GOAL-PROGRAMMING APPROACH TO ASSESSING URBAN TRANSIT SYSTEMS

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Transportation systems often are evaluated to see whether they satisfy a variety of community goals. Of primary concern in this study is the development of a procedure for using the goal-programming technique, a modification and extension of linear programming, to evaluate urban transit systems for meeting the transportation-related goals of a community. These goals are intended to be general enough to permit adaptation of the goal-programming technique for the solution of a wide variety of urban problems. First, constraints are formulated from the inputs from a community; then the output variables are chosen to correlate with basic characteristics of urban transit systems to select a system or group of systems to fulfill the community transportation requirements. A computer program is employed to ease application of the goal programming and allow flexibility for a complex set of equations. A set of sample community goals are assumed to illustrate how the technique is practical in actual applications.

•DURING this century, the population of the nation's urban areas has grown enormously, and all indications are that these trends will continue. Because of the extreme orientation to the use of automobiles for transportation, a series of problems have become increasingly prevalent. Congestion of urban streets and freeways, especially at times of peak travel, increases travel times, and accident rates soar. Air and noise pollution has reached hazardous levels. Attempts to build new highways to deal with increasing traffic have met with resistance because of their disruptive effects on the community and because new highways are "self-defeating" in that they cause more trips to be generated. Because of these and many other problems, the basic goals of the American people are changing and environmental and social considerations are being valued more highly than rapid automobile travel within the urban area. Therefore, many communities are considering the feasibility of public transit systems to meet current and projected transportation needs.

Determining which system is best for a given area is a difficult problem. A wide variety of technologies are available, from moving walkways to large rail rapid transit systems, each of which meets the needs of certain situations. Work previously done in this field centered on discussing the many criteria that should be considered when transportation systems are evaluated. The cost-effectiveness technique, in particular, has been the subject of many previous studies; this technique generally incorporates the social, environmental, economic, and performance objectives of a transportation system. Recent studies by Ellis (7) and Ward (30) are good examples of analyses of these aspects. The latter is perhaps one of the most important developments because of its in-depth look at the wide range of these factors. The shortcoming of many of these studies is that they consider the total view of things that should be evaluated but often give no measurable criteria to determine how the desirable objectives could be used to decide among technologies.

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Other studies have developed techniques for evaluating alternative systems. However, many of these studies have offered solutions in very general terms (such as circulation and line-haul) and described the type of urban setting in which a system might be useful, but they have given little systematic basis for selection. Meyer, Kain, and Wohl (18) attempted to evaluate automobile, bus, and rail travel by reducing all 3 methods to common performance factors and by using a dollar-based evaluation. On a theoretical basis, the concept certainly provides interesting considerations of the effects of various urban actions on transportation and vice versa. However, this procedure is quite complicated and contains a wide variety of assumptions about interest rates, costs, and the like that hinder its practicality. Hoel (13) evaluated city-center distribution systems by using a model that determines total travel time and gives different weights to walking, waiting, and movement times. He noted that determining the values to place on these different aspects was difficult and subjective at best. Perhaps the values would even be dynamic and change with types of trips.

These previously mentioned studies are indicative of the types of solutions offered concerning the problem of system selection. However, there are currently no effective methods for assessing system candidates and initially choosing a system. Therefore, there is an urgent need to develop an evaluation technique for initially determining the group of urban public transit systems that would be most capable of providing the basic transportation needs of a community. Such a technique can be adapted to public transit assessment without having to resort to reducing all values to a common denominator such as dollars. It also can serve as a device to choose a small number from among many alternatives for more detailed examination.

STUDY OBJECTIVES

The basic objective of this study was to develop an evaluation technique by which an urban area can input the values and priorities of its transportation goals into an analytical process and, with the output, can identify a group of transit systems that will satisfy these goals to a reasonable extent. Because the transportation system must satisfy a variety of community goals, the candidate systems must be assessed to decide which best fits the range of these goals.

