dependability will be reflected by the number of scheduled flights actually completed, and the on-time arrival and departure figures for the air service. Unanticipated delays may be caused by refueling and maintenance problems, airport congestion, weather conditions, preflight preparation, or baggage problems. CAB statistics show that for the last two years Pan American has completed 96.8 percent of all scheduled flights on their Atlantic routes. Comparable figures for the other services are not readily available since they are foreign carriers, but they will be presumed equivalent.

Loss or Damage

Baggage problems are minimal on all three services. There is a greater potential for loss on Laker since more handling is required. On the other hand Concorde probably has the lowest potential for loss because of the special attention paid to all aspects of passenger service by British Airways.

Automation

None of the services use any automated procedures for passenger handling which are not relatively standard and generally favorably accepted by the traveling public.

Comfort

Pronounced differences between the three air carriers are evident in the parameters comfort, amenities, and personal service. Pan Am provides the standard or normal service in each case. Concorde represents a concerted effort to improve on these parameters, while Laker has decided to de-emphasize them in the interest of lower fares.

The Concorde flies at an altitude (50,000 to 60,000 feet) and speed (Mach 2) that insures a smooth flight. The atmospheric turbulence which is present at lower altitudes is not present at these heights. British Airways describes the Concorde as the smoothest aircraft in service. In-flight vibration measurements taken on the Air France Concorde support this claim. The short flight time also enhances passenger comfort as does the daylight flight schedule. Passengers arrive refreshed and relaxed, and do not experience the phenomenon of jet lag common on longer flights.

Concorde cabin pressure does not vary during the flight. It is maintained at a pressure equivalent to that in downtown Denver (about 5500 feet).

Concorde seats have been designed for comfort and a sense of privacy. They have high backs and wrap-around adjustable head rests. However, they are narrower than the first class seats on Pan Am: 17" instead of 21". They are the same width as Pan Am's coach seats although their unique design makes them much more comfortable.

Another factor influencing comfort is the crowding of the plane. Both Laker and Pan Am typically fly over 200 passengers per flight, while the Concorde carries only 100 passengers. The seating arrangement on the Concord--2 seats on either side of a single aisle--is more comfortable than the eleven or eight across arrangement of Pan Am and Laker respectively.

Amenities

On Pan American's coach service two meals are served: a dinner and a breakfast. Drinks are extra. An in-flight movie is shown, and music, magazines and newspapers are available. First class service is more extensive and more personal.

British Airways aims to provide "an exercise in gracious living." A first-rate, multi-course meal is served including an apertif, caviar, after dinner cheeses, pastries and fruit, coffee and liqueurs. Champaign is served in the lounge before the flight, and on the plane shortly after take-off. Meals are served on specially designed china. Magazines, cards, slippers, cigars, cigarettes, and stereo earphones are offered to the passengers. There is no movie due to the short time of flight.

Laker Airways serves routine meals to those who have signed up for them and paid extra. Drinks may be purchased in flight. Music and a movie are provided with a charge for the earphone.

Step 2. <u>Scoring of the Concept-Activity Matrices</u>

A matrix grid of concept-activity relationships was prepared for each parameter. For each block in each grid for which there was a change from the way that activity was conducted by the NORM concept, a brief description of how the concept altered the appropriate parameter for the activity was noted. In essence, this constituted engineering design inputs to which value transfer functions were to be applied.

The final scorings resulting from the value judgement transfers were obtained in the following manner. A set of matrix grids containing the engineering design variations was presented to each member of three panels of impartial judges. These judges were selected to represent the viewpoints of three particular travel groups possibly having different motivations influencing their selection of a concept for transatlantic travel. The groups were:

Group 1. - Business travel

Group 2. - Individuals traveling on personal business

Group 3. - Individuals traveling for pleasure

The formation of small size judging panels is in reality a short cut on a more extensive procedure of group sampling which should be used in an important evaluation. However, the small panels are certainly sufficient for the present purposes of demonstration. The panels were given instructions as to how to interpret the information on the grids and how to formulate scores. The NORM concept automatically received a score of 10 in every block. For the other concepts, scores greater than 10 reflected improvements in how a concept contributed to that activity in relation to the parameter applying to that particular grid. If the concept made the activity worse, then the score would be less than 10. It is important to note that throughout the entire process the judges were not aware of the specific concepts being considered. They were only told that the system involved represented an air trip with ground origin in downtown Manhattan and ground termination in the central districts of London. An example of the grid for the parameter, Time, is shown in Table 3.

After completion of the initial scoring which was done independently by each participant, the groups then met individually to discuss their scoring and to reach a consensus opinion on each number which they felt could adequately represent the value judgement appropriate to the motivation of that particular group. The panels were also asked to combine the non-air activities into a single representative score for each concept as viewed from each parameter. The results are shown in Table 4 for Group 1, Table 5 for Group 2, and Table 6 for Group 3.

Step 3. Scoring of the Activity-Parameter Matrix

In this example, this matrix was established as a single grid. In more detailed analyses it may be desirable to have each traveler group score their own grid to better reflect their particular perceptions of the questions involved. The terms in the matrix represent the extent to which the activity groups contribute to the overall value of each parameter in a transatlantic air trip. In the example case, all judges met together as a single group to repeat the process described in Step 2. They were instructed to distribute ten points for each parameter among the various activities involved and then adjust to provide integers for the two collective activities used (air and non-air). The results of this exercise are shown in Table 7.

Step 4. The First Multiplication

The next step is to combine the information in the Activity-Parameter matrix with that contained in the three sets of Concept-Activity matrices. This is accomplished in a multiplication process governed by the selection rules discussed in earlier sections of this report. The result is a single matrix for each group as shown in Table 8.

Each term in a matrix is a number which represents the relative value of the contribution which that concept makes to the overall changes in that parameter relative to the NORM in the opinion of that group. Because of the numerical scales selected, the NORM value automatically becomes 100. A number greater than 100 signifies an improvement in the parameter. For example, looking at the Group 1 matrix, Concept 2 improves the time factor (i.e. reduces trip time) but makes the cost worse (i.e. increases the fare). By comparing a given entry among groups, the relative value of a specific change can be determined. For example, the fact that all three groups show the C2-TIM entry as greater than 100 means that they all acknowledge that this concept will save trip time relative to the NORM. However, this time savings (which is the same number of actual minutes for all groups) is of most value to Group 1 (140) and of least extra value to Group 3 (116).

Step 5. Scoring of the Group-Parameter Matrix

The purpose of this single matrix is to determine the relative importance which each group places on each parameter when making their final decisions about using a particular service for a transatlantic trip. Each judge is asked to distribute 100 points among the various parameters in a manner which will reflect his or her personal opinion regarding their importance. The judges of each group then meet together to reach a consensus for that group. The results are shown in Table 9. An examination of this matrix will indicate the characteristics of the groups. For example, Group 1 places a high value on time, and convenience ranks quite high, but cost is of little importance. On the other hand, since Group 3 is involved with discretionary travel, cost is most important, time is of little importance, and comfort is more important than convenience.

Step 6. The Second Matrix Multiplication

The Group-Parameter matrix is now combined with the set of three Concept-Parameter matrices obtained in Step 4 by means of the appropriate multiplication process. This results in a single Concept-Group matrix as shown in Table 10. The entries in the matrix show the relative value which each group has placed on the four concepts. Again, it is important to remember that the judges involved in the three groups have no knowledge of what the actual realization of these concepts might be. The closest they came was in Step 1 when they were asked to place a value on the prospective change in each parameter relative to each activity which an otherwise undescribed concept might bring about. They had no information given them which would identify the physical manifestations causing that change.

The results show that both Groups 1 and 2 would be expected to prefer Concept 2 with Concept 3 also being more desirable than the NORM. However, Group 3 recognizes Concept 2 as the only possible improvement over the NORM.

Step 7. Scoring the Group-Rank Vector

The information contained in this single column matrix, or vector, represents a measure of the relative importance of each group in making a final selection of concepts. It is the responsibility of the individual or group of individuals making the final decision to determine how these numbers are to be obtained. In the present example, the method is straightforward. Since we are concerned with traveler groups, we are particularly interested in the extent to which each group is likely to make transatlantic trips. Thus the numbers can reflect past market-share data as they do in Table 11.

Step 8. The Third Matrix Multiplication

This combines the Group-Rank vector with the Concept-Group evaluations obtained from Step 6, through a simple multiplication. The results, shown in Table 12, indicate that, with the postulated market mix, and with the value assessments made by the judges, Concept 2, the Concorde, is the preferred system, with the SCAR also being an improvement over the current NORM. This does not mean that the Concorde has the best profit potential, since there was nothing put in this analysis to relate the revenue (fare) to operating cost. The term marked COST is the cost to the user (fare), and so if this fare does not adequately reflect operating cost, then a change in fare to achieve this may change the concept choice considerably. On the other hand, if an operator is evaluating several service options that might be under consideration, and has entered fare data for all of them to reflect acceptable levels of return, then the relative market preference results given by Step 8 above will reflect relative profit potential.

It can also be instructive to go back into the process and examine the reasons for the results being what they are. This can be done formally by performing a sensitivity analysis along the lines indicated in Section 3. However, much useful information can usually be obtained from simple inspection of the elements of the various matrices. Different approaches would be used depending upon the perspective involved. For example, if one was interested in why the SCAR, although faster and less expensive than the Concorde, would be judged inferior, the answer can be found in Table 8. The advantages of Comfort, Amenities, and Personal Service for the Concorde clearly outweigh the disadvantages in Time and Cost, the latter being relatively unimportant to the largest market share. Thus, if the SCAR is to be really effective in this scenario, some attention should be given to improving the various aspects of personal service over the standard Pan Am scenario. In fact, it may behoove Pan Am to introduce a deluxe service. This could be easily analyzed by setting up a C4 with the NORM values in all categories except Comfort, Amenities and Personal Service which would be set at the Concorde level.

Another possibility would be that the SCAR team might suspect the decisions of the judge panels as not being really representative. In this case, working through the computer program, either in a sensitivity mode or by recalculation with a range of parameters, the overall impact of various possible values for these entries can be examined. If the changes required to change concept rankings are small, then the analyst would be encouraged to strive for evaluation by a larger panel. If the required changes are large, then it would be highly doubtful if the final result could be changed by refining the values for the parameters.

Using the same type of analyses as described above the designers would know the extent to which various combinations of descriptors would need to be changed to alter the concept ranking. Working back through the value curves, they could then determine the percentage change required in physical design parameters in order to make an appreciable difference in the final outcome.

