Quantitative Methods for Evaluation and Selection of TSM Project Alternatives

DAVID REINKE AND DAVID CURRY

The evaluation of transportation system management (TSM) projects should ideally include a ranking of their relative desirability. Project ranking requires a consistent method of summarizing the evaluation of each project. Three methods of presenting the results of a TSM project evaluation are compared. These methods are quantitative techniques that were specified for evaluation and selection of TSM project alternatives in a 1982 study for the California Department of Transportation. The following findings are discussed. First, simple displays of project outcomes are useful adjuncts to cost-benefit information but are by themselves insufficient for aiding project decision making. Second, cost-benefit data clearly facilitate economic assessment of project alternatives. Third, cost-effectiveness information is highly prone to arbitrary assumptions and misinterpretations, especially when more than one effectiveness criterion is used, unless (a) the criteria can be expressed in a formula that relates noncostable outcomes to project cost and (b) no cost-benefit relations can validly be defined. These results are applicable to other states and can be used to evaluate construction and TSM projects.

Three ways to present the results of an evaluation of transportation system management (TSM) project alternatives are compared. At the simplest level, referred to here as an outcome display, TSM project results can be organized and listed. Two other ways--cost-benefit and cost-effectiveness analysis--can be used to aggregate and summarize information from the evaluation so that it is easier to interpret. Examples from actual TSM evaluations illustrate the three approaches and provide guidelines for each approach. A combination of outcome display and cost-benefit information is recommended in most cases.

The research for this paper was developed for a particular study (1), but its results can be applied to states other than California and to construction projects and TSM projects.

OUTCOME DISPLAY

A simple display of project outcomes by evaluation criteria can be a convenient way to summarize and compare projects. Table 1 (1, p. E-8) is an abridged version of a display of project outcomes from a prototype TSM study of a section of an urban arterial (2).

Although the table rates project outcomes only as positive, negative, or no effect, numerical results or rating scales could be displayed in place of the +, -, and o signs. A simple rating scale is often useful because the results can then be added--assuming that care is taken to avoid double counting and nonlinear rating scales. An example of a numerical performance scale is 0 = unacceptable (a fatal flaw), 1 = poor, 2 = good, and 3 = excellent.

We recommend a scale of no more than five points in order to keep the rating simple. Considerable creativity is possible in the choice of adjectives or numbers represented by a numerical scale, and the adjective or number can differ by outcome. For example, air quality effects could be rated by the scale given above, while noise level ratings could be expressed in dbA, and equity of financing by a scale for which 0 = very discriminatory, 1 = discriminatory, 2 = somewhat nondiscriminatory, and 3 = nondiscriminatory.

The advantage of outcome displays is that they allow easy comparison between projects according to any set of evaluation criteria. The format shown also provides ready reference back to the original problem statement because outcomes related to specific project objectives are themselves specified as criteria. The disadvantage of such a table is that there is no single figure of economic merit; therefore, choices among alternatives may have to be made on highly subjective grounds. For example, the alternative in Table 1 that is marked not recommended has more o and - ratings than the recommended alternatives. But it does not require much imagination to visualize a group of project alternatives among which the choice is not obvious.

Two issues that the outcome display helps to illuminate are the choice of evaluation criteria and consideration of the effects of trade-offs between different objectives. The evaluation criteria should be based on the transportation system objectives, and their number should be kept small (1). They should address all important objectives of the project in question but be omitted for minor objectives or for outcomes that are not significant.

Trade-offs among project features could be analyzed by varying the scale, location, timing, or focus of a project and noting the incremental effects on cost and other outcomes in other columns of the same table or in a separate table. Consideration of trade-offs is one way to generate additional project alternatives, which is not often done in evaluations of TSM projects. Generally, the alternatives can most readily be considered in the order of increasing cost, with each increment of cost (compared with other acceptable alternatives) considered separately.

The outcome display should be used as a first step in any evaluation because it is easy to generate, it may serve the purposes of the decision in question, and it provides an intuitively useful summary. Whether to proceed with the greater quantification requirements of cost-benefit or cost-effectiveness analyses will depend on the value of the information they add. The original outcome display

Table 1. Example of outcome display.

