Multicriteria Evaluation of Alternative Transit System Designs

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ABSTRACT

One of the most important but underdeveloped parts of the transit planning process is the evaluation of alternative designs. The results from evaluation studies provide a basis for decision making. Evaluation of alternative transit system designs is now even more important because of reduced public funds. A computer-based multicriteria method using concordance analysis is described and applied to evaluate alternative transit system designs. Development of objectives and criteria, normalization methods, and the use of relative important weights are presented. A nonlinear method of normalization technique that uses a logistic curve is introduced. The shape of this curve can be varied by the user. An application of the multicriteria evaluation methodology to five alternative transit system designs is presented to illustrate how the best design can be identified.

Evaluating alternatives is one of the major tasks in the field of planning. Decision makers must rely on evaluation results to determine the comparative performance of alternatives as measured against project goals. The increased complexity of today's problems in public transit planning has made evaluation and decision making a particularly difficult task. The problem has become more complicated recently because of reduced public funds, more acute political concerns, forecasts that involve more uncertainty, and heightened awareness of environmental impacts. In such situations, a systematic procedure for conducting an evaluation process can be useful and necessary. An evaluation method is a means by which the pros and cons of alternative plans can be described in a logical framework so as to assess their various net benefits.

Transit planning is one of many multiobjective problems that have conflicting goals. This means that better performance of one objective often cannot be achieved without negatively affecting other objectives. In addition to these inherent conflicts, the differing opinions of local government agencies, political groups, citizen groups, and system users have to be taken into account. In this paper, a recently developed multicriteria evaluation methodology is described and used to evaluate several alternative transit system designs. Development of objectives and criteria, normalization methods, and the use of weights to represent the relative importance of different criteria are discussed. An application of this methodology that identifies the best out of five alternative transit system designs for a hypothetical city is also presented.

EVALUATING TRANSIT SYSTEMS

A public system such as a transit system needs to be evaluated periodically to justify the public money spent to run it. Evaluation is also required to analyze alternative designs resulting from modifications or changes in the route network, demand patterns, or other schedule or service allocation changes. Previous literature on this topic includes a paper by Dajani and Gilbert (1) who have presented a framework for evaluating transit systems using performance measures and a ranking approach. Fielding, Glauthier, and Lave (2) defined three efficiency, four-effectiveness, and two system-level indicators to evaluate transit systems using operating and financial data. Both papers assume that the comparisons among transit agencies can be made by grouping them properly. Mundle and Cherwony (3) suggested a methodology consisting of uncontrolled and controlled comparisons of performance measures among transit agencies. This method overcomes the drawback of not totally reflecting the differences in operating characteristics or environment among transit systems. Holec, Schwager, and Fandialan (4) used Section 15 data to develop performance indicators and then used them in routine evaluations in Michigan. The evaluation involved identifying the variation in performance values of the system considered compared to others or to itself over time. Fielding, Babitsky, and Brenner (5) used Fiscal Year 1980 Section 15 data and factor analysis to select the seven best indicators. These seven indicators were recommended for the performance evaluation of a system over a time period or among different systems.

All the articles reviewed have used the magnitude of the performance measures directly to evaluate or compare the transit systems. But this is valid only when all the measures carry equal weight or the set has a dominant alternative that has better performance values in all the measures considered. Only Dajani and Gilbert (1) have discussed the problem of differing preferences between performance measures. An evaluation procedure needs to take into consideration different perspectives, such as the federal or local government, community, transit agency, citizen groups, and users. These perspectives give rise to multiple minimizing and maximizing objectives. An evaluation framework should be therefore be robust enough to include all multiple performance measures and multiple weight sets to represent different views about the relative importance of the performance measures. The evaluation method should be flexible enough so that the user can add and delete performance measures/criteria and weight sets depending on

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the purpose and objectives of the evaluation process. Based on these requirements, a multicriteria methodology called concordance analysis has been chosen for this study. The following sections briefly explain this recently developed multicriteria methodology.

MULTICRITERIA METHODOLOGY

Recent developments in the area of decision analysis have generated a number of methods for dealing with complex decision-making problems such as the transportation planning problem (6,7). Multicriteria analysis has been used in many fields successfully including transportation planning (7-13). In the literature, some authors have used the terms "multiobjective decision making," "multicriteria decision making," and multiattribute decision making" interchangeably. In this paper, the following definitions will be used, following Giuliano et al. (10). Objectives are the measurable targets representing the project goals and these objectives are made empirically operational in the form of criteria that are used in determining the extent to which the objectives have been achieved. The multiobjective problem is defined as a problem where there is more than one objective and the objectives cannot be combined in any way. Because of different viewpoints and values held by decision makers, there is generally no "best" alternative in any situation. What is best for one set of decision makers may not be best for another when conflicting objectives exist. The multiobjective method of evaluation seeks to identify the set of "best possible" alternatives, recognizing that different preferences exist.