The goal-programming technique, a modification and extension of linear programming, allows a simultaneous solution of a series of complex objectives rather than a single objective. This study was intended to show that such a technique is usable for evaluating transportation systems by means of a series of ranked subgoals. This study also attempted to develop criteria so that the characteristics of various urban transportation systems can be correlated with the output of the goal-programming application. For illustrative purposes, the solution technique then was tested through application to an example urban transportation problem.

METHOD OF APPROACH

In deciding on an approach to urban transit assessment, one must develop a technique that has a variety of characteristics. First, analysis rather than description is desirable to give a quantitative basis for comparing the actual values of a particular urban area with available systems. Second, the procedure should be flexible to permit the inclusion of a variety of goals. Finally, it should be computer adaptable to allow use of a complex set of equations if the need arises in a particular situation or procedure development warrants their use. The goal-programming technique, which was developed primarily as a management tool, has obvious advantages for application to the urban transportation assessment problem. The most important advantage is its great flexibility in accepting a wide variety of constraints. Government groups, decision makers, or planners in the urban area may have difficulty in quantifying their exact transportation needs and may have only approximate values and priorities. These problems can be resolved by goal programming even though the multiple goals in some ways may be conflicting. The technique can be applied to satisfy the goals to the extent possible based on the priority assigned them. Moreover, it will give exact solutions with values to the identifiable variables that can be correlated with candidate-system characteristics. Because the nature of this solution technique seems to fit the requirements of transportation planning so well, the possibility of adapting it to technological system evaluation was explored in this study.

The theory and application of this technique are well documented in a recent book by Lee (16). Basically, the goal-programming method is a form of linear programming that allows the simultaneous solution of a system of subgoals rather than a single objective function. Goal programming, instead of directly maximizing or minimizing the objective function, minimizes deviation between goals and what can be achieved within the given set of constraints. The deviation of the variables of the subgoals from the constraints is represented in the objective function usually with a positive or negative deviation or both positive and negative deviations from each constraint. Then the objective function becomes the minimization of these deviations based on the relative importance or priority assigned to them.

In keeping with the objective of the study, we first formulated the constraint equations in order to accept inputs about the community that could be reasonably expected to be available or decided on by the transportation decision-making groups. The variables, whose values would be the output of the program, were chosen to correlate with available information on public transit systems and to be extensive enough to describe a system or group of systems sufficiently to identify them from among others.

The original intention of the study was to include variables dealing with social and environmental as well as performance and economic factors. Close study revealed that the social and environmental effects of a system are primarily a function of right-of-way (ROW) routing and type of propulsion respectively. The propulsion system, which affects the level of noise and air pollution produced, often can be changed or chosen to meet the needs of the community if the normal one is unacceptable. In other words, many systems can use a variety of propulsion methods, such as electrical pickups, diesel engines, or electric storage batteries, and give approximately the same performance. Systems based on electrical motors are particularly pollution free if emissions at the power-generating plant are kept to acceptable levels; almost all technologies use or can be adapted to use this type of propulsion. Therefore, in most cases, the propulsion systems will be acceptable, or systems can be adapted to meet community environmental standards.

In a similar way, the guideway routing of the system is a major factor in determining the type and extent of community disruption. If the system uses an existing ROW (public buses on existing streets), problems are minimal. If the system requires a separate ROW, or performs better with one, then problems multiply. However, the solution revolves around careful choice of the route of the ROW and expeditious use of elevated, grade-level, and underground sections that best fit each situation. Consequently, this problem can best be solved through proper routing after a system is chosen rather than during the choosing process. Because judgments and variations made after the system is chosen have a large influence on social and environmental factors, we decided to concentrate on the requirements of transportation-performance-related subgoals and tried to choose a group of systems on this basis. The impact of the system on socioeconomic development and environmental compatibility then could be investigated on the basis of available types of propulsion and alternative ROW routing. This procedure appears to integrate well with the environmental impact statement (EIS) for an area if any large-scale transportation improvement is to be considered. The EIS requires an evaluation of all other alternatives to the proposal, which is a rather broad requirement. It would be a reasonable argument that the systems eliminated from evaluation by the goal-programming procedure do not satisfy the transportation needs of the area and therefore are not usable alternatives regardless of their environmental compatibility.