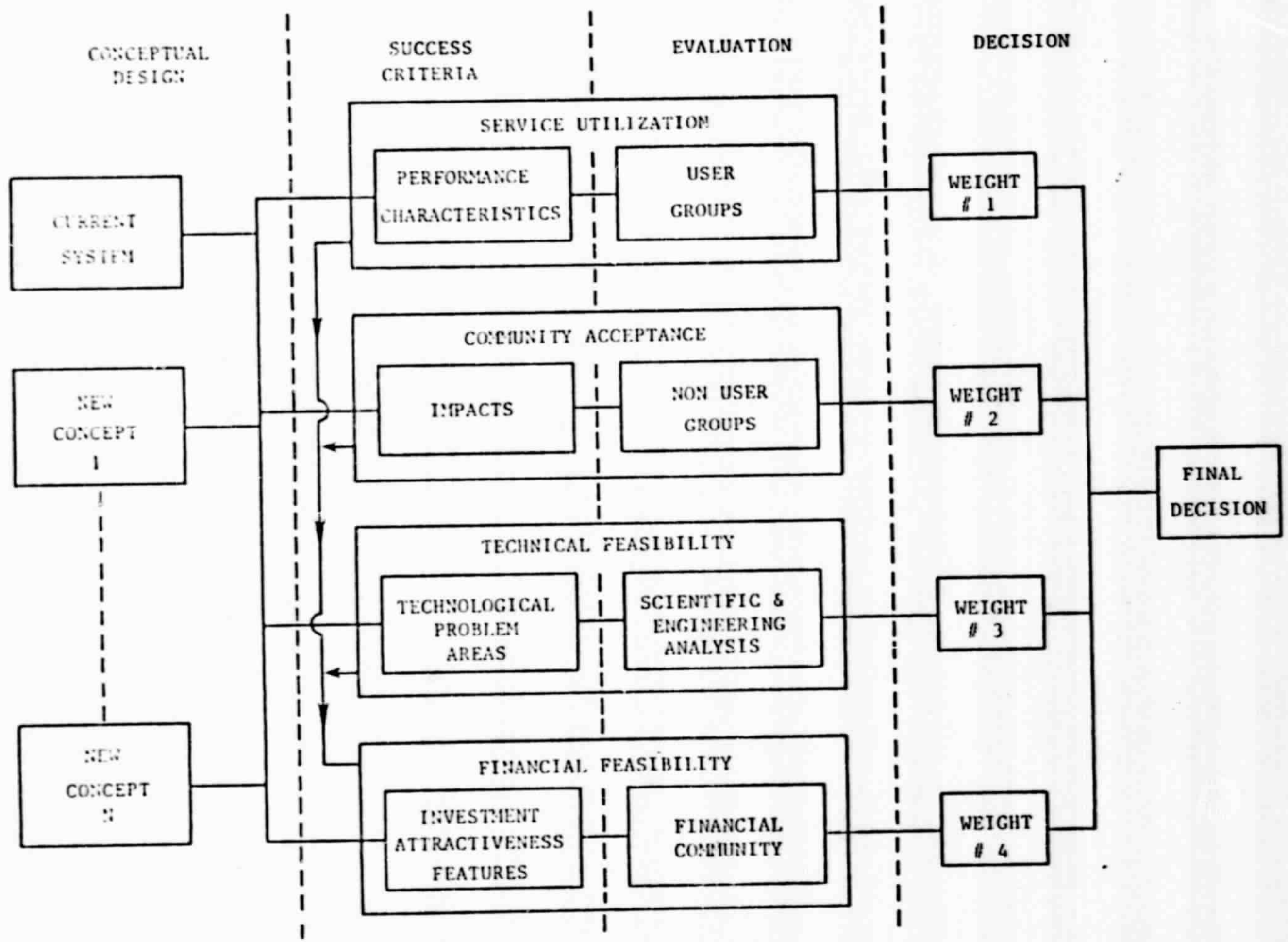

Figure 1. Schematic of Evaluation Process for Innovations in Transportation System Design

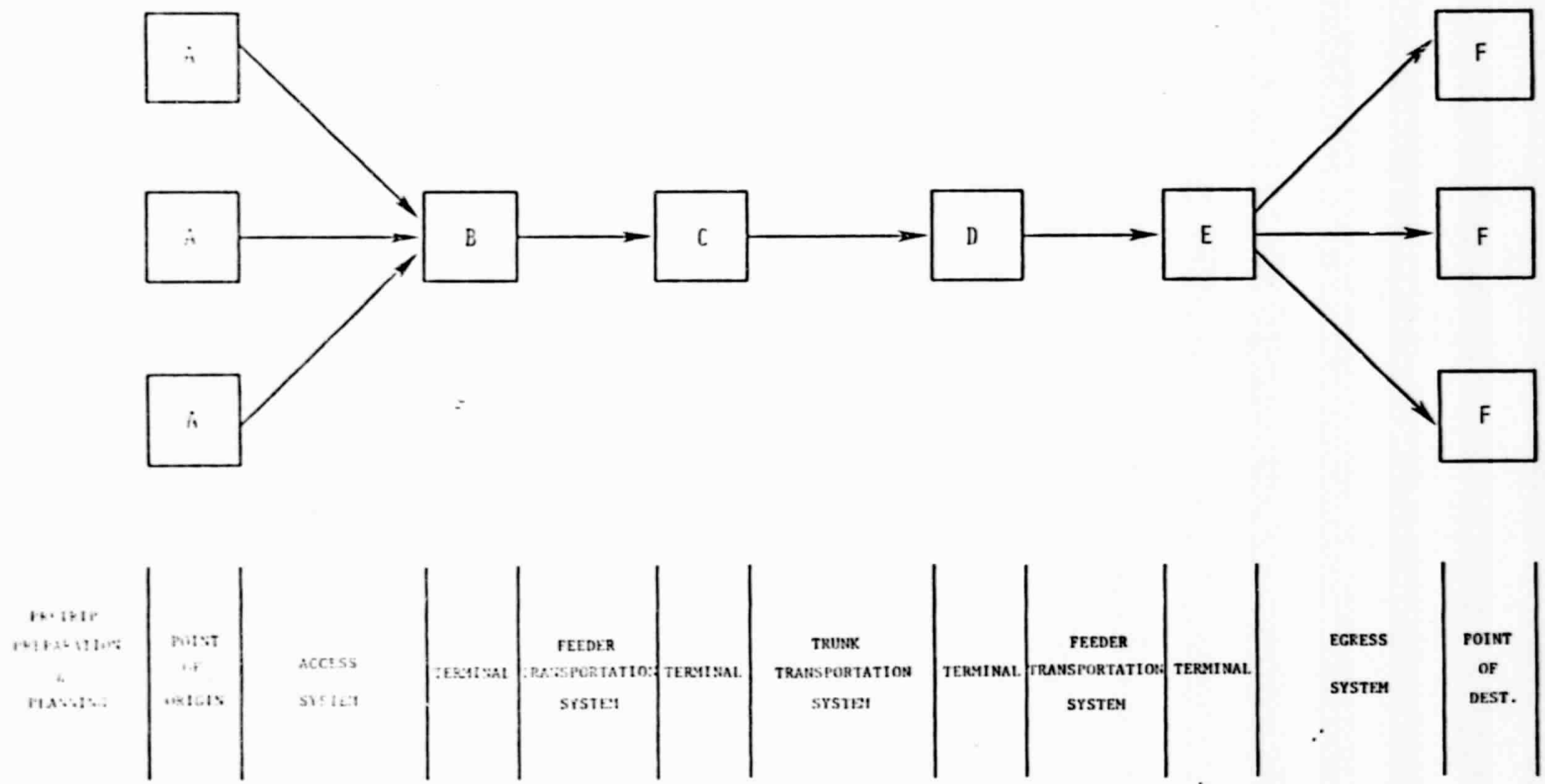

Figure 2. Schematic of a Door-to-Door Transportation System

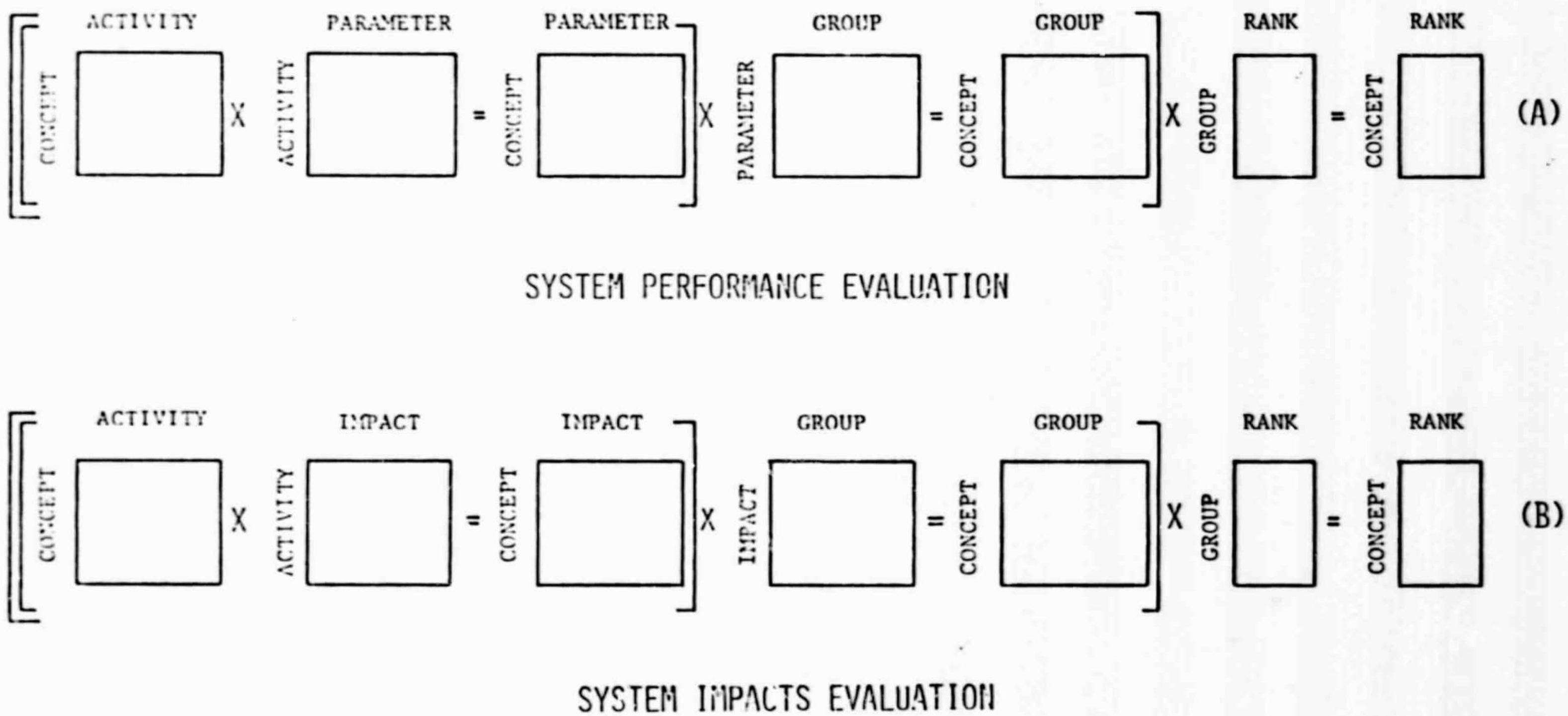

Figure 3. Matrix Multiplication Method for Evaluation of New Concepts in Transportation