There are two general categories of multiobjective problem-solving methods. One is based on whether the problem is conceptualized as continuous or discrete (7). The transit system evaluation problem in this study is a discrete problem. Discrete methods are simple and do not require extensive mathematical expertise and there are many methods available to use in solving them. The method selected for this study is concordance analysis and it is explained in Giuliano et al. (7).

The framework used for the evaluation of different alternatives for a transit system is shown in Figure 1. The decision makers in the process could be federal or local government officials, or both, transit system users, citizen groups, transit agency personnel, or other elected officials. The role played by these decision makers will vary at different stages of the evaluation process depending on many factors such as the local government's policies, the transit agency's policies, the involvement of citizens, and the political agenda in the region.

CONCORDANCE ANALYSIS

Concordance analysis is a multicriteria evaluation technique in which alternative plans are evaluated by a series of pairwise comparisons across a set of criteria. It is based on the Electre method developed originally in France. References to and discussions of the development of the Electre and concordance methods are presented in Nijkamp and Van Delft (14), Giuliano et al. (10), and Guiliano (15). The concordance analysis technique used in this research is an improved version of the program developed by Giuliano et al. (10). Improvements have been made in the normalization procedure by adding a nonlinear normalization method.

The first step in applying concordance analysis is to develop the project effects matrix. This ma-
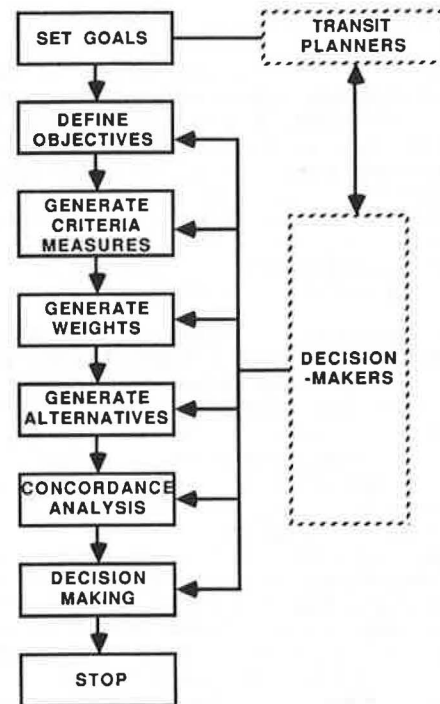

FIGURE 1 Framework for the evaluation of transit system improvement alternatives.

trix contains the performance values of all the criteria/attributes used to evaluate all alternatives. For an analysis with 'm' alternatives and 'n' criteria, the project effect matrix 'X' contains m x n elements. In general, the raw values are measured in different units. To make the various criterion scores compatible, it is necessary to transform them into one common measurement unit. The normalization procedure adopted in this study transforms each value in the raw project effects matrix so that all the normalized values are dimensionless and lie between 0 and 1, and so that the higher values are always better. Various types of linear and nonlinear normalization procedures are available. Two linear methods and one nonlinear transformation method are used in this study. The first method, magnitude-scaled normalization, uses

$$r_{ij} = x_{ij}/x_{ij}*$$

where

r = normalized value,
x = raw project effect,
i = 1, 2, . . ., m alternatives,
j = 1, 2, . . ., n criteria, and
$x_{ij}*$ = max (x_{ij}), for j = 1, 2, . . ., n.

The advantage of this normalization method is that all outcomes are transformed in a linear way, so that the relative order of magnitude of the values remains the same. In the case of a criterion with a "less-is-better" objective the following is used:

$$r_{ij} = 1 - (x_{ij}/x_{ij}*)$$

The second linear method, interval-scaled normalization, uses

$$r_{ij} = (x_{ij} - x_{ij}**)/(x_{ij}* - x_{ij}**)$$

where $x_{ij}**$ is min(x_{ij}) for j = 1, 2, . . . n.

In the case of a criterion with a less-is-better objective:

$$r_{ij} = 1 - \{(x_{ij} - x_{ij}^{**}) - (x_{ij}^{*} - x_{ij}^{**})\}$$

The advantage of the interval method is that the scale of measurement varies precisely between 0 and 1 for each criterion. A possible drawback of this procedure is that the interval method does not lead to a proportional change in outcomes. The magnitude-scaled method is useful in normalizing a project effect matrix that will be analyzed by a weighted summation technique. The interval-scaled method is especially appropriate where a technique is used that performs a pairwise comparison of the criterion scores (16).

In the literature, a criterion with a more-is-better objective is called a "benefit criterion" and one with a less-is-better objective is called a "cost criterion." The same terminology will be used here. In the raw project effects matrix, higher values are better for a benefit criterion and lower ones are better for a cost criterion. In the normalized projects effect matrix, higher values for both benefit and cost criteria are better.