SYSTEM PERFORMANCE REQUIREMENTS

Extensive studies of the characteristics of current and planned urban transportation systems have been made. These studies, by their nature, have several weaknesses. For example, the Chilton study (5) and the Handman et al. study (9) suffered from a lack of available information on proposed systems and from the difficulty of deciding what information about the systems to include, both of which are typical problems. Furthermore, because developmental work is in progress on many of the proposed (and even operational) systems and because of accompanying concept and performance changes, the data often have been outdated. However, these studies do serve as a good source for determining the range of performance of groups of systems and, no doubt, have been very helpful to urban planners in view of the lack of a procedure for other means of initial assessment.

In this study, the transportation systems available for urban applications were subdivided into 5 basic groups, and performance characteristics were listed as representative of each group. Because many of the systems are still in prototype stages (especially moving walkways, personal vehicles, and jitneys), the characteristics often were based on sketchy data. However, as the systems are refined and more data become available, the figures can be updated easily and the number of groups can be increased to give greater selectivity.

Input Constraints

As noted before, only the system performance characteristics are included in this analysis. Input by the community, in the form of equation constraints for a goal program, was chosen to represent the important characteristics of a system to the traveler and the overall transportation needs of the area.

System Speed, Waiting Time, and Total Perceived Travel Time

Many studies have shown that total travel time, which consists of waiting time, line-haul time, and terminal access time, is perhaps the most important determinant of modal choice. Waiting time usually is seen as more critical than other time elements. We felt that, from the size and layout of the community and previous studies of acceptable performance levels, transportation planners could specify desired values of system speed for the normal or average trip (converted to time by using average trip length), average acceptable waiting times for a vehicle, and total perceived travel time for the average user.

System Extensiveness

To provide an input concerning the access time to and from stations, an extensiveness variable, defined here as the average desirable walking time to a terminal, should be included. This access time will be a function of terminal density, in terms of the area served by each station. One method of determining this average desirable time would be to identify the generators where stations are desirable and, by using half the average distance between them, calculate the average time after assuming a given walking speed. This extensiveness concept is equivalent to system accessibility because it determines how fully the urban area will be covered by the system and, therefore, how accessible it will be to individual origins and destinations.

System Capacity

The input most important to the planners on a community basis is probably system capacity, or the number of passengers the system can transport in a given period. This is especially important in commuter-oriented situations where peak-hour flows are high. An overcrowded system results in long passenger waiting times, which are undesirable to users. Therefore, the system must be sufficient to meet demands with acceptable delay times, and an input dealing with peak-hour capacity is included.

Acceptable Fare Level

Another input important to both individuals and the community is acceptable fare level, or the charge above which the system probably would not be attractive to a sufficient number of customers. It is also critical to the community because costs above the acceptable level must be made up by the community to maintain service. The input level may even include some subsidy amount if it will be available.

Output Variables

After the community-constraint inputs have been determined, linear equations linking them with system characteristics as variables must be formulated. These variables should be as precise as possible to specify a given group of systems but should be general enough so that data on the variables can be obtained from reliable sources. The availability of information proved to be a problem because many of the beltway, jitney, and personal vehicle systems are prototypes or merely advanced concepts, and performance information concerning aspects such as cost is quite difficult to find.

System Costs

The system-cost constraint correlates directly with the variable. It is made up of capital and operating costs exclusive of ROW costs. The acceptable fare level is a direct function of the anticipated system cost and differs only by deviation variables.

Average Headway, Travel Time, and Terminal-Access Time

Travel time is a function of average system speeds, and the average trip length must be converted to travel speed for system comparisons. Waiting time can be seen as a function of the headway between vehicles. Obviously, if it is a demand-responsive, delays will be minimal, and, for a continually available system, delays might be only a few seconds. Similarly, system extensiveness can be correlated with a terminal-access time that is calculated by using the average station spacing and an assumed walking speed. These 3 variables also are used in the equation for the total perceived travel time, which is a function of walking, waiting, and line-haul, or riding, time. Studies have shown that users value or judge these times differently, and they should be weighted differently when a total perceived time is calculated.