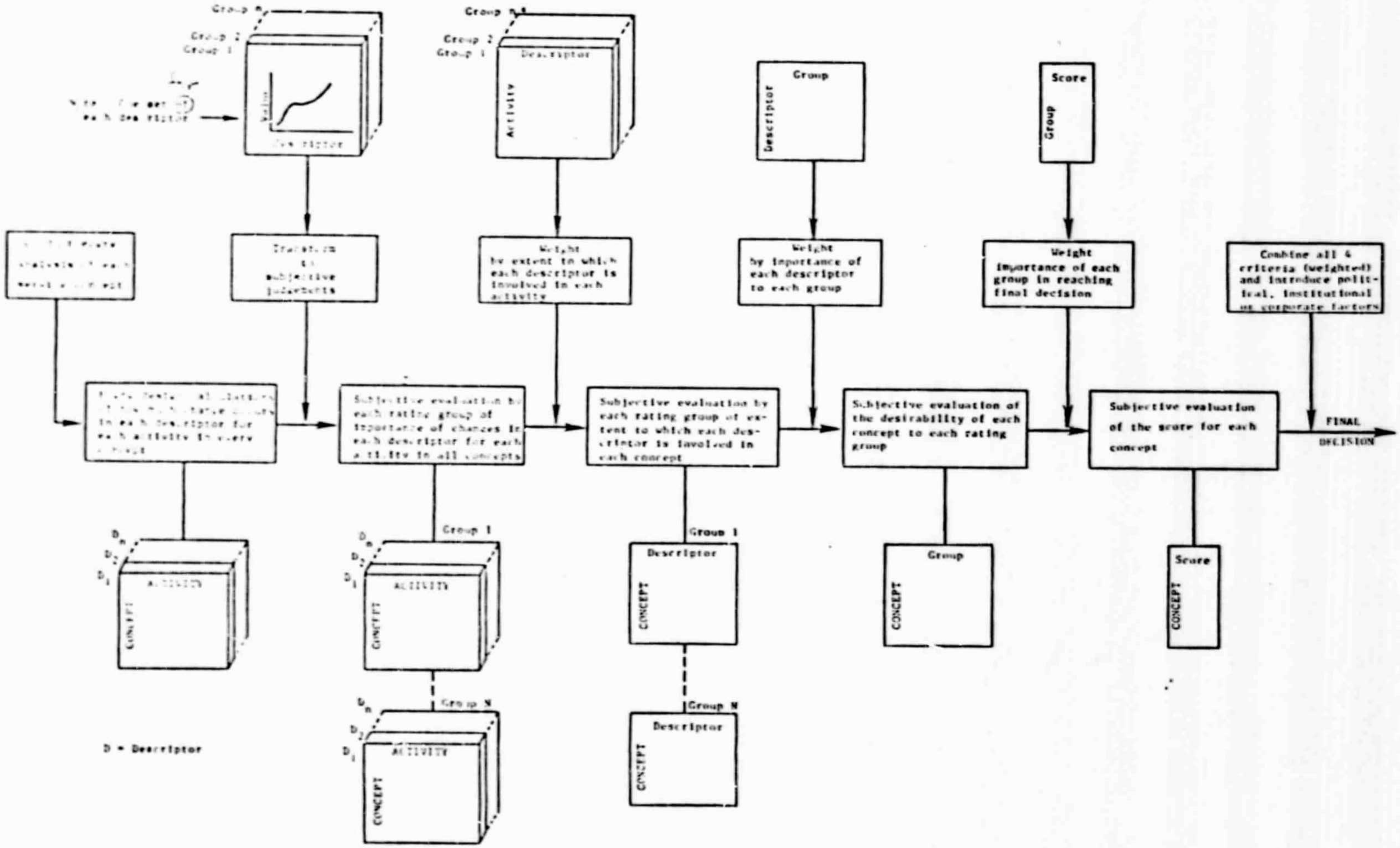

Figure 4. Schematic of Any Track in Matrix Multiplication Method

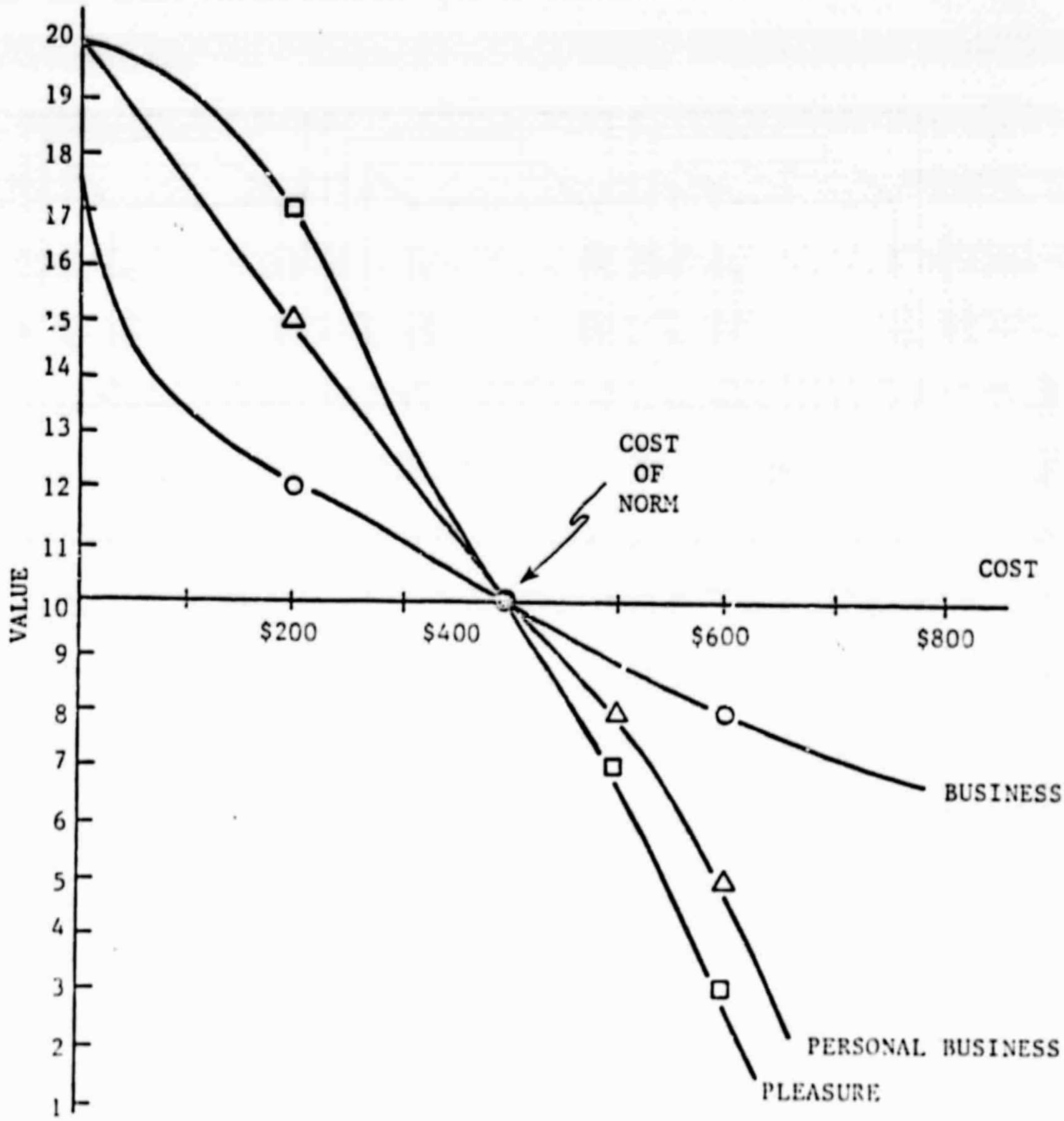

Figure 5. Transfer Functions for Cost in Transatlantic Air Travel

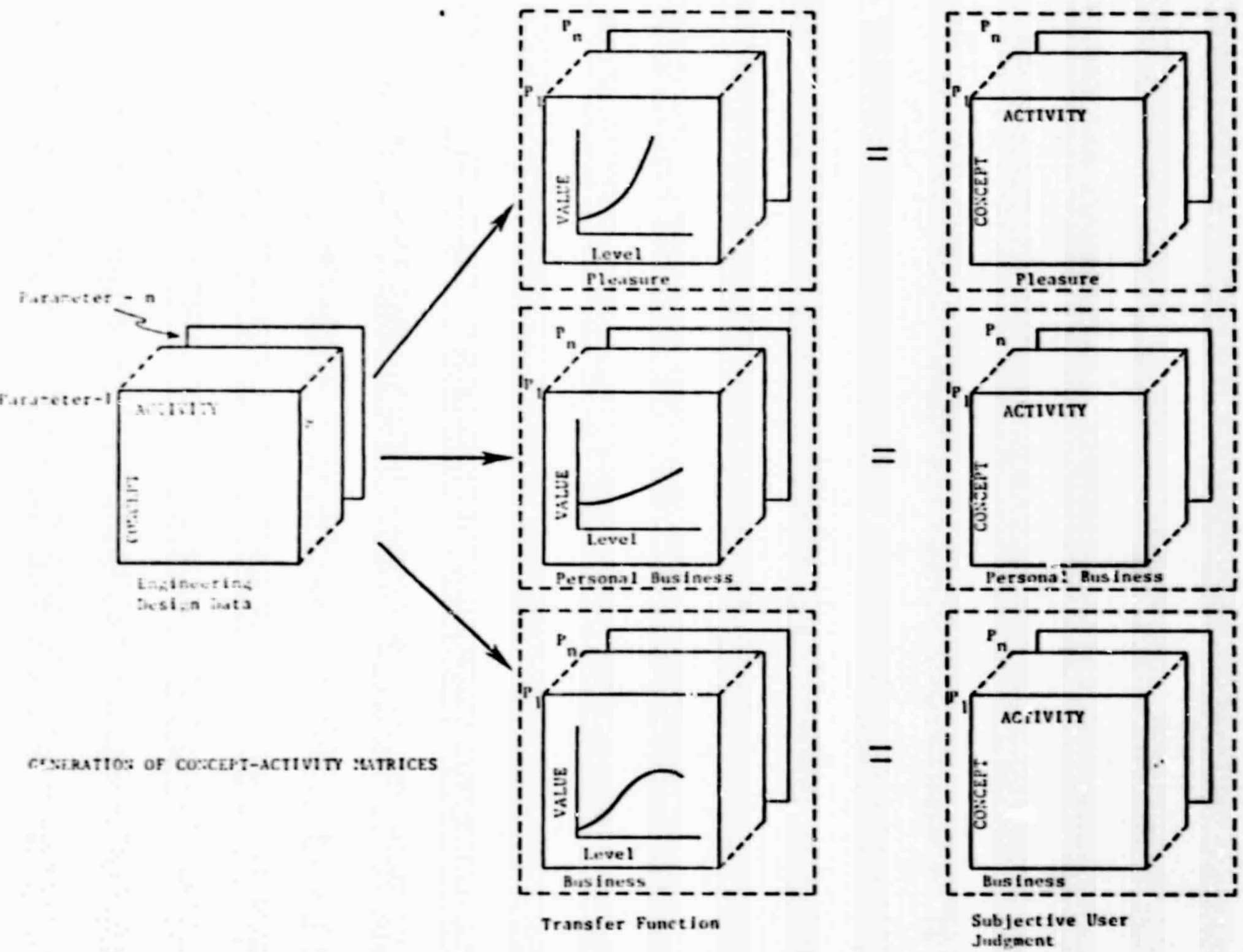

Figure 6. Operation of the Transfer Functions

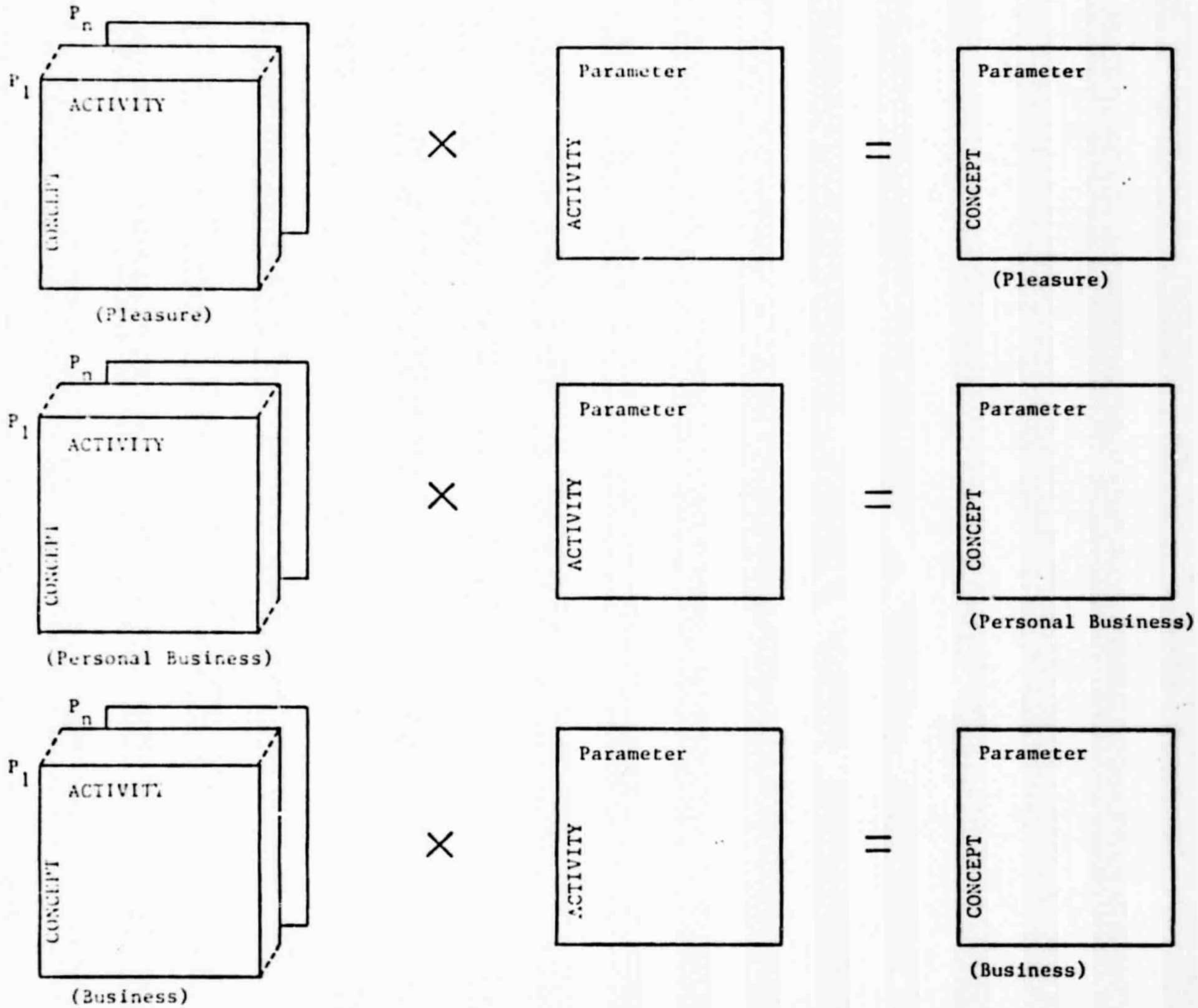

Figure 7. First Matrix Multiplication

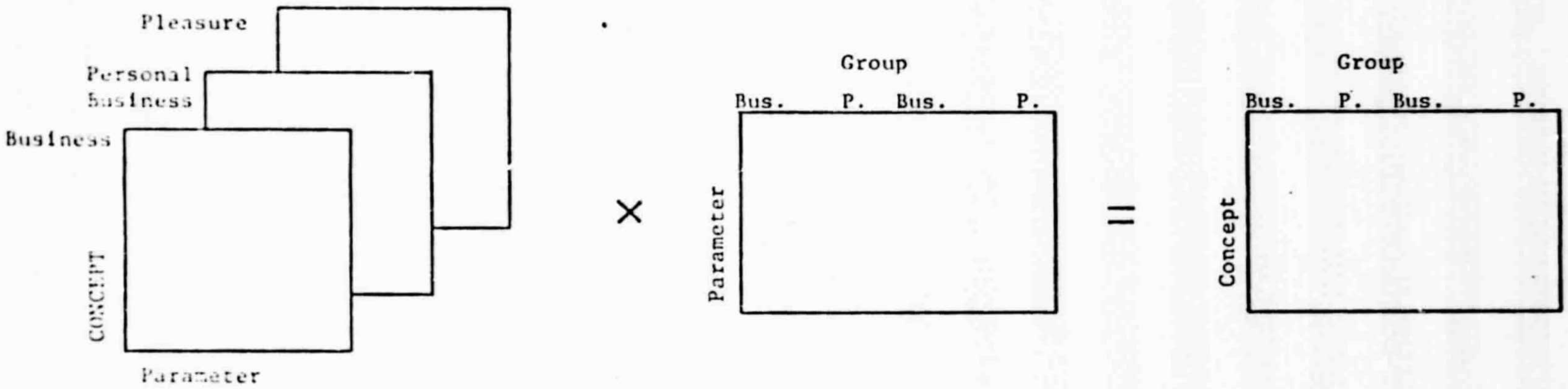

Figure 8. The Second Matrix Multiplication

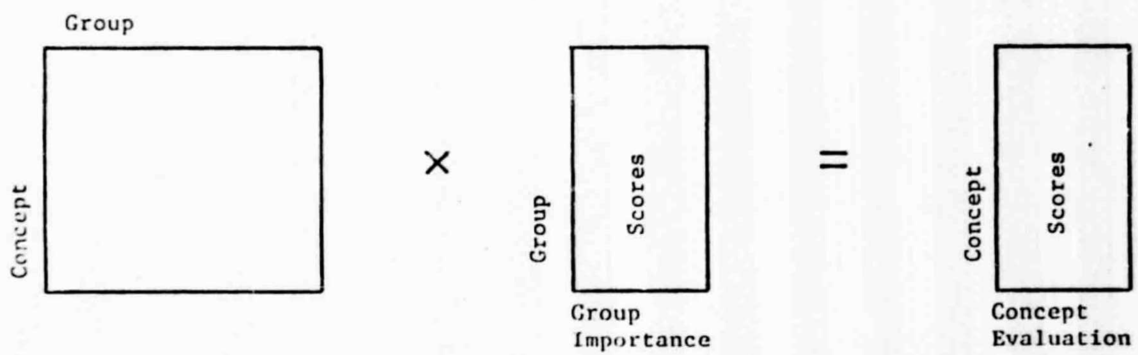

Figure 9. The Final Matrix Multiplication

Table 1

List of Appropriate Descriptors

Acceptance Parameters

- Safety
- Dependability
- Time
- Convenience
- Cost
- Level of Service
- Amenities
- Comfort
- Loss or Damage
- Degree of Automation

Community Impacts

- Energy
- Land Use
- Air Pollution
- Water Pollution
- Noise
- Congestion
- Labor
- Economic Development
- Public Subsidy
- Competition

Technology Problem Areas

- Basic Research
  - Materials
  - Aerodynamics
  - Propulsion
  - Structures
  - Electronics
  - Computer Science
- Engineering Development
  - Nature of Final Product
  - Vehicle Control
  - Automation
  - Computer Software
- Manufacturing Processes
- Operational Procedures
  - Navigation
  - Air Traffic Control
  - Ground Traffic Control
  - Route Development
  - Reservations
  - Scheduling
  - Vehicle/Airport Compatibility
- Distribution and Servicing

Investment Attractiveness

- Nature of the Requirement
  - Investment for Equip.
  - Operating Capital