The third type of normalization used allows for nonlinear variation. In the transportation planning field, one cannot assume a linear form for all utility curves. Many of the criteria used in the analysis may behave nonlinearly and a nonlinear normalization technique is needed. This utility curve is assumed to have an S-shape (like the logistic curve) symmetric about its midpoint. This curve can have a linear portion in its middle. The shape of the curve can be defined differently for each criterion by changing the input parameters. The logistic curve used in this study is of the form

$$r = e^{G(x)}/[1 + e^{G(x)}]$$

where

    r = the normalized value,
  $G(x)$ = some function of the level of performance x, measured in performance units, and
    e = the base of natural logarithms.

As shown in Figure 2, such a function describes an S-shaped curve, which is asymptotic above to the line $y = 1.0$ and below to the x-axis. In addition, over the range $y = 0.2$ to $y = 0.8$, it can be varied by the user to fit different criteria. A utility curve of this form implies a relationship between performance and normalized value that is linear over a certain range, while having an exponential decay near the upper and lower limits. It describes a re-
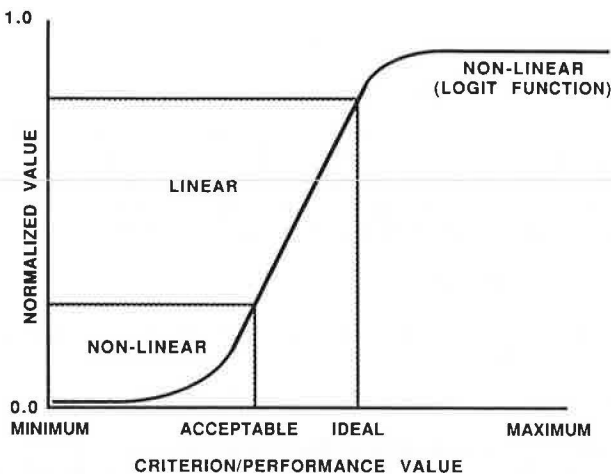
lation in which the principle of diminishing rate-of-return applies to both high and lower levels of performance.

Although the general shape of the curve is the same for all decision makers and all performance measures, the exact relationship between performance level and normalized value must be determined by inputs that are used to calculate the G(x) function in the preceding equation. A simple linear form was chosen as follows (17):

$$G(x) = ax + b$$

To determine the values of a and b, the analyst is asked to specify two points on the curve. This is accomplished by specifying an ideal and an acceptable value for each performance measure in performance units. An ideal value is defined as the level of performance beyond which further improvement will bring only a minimal inc ease in the normalized value (i.e., the point of diminishing returns). The acceptable value is defined as the minimum (or maximum), which is the lowest (or highest) level of performance that will be tolerated. The user also has to define the corresponding normalized values for the ideal and acceptable values of the performance measure. With these inputs, the following three equations can be used to normalize a given project effects matrix. For $A_j \le x_{ij} \le I_j$,

$$r_{ij} = \{r(I_j) - r(a_j)\} * C/E + r(A_j)$$

For $x_{ij} < A_j$,

$$r_{ij} = e^{\ln(M/N)(C/E) + \ln(N)}/1 + e^{\ln(M/N)(C/E) + \ln(N)}$$

For $x_{ij} > I_j$,

$$r_{ij} = e^{\ln(M/N)(D/E) + \ln(M)}/1 + e^{\ln(M/N)(D/E) + \ln(M)}$$

where

    r = the normalized value,
  x_{ij} = the value of the jth criterion of the ith alternative, for which the normalized value needs to be determined,
  I_j = the ideal value for the jth criterion,
  A_j = the acceptable value for the jth criterion,
  M = $\{r(I_j)/(1 - r(I_j))\}$,
  N = $\{r(A_j)/(1 - r(A_j))\}$,
  C = $(x_{ij} - A_j)$,
  D = $(x_{ij} - I_j)$, and
  E = $(I_j - A_j)$.

(Note that the same equations can be used for both benefit and cost criteria.)

WEIGHTS FOR THE CRITERIA

After normalizing the raw project effects matrix, the next step is to establish the relative importance or priority for the criteria included in the evaluation. The relative importance of criteria to one another is reflected by a set of weights. There are different techniques available to assign weights to the criteria (18-20). The assignment of weights to the set of project criteria is a critical part of any evaluation as it establishes the relative importance of each objective. These weights have a major effect on the final evaluation results. In some cases a slight variation of these weights can yield another ranking of the alternatives under consideration. In transit planning because decision making involves more than one interest group, it is generally useful

FIGURE 2 General form of nonlinear utility curve.

to device one or more sets of weights for each group involved. The best alternative will be the one that ranks higher than the others for all of these weight sets. These weights have to be normalized using

$$w_j / \Sigma w_j$$

for j = 1, . . . n, and summation over j = 1, . . . n.

The other steps in the concordance analysis involve developing the concordance and discordance sets, calculating the concordance and discordance index matrices and dominance values, and ranking the alternatives. These steps have been discussed in detail in Giuliano et al. (10) and Giuliano (15) and are not repeated here because of space limitations.