Vehicle Size

System capacity is a function of both vehicle size and service frequency in a time period. Because knowing system vehicle size is desirable, vehicle spacing is taken as the average maximum waiting time, or the maximum time the user would have to wait with average vehicle spacing. By means of this time between vehicles, minimum system capacity would be found by using a vehicle of specified size. The function is formulated by using the vehicle size as the variable multiplied by 3,600 divided by average maximum waiting time in seconds to convert it to passengers per hour.

The subgoal equations for the goal-programming techniques therefore will be made up of the following constraints (inputs) and variables (outputs):

Constraint	Variable
Acceptable fare level	System costs
Average maximum waiting time for a vehicle	Average headways
System speeds	Average travel time
System extensiveness	Terminal access time
System capacity	Vehicle size
Total perceived travel time	Headway, travel speed, and terminal access time

These characteristics would serve to define quite clearly a group of systems with comparable performance. They also fit the previously specified requirements concerning reasonable availability of data.

MODEL FORMULATION

By using the constraints and variables determined previously, one can formulate the goal-programming model. More specifically, the model is developed by determining the allowable deviations and writing the "objective" equation.

Constraint Equations

A more extensive discussion of the use of goal programming and formulation of the equations can be found in the book by Lee (16). Basically, the constraints are set up in an equality format, with the d_x indicating positive (d^+) and negative (d^-) deviation from the constraint value. For the constraints where only 1 direction of deviation is allowable, only that deviation variable is included. The constraint or subgoal equations, then, are as follows:

$$A_2X_2 + A_3X_3 + A_4X_4 + d_1^- - d_1^+ = PTT \tag{1}$$

$$X_1 \le AF \qquad X_1 + d_2^- - d_2^+ = AF \tag{2}$$

$$X_2 \le WT \qquad X_2 - d_3^+ + d_3^- = WT \tag{3}$$

$$X_3 \le AT/SS \qquad X_3 + d_4^- - d_4^+ = AT/SS \tag{4}$$

$$X_4 \le EXT \qquad X_4 + d_5^- - d_5^+ = EXT \tag{5}$$

$$A_1X_5 \ge CAP \qquad A_1X_5 - d_6^+ = CAP \tag{6}$$

where

A_2,A_3,A_4 = weighting constants,

X_2 = headway,
X_3 = travel time,
X_4 = terminal access time,
PTT = perceived travel time,
X_1 = system costs,
AF = acceptable fare,
WT = average maximum waiting time,
AT = average trip length,
SS = system speed,
EXT = extensiveness,
A_1 = 3,600/average maximum waiting time,
X_5 = vehicle size, and
CAP = peak-hour capacity.

The constants in equation 1 are not specified, but are left for the transportation planners in the urban area to determine. The constants will reflect the weight placed by a particular area on each component of the total time. Studies have shown that waiting time generally is valued about 2.5 times more than riding time and that walking time generally is valued about 2.0 times more than riding time (11). However, these values do differ among studies, and other values can be chosen. It also should be noted that consideration of the constraint equations will show that capacity allows deviation in 1 direction only. In other words, the system capacity must be equal to or greater than the demand. The other 5 variables can vary up or down around the input value, although there is a desirable deviation direction in each case. An exception might be extensiveness if the acceptable absolute maximum walking time were used. If so, the equation could be adjusted accordingly by deleting the d^+ deviation from the constraint equation.