  - Payback Period
  - Lead Time to Operation
- Creditability of Candidate
  - Past Record
  - Current Financial Status
  - Future Plans
  - Management Team
- Market Risk
  - Market Size
  - Geographical Distribution
  - Break Even Load Factor
  - Position of Candidate
- Competition for Funds
- Costs of Operation
  - DOC
  - IOC
- Return on Investment

Table 2

Principal Interest Groups

Service Utilization

* Passengers
  - Employee funded
  - Personal business
  - Pleasure

* Cargo Users
  - Shippers
  - Receivers

* System Employees
  - Management
  - Operational level
  - Service
  - Sales and promotion
  - Security

* Government
  - Local officials
  - State promotional agencies
  - Federal promotional agencies
  - Regulators
  - Legislators

Community Acceptance

* Community Interest
  - Individuals
  - Neighborhood civic groups
  - Chambers of Commerce
  - Industrial development agencies
  - Local labor unions
  - Other special purpose groups

* Regional & National Lobbies
  - Environmentalists
  - Labor
  - Conservation groups
  - Other special purpose groups

Financial Feasibility

* Operators
  - Stockholder equity

* Financial Community
  - Banks
  - Insurance companies
  - Institutional funds
  - Venture capital

* Government
  - Legislators
  - Local officials
  - State promotional agencies
  - Federal promotional agecies

Technological Feasibility

* Operators
  - Engineering staffs
  - R. & D. labs

* Suppliers
  - Vehicle manufacturers
  - Equipment manufacturers
  - Fuel vendors