CONCORD-NL (computer program)

A computer program has been written for the concordance analysis procedure discussed here. The program is an interactive program written in FORTRAN 77. It is operational on the Cyber 180/855 at the Academic Computing Center at the University of Washington. The program can handle 30 alternatives, 30 criteria, and 10 sets of weights. Data input can be made either interactively or from disk files. Alternatives can be added to or deleted from the analysis. The program allows the user to use any one of the three normalization methods for each criterion. If the nonlinear normalization method is chosen, the user must define the parameters of the normalization curve to fit the criterion's characteristics.

APPLICATION OF CONCORDANCE ANALYSIS

Concordance analysis was used to evaluate a set of alternative transit system designs developed for a problem assigned to senior students from the Civil Engineering and Urban Planning departments as a class project. They were asked to develop a high-performance transit system design for the 1-hr a.m. peak period. Each design team was required to maximize all benefit criteria while minimizing all cost criteria. The final (best) designs submitted by these students were evaluated using concordance analysis.

Students used an interactive graphic software system called the Transit Network Optimization Program (TNOP) to design their alternatives (21). TNOP can be used to generate many alternative designs quickly. It calculates values for various key performance measures that can be used for evaluation purposes. In addition to this, graphic maps and charts are also generated. TNOP can be used to design and calculate the performance of alternative fixed-route, fixed-schedule bus and rail transit systems. Through interactive graphic computing, TNOP allows the user to generate a wide range of design alternatives and to easily compare their performance characteristics.

The transit network and the origin-destination patterns are shown in Figure 3. This figure represents 97 nodes and 181 two-way bus links. The transit origindestination matrix contains 41,370 trips (for the 1-hr a.m. peak period). The students initially used another interactive graphic program called FLOWMAP to study the commuter flow patterns (22). FLOWMAP is operational at the University of Washington and produces a wide variety of origin-destination maps. It provides the user with the ability to examine the spatial pattern of the origin-destination data much more effectively than is otherwise possible. Based on this information, students used various modules of TNOP to define the transit lines, specify the service allocated to each route, assign the trips, look at the overview statistics of the system and routes, review the network loading and transfer patterns, and execute the timetable optimization subroutine. The performance values from the best designs developed by the students were used to conduct the concordance analysis.

EVALUATION OF ALTERNATE DESIGNS

The first step in the evaluation process is to select the objectives and the criteria that will represent the objectives. The selected objectives should be helpful in evaluating alternative transit designs and should also be able to represent the different

ORIGINS (>) AND DESTINATIONS (^) OF HYPOTHETICAL CITY NODES   □□□□□   500 TRIPS
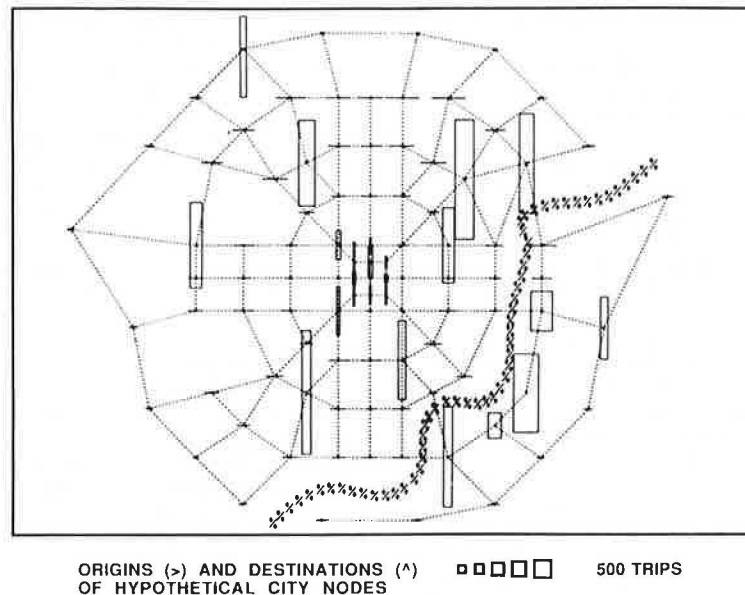
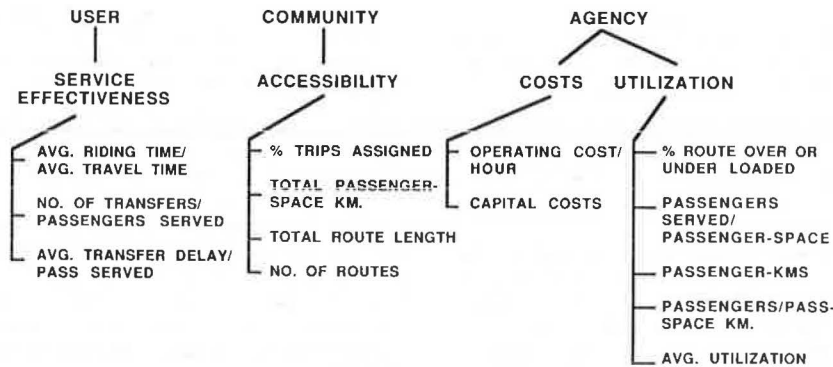FIGURE 3 Origins and destinations of hypothetical city nodes.