	Candidate TSM Project		
Evaluation Criteria	Signal Interconnect	Eliminate 10 Curb Cuts	Expand Park-and-Ride Lots
Corridor mobility			
Transit use	+	o	+
Commercial vehicle trips	+	-	o
Peak-period trips	+	+	+
Travel-time delay	+	+	+
Safety: accident rate	+	+	
Social and environmental			
Air quality	+	o	+
Energy use	+	o	
Transit rider comfort and convenience	o	o	+
Existing land use: local access to local commercial and industrial center	+	-	
Cost ($)	150 000	66 000	100 000
Result	Recommend	Not recommend	Recommend

Note: + = positive effect, - = negative effect, and o = no effect.

should also be used to complement a cost-benefit or cost-effectiveness summary.

COST-BENEFIT ANALYSIS

Cost-benefit analysis is a method of aggregating outcomes that can be assigned a monetary value into a single measure. A frequently used criterion that summarizes the results of an economic evaluation is the benefit/cost ratio, which is computed as follows:

1. Add up all project or program costs,
2. Assign dollar values to outcomes when possible (e.g., value of time saved, value per accident reduced) and compute a total dollar figure to represent the value of the benefits, and
3. Find the ratio of benefits to costs.

Benefit/cost ratios of 1.0 or greater are judged to be favorable. Equivalent criteria are the cost per dollar of benefits, for which amounts under $1 are judged to be favorable, or the internal rate of return, for which rates above the minimum attractive rate of return are favorable. With any of these criteria, important results that cannot readily be valued in dollars can still be considered in the form of the outcome display just described.

The authoritative guide to highway cost-benefit analysis is the 1977 AASHTO report (3). Cost-benefit analysis has also been applied to TSM projects according to the guidelines in that report. Two examples are shown in Tables 2 (4, p. 2-15) and 3 (4, p. 2-19), which deal, respectively, with parking management and flextime promotion programs of Seattle Commuter Pool, a regional ridesharing agency (4). The tables are self-explanatory, moving in sequence from outcomes to benefits to costs to the calculation of benefit/cost ratios.

The source report also evaluates Commuter Pool's vanpool and ride-matching programs in the same manner, obtaining benefit/cost ratios of 11 to 21 for vanpools and 53 for the ride-match services. With ratios of 11 to 14 for parking management (in Table 2), these indicate impressive economic justifications for ridesharing programs. The ratio of 101 for flextime in Table 3 is unusually high due to inclusion of productivity benefits (line d). For the Seattle evaluation, the economic merit of these programs was the principal evaluation criterion of interest, so no additional information was presented except for the efficiency measure in line h of Table 2 and the footnote regarding outside use of the flextime manual in Table 3.

Users of cost-benefit analyses should, however, be aware of several points. Whenever a cost-benefit analysis is used to evaluate projects whose outcomes are considered over more than 5 years, future costs and benefits should be discounted in order to compute their equivalent present or annual value. This is especially important when the projects being compared have different patterns of costs and benefits over time. The interest rate for discounting should generally be 4 percent [the approximate long-range cost of capital, assuming the use of constant dollars (no inflation)]. If future costs and benefits are inflated, the discount rate and the inflation rate should be combined. For example, if an inflation rate of 10 percent is used, the combined rate will be (4 percent x 10 percent) + 10 percent, or 10.4 percent.

If a project entails any significant risks or uncertainty, there are three simple ways to allow for it:

1. Add 1 to 2 percent to the discount rate,
2. Increase the minimum acceptable benefit/cost ratio to between 1.1 and 1.2, or
3. Estimate the range of possible outcomes rather than the most likely single numbers.

Table 2. Parking management evaluation.

Evaluation Criteria	Description	Value
Outcomes	a. New downtown parking carpool registrations	292
	b. New park-and-pool carpools: 1500 spaces maintained x 35 percent occupancy rate	525
	c. New high-occupancy vehicle (HOV) priority parking spaces facilitated at employment sites (estimate)	300
Benefits	d. User benefits per new carpool ($)	4830
	e. Land use benefits per new carpool = 0.94 space saved per pool x $1.80/day x 250 working days/year x 12.66 (present worth factor for 18 years at 4 percent) ($)	5355
	f. Total benefits = (a + b + c) x 20 percent influenced to pool x (d + e) ($)	2 275 300
Cost	g. 1980 cost of parking management element ($)	161 000
Efficiency measure	h. Program cost per new HOV space = g/(a + b + c) ($)	155
1980 benefit/cost ratio	i. Benefit/cost ratio = f/g	14
Typical benefit/cost ratio	j. Benefit/cost ratio with b reduced to 167 (b ÷ 2.7 years) to reflect replacement carpools only	11

Table 3. Flextime promotion.