* Professional Groups
  - Planners
  - Researchers
  - Consulting firms

* Government
  - Regulators
  - Federal research labs

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Table 3

Concept-Activity Scoring Grid

Parameter: Time

Concept	Pre-Trip Planning	Local Access	Activities @ Dep. Airport	Air Trip	Activities @ Arr. Airport	Egress @ Dest.
NORM	Minimal effort 10	75 min. 10	25 min. 10	6 hr 40 m. 10	53 min. 10	35 min. 10
C-1	None Possible 8	90+ min. 8	30 min- 3 hours 6	6 hr 45 m. 10	60 min. 9	45 min. 8
C-2	Minimal Effort 10	75 min. 16	12 min. 12	3 hr 45 m. 15	30 min 12	35 min. 10
C-3	Minimal Effort 10	75 min. 10	25 min. 10	2 hr 30 m. 17	53 min. 10	35 min. 10

Table 4

The Concept - Activity Matrix: Group 1 - Business Travelers

	Air	NonAir
NORM	10.0	10.0
C1	12.0	10.0
C2	8.0	10.0
C3	9.0	10.0

Parameter: Cost

	Air	NonAir
NORM	10.0	10.0
C1	10.0	7.0
C2	15.0	10.0
C3	17.0	10.0

Parameter: Time

	AIR	NonAir
NORM	10.0	10.0
C1	8.0	10.0
C2	15.0	10.0
C3	10.0	10.0

Parameter: Comfort

	Air	NonAir
NORM	10.0	10.0
C1	10.0	6.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Convenience

	Air	NonAir
NORM	10.0	10.0
C1	8.0	10.0
C2	16.0	12.0
C3	10.0	10.0

Parameter: Amenities

	Air	NonAir
NORM	10.0	10.0
C1	10.0	8.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Loss

	Air	NonAir
NORM	10.0	10.0
C1	10.0	6.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Dependability

	Air	NonAir
NORM	10.0	10.0
C1	7.0	8.0
C2	17.0	12.0
C3	10.0	10.0

Parameter: Personal Service

	Air	NonAir
NORM	10.0	10.0
C1	10.0	10.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Safety

	Air	NonAir
NORM	10.0	10.0
C1	10.0	10.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Automation

Table 5

The Concept - Activity Matrix

Group 2: Personal Business

Parameter: Cost

	Air	NonAir
NORM	10.0	10.0
C1	15.0	10.0
C2	5.0	10.0
C3	8.0	10.0

Parameter: Time

	Air	NonAir
NORM	10.0	10.0
C1	10.0	7.0
C2	14.0	10.0
C3	15.0	10.0

Parameter: Comfort

	Air	NonAir
NORM	10.0	10.0
C1	8.0	10.0
C2	14.0	10.0
C3	10.0	10.0

Parameter: Convenience

	Air	NonAir
NORM	10.0	10.0
C1	10.0	6.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Amenities

	Air	NonAir
NORM	10.0	10.0
C1	8.0	10.0
C2	16.0	12.0
C3	10.0	10.0

Parameter: Loss

	Air	NonAir
NORM	10.0	10.0
C1	10.0	8.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Dependability

	Air	NonAir
NORM	10.0	10.0
C1	10.0	7.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Personal Service

	Air	NonAir
NORM	10.0	10.0
C1	8.0	9.0
C2	17.0	12.0
C3	10.0	10.0

Parameter: Safety

	Air	NonAir
NORM	10.0	10.0
C1	10.0	10.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Automation

	Air	NonAir
NORM	10.0	10.0
C1	10.0	10.0
C2	10.0	10.0
C3	10.0	10.0

Table 6

The Concept - Activity Matrix

Group 3: Pleasure Travel

	Air	NonAir
NORM	10.0	10.0
C1	17.0	10.0
C2	3.0	10.0
C3	7.0	10.0

Parameter: Cost

	Air	NonAir
NORM	10.0	10.0
C1	10.0	9.0
C2	12.0	10.0
C3	13.0	10.0

Parameter: Time

	Air	NonAir
NORM	10.0	10.0
C1	9.0	10.0
C2	14.0	10.0
C3	10.0	10.0

Parameter: Comfort

	Air	NonAir
NORM	10.0	10.0
C1	10.0	9.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Convenience

	Air	NonAir
NORM	10.0	10.0
C1	9.0	10.0
C2	16.0	12.0
C3	10.0	10.0

Parameter: Amenities

	Air	NonAir
NORM	10.0	10.0
C1	10.0	8.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Loss

	Air	NonAir
NORM	10.0	10.0
C1	10.0	8.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Dependability

	Air	NonAir
NORM	10.0	10.0
C1	9.0	9.0
C2	17.0	12.0
C3	10.0	10.0

Parameter: Personal Service

	Air	NonAir
NORM	10.0	10.0
C1	10.0	10.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Safety

	Air	NonAir
NORM	10.0	10.0
C1	10.0	10.0
C2	10.0	10.0
C3	10.0	10.0

Parameter: Automation

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Table 7

Activity - Parameter Matrix

	COS	TIM	COM	CON	AME	LOS	DEP	PER	SAF	AUT
AIR	8.0	8.0	8.0	5.0	7.0	3.0	8.0	5.0	9.0	3.0
NONAIR	2.0	2.0	2.0	5.0	3.0	7.0	2.0	5.0	1.0	7.0

Table 8

Calculated Concept - Parameter Matricies

FOR GROUP 1

	COS	TIM	COM	CON	AME	LOS	DEP	PER	SAF	AU
NORM	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.
C1	116.0	94.0	84.0	80.0	86.0	86.0	92.0	75.0	100.0	100.
C2	84.0	140.0	140.0	100.0	148.0	100.0	100.0	145.0	100.0	100.
C3	98.0	156.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.

FOR GROUP 2

	COS	TIM	COM	CON	AME	LOS	DEP	PER	SAF	AU
NORM	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.
C1	140.0	94.0	84.0	80.0	86.0	86.0	94.0	85.0	100.0	100.
C2	60.0	132.0	132.0	100.0	148.0	100.0	100.0	145.0	100.0	100.
C3	84.0	140.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.

FOR GROUP 3

	COS	TIM	COM	CON	AME	LOS	DEP	PER	SAF	AU
NORM	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.
C1	156.0	93.0	92.0	95.0	93.0	88.0	96.0	90.0	100.0	100.
C2	44.0	116.0	132.0	100.0	148.0	100.0	100.0	145.0	100.0	100.
C3	74.0	184.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.

Table 9

Scoring of the Group - Parameter Matrix

	Group 1	Group 2	Group 3
Cost	5.0	10.0	20.0
Time	20.0	15.0	5.0
Comfort	5.0	5.0	10.0
Convenience	10.0	10.0	5.0
Amenities	5.0	5.0	5.0
Loss	10.0	10.0	10.0
Dependability	15.0	15.0	10.0
Pers. Service	5.0	5.0	10.0
Safety	20.0	20.0	20.0
Automation	5.0	5.0	5.0

Table 10

Calculation of the Concept - Group Matrix

	Group 1	Group 2	Group 3
NORM	10000.0	10000.0	10000.0
C1	9225.0	9665.0	10690.0
C2	11385.0	10705.0	9970.0
C3	11080.0	10440.0	9640.0

Table 11

The Group - Rank Vector

Group 1	5.0
Group 2	3.0
Group 3	2.0

Table 12

Calculation of the Concept - Rank Vector

NORM	100000.0
C1	96470.0
C2	108980.0
C3	106000.0

Appendix A - Detailed Formulation of the Matrix Multiplication Method for Evaluation New Concepts in Transportation Systems.

I. THE SYSTEM PERFORMANCE EVALUATION

A. Concept-Activity Matrix

In evaluating the initial matrix, i.e., the concept-activity matrix, it appears desirable to make the ratings which constitute the matrix elements in terms of the improvement which each concept brings to each activity for each parameter involved. Thus, for example, a separate evaluation is made for the effect of concept α on the access activity with regard to time, cost, dependability, etc. This leads to a group of k concept-activity matrices, defined by the rating

R_{ijk} = the improvement in activity, j, due to concept i, relative to parameter k.

To illustrate the procedure, consider a simple example of the improvement in three activities (j = A = Access, C = Cruise, T = Ticketing) due to three potential new concepts (i = α, β, r) in terms of three parameters (k = t = time, d = dependability, \$ = user cost). This will give rise to three concept-activity matrices as follows.

First Matrix

$$\begin{array}{c} \\ \alpha \\ \beta \\ r \end{array}\begin{array}{c} \begin{array}{ccc} A & C & T \end{array} \\ \left[\begin{array}{ccc} \; & \; & \; \\ \; & \; & \; \\ \; & \; & \; \end{array}\right]_t \end{array} = \begin{bmatrix} R_{\alpha At} & R_{\alpha Ct} & R_{\alpha Tt} \\ R_{\beta At} & R_{\beta Ct} & R_{\beta Tt} \\ R_{rAt} & R_{rCt} & R_{rTt} \end{bmatrix}$$

where

$R_{\alpha At}$ is the improvement in access due to concept α when considered from the point of view of time.

$R_{\beta Ct}$ is the improvement in cruise due to concept β when considered from the point of view of time.

etc.

Second Matrix

$$\begin{array}{c} \\ \alpha \\ \beta \\ r \end{array}\begin{array}{c} \begin{array}{ccc} A & C & T \end{array} \\ \left[\begin{array}{ccc} \quad & \quad & \quad \\ & & \\ & & \end{array}\right]_d \end{array} = \begin{bmatrix} R_{\alpha Ad} & R_{\alpha Cd} & R_{\alpha Td} \\ R_{\beta Ad} & R_{\beta Cd} & R_{\beta Td} \\ R_{rAd} & R_{rCd} & R_{rTd} \end{bmatrix}.$$

where

$R_{\alpha Ad}$ is the improvement in access due to concept α when considered from the point of view of dependability.

$R_{\beta Cd}$ is the improvement in cruise due to concept β when considered from the point of view of dependability.

etc.

Third Matrix

$$\begin{array}{c} \\ \alpha \\ \beta \\ r \end{array}\begin{array}{c} \begin{array}{ccc} A & C & T \end{array} \\ \left[\begin{array}{ccc} \quad & \quad & \quad \\ & & \\ & & \end{array}\right]_\$ \end{array} = \begin{bmatrix} R_{\alpha A\$} & R_{\alpha C\$} & R_{\alpha T\$} \\ R_{\beta A\$} & R_{\beta C\$} & R_{\beta T\$} \\ R_{rA\$} & R_{rC\$} & R_{rT\$} \end{bmatrix}$$

where

$R_{\alpha A\$}$ is the improvement in access due to concept α when considered from the point of view of cost.

$R_{\beta C\$}$ is the improvement in cruise due to concept β when considered from the point of view of cost.

etc.

Since these ratings are concerned with improvements in an activity, the values used must reflect the following two properties:

a. a norm must be defined which describes the present situation to which all new concepts must be compared; and

b. some concepts may worsen the present situation for particular combinations of parameters and activities; thus a bipolar-type rating scale is essential.