FIGURE 4 Objectives and criteria.

perspectives of the evaluations. After a careful review, the following objectives were chosen:

1. Minimize cost,
2. Maximize utilization,
3. Maximize accessibility, and
4. Maximize service effectiveness.

The next step is to select criteria that will represent the objectives chosen for the evaluation. Much care has to be exercised in this step because it defines the evaluation approach in detail. Figure 4 shows the objectives and criteria and the relation between them in a hierarchical tree form. A brief definition of the criteria used in this study is presented here as follows:

1. Operating costs per hour: These include administrative costs, operating and maintenance costs of vehicles, and crew costs.

2. Capital costs: These include all capital costs including vehicle cost and permanent structure cost.

3. Percentage of routes not within 10 percent of capacity: This includes the percentage of routes where the maximum load is not within 10 percent of the total capacity provided on a route for the 1-hr a.m. peak period.

4. Number of passengers served per passenger space provided: This is calculated by dividing the total number of passengers assigned in the system by the total passenger space service provided. The total passenger space is calculated by adding total capacity of seats and standees for all routes in a 1-hr period.

5. Passenger kilometers: The volume for each link is multiplied by the length of corresponding link, and the passenger-kilometers values for all links are summed.

6. Number of passengers served per passenger space kilometers of service: This includes the total number of passengers served over the total passenger space kilometers of service. Total passenger space kilometers are calculated by summing the product of total capacity of vehicles by the route length for all the routes.

7. System-wide average utilization: The average utilization on each route is first calculated by dividing the average volume on the links by the total capacity of the route. The total capacity is calculated by multiplying the total vehicle capacity by the number of trips made. The average volume of a route is determined by summing, for all links on that route, the product of the link volume and the link length and dividing the result by the line length.

8. Percent trips assigned: This is the total number of trips that could reach their destinations using a design over the total number of trips in the network that need transit service.

9. Total passenger space kilometers: This is the sum of the product of total capacity of each route by its length over all routes.

10. Total route length: This is the sum of link lengths included in each route, for all routes.

11. Number of routes: This is the total number of routes defined in the system.

12. Average riding time/average travel time: The riding time is the in-vehicle time. In TNOP, it is the product of the link volume values and link travel times, summed over all links and divided by the number of assigned trips. The average travel time is the summation of average riding time, average wait time, average transfer time, and average walk time.

13. Number of transfers per passengers served: This is the total number of transfers divided by the total number of passengers served.

14. Average transfer delay per passenger served: This is the total average transfer delay (in minutes) in the system divided by the total number of passengers.

Table 1 gives the project effects matrix for the five alternative designs included in the evaluation. By looking at the project effects matrix, it is difficult to get any idea as to which design is superior. Some of them are less expensive, but others are better in other respects. There is no single alternative in this set that dominates all the others for all criteria. Concordance analysis can be extremely useful in a situation like this. The next step is to choose the normalization methods for each criterion by choosing shapes for their utility curves. Table 2 gives the normalization methods and parameters selected for these 14 criteria. All the attributes using physical characteristics use linear methods and the others use the nonlinear method of normalization. Figures 5-8 show the shapes of utility curves for these criteria. Table 3 gives the normalized project effects matrix. In this matrix, higher values are better for all criteria. Still, given these data alone, it cannot clearly be determined which design is superior because the relative importance of the criteria differs.

OBTAINING WEIGHT SETS

To use concordance analysis, one needs to get a few sets of weighs together that will represent different decision makers' values and perceptions. For this study, a hierarchical comparison technique was used. This technique assumes that, at each branch of the tree, all the factors contributing to the worth of a higher level element have been identified. Decision makers are then asked to judge the relative importance of the contribution of each lower level element to the one above by dividing a constant sum among

TABLE 1 Raw Project Effects Matrix

	Alternative				
Number and Performance Measure	1 (100)	2 (200)	3 (300)	4 (400)	5 (500)
1 Operating costs per hour	27,712.000	28,980.000	33,014.000	35,081.000	30,132.000
2 Capital costs	1,576.000	2,242.000	770.000	2,359.000	1,777.000
3 Percent routes within 10 percent capacity	14.000	0.000	44.000	14.000	10.000
4 Passengers served/passenger space provided*	1.910	1.490	2.170	1.580	2.000
5 Passenger kilometers*	550 700.000	882 700.000	581 300.000	754 900.000	519 200.000
6 Passengers per passenger space kilometers*	0.029	0.026	0.030	0.018	0.031
7 Average utilization*	41.600	57.100	44.600	54.200	40.700
8 Percent trips assigned*	86.900	95.900	92.900	96.100	89.400
9 Total passenger space kilometers*	1 235 972.000	1 523 584.000	1 276 182.000	2 175 817.000	1 220 478.000
10 Total route length*	439.000	458.000	557.000	475.000	654.000
11 Number of routes*	7.000	10.000	9.000	11.000	10.000
12 Average riding time/travel time*	0.640	0.750	0.710	0.750	0.710
13 Number of transfers	0.630	0.510	0.580	0.610	0.520
14 Average transfer delay/passenger	2.510	2.060	2.080	1.060	2.410

Note: * = a more-is-better system; otherwise assume a less-is-better system; and ( ) is the design number.