Evaluation Criteria	Description	Value
Outcomes	a. Commuter Pool survey results: 3374 employees in Seattle area firms assisted to convert to flextime in 1980 x 0.5 to discount for other influences on cooperating employers	1687[a]
	b. Estimated persons induced to rideshare by flextime introduction = a x 0.096	162
Benefits	c. Average daily time saved per flextimer = 2.3 min/trip (one-half of Boston experience) x 2 trips/day x $0.05/min value of time ($)	0.23
	d. Daily value of increased productivity per worker ($)	0.50
	e. One-time employer implementation cost per worker ($)	100
	f. Total benefits = a(c + d) x 250 working days/year x 15.62 [present worth factor for 25 years at 4 percent (total, $4 809 000)] + b x $2100 benefits per carpooler (total, $34 000) – a x f (total, $168 700) ($)	4 674 300
Costs	g. 1980 cost of flextime promotion ($)	46 500
Benefit/cost ratio	h. Benefit/cost ratio = f/g	101

[a]In addition, the Commuter Pool flextime manual was sold to other companies outside of the Seattle area that have adopted flextime, including Crocker Bank in San Francisco with 17 000 employees.

More sophisticated ways of dealing with risk entail assigning probabilities to different outcomes, but this is unlikely to be necessary in TSM studies.

The value of time will be an important issue in the economic evaluation of many TSM projects. First, there is no definite standard for the value of time to be used. Various studies of traveler behavior show that travelers tend to value in-vehicle time (e.g., driving time and on-board transit time) between 20 and 130 percent of their wage rate, and out-of-vehicle time (e.g., waiting time for transit) by a factor between 2 and 3 times higher than in-vehicle time. A reasonable standard would be to use half the average wage rate for in-vehicle time and the full wage rate for out-of-vehicle time. A related problem is that the relative value of time for travel under different conditions has not been clearly identified. For example, there is probably a higher value placed on driving than on riding in a carpool or vanpool, and a higher value on standing in a transit vehicle than riding in a comfortable seat where reading is possible; but no one knows by how much.

Another issue in valuing time savings is that research has clearly shown that the perceived value of travel-time savings varies with the purpose of the trip and with the amount of time saved per trip (3). Savings under 5 min/trip have low values and only savings of 15 min or more are fully valued at the rates cited above. Many transportation providers ignore this finding or argue that the data for applying it are not always available. We recommend either a precise or an approximate method of valuing time savings, depending on the rigor required in the study. The precise method is to ignore time differences per trip of 5 min or less, use straight-line interpolation for savings between 5 and 15 min, and use the full values for savings of 15 min or more per trip. The approximate method is to ignore savings under 10 min/trip and use the full value for savings of 10 min or more, which will avoid the need to value time in all but the most dramatic types of improvements. Whatever the standard used, it should be applied uniformly across the region; this is another coordination task for the regional transportation planning agency.

Benefit/cost ratios can be misleading if there is no standard way to categorize costs and benefits. For example, one of the outcomes of a ridesharing program will be that some transit users will become carpoolers. Depending on the amount of transit fares lost as a result, the benefit/cost ratio could be different if this value is treated as a benefit to users rather than as a cost to the transit agency. The treatment should depend on whose point of view is being considered. If it is the traveler's point of view, which is usual, the savings in fares are clearly a benefit and offset any similar costs for the ridesharing journey. A definite standard for classifying such outcomes should be used for all analyses in the region.

