Measuring Cost-Effectiveness of Rail Transit Projects

R. S. MARSHMENT

UMTA evaluates the cost-effectiveness of competing rail transit projects by using an index proposing to measure the average cost per new rider of shifting from all-bus service to rail transit. The unusual manner in which costs and benefits are measured and included in the UMTA cost-effectiveness formula prompts this investigation of the ability of the index to identify desirable projects when the selection criterion is an excess of benefits over costs. The methodology uses 10 economic assumptions and an investment model for evaluating rail projects. Using the model, the UMTA cost-effectiveness index and an alternative index incorporating nonuser benefits are computed for three projects. By ranking the projects according to the net benefits they generate, the UMTA index is shown to be an unreliable indicator of economic efficiency.

UMTA is charged under Section 3(i) of the Urban Mass Transportation Act of 1964, as amended, with assisting in the development of those fixed guideway mass transit projects that are demonstrated through the evaluation of alternatives to be cost-effective. This legislative mandate acknowledges UMTA's practice, instituted in 1984, of requiring urban areas seeking federal financial assistance for rail transit projects to employ standardized planning practices and measures of costs and benefits. UMTA maintains that cost-effectiveness computed according to its protocol is a valid indicator of project merit when the comparison is among rail projects proposed by various urban areas.

The UMTA cost-effectiveness index can be approximately described as the annualized average cost per new transit rider attracted by a rail investment compared with improved bus service. UMTA prefers projects with cost-effectiveness indexes less than $6.00. Projects meeting this threshold and passing other environmental and financial tests are permitted to advance toward construction. Congress renders final judgment on project financing and has modified UMTA staff recommendations from time to time (*1*).

The need for criteria by which to judge the merits of competing fixed guideway projects is obvious. Nevertheless, many criticisms have been leveled against the UMTA cost-effectiveness index. Some of this criticism concerns perceived inequities in the way UMTA requires certain computations to be performed and costs and benefits measured (*2,3*). UMTA admits to interpretation difficulties when the index takes on negative values and when there are high-occupancy vehicle components in a project (*4*). This paper suggests that many of the problems with the UMTA index can be traced to its initial improper specification. By close examination of the assumptions underlying UMTA's cost-effectiveness index, the measure can be shown to be an ambiguous indicator of project merit that potentially leads to inferior project selection.

UMTA COST-EFFECTIVENESS INDEX

UMTA describes the method of computing the cost-effectiveness index in draft guidelines published in 1986 (*4*). Equation 1 summarizes the calculation that is made for a single year at the end of a 15-year period.

$$CEI = \frac{\Delta\$CAP + \Delta\$O\&M - B(v_b)}{\Delta v} \quad (1)$$

where

$$\Delta\$CAP = \$CAP_r(v_r) - \$CAP_b(v_b) \quad (2)$$

$$\Delta\$O\&M = \$O\&M_r(v_r) - \$O\&M_b(v_b) \quad (3)$$

$$B(v_b) = \$TT_r(v_b) - \$TT_b(v_b) \quad (4)$$

$$\Delta v = v_r - v_b \quad (5)$$

and

r = the fixed guideway alternative,
b = the best all-bus alternative,
$\$CAP$ = annualized capital cost,
$\$O\&M$ = annualized operating and maintenance cost,
$\$TT$ = travel time cost,
B = user benefits, and
v = annual patronage.

All cost terms in Equation 1 are annualized 1-year totals expressed in current dollars.

UMTA imposes strict guidelines on the number and type of engineering studies that must be performed to develop cost estimates and patronage forecasts (*5*). For example, estimates of capital, operating, and maintenance costs must be developed in parallel with patronage forecasts to ensure a minimum-cost solution. This requirement justifies expressing the cost terms in Equations 2 and 3 as functions of passenger volumes. Benefits to travelers who would patronize the bus alternative are measured in dollars and weighted by trip purpose and are included in the numerator of Equation 1 as an offset to sponsor costs.

UMTA specifies that at least three alternatives be examined in a fixed guideway study: (a) the no-build plan; (b) a trans-

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Division of Regional and City Planning, University of Oklahoma, Norman, Okla. 73072.

portation system management (TSM) plan; and (c) the fixed guideway alternative(s). The no-build alternative serves as the benchmark for assessing the social and environmental consequences of the proposed action but is not involved in determining cost-effectiveness, which is computed by comparing the TSM and fixed guideway alternatives. The TSM plan allows for significant improvements in corridor transit service using only existing infrastructure, that is, without construction of a new transit guideway. The TSM plan represents the best all-bus program of service and facility improvements and is identified as the bus alternative in Equations 2 through 5. Compared with rail transit investments, TSM plans will be relatively low cost, emphasizing demand management and operational strategies.

ASSUMPTIONS

Projects generating benefits that exceed costs are economically efficient and may warrant investment. Strict application of this economic efficiency test to rail transit investments is not practical given current capabilities to forecast benefits for the life of durable rail transit lines (*3*). As a compromise, the UMTA cost-effectiveness index is computed by using annualized costs and predicted annual patronage 15 years in the future.

Technical limitations in forecasting patronage and calculating benefits cannot be resolved in the short term. Consequently, to develop a mechanism for ranking competing projects that depends on an economic efficiency criterion, UMTA has made nine simplifying (and unstated) assumptions:

1. There are economically efficient projects in which to invest;
2. TSM investments are always economically efficient;
3. Conditions in a single horizon year represent conditions for all previous and subsequent years;
4. The price of travel equals marginal user cost;
5. There are scale economies in corridor transit service;
6. Transit demand is downward sloping and linear;
7. Nonuser benefits vary directly with changes in transit patronage;
8. Work-trip travel time savings are twice as valuable as non-work-trip savings; and
9. The value of travel time does not vary with income.