TABLE 2 Normalization Method and Parameters

		Attribute Value[a]		Worth Curve Value[a]	
Number and Performance Measure	Method	Ideal	Acceptable	Ideal	Acceptable
1 Operating costs per hour	3	25,000.00	30,000.00	0.95	0.20
2 Capital costs	3	1,500.00	2,000.00	0.95	0.20
3 Percent routes within 10 percent capacity	3	15.00	25.00	0.80	0.20
4 Passengers served/passenger space provided	2	0.00	0.00	0.80	0.20
5 Passenger kilometers	2	0.00	0.00	0.80	0.20
6 Passengers/passenger space kilometers	2	0.00	0.00	0.80	0.20
7 Average utilization	3	55.00	50.00	0.80	0.20
8 Percent trips assigned	3	95.00	90.00	0.80	0.20
9 Total passenger space kilometers	2	0.00	0.00	0.80	0.20
10 Total route length	2	0.00	0.00	0.80	0.20
11 Number of routes	2	0.00	0.00	0.80	0.20
12 Average riding time/travel time	3	0.75	0.70	0.80	0.20
13 Number of transfers	3	0.25	0.50	0.80	0.20
14 Average transfer delay/passenger	3	1.50	2.00	0.80	0.20

Note: Method 1 is a magnitude-scaled normalization, Method 2 is an interval-scaled normalization, and Method 3 is a non-linear normalization—logit curve.
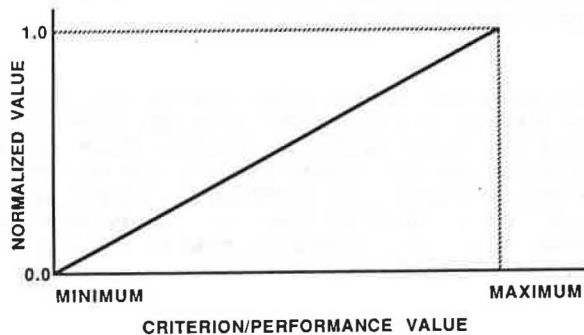[a]Applicable to Method 3 only.

FIGURE 5 Structure of the utility curve used for passengers served per passenger space provided, passenger kilometers, passengers served per passenger space kilometers, total passenger space kilometers, total route length, and number of routes.

them. The process begins by weighting the highest level general goals and proceeding down the tree until the bottom level attributes are reached. Weights are calculated for each attribute by starting with the top value and forming a product of the values that appear at each branch as one progresses down the tree. Both the point division and weight computation may be conducted by working from the bottom to the top of the tree, if desired. Eight different sets of weights were developed using this method to represent different values and perspectives. The normalized weight set is given in Table 4. These eight sets of weights reflect four different perspectives as given in the following table:

Values and Perspectives Represented	Weight Sets
User	1,2
Transit agency	3,4
Community	5,6
Federal agency	7,8

RESULTS

Concordance analysis was applied to rank the five alternatives. The analysis included eight sets of weights. Table 5 gives the average dominance ranking, and the final ranking of the alternatives is as follows:

Rank	Alternative	Design Number
1	2	200
2	4 (not totally nondominated)	400
3	3 (not totally nondominated)	300
4	5 (not totally nondominated)	500
5	1 (not totally nondominated)	100

From the dominance ranking, one can find that alternative 2 got a total of 12.0 points (lower values are better because this number is the summation of the average ranking for all weighting sets) closely
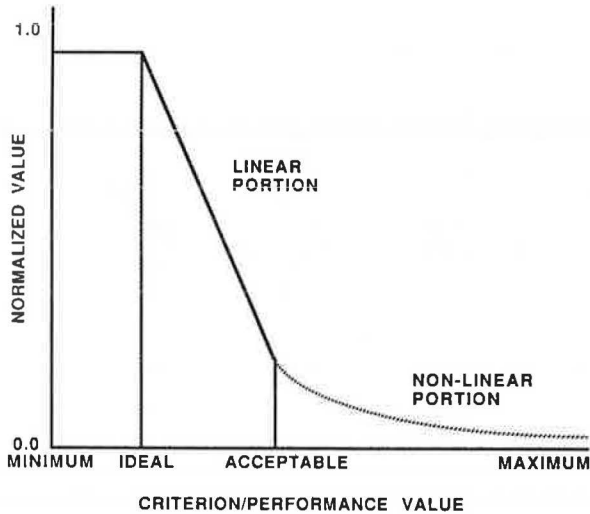
FIGURE 6 Structure of the utility curve used for operating cost per hour and capital cost per hour.
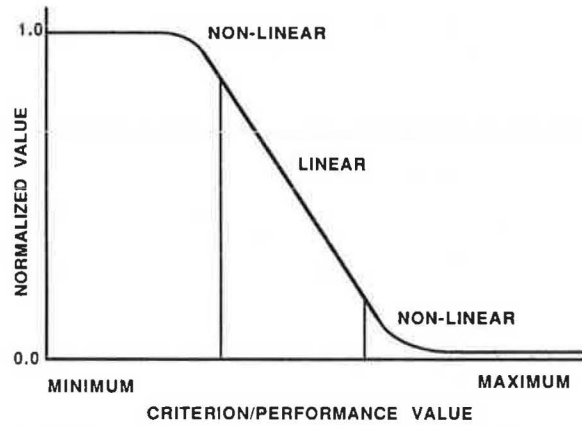