Objective Function

After the constraint equations are derived, the objective equation then is formulated to minimize the deviation variables. Priorities are assigned to each variable in the objective equation, and the program attempts to obtain the minimization of the subgoals with the highest priorities first. The priorities are assigned by the community in the manner desired. Here, the priorities are assumed to be in the order given below. The objective function is written to emphasize the direction of the desirable deviation in each case, and the basic equation becomes

$$\text{Min } Z = P_1 d_1^- + P_2 d_2^- + P_3 d_3^- + P_4 d_4^- + P_5 d_5^- + P_6 d_6^+ \qquad (7)$$

$$A_2 X_2 + A_3 X_3 + A_4 X_4 + d_1^- - d_1^+ = PTT \qquad (8)$$

$$X_1 + d_2^- - d_2^+ = AF \qquad (9)$$

$$X_2 - d_3^+ + d_3^- = WT \qquad (10)$$

$$X_3 + d_4^- - d_4^+ = AT/SS \qquad (11)$$

$$X_4 + d_5^- - d_5^+ = EXT \qquad (12)$$

$$A_1X_6 - d_6^+ = CAP \tag{13}$$

All values of X and d are equal to or greater than 0.

Solution Program

With this format, the goal program can be solved through a variety of methods, including graphic and simplex techniques. A computer program also was developed by Lee (16) for a wide variety of goal-programming applications, and this is used in the example application.

The priorities shown in the objective function deserve more discussion. By using the priorities, one considers the low-order goals only after higher order goals are achieved as desired. Therefore, the transportation planners must discuss the goals, decide which are most important for the community concerned, and order them accordingly. If the same priority is assigned to 2 subgoals, these subgoals must be commensurable, and a coefficient of regret must be used.

SYSTEM CHARACTERISTICS

After the goal-programming equations have been formulated and outputs have been obtained, alternative transit systems must be characterized to correlate them with the variable outputs. Also some boundaries must be set on the types of systems included. These boundaries were drawn basically to include current and proposed types of public transportation applicable for use in an urban situation for movement of larger numbers of people within the area.

System Groups

Dividing the various systems into general categories was more difficult than setting boundaries. It was felt that the 2 categories often used (line-haul, circulation) were not enough, but the 9 offered by Rea and Miller (22) were too detailed. Five major classes were chosen, and their characteristics are given in Table 1. The rail rapid transit class contains predominantly the traditional subway-type systems with variations in types of wheels, propulsion, and the like. Monorails also are included in this category. The rubber-tired bus operating on local streets is included in the bus group. These buses can use a variety of propulsion systems if at least separate bus lanes exist. A variety of systems, such as the one at Morgantown, fall in the jitney category. Jitneys generally operate on separate ROW and use small, automated vehicles. The electric car and other personal vehicles are in the personal-vehicle class. Some of these

Table 1. Transit system characteristics.

System Group	Costs (dollars/ passenger-mile)	Average Headway (sec)	Average Travel Speed (mph)	Terminal Access Time (sec)	Vehicle Size (passengers/ vehicle)	Necessity of Separate Right-of-Way
Rail rapid transit	0.241	120	25 to 40	300	60[a]	Yes
Bus	0.081	180 to 300	5 to 15	180	35 to 50	Optional
Jitney	0.060	10 to 60	10 to 20	180	6 to 30[a]	Yes
Personal vehicle	0.075	30	20	120	2	Optional
Moving walkway	0.045	5	2 to 8	72	0 to 2	Yes

Note: \$1/passenger-mile = \$0.625/passenger-km. 1 mph = 1.6 km/h.

[a] 10 cars/train.

vehicles are dual mode and all are assumed to be publicly owned. Mechanical pedestrian aids are found in the moving walkway category. These aids usually are some type of continuously moving belt system that permits frequent access. Most existing transportation systems fall within one of these categories. The categorization is quite general, but the system operating and performance characteristics in each group are similar. Values for each of the 5 variables as given in Table 1 were estimated in part on the basis of state-of-the-art projections.

It should be noted that Table 1 was derived from a wide variety of sources, and its compilation is a good example of the difficulty of evaluating systems without a systematic process. Vehicle size data came primarily from the study of systems by Handman et al. (9) and are based on seating capacity alone (standees were not considered). Average travel speeds came from Chilton (5), and this source also was used to supplement vehicle size data. Headway figures, particularly for the rail rapid transit, jitney, and moving walkway groups, were drawn from a study by the Transportation Research Institute (27); this study also contained considerable additional information on these systems.