Like all aggregate measures, the computation of a benefit/cost ratio results in some loss of information. There may be other problems with using this measure, particularly how to value various outcomes. Cost-benefit analysis is, however, a useful technique for quickly summarizing large amounts of information, especially when there are many different types of outcomes to consider in the evaluation. Moreover, use of this method does not preclude the consideration of other outcomes that cannot be valued in dollars or are not quantifiable; in fact, it can help bring these to the forefront because a large number of other outcomes will have been aggregated. Therefore, this method should be used only under the following conditions:

1. Several outcomes must be considered, and cost-benefit analysis can usefully summarize some of them; or there is interest in the economic merit of the project or in the relative economic merits of alternative projects; and
2. Standard procedures are followed to resolve issues about valuation of outcomes, interest rates, and classification of outcomes.

Cost-benefit analysis does not relieve the planning agency of its responsibilities to note all significant project outcomes--quantifiable or not--and to identify and analyze significant trade-offs. The use of a simple outcome display, as discussed in the previous section, can therefore be a useful supplement.

COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness analysis entails the calculation of one or more indices for a project, each of which is the ratio of project costs to some outcome measure. If there is a single predominant goal for the project, such as reducing delay or increasing capacity, total project costs can be assigned to a single associated cost-effectiveness index such as cost per passenger-minute saved or cost per added vehicle per hour of capacity.

The table below (5, p. II-22) gives an example of a single cost-effectiveness index--cost per vehicle mile of travel (VMT) reduced--for the Golden Gate Bridge, Highway, and Transportation District (GGBHTD) vanpool project (5); the table also gives an alternative index--program cost per dollar of user benefit--which is simply an inverse benefit/cost ratio:

Evaluation Criteria	Value
Eligible users	45 000
Program characteristic (annual)	
One-way trips served	312 500
Program cost ($)	264 300
VMT reduced	6 800 000
User benefits ($)	1 079 800
Performance measure ($)	
Program cost per VMT reduced	0.039
Program cost per dollar of user benefit	0.24

[Note that costs are expressed in 1980 dollars, and all costs and benefits (including VMT reductions) are present values obtained by using a 10 percent discount rate over a 5-year program period.]

It is immediately apparent from the latter index (program cost per dollar of user benefit) that this is an attractive project economically because only $0.24 in program costs produced $1 in user benefits. By comparison, the $0.039 cost per VMT reduced is less clear and requires more information before it can be understood, in particular:

1. What is a reduction of one VMT worth?
2. Is $0.039 an attractive cost per VMT in comparison with its value?
3. Is VMT reduction the only goal of the GGBHTD vanpool program? If there are other goals, such as reducing air pollution or energy consumption, should not part of the program cost be allocated to the other goals?

A usual practice is to allocate program costs among different goals in calculating multiple cost-effectiveness measures in order to avoid double counting. But such allocations are arbitrary because there is no intuitive or commonly accepted way to arrive at the correct allocation. Moreover, the resulting cost-effectiveness measures are usually difficult to interpret and may produce conflicting results unless a fortunate choice of cost allocations has been made.

Table 4 (6, p. 120) gives an example of such a cost allocation for an evaluation of four alternatives for mixed-mode operations on the San Bernardino Freeway Busway. Option A is the addition of two unrestricted freeway lanes only, and option B is the busway as actually constructed. Option C is a lower-cost busway with less-cost-effective features omitted, and option D is the same as option C with reversible, contiguous lanes (which are similar to the Shirley Highway Busway approaching Washington, D.C.). The allocation is made by assigning a relative importance to each cost, and then allocating the costs of each option among the results according to these weights.

The cost-effectiveness indices for the first two goals in Table 4, measured respectively by person-trips per assigned dollar and assigned dollars per person-hour saved, are shown in Figures 1 (6, p. 121) and 2 (6, p. 123). Figure 1 shows that option D is superior to the other options in person-trips per assigned dollar (note that lined blocks are based on the peak hour and the total is based on the peak 4 hr). Figure 2 shows that options C and D have a lower assigned cost per person-hour saved--on the order of $4.20 compared with $5 for stage 2 of option B.

But the analysis begs the question: What is a reasonable cost per person-hour saved? If a reasonable cost is $4, then all options are too expensive; or if a reasonable cost if $6, then all options are acceptable by this criterion. If only 10 percent rather than 20 percent of total costs were assigned to improved level of service, the assigned costs per person-hour saved would be only half of the numbers shown in Figure 2.