FIGURE 7 Structure of the utility curve used for percent routes not within 10 percent capacity, the number of transfers per passenger, and the average transfer delay per passenger served.

followed by 14.0 for alternative 4. Based on this, design 2 is ranked first and design 4 is ranked second. For the weight sets considered, alternative 2 is the only nondominated (superior) alternative. Alternative 2 is nondominated for all the weighting sets, whereas alternative 4 is nondominated for all sets except 3 and 4, which represent the values and perspectives of the transit agency. If weighting sets 3 and 4 are not considered, the results will be different, as given in Table 6, and the following table of the final rankings:

Rank	Alternative	Design Number
1	4	400
2	2	200
3	3 (not totally nondominated)	300
4	5 (not totally nondominated)	500
5	1 (not totally nondominated)	100

According to this ranking, alternative 4 ranks first with a total of 9.0 points and alternative 2 ranks second with 9.5 points. This illustrates the crucial importance of different perspectives and how they can influence the results of the analysis. In this analysis (without weight sets 3 and 4), both alternatives 4 and 2 are nondominated. Even though alternative 4 is better for many criteria that represent the objectives of the user and community, the cost of this design is the highest. Because of this, the heavy weights given by the transit agency for oper-
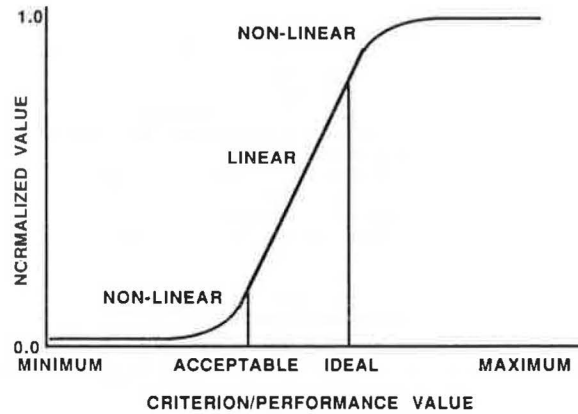

FIGURE 8 Structure of the utility curve used for system-wide average utilization, the percent of trips assigned, and the average riding time per travel time.

ating costs and capital costs prevent this alternative from being ranked first when the analysis includes all eight weighting schemes. These results illustrate how concordance analysis can be used to aid the evaluation of alternative transit system designs taking different values and perspectives into account in a more rigorous way than is the case with existing evaluation methods.

TABLE 3 Normalized Project Effects Matrix (more-is-better system)

Number and Performance Measure	Alternative				
	1	2	3	4	5
1 Operating costs per hour	0.645	0.377	0.018	0.003	0.182
2 Capital costs	0.908	0.030	1.000	0.011	0.633
3 Percent routes within 10 percent capacity	0.841	0.996	0.001	0.841	0.941
4 Passengers served/passenger space provided	0.618	0.000	1.000	0.132	0.750
5 Passenger kilometers	0.087	1.000	0.171	0.648	0.000
6 Passengers/passenger space kilometers	0.846	0.615	0.923	0.000	1.000
7 Average utilization	0.002	0.928	0.012	0.704	0.001
8 Percent trips assigned	0.043	0.868	0.548	0.880	0.152
9 Total passenger space kilometers	0.016	0.317	0.058	1.000	0.000
10 Total route length	0.000	0.088	0.549	0.167	1.000
11 Number of routes	0.000	0.750	0.500	1.000	0.750
12 Average riding time/travel time	0.009	0.800	0.320	0.800	0.320
13 Number of transfers	0.056	0.183	0.093	0.069	0.167
14 Average transfer delay/passenger	0.015	0.152	0.138	0.979	0.025