Cost and terminal-access-time figures were difficult to obtain. Access time was found by multiplying half the average distance between stations by the walking speed of the normal pedestrian [3 mph (4.8 km/h)]. In no case was the distance used greater than 0.25 mile (0.4 km); to expect users to walk farther than this is unrealistic (31). Although these calculations have shortcomings, they provide a good basis for comparing the systems.

Cost information on the use of buses and rail rapid transit came from a study by Reed (23). This study is a detailed analysis of the cost of different trip lengths that uses transit methods versus the automobile. A paper by Levinson (17), which deals with smaller capacity systems (jitney and moving walkways), derived the cost figures for these groups. All figures included average construction costs and anticipated operating costs but were adjusted to exclude any ROW costs. The values given are for the time before the energy crisis, and, with inflation, the cost figures may in some cases be somewhat below current estimates. More accurate figures are difficult to determine because of economic conditions, but the ones given serve as a good basis for comparison.

Obtaining information on personal vehicles proved to be most difficult because of the limited number of proposed systems. As a result, much of the data came from the University of Pennsylvania (28) and was integrated with information on dual-mode systems such as StaRRcar.

The figures in Table 1 represent a summary of the data on the appropriate groups from a wide variety of sources. To be useful, the estimated values of system characteristics must be updated periodically as system technology advances and better data become available. The cost data are particularily fast changing and should be adjusted as demonstrations, actual applications, and economic conditions allow better estimates to be made.

A great deal more information could have been given concerning each system. For example, systems with separate ROW differ in social disruption and safety levels from systems without separate ROW. However, greater research of all the indicated systems is necessary before a detailed evaluation can be made. The option of a separate ROW is given because this is such a key factor and because performance with and without it can be markedly different.

Correlation of Variables

One must correlate the tabulated characteristics and the variable values to see which group of systems best fits the transportation needs. Simply making a manual match and noting which system contains the values of each variable are possible. Many times it will be obvious which group best fits the values. There may be situations, though, in which the values are scattered throughout different groups. In these cases, several alternatives must be considered. The first is a weighting evaluation system that consists of assigning weights to the variables according to their importance and totaling the weights in each group to see which scores highest. This is probably the least desirable; however, there are cases when it might be usable especially if the number of variables was significantly increased. Another alternative is to look at the group containing the greatest number of variables or the most important variable and correlate the other output variables with the performance values of this system group. An acceptable correlation may well be found for the others even if the variables do not fall directly within the range. A third alternative, if there are 2 groups of systems that contain the variables, is to attempt to blend the 2 systems to design a system that incorporates the desirable aspects of both. This would be most difficult, but it should at least be considered. A technology within 1 of the 2 groups may be closer to the other group than most, and slight modification would allow it to fit all the goals. The last alternative is a situation in which no single group is better than the others. In this situation, the transportation planners should look at their input values with a view toward modifying them. If their goals are so diverse that no system can fulfill them, then perhaps the values are not realistic. A careful reevaluation to make them more commensurate with each other would seem to be indicated in this case.

EXAMPLE APPLICATION

The example case was chosen to represent a typical, hypothetical set of community values to demonstrate the use of the goal-programming technique. The community is assumed to be of medium size with a population of around 500,000 in a central area of reasonably homogeneous travel demand. Peak-hour trips are projected to average 5,000 passengers/hour for the 1995 planning date because the area is not highly commuter oriented. The system chosen must have sufficient capacity to meet this demand, and a high level of service is expected.

A bus system previously operated in the area failed financially, and currently there is no public transit. In preparation for a new system, which was made necessary because of the crowded road conditions, a transportation planning group studied the transportation requirements and financial standing of the community. In conjunction with information found in the appropriate technical literature, a set of constraints for the new system was determined. For example, an average maximum waiting time of 40 sec was deemed desirable together with travel speeds averaging 20 mph (32 km/h) for the typical 3-mile (4.8-km) trip. Because accessibility to the system is important, a maximum walking time of 5 min to the terminals is specified. A study of current and potential transit users shows that a total perceived door-to-door trip of 20 min is acceptable to the majority of them. Operating expenses of communities of similar size with transit systems and modal-split cost data show that 8 cents/passenger-mile (5 cents/passenger-km) is a reasonable limit for fares. Results of a local survey show that the following weights are placed on the various aspects of travel time:

1. Riding time = 1.0,
2. Terminal waiting time = 2.5, and
3. Terminal access time = 2.0.

These values are inserted into the goal-programming equations and then processed by the computer program.