This example shows the hazards of cost-effectiveness analysis where there are two or more goals. In contrast, the cost-benefit analysis adds up the dollar value of travel-time savings, reduced travel costs, improved safety, energy saving, and, if possible, air pollutant emissions. This would combine the value of the outcomes for five of the seven goals given in Table 4. If benefits exceed costs based on these outcomes, added capacity and provision for future contingencies can simply be regarded as nonpriced fringe benefits. If total benefits still do not exceed total costs, then only one question remains to be answered: Is the value of any added capacity or added provisions for future contingencies offered by an option large enough that benefits would exceed costs? This may not be a simple question, but dealing with it is easier than dealing with seven independent goals and corresponding criteria in a cost-effectiveness framework.

There is one valid way of including multiple measures of effectiveness in a cost-effectiveness framework that avoids the procedure of allocating project costs among different goals. This is the practice of expressing the criterion in a formula that contains two or more terms, where each term identifies an outcome not readily valued in dollars. For example, the following cost-effectiveness index is used by the California Department of Transportation (Caltrans) for ranking roadside noise barriers:

$$\text{Noise attenuation index} = [R \times (E - 70\ \text{dbA})^2 \times N]/C \quad (1)$$

where

R = noise reduction achievable by sound barrier (dbA),

Table 4. Relative cost of options assigned to each goal for San Bernardino Freeway busway.

Goal	Relative Importance (%)	Equivalent Annual Cost by Option ($000s) A	B	C	D
Added capacity	20	310	1528	1245	1232
Improved level of service	20	310	1528	1245	1232
Reduced cost of travel	20	310	1528	1245	1232
Improved safety	15	232	1146	934	924
Reduced environmental impacts					
Air pollutants	10	155	764	622	616
Energy savings	10	155	764	622	616
Future contingencies	5	77	382	311	308
Total		1549	7640	6224	6160

Figure 1. Capacity cost-effectiveness.

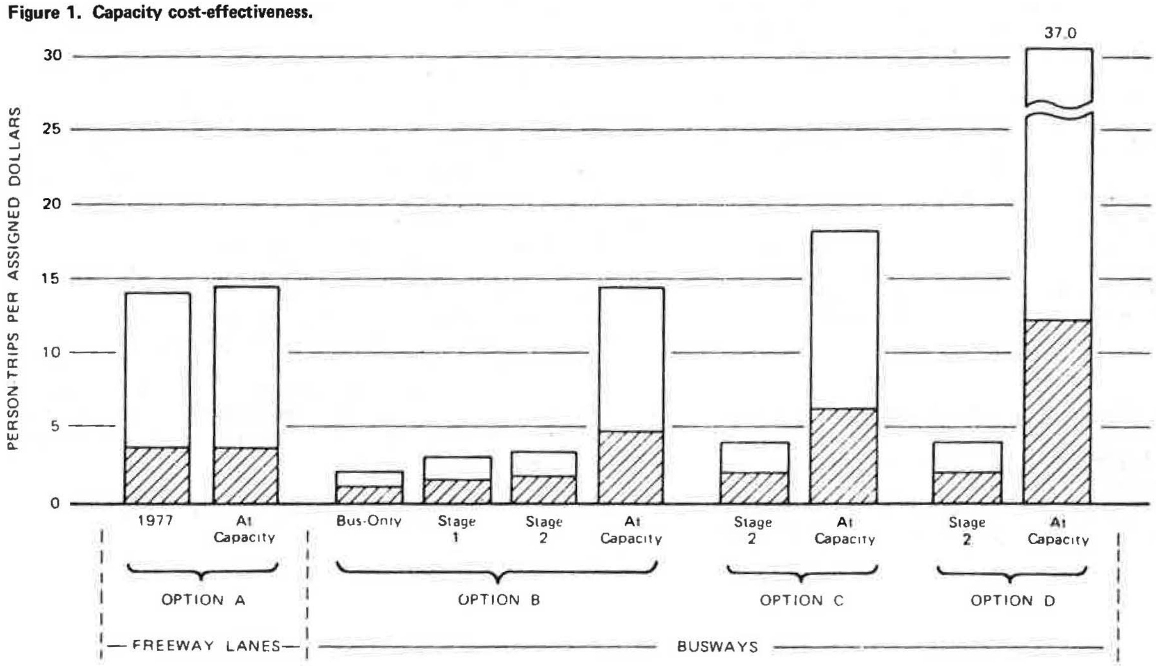
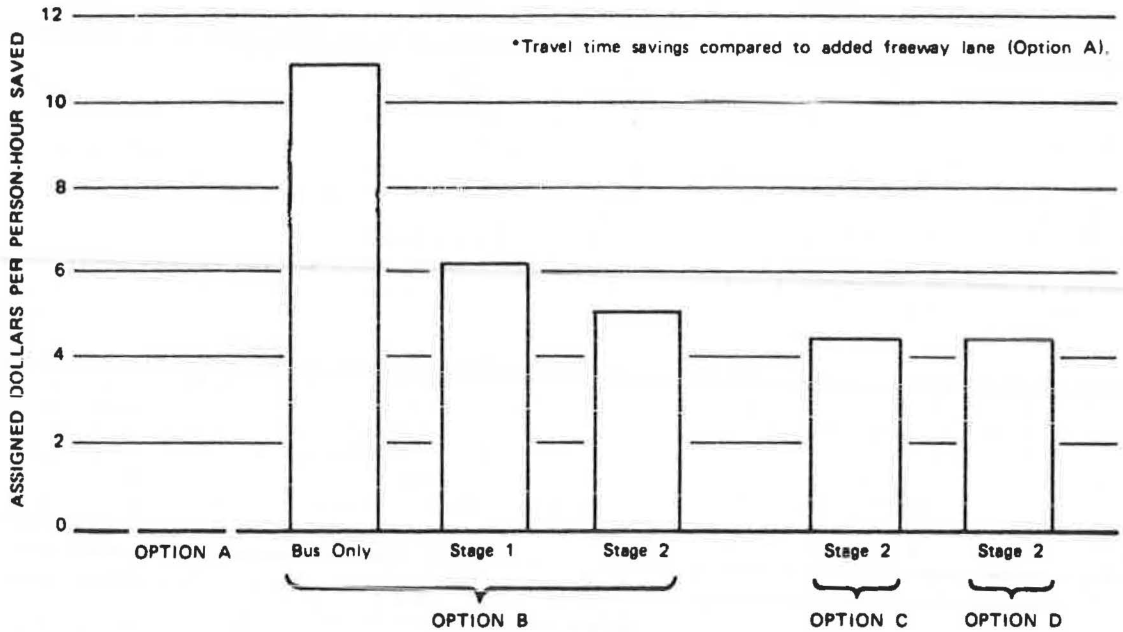