TABLE 4 Normalized Weights

Number and Performance Measure	Weighting Scheme							
	1	2	3	4	5	6	7	8
1 Operating costs per hour	0.028	0.030	0.125	0.150	0.088	0.053	0.072	0.120
2 Capital costs	0.042	0.030	0.125	0.150	0.038	0.053	0.048	0.180
3 Percent routes within 10 percent capacity	0.013	0.028	0.050	0.020	0.025	0.078	0.045	0.060
4 Passengers served per passenger space provided	0.039	0.028	0.050	0.060	0.025	0.020	0.027	0.030
5 Passenger kilometers	0.033	0.028	0.050	0.040	0.025	0.020	0.018	0.020
6 Passengers per passenger space kilometers	0.026	0.028	0.050	0.040	0.025	0.029	0.045	0.010
7 Average utilization	0.020	0.028	0.050	0.040	0.025	0.049	0.045	0.080
8 Percent trips assigned	0.090	0.075	0.075	0.135	0.125	0.180	0.100	0.090
9 Total passenger space kilometers	0.060	0.075	0.075	0.075	0.125	0.030	0.150	0.060
10 Total route length	0.090	0.075	0.075	0.060	0.125	0.030	0.150	0.060
11 Number of routes	0.060	0.075	0.025	0.030	0.125	0.060	0.100	0.090
12 Average riding time/travel time	0.200	0.175	0.063	0.070	0.150	0.120	0.040	0.060
13 Number of transfers	0.150	0.175	0.125	0.070	0.050	0.160	0.120	0.060
14 Average transfer delay/passenger	0.150	0.150	0.063	0.060	0.050	0.120	0.040	0.080

Note: Columns total 1.00.

TABLE 5 Average Dominance Ranking Using Eight Weighting Schemes

Weighting Scheme	Alternative[a]				
	1	2	3	4	5
1	5.00 (0)	1.50 (1)	3.00 (0)	1.50 (1)	4.00 (0)
2	5.00 (0)	1.50 (1)	3.50 (0)	1.50 (1)	3.50 (0)
3	5.00 (0)	1.00 (1)	3.00 (0)	3.00 (0)	3.00 (0)
4	5.00 (0)	1.50 (1)	2.50 (1)	2.00 (0)	4.00 (0)
5	5.00 (0)	2.00 (1)	3.50 (0)	1.00 (1)	3.50 (0)
6	5.00 (0)	1.50 (1)	3.50 (0)	1.50 (1)	3.50 (0)
7	5.00 (1)	1.50 (1)	3.50 (0)	1.50 (1)	3.50 (1)
8	5.00 (0)	1.50 (1)	3.00 (0)	2.00 (1)	3.50 (0)
Total	40.00	12.00	25.50	14.00	28.50

Note: (1) = nondominated and (0) = dominated.
[a]Includes concordance + discordance.

TABLE 6 Average Dominance Ranking Using Six Weighting Schemes

Weighting Scheme	Alternative[a]				
	1	2	3	4	5
1	5.00 (0)	1.50 (1)	3.00 (0)	1.50 (1)	4.00 (0)
2	5.00 (0)	1.50 (1)	3.50 (0)	1.50 (1)	3.50 (0)
3	5.00 (0)	2.00 (1)	3.50 (0)	1.00 (1)	3.50 (0)
4	5.00 (0)	1.50 (1)	3.50 (0)	1.50 (1)	3.50 (0)
5	5.00 (0)	1.50 (1)	3.50 (0)	1.50 (1)	3.50 (1)
6	5.00 (0)	1.50 (1)	3.00 (0)	2.00 (1)	3.50 (0)
Total	30.00	9.50	20.00	9.00	21.50

Note: (1) = nondominated and (0) = dominated.
[a]Includes concordance + discordance.

CONCLUSIONS AND SUGGESTED FUTURE RESEARCH TOPICS

Assessing alternative transit system designs is a typical multiobjective evaluation problem that has many conflicting objectives. Proposed in this paper is a simple but effective approach to solving such problems using concordance analysis. This technique can be applied to the evaluation of alternatives within a particular transit system or to the ranking of alternatives from different cities competing for federal funds. Concordance analysis could be a powerful aid to decision making for problems involving multiple objectives. It provides a logical but flexible approach. Application of this methodology to transit system evaluations allows for the inclusion of the different perspectives of multiple decision makers in the evaluation procedure in a well-defined scientific manner. Concordance analysis takes care of the problem of comparing different criteria measured in different units and having different importance ratings. This multicriteria evaluation technique is more transparent and easily understood because public and other groups can participate and express their opinions through weighting of criteria.

Further research is required in the areas of (a) criteria selection, (b) guidelines for selecting appropriate values to determine the shape of the nonlinear utility curves used to normalize the project effects data, and (c) weight definition and collection methods. Further research is also required to identify the basic objectives and measures that are most suitable for evaluating transit system alternatives is an alternatives analysis study. Depending on the problem, additional objectives and performance measures can be added. Because this is a difficult task and guidelines would be useful at every agency level, perhaps some region-specific sets of weights could be developed using hierarchical comparison methods to represent diverse but relevant perspectives. A large survey could be conducted among relevant decision-maker groups in different regions to get several sets of weights for different types of transit project evaluations. These results could be used by UMTA on a regional basis.

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