ANALYSIS OF RESULTS

For the stated example problem the results are:

Variable	Computed Value	Priority
PTT = $2.5X_2 + 1.0X_3 + 2.0X_4$, seconds	1,200	1
X_1, cents	8	2
X_2, seconds	40.0	3
X_3, seconds	540	4
X_4, seconds	280	5
X_5, passengers per vehicle	56	6

The analysis attempts to achieve each goal by meeting the constraints as closely as possible. PTT is achieved exactly; therefore it is given the highest priority. The results may be interpreted as showing the minimum values of system performance needed to satisfy all constraint equations. Because X_4 is rated lowest of the time-related factors, it is adjusted so that the first priority constraint of PTT = 1,200 sec would be met.

Because the program will adjust first the priorities of lowest value, care should be taken when assigning them so that the variables, when adjusted, will reflect the maximum attractiveness to the user. In other words, the variables that are deviated to meet the higher priorities of constraints (in this case, X_4) should be those that are important to the user. To have a system with a PTT of 1,200 sec and a 280-sec walk is probably better than to have one with a PTT of 1,200 sec, a 400-sec walk, and shorter ride because the user considers walking and waiting to be more distasteful than riding. Some initial rough calculations also might be helpful to ensure that the variables that will be adjusted have enough flexibility to absorb the deviation. In some cases, a variable might be reduced to 0, which would have little real meaning. If the equations are so complex that it is not readily apparent which variables will receive the deviation, a trial run could be made. If unrealistic values occur, then the priorities can be adjusted.

After the desired performance characteristics have been found, one has to correlate them with the data in Table 1. For the example, it is apparent that all the systems meet the cost constraint [8 cents/passenger-mile (5 cents/passenger-km)]; that jitney, personal vehicles, and moving walkway meet the headway requirements (less than 40 sec); and that rail, jitney, and personal vehicles meet the travel speed [20 mph (32 km/h)]. The terminal density constraint (280 sec) is met by all system groups except rail. Jitney, bus, and rail fulfill the capacity requirement (56 passengers/vehicle assuming multiple jitney cars). Therefore, jitney systems satisfy all the needed characteristics and should be evaluated further to determine which actual technology meets the full range of social, environmental, and transportation goals of the community.

It can be seen from this example that correlating results with the system characteristics gives a good indication of the needed systems. If additional constraints are needed or developed, the computer program can easily solve more complex problems. The fact that the variables are deviated in the order of lowest priority should be taken into account when deciding on the ordering of the variables. Those characteristics judged as most attractive should be lowered in priority in order to be adjusted in the direction of this attractiveness.

CONCLUSIONS

This study suggests the application of the goal-programming technique to urban transportation evaluation. The choice of variables, equations, and assumptions was made to keep the procedure simple and reasonably clear and to allow concentration on determining the usability of the goal-programming procedures for initial public transit assessment application. The main point is that the goal-programming technique is available for use in the assessment of highly complex transportation systems. This technique is of course only a part of the overall picture of transportation system planning, but techniques of this type can effectively indicate to the planner those systems that merit close evaluation for service performance.

For this technique to be usable in an actual application, each community would have to carefully evaluate its own goals and the assumptions made by this study and determine which conflicts occur. Making a model applicable without alterations to any urban situation would never be possible. Revision and tailoring of the procedures to each individual application are expected to be necessary. For example, suppose the community, after having determined which group of systems fits its transportation needs, evaluated these systems and decided that they were not satisfactorily compatible with its social and environmental goals or developing concerns such as energy consumption. If these social goals and energy consumption were considered more important than transportation goals, the community could determine constraint equations for the socioenvironmental goals that would fit into the goal-programming format along with the transportation performance goals and thereby integrate these aspects into the system evaluation.

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