Figure 2. Travel-time cost-effectiveness.



E = existing noise level (dbA) at the first row of houses from the highway,
N = number of dwelling units benefited by noise barrier, and
C = project cost ($000s).

There are no known examples of this approach to TSM projects, and the approach can be recommended only when a cost-benefit analysis is not feasible.

In summary, cost-effectiveness has the appeal that it can be simpler than cost-benefit analysis when only a single effectiveness measure is used because benefits do not have to be valued in dollars. But a cost-effectiveness analysis has several serious disadvantages:

1. When there is more than one important result, project costs must be allocated among the different results in some arbitrary way (unless the formula approach just illustrated for a noise attentuation index is used).
2. Cost-effectiveness criteria do not permit selecting or ranking of project alternatives with multiple outcomes unless, by chance, one project alternative is clearly superior for all outcomes.
3. Cost-effectiveness criteria do not show whether or not a project is economically attractive unless thresholds of desirability (e.g., $5/person-hr saved) are set for all criteria. But doing that would enable direct computation of the benefits and a much simpler cost-benefit display of results.

CONCLUSIONS

Ranking of TSM projects requires a consistent method for summarizing the results of the evaluation of each project alternative. We have discussed three methods for summarizing the evaluation results: outcome display, cost-benefit analysis, and cost-effectiveness analysis. A simple display of outcomes is a useful first step in summarizing the evaluation and is also a useful supplement to any further analysis. We prefer cost-benefit analysis as a consistent way to combine project outcomes that can be valued in dollars; however, use of this method does not relieve the planner of the responsibility for considering other important outcomes that cannot be conveniently included in the cost-benefit analysis. We recommend cost-effectiveness analysis only for evaluating TSM project alternatives that have a single important outcome that cannot be readily valued in dollars.

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