Out present recommendation is to use a rating scale of 1→20 with 10 representing the present situation and values >10 representing improvements. Note that the value of 0 is excluded from the scale. This is to protect against using it to reflect a low-value but non-negligible relationship. Because of its unique properties, it completely eliminates terms from further consideration in the matrix multiplication, even if the other components of the terms are quite large.

B. Activity-Parameter Matrix

This is still viewed as a single matrix, with the elements, $K_{j\ell}$, representing the contribution of an activity, j, to the parameter, ℓ. As an illustration, we are interested in a value to express the contribution of access to the total trip time, or the contribution of the ticketing process to the overall trip dependability, etc.

In this case the rating panel will be composed of members of the various interest groups (i.e., the workshop participants) and it is important that they be instructed to make their evaluations from the point of view of the operation of the overall system--not from that of the particular activity involved. Thus, to continue the above example, we are interested in the contribution of the ticketing to the overall trip time--not the involvement of time in the ticketing process, nor the importance of the ticketing process to the group interests, etc.

This time a unipolar rating scale can be used, and we recommend 1→10, with 10 representing the highest contribution.

The matrix will be as follows.

$$
\begin{array}{cc}
 & \begin{array}{ccc} t & d & \$ \end{array} \\
\begin{array}{c} A \\ C \\ T \end{array} & \begin{bmatrix} K_{At} & K_{Ad} & K_{A\$} \\ K_{Ct} & K_{Cd} & K_{C\$} \\ K_{Tt} & K_{Td} & K_{T\$} \end{bmatrix}
\end{array}
$$

where

K_{Cd} = the contribution of the cruise activity to the overall dependability of the system performance.

etc.

C. The First Matrix Multiplication

In theory, the result of this initial multiplication should be to produce elements whose values represent a measure of the ability of that particular concept to contribute to the improvement of that particular parameter from the point of view of the overall system operation; e.g., how much the α concept is likely to contribute to an improvement in cost of the entire trip to the user. The major importance of these numbers lies in their relative value, since it is here that the decision maker can see what the prospects are for each proposed new concept relative to others.

Because of the multiplicity of the matrix units in the concept-activity matrix, it is necessary to construct a relation for the proper multiplication protocol. This can be done as follows:

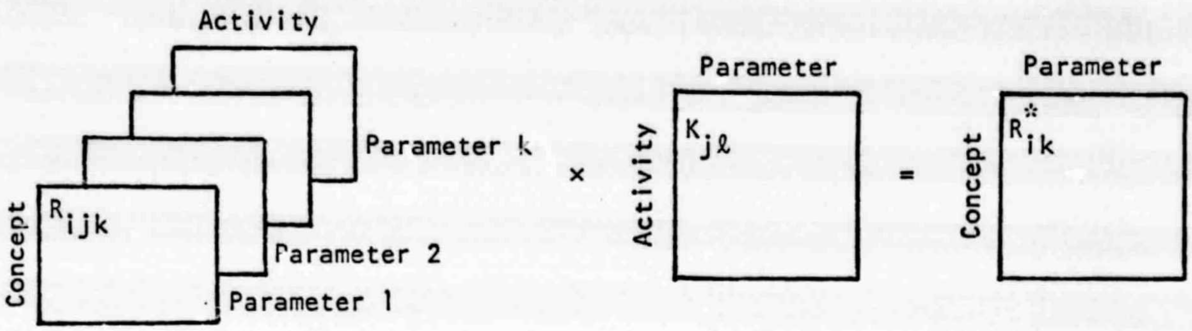
$$R^{*}_{ik} = \sum R_{ijk} \cdot K_{j\ell} \cdot \delta_{k\ell} \tag{1}$$

where

$\delta_{k\ell}$ is the Kronecker delta function,

$$\delta_{k\ell} = \begin{matrix} 0 & \text{if } k \neq \ell \\ 1 & \text{if } k = \ell \end{matrix} .$$

Schematically, this can be shown as



Writing the matrices constructed earlier, the multiplication process is as follows:

$$\begin{array}{cc} & \begin{array}{ccc} A & C & T \end{array} \\ \begin{array}{c}\alpha\\ \beta\\ r\end{array} & \begin{bmatrix} R_{\alpha At} & R_{\alpha Ct} & R_{\alpha Tt} \\ R_{\beta At} & R_{\beta Ct} & R_{\beta Tt} \\ R_{rAt} & R_{rCt} & R_{rTt} \end{bmatrix} \end{array} \times \begin{array}{cc} & \begin{array}{ccc} t & d & \$ \end{array} \\ \begin{array}{c}A\\ C\\ T\end{array} & \begin{bmatrix} K_{At} & K_{Ad} & K_{A\$} \\ K_{Ct} & K_{Cd} & K_{C\$} \\ K_{Tt} & K_{Td} & K_{T\$} \end{bmatrix} \end{array}$$

$$\begin{array}{cc} \begin{array}{c}\alpha\\ \beta\\ r\end{array} & \begin{bmatrix} R_{\alpha Ad} & R_{\alpha Cd} & R_{\alpha Td} \\ R_{\beta Ad} & R_{\beta Cd} & R_{\beta Td} \\ R_{rAd} & R_{rCd} & R_{rTd} \end{bmatrix} \end{array} \times \begin{array}{cc} \begin{array}{c}A\\ C\\ T\end{array} & \begin{bmatrix} K_{At} & K_{Ad} & K_{A\$} \\ K_{Ct} & K_{Cd} & K_{C\$} \\ K_{Tt} & K_{Td} & K_{T\$} \end{bmatrix} \end{array}$$

$$\begin{array}{cc} \begin{array}{c}\alpha\\ \beta\\ r\end{array} & \begin{bmatrix} R_{\alpha A\$} & R_{\alpha C\$} & R_{\alpha T\$} \\ R_{\beta A\$} & R_{\beta C\$} & R_{\beta T\$} \\ R_{rA\$} & R_{rC\$} & R_{rT\$} \end{bmatrix} \end{array} \times \begin{array}{cc} \begin{array}{c}A\\ C\\ \end{array} & \begin{bmatrix} K_{At} & K_{Ad} & K_{A\$} \\ K_{Ct} & K_{Cd} & K_{C\$} \\ K_{Tt} & K_{Td} & K_{T\$} \end{bmatrix} \end{array}$$

Recalling the matrix multiplication rule, the product elements of any two matrices *1* and *2* are

$$\begin{bmatrix} \mathit{1}\ 1R \times \mathit{2}\ 1C; & \mathit{1}\ 1R \times \mathit{2}\ 2C; & \mathit{1}\ 1R \times \mathit{2}\ 3C \\ \mathit{1}\ 2R \times \mathit{2}\ 1C; & \mathit{1}\ 2R \times \mathit{2}\ 2C; & \mathit{1}\ 2R \times \mathit{2}\ 3C \\ \mathit{1}\ 3R \times \mathit{2}\ 1C; & \mathit{1}\ 3R \times \mathit{2}\ 2C; & \mathit{1}\ 3R \times \mathit{2}\ 3C \end{bmatrix}$$

where 1R = first row
2R = second row
etc.
1C = first column
2C = second column
etc.

Thus performing these operations in accordance with equation (1), we obtain

$$\begin{array}{cc} & \begin{array}{ccc} t & d & \$ \end{array} \\ \begin{array}{c} \alpha \\ \\ \beta \\ \\ r \\ \end{array} & \left[\begin{array}{lll} \begin{array}{l} R^*_{\alpha t}=R_{\alpha At}K_{At}+R_{\alpha Ct}K_{Ct} \\ \quad +R_{\alpha Tt}K_{Tt} \end{array} ; & \begin{array}{l} R^*_{\alpha d}=R_{\alpha Ad}K_{Ad}+R_{\alpha Cd}K_{Cd} \\ \quad +R_{\alpha Td}K_{Td} \end{array} ; & \begin{array}{l} R^*_{\alpha \$}=R_{\alpha A\$}K_{A\$}+R_{\alpha C\$}K_{C\$} \\ \quad +R_{\alpha T\$}K_{T\$} \end{array} \\ \begin{array}{l} R^*_{\beta t}=R_{\beta At}K_{At}+R_{\beta Ct}K_{Ct} \\ \quad +R_{\beta Tt}K_{Tt} \end{array} ; & \begin{array}{l} R^*_{\beta d}=R_{\beta Ad}K_{Ad}+R_{\beta Cd}K_{Cd} \\ \quad +R_{\beta Td}K_{Td} \end{array} ; & \begin{array}{l} R^*_{\beta \$}=R_{\beta A\$}K_{A\$}+R_{\beta C\$}K_{C\$} \\ \quad +R_{\beta T\$}K_{T\$} \end{array} \\ \begin{array}{l} R^*_{rt}=R_{rAt}K_{At}+R_{rCt}K_{Ct} \\ \quad +R_{rTt}K_{Tt} \end{array} ; & \begin{array}{l} R^*_{rd}=R_{rAd}K_{Ad}+R_{rCd}K_{Cd} \\ \quad +R_{rTd}K_{Td} \end{array} ; & \begin{array}{l} R^*_{r\$}=R_{rA\$}K_{A\$}+R_{rC\$}K_{C\$} \\ \quad +R_{rT\$}K_{T\$} \end{array} \end{array}\right] \end{array}$$

To translate one of these terms physically

$R^*_{\alpha\$}$ ≡ how much the α concept will contribute to an improvement in cost to the user for the entire trip

= improvement in the cost of access due to concept α <u>multiplied by</u> the contribution of access to the overall trip cost

<u>plus</u> the improvement in the cost of cruise due to concept α <u>multiplied by</u> the contribution of cruise to the overall trip cost

<u>plus</u> the improvement in the cost of ticketing due to concept α <u>multiplied by</u> the contribution of ticketing to the overall trip cost.

D. Parameter-Group Matrix

This time the matrix elements V_{kp} represent the importance or value of a particular parameter, k, to a group, p. Using the same three parameters as previously (t, d, $) and selecting three groups for the illustration (operators, p = 1; passengers, p = 2; and observers, p = 3), we have the following designation for the parameter-group matrix:

$$\begin{array}{cc} & \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{array}{c} t \\ d \\ \$ \end{array} & \begin{bmatrix} V_{t1} & V_{t2} & V_{t3} \\ V_{d1} & V_{d2} & V_{d3} \\ V_{\$1} & V_{\$2} & V_{\$3} \end{bmatrix} \end{array}$$

Again, it should be emphasized that this evaluation should be made on the basis of value of the parameter to the overall performance of the operating system. The scale is unipolar and, again, a scale of 1→10 is recommended with 10 being the highest importance or value.

E. The Second Matrix Multiplication

This multiplication combines the contribution which each concept will make to the various system operating parameters with the importance of each parameter to the various groups of concern to the decision makers. The resulting elements represent the importance of implementing each concept to each group (as viewed from improvements in system performance). As before, the chief value of this information to the decision maker is in a study of the relative values of the numbers.