Assumption 1 is justified by the willingness of all levels of government to spend money on rail mass transit projects. The effect of Assumption 2 is to require that rail transit investments provide more net benefits than a lesser investment in expanded bus service. UMTA reasons that the TSM plan, rather than the no-build alternative, is the best benchmark for comparison because the benefits and costs of the build alternatives are better isolated.

In many cases, the TSM alternative presents an opportunity to identify improvements that are desirable today. Therefore, potentially large benefits are available from making changes in a do-nothing alternative that is largely based on today's situation. Because these benefits are independent of any major investment, they should not be attributed to the guideway options. This miscounting of benefits cannot be avoided if the do-nothing is used as the baseline since the average measures of cost-effectiveness would include the benefits of the TSM improvements over the do-nothing alternative. This problem is avoided if the TSM alternative serves as the baseline because the benefits produced by the TSM actions do not enter into the calculations (*4*).

Assumption 3 is not compelling, since patronage growth can vary from area to area. The alternatives to this assumption are not appealing: (a) develop models to predict patronage in each year for the life of the project; (b) interpolate between two or more patronage forecasts; or (c) delete user benefits from the cost-effectiveness assessment.

UMTA's insistence that unit operating and maintenance costs be minimized for a given level of demand, a process known as equilibration, justifies the assumption of marginal-cost pricing (Assumption 4). In practice, the UMTA methodology results in passengers paying a marginal user cost.

Assumption 5 indicates that average costs are falling over the range of patronage volumes at which new rail transit lines operate. The need for public subsidies to construct and operate rail transit is well documented, which supports a low-demand investment environment (*6*). A downward sloping demand curve (Assumption 6) is the standard assumption, although the specification of a liner relationship is a computational convenience.

Assumption 7 has not been empirically substantiated but appears to have some merit (*7*). Auto trips diverted to transit do generate nonuser benefits, such as air quality improvement, energy savings, and congestion reduction. It is less clear that the change in transit volume is the proper indicator of these nonuser benefits. Assumptions 8 and 9 are used to establish the dollar value of user benefits (*8*).

EVALUATING BUS AND RAIL TRANSIT INVESTMENTS

To be funded by UMTA, a proposed rail transit investment should satisfy two criteria. First, the investment should be economically efficient, i.e., total benefits should exceed incremental costs. Second, because there may be more projects satisfying the first criterion than there is money, those projects generating the greatest surplus of benefits over costs should be funded first.

Congress has directed UMTA to assist in developing cost-effective fixed guideway transit projects because of a belief that there exist rail transit projects that produce total (user and nonuser) benefits higher than costs. Because few rail transit projects generate more user benefits than costs, a project must produce significant nonuser benefits to be economically efficient. But nonuser benefits are difficult to measure in dollar terms, and UMTA specifically proscribes their use in calculating cost-effectiveness.

UMTA incorporates nonuser benefits in its project evaluations in two ways. First, UMTA favors projects in which local financial participation in the capital cost exceeds the minimum required. The difference between the minimum required and the amount locally committed is regarded as the shadow price of nonuser benefits. The second method rests on the assumption that the principal means by which a rail project generates nonuser benefits is through diversion of auto

TABLE 1 ALTERNATIVE TRANSIT INVESTMENTS IN THREE CITIES

	Project					
	One		Two		Three	
	Rail	Bus	Rail	Bus	Rail	Bus
Volume (v)	39.39	20.00	59.00	44.00	67.29	61.79
Capital Cost ($)	40.00	10.00	40.00	10.00	40.00	10.00
Operating and Maintenance Cost ($)	17.83	21.71	20.11	33.45	20.50	35.97
Marginal Cost	0.09	0.43	0.08	0.12	0.12	0.27
Benefits to Existing Users ($)	6.73		1.66		9.03	
Benefits to New Riders ($)	3.26		0.28		0.40	
Cost Effectiveness (*CEI*)	1.00		1.00		1.00	
Cost Effectiveness (n)	4.95		52.57		12.75	

Costs and volumes in millions.

drivers to transit. Thus, the denominator in Equation 1, the number of new riders, does double duty. It measures a component of user benefits, namely, the number of new riders, and indirectly represents nonuser benefits, which is allowed by Assumption 7.

This method of incorporating nonuser benefits is cumbersome and unsystematic and rests on controversial assumptions about willingness and ability to pay. One particularly troubling feature of the UMTA procedure is the use of two different measures of benefits—the dollar value of travel time savings for one group and the number of new riders for the other. The more traditional approach is to value all benefits in terms of the value of the travel time savings (*9–11*).

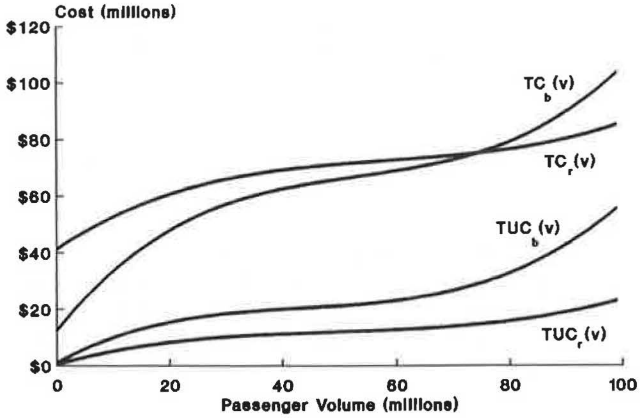

FIGURE 1 Long-run total and user cost model of corridor transit service.