The multiplication relation can be written as

$$[R^{*}_{ik}] \times [V_{kp}] = [I_{ip}]$$

or expanding

$$\begin{array}{cc} & \begin{array}{ccc} t & d & \$ \end{array} \\ \begin{array}{c} \alpha \\ \beta \\ r \end{array} & \begin{bmatrix} R^{*}_{\alpha t} & R^{*}_{\alpha d} & R^{*}_{\alpha \$} \\ R^{*}_{\beta d} & R^{*}_{\beta d} & R^{*}_{\beta \$} \\ R^{*}_{rt} & R^{*}_{rd} & R^{*}_{r\$} \end{bmatrix} \end{array} \times \begin{array}{cc} & \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{array}{c} t \\ d \\ \$ \end{array} & \begin{bmatrix} V_{t1} & V_{t2} & V_{t3} \\ V_{d1} & V_{d2} & V_{d3} \\ V_{\$1} & V_{\$2} & V_{\$3} \end{bmatrix} \end{array} = \text{(see next page)}$$

$$
\begin{array}{c}
 \\ \alpha \\ \\ \beta \\ \\ r \\ \\
\end{array}
\begin{array}{c}
\begin{array}{ccc} \quad 1 \quad & \quad 2 \quad & \quad 3 \quad \end{array} \\
\begin{bmatrix}
I_{\alpha 1}=R^*_{\alpha t}V_{t1}+R^*_{\alpha d}V_{d1} ; & I_{\alpha 2}=R^*_{\alpha t}V_{t2}+R^*_{\alpha d}V_{d2} ; & I_{\alpha 3}=R^*_{\alpha t}V_{t3}+R^*_{\alpha d}V_{d3} \\
+R^*_{\alpha \$}V_{\$1} & +R^*_{\alpha \$}V_{\$2} & +R^*_{\alpha \$}V_{\$3} \\
I_{\beta 1}=R^*_{\beta t}V_{t1}+R^*_{\beta d}V_{d1} ; & I_{\beta 2}=R^*_{\beta t}V_{t2}+R^*_{\beta d}V_{d2} ; & I_{\beta 3}=R^*_{\beta t}V_{t3}+R^*_{\beta d}V_{d3} \\
+R^*_{\beta \$}V_{\$1} & +R^*_{\beta \$}V_{\$2} & +R^*_{\beta \$}V_{\$3} \\
I_{r1}=R^*_{rt}V_{t1}+R^*_{rd}V_{d1} ; & I_{r2}=R^*_{rt}V_{t2}+R^*_{rd}V_{d2} ; & I_{r3}=R^*_{rt}V_{t3}+R^*_{rd}Vd_{3} \\
+R^*_{r\$}V_{\$1} & +R^*_{r\$}V_{\$2} & +R^*_{r\$}V_{\$3}
\end{bmatrix}
\end{array}
$$

Again analyzing one of the terms from the point of view of our illustration, we have

$I_{\alpha 3}$ = importance of concept α to the group 3 (observer group) for improving system operating characteristics

= the extent to which concept α will lead to an improvement in overall trip time <u>multiplied by</u> the importance of trip time as an operating parameter to the observer group

<u>plus</u> the extent to which concept α will lead to an improvement in overall trip dependability <u>multiplied by</u> the importance of trip dependability as an operating parameter to the observer

<u>plus</u> the extent to which the concept α will lead to an improvement in overall cost to the user <u>multiplied by</u> the importance of user cost as an operating parameter to the observers.

F. <u>The Group Ranking Matrix</u>

The final step in the process is for the decision makers to rank the importance of the opinions of each group in the decision process. This is a simple 1-column matrix which assigns a number W_p to each group which will then be used in a weighting process.

$$\begin{array}{c} \\ 1 \\ 2 \\ 3 \end{array}\begin{array}{c} W \\ \begin{bmatrix} W_1 \\ W_2 \\ W_3 \end{bmatrix} \end{array}$$

The judgment is unipolar and a scale of 1 to 10, with 10 as most important, is recommended.

G. The Third Matrix Multiplication

This is the final step in the evaluation process for improvement in system operating characteristics. It combines the importance of the various concepts for improving the operating characteristics of a system as viewed by each of the groups with the decision makers evaluation of the importance of each of these groups in the decision process. The result is a final figure of merit, F_i, for each concept.

The matrix equation is

$$[I_{ip}] \times [W_p] = [F_i]$$

or expanding

$$\begin{array}{c} \\ \alpha \\ \beta \\ r \end{array}\begin{array}{c} \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{bmatrix} I_{\alpha 1} & I_{\alpha 2} & I_{\alpha 3} \\ I_{\beta 1} & I_{\beta 2} & I_{\beta 3} \\ I_{r1} & I_{r2} & I_{r3} \end{bmatrix} \end{array} \times \begin{array}{c} 1 \\ 2 \\ 3 \end{array}\begin{bmatrix} W_1 \\ W_2 \\ W_3 \end{bmatrix} = \begin{array}{c} 1 \\ 2 \\ 3 \end{array}\begin{bmatrix} I_{\alpha 1}W_1 + I_{\alpha 2}W_2 + I_{\alpha 3}W_3 = F_\alpha \\ I_{\beta 1}W_1 + I_{\beta 2}W_2 + I_{\beta 3}W_3 = F_\beta \\ I_{r1}W_1 + I_{r2}W_2 + I_{r3}W_3 = F_r \end{bmatrix}$$

In words, e.g.,

F_β = the final figure of merit for potential implementation of concept β as far as operating characteristics are concerned

= importance of concept β for improving the operating characteristics of the overall trip as viewed by group 1 <u>multiplied by</u> the importance of group 1 in the decision process

<u>plus</u> the importance of concept β for improving the operating characteristics of the overall trip as viewed by group 2 <u>multiplied by</u> the importance of group 2 in the decision process

plus the importance of concept β for improving the operating characteristics of the overall trip as viewed by group 3 multiplied by the importance of group 3 in the decision process.

The F_i matrix in the above form provides information on which concept appears to best meet the needs of the decision maker, which is second best, etc. It also provides a measure of the relative improvement between concepts. It should be noted that if this information is to be used to its fullest extent, one of the concepts evaluated should always be the system which now exists. Thus it is of value to normalize the results to this system. Denoting the present system as F^*, we can form

$$\frac{[F_i]}{F^*} = \begin{bmatrix} F_\alpha/F^* \\ F_\beta/F^* \\ F_r/F^* \end{bmatrix}$$

This normalized matrix provides a quick evaluation of how much better (or worse) a proposed concept is relative to what currently exists.

II THE IMPACTS EVALUATION

The analysis of the impact evaluation is analogous in form to that of the system performance. Following the same procedure as before, we arbitrarily select three impact areas to use in an illustrative example. The impacts replace the parameters and so we shall designate them by the subscripts k or ℓ as appropriate. Thus we consider three impacts (k = x = ground congestion, n = noise, and e = energy).

A. The Concept-Activity Matrix

Analogous to the previous case, we define the quantity

$\hat{R}_{ijk}$ = the improvement in the activity j due to concept i relative to the impact area k.

Note: The same symbols for the various matrix element terms will be used, applying the ^ designation to identify these as belonging to the impacts evaluation.

We again develop a series of concept-activity matrices, each relative to one of the impact parameters.

First Matrix

$$\begin{array}{cc} & \begin{array}{ccc} A & C & T \end{array} \\ \begin{array}{c} \alpha \\ \beta \\ r \end{array} & \left[\begin{array}{ccc} \quad & \quad & \quad \\ \quad & \quad & \quad \\ \quad & \quad & \quad \end{array}\right]_x \end{array} = \begin{bmatrix} \hat{R}_{\alpha Ax} & \hat{R}_{\alpha Cx} & \hat{R}_{\alpha Tx} \\ \hat{R}_{\beta Ax} & \hat{R}_{\beta Cx} & \hat{R}_{\beta Tx} \\ \hat{R}_{rAx} & \hat{R}_{rCx} & \hat{R}_{rTx} \end{bmatrix}$$

where, e.g.,

$\hat{R}_{\alpha Ax}$ is the improvement in access due to concept α considered from the point of view of ground congestion.

$\hat{R}_{\beta Cx}$ is the improvement in the cruise activity due to concept β considered from the point of view of ground congestion.

etc.

Second Matrix

$$\begin{array}{c|c} & \begin{matrix} A & C & T \end{matrix} \\ \begin{matrix} \alpha \\ \beta \\ r \end{matrix} & \left[\begin{matrix} \quad & \quad & \quad \\ & & \\ & & \end{matrix} \right]_n \end{array} = \begin{bmatrix} \hat{R}_{\alpha An} & \hat{R}_{\alpha Cn} & \hat{R}_{\alpha Tn} \\ \hat{R}_{\beta An} & \hat{R}_{\beta Cn} & \hat{R}_{\beta Tn} \\ \hat{R}_{rAn} & \hat{R}_{rCn} & \hat{R}_{rTn} \end{bmatrix}$$

where

$\hat{R}_{\alpha An}$ is the improvement in access due to concept α when considered from the point of view of noise.

etc.

Third Matrix

$$\begin{array}{c|c} & \begin{matrix} A & C & T \end{matrix} \\ \begin{matrix} \alpha \\ \beta \\ r \end{matrix} & \left[\begin{matrix} \quad & \quad & \quad \\ & & \\ & & \end{matrix} \right]_e \end{array} = \begin{bmatrix} \hat{R}_{\alpha Ae} & \hat{R}_{\alpha Ce} & \hat{R}_{\alpha Te} \\ \hat{R}_{\beta Ae} & \hat{R}_{\beta Ce} & \hat{R}_{\beta Te} \\ \hat{R}_{rAc} & \hat{R}_{rCe} & \hat{R}_{rTe} \end{bmatrix}$$

where

$\hat{R}_{rAe}$ is the improvement in access due to concept α when considered from the point of view of energy conservation.

etc.

In making these ratings, the same scales and conventions as before are used. Thus the $\hat{R}$ values are on a scale of 1→20 with 10 representing the value for the present situation.

B. Activity-Impact Matrix

This is a single matrix with the elements $\hat{K}_{j\ell}$ representing the contribution of an activity, j, to the impact area, ℓ. The rating scale is again 1→10 with 10 being the highest value. Again, the rating must be made with the overall system operation in mind.

The matrix will be

$$\begin{array}{cc} & \begin{array}{ccc} x & n & e \end{array} \\ \begin{array}{c} A \\ C \\ T \end{array} & \begin{bmatrix} \hat{K}_{Ax} & \hat{K}_{An} & \hat{K}_{Ae} \\ \hat{K}_{Cx} & \hat{K}_{Cn} & \hat{K}_{Ce} \\ \hat{K}_{Tx} & \hat{K}_{Tn} & \hat{K}_{Te} \end{bmatrix} \end{array}$$

where

$\hat{K}_{Cn}$ is the contribution of the cruise activity to the overall noise impact area.

etc.

C. The First Matrix Multiplication

The multiplication is carried out in accordance with the relationship

$$\hat{R}^{*}_{ik} = \sum \hat{R}_{ijk} \cdot \hat{K}_{j\ell} \cdot \delta_{k\ell}$$

where

$\delta_{k\ell}$ = the Kronecker delta function.

Proceeding as before we write

$$
\begin{array}{cc}
 & \begin{array}{ccc} \quad x \quad & \quad n \quad & \quad e \quad \end{array} \\
\begin{array}{c} \alpha \\ \\ \beta \\ \\ r \end{array} &
\left[\begin{array}{lll}
\hat{R}^*_{\alpha x} = \hat{R}_{\alpha Ax}\hat{K}_{Ax} + \hat{R}_{\alpha Cx}\hat{K}_{Cx} \;; & \hat{R}^*_{\alpha n} = \hat{R}_{\alpha An}\hat{K}_{An} + \hat{R}_{\alpha Cn}\hat{K}_{Cn} \;; & \hat{R}^*_{\alpha e} = \hat{R}_{\alpha Ae}\hat{K}_{Ae} + \hat{R}_{\alpha Ce}\hat{K}_{Ce} \\
\quad + \hat{R}_{\alpha Tx}\hat{K}_{Tx} & \quad + \hat{R}_{\alpha Tn}\hat{K}_{Tn} & \quad + \hat{R}_{\alpha Te}\hat{K}_{Te} \\
\hat{R}^*_{\beta x} = \hat{R}_{\beta Ax}\hat{K}_{Ax} + \hat{R}_{\beta Cx}\hat{K}_{Cx} \;; & \hat{R}^*_{\beta n} = \hat{R}_{\beta An}\hat{K}_{An} + \hat{R}_{\beta Cn}\hat{K}_{Cn} \;; & \hat{R}^*_{\beta e} = \hat{R}_{\beta Ae}\hat{K}_{Ae} + \hat{R}_{\beta Ce}\hat{K}_{Ce} \\
\quad + \hat{R}_{\beta Tx}\hat{K}_{Tx} & \quad + \hat{R}_{\beta Tn}\hat{K}_{Tn} & \quad + \hat{R}_{\beta Te}\hat{K}_{Te} \\
\hat{R}^*_{rx} = \hat{R}_{rAx}\hat{K}_{Ax} + \hat{R}_{rCx}\hat{K}_{Cx} \;; & \hat{R}^*_{rn} = \hat{R}_{rAn}\hat{K}_{An} + \hat{R}_{rCn}\hat{K}_{Cn} \;; & \hat{R}^*_{re} = \hat{R}_{rAe}\hat{K}_{Ae} + \hat{R}_{rCe}\hat{K}_{Ce} \\
\quad + \hat{R}_{rTx}\hat{K}_{Tx} & \quad + \hat{R}_{rTn}\hat{K}_{Tn} & \quad + \hat{R}_{rTe}\hat{K}_{Te}
\end{array}\right]
\end{array}
$$

To illustrate the meaning of one of the terms, we can say that

$\hat{R}^*_{\alpha e}$ = the improvement to be made by the α concept to energy consumption throughout the entire trip.

or

$\hat{R}^*_{\alpha e}$ = the improvement in the energy consumption during access under concept α multiplied by the contribution of access to the energy consumption for the entire trip

plus the improvement in the energy consumption during cruise under concept α multiplied by the contribution of cruise to the energy consumption for the entire trip

plus the improvement in the energy consumption due to ticketing under concept α multiplied by the contribution of ticketing to the energy consumption for the entire trip.

D. Impact-Group Matrix

The matrix element $\hat{V}_{kp}$ represents the importance or value of a particular impact area k to a group, p.

Then, using the same groups as before (operator, p = 1, passenger, p = 2, and observers, p = 3), we have

$$\begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline x & \hat{V}_{x1} & \hat{V}_{x2} & \hat{V}_{x3} \\ n & \hat{V}_{n1} & \hat{V}_{n2} & \hat{V}_{n3} \\ e & \hat{V}_{e1} & \hat{V}_{e2} & \hat{V}_{e3} \end{array}$$

Use a scale of 1→10 with 10 representing highest importance.

E. The Second Matrix Multiplication

This multiplication combines the contribution which each concept will make to the various impact areas with the importance of each impact to the various groups making the evaluations. The resulting elements represent the importance of implementing each concept to each group as viewed from the impacts which each concept will cause. Again, the chief value of the information to the decision maker is in a study of the relative values of the number.

The multiplication relation can be written as

$$[\hat{R}^*_{ik}] \quad [\hat{V}_{kp}] = [\hat{I}_{ip}]$$

or expanding

$$\begin{array}{c|ccc} & x & n & e \\ \hline \alpha & \hat{R}^*_{\alpha x} & \hat{R}^*_{\alpha n} & \hat{R}^*_{\alpha e} \\ \beta & \hat{R}^*_{\beta x} & \hat{R}^*_{\beta n} & \hat{R}^*_{\beta e} \\ r & \hat{R}^*_{rx} & \hat{R}^*_{rn} & \hat{R}^*_{re} \end{array} \times \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline x & \hat{V}_{x1} & \hat{V}_{x2} & \hat{V}_{x3} \\ n & \hat{V}_{n1} & \hat{V}_{n2} & \hat{V}_{n3} \\ e & \hat{V}_{e1} & \hat{V}_{e2} & \hat{V}_{e3} \end{array} =$$

$$\begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline \alpha & \hat{I}_{\alpha 1}=\hat{R}^*_{\alpha x}\hat{V}_{x1}+\hat{R}^*_{\alpha n}\hat{V}_{n1}+\hat{R}^*_{\alpha e}\hat{V}_{e1}\ ; & \hat{I}_{\alpha 2}=\hat{R}^*_{\alpha x}\hat{V}_{x2}+\hat{R}^*_{\alpha n}\hat{V}_{n2}+\hat{R}^*_{\alpha e}\hat{V}_{e2}\ ; & \hat{I}_{\alpha 3}=\hat{R}^*_{\alpha x}\hat{V}_{x3}+\hat{R}^*_{\alpha n}\hat{V}_{n3}+\hat{R}^*_{\alpha e}\hat{V}_{e3} \\ \beta & \hat{I}_{\beta 1}=\hat{R}^*_{\beta x}\hat{V}_{x1}+\hat{R}^*_{\beta n}\hat{V}_{n1}+\hat{R}^*_{\beta e}\hat{V}_{e1}\ ; & \hat{I}_{\beta 2}=\hat{R}^*_{\beta x}\hat{V}_{x2}+\hat{R}^*_{\beta n}\hat{V}_{n2}+\hat{R}^*_{\beta e}\hat{V}_{e2}\ ; & \hat{I}_{\beta 3}=\hat{R}^*_{\beta x}\hat{V}_{x3}+\hat{R}^*_{\beta n}\hat{V}_{n3}+\hat{R}^*_{\beta e}\hat{V}_{e3} \\ r & \hat{I}_{r1}=\hat{R}^*_{rx}\hat{V}_{x1}+\hat{R}^*_{rn}\hat{V}_{n1}+\hat{R}^*_{re}\hat{V}_{e1}\ ; & \hat{I}_{r2}=\hat{R}^*_{rx}\hat{V}_{x2}+\hat{R}^*_{rn}\hat{V}_{n2}+\hat{R}^*_{re}\hat{V}_{e2}\ ; & \hat{I}_{r3}=\hat{R}^*_{rx}\hat{V}_{x3}+\hat{R}^*_{rn}\hat{V}_{n3}+\hat{R}^*_{re}\hat{V}_{e3} \end{array}$$

where we can define a typical element, say $\hat{I}_{\alpha 3}$, as

$\hat{I}_{\alpha 3}$ = the value of concept α to group 3 (the observer group) when considered from the point of view of the overall impact on societal problems

= the extent to which concept α will lead to an improvement in ground congestion <u>multiplied by</u> the importance of ground congestion as an impact

<u>plus</u> the extent to which concept α will lead to an improvement in noise <u>multiplied by</u> the importance of noise in an overall impact consideration

<u>plus</u> the extent to which concept α will lead to an improvement in energy conservation <u>multiplied by</u> the importance of energy conservation in an overall impact consideration.

F. The Group Ranking Matrix

This is identical procedurally with what was done in Section I. However the values of the matrix elements could well be different, since the relative importance of the groups could be different when they are considering societal impacts rather than system operating characteristics.

G. The Third Matrix Multiplication

This is the final step in the evaluation process for determining the best concept from the point of view of environmental impacts. It combines the value of each concept to each group when considered from the point of view of environmental impact with the decision maker's judgment of the importance of these groups in the decision process.

The matrix equation is

$$[\hat{I}_{ip}] \times [\hat{W}_p] = [\hat{F}_i]$$

or expanding

$$\begin{array}{cc} & \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{array}{c} \alpha \\ \beta \\ r \end{array} & \begin{bmatrix} \hat{I}_{\alpha 1} & \hat{I}_{\alpha 2} & \hat{I}_{\alpha 3} \\ \hat{I}_{\beta 1} & \hat{I}_{\beta 2} & \hat{I}_{\beta 3} \\ \hat{I}_{r1} & \hat{I}_{r2} & \hat{I}_{r3} \end{bmatrix} \end{array} \times \begin{array}{c} 1 \\ 2 \\ 3 \end{array} \begin{bmatrix} \hat{W}_1 \\ \hat{W}_2 \\ \hat{W}_3 \end{bmatrix} = \begin{array}{c} 1 \\ 2 \\ 3 \end{array} \begin{bmatrix} \hat{F}_\alpha = \hat{I}_{\alpha 1}\hat{W}_1 + \hat{I}_{\alpha 2}\hat{W}_2 + \hat{I}_{\alpha 3}\hat{W}_3 \\ \hat{F}_\beta = \hat{I}_{\beta 1}\hat{W}_1 + \hat{I}_{\beta 2}\hat{W}_2 + \hat{I}_{\beta 3}\hat{W}_3 \\ \hat{F}_r = \hat{I}_{r1}\hat{W}_1 + \hat{I}_{r2}\hat{W}_2 + \hat{I}_{r3}\hat{W}_3 \end{bmatrix}$$

In words,

$\hat{F}_\beta$ = the final figure of merit for potential implementation of concept β as far as environmental impacts are concerned

= the value of concept β for improving the environment in the opinion of group 1 <u>multiplied by</u> the importance attached to group 1 in the overall decision process

<u>plus</u> the value of concept β for improving the environment in the opinion of group 2 <u>multiplied by</u> the importance attached to group 2 in the overall decision process

<u>plus</u> the value of concept β for improving the environment in the opinion of group 3 <u>multiplied by</u> the importance attached to group 3 in the overall decision process.

In the normalized form:

$$\frac{\hat{F}_i}{\hat{F}^*} = \begin{bmatrix} \hat{F}_\alpha/\hat{F}^* \\ \hat{F}_\beta/\hat{F}^* \\ \hat{F}_\gamma/\hat{F}^* \end{bmatrix}$$

where $\hat{F}^*$ denotes the environmental impact of the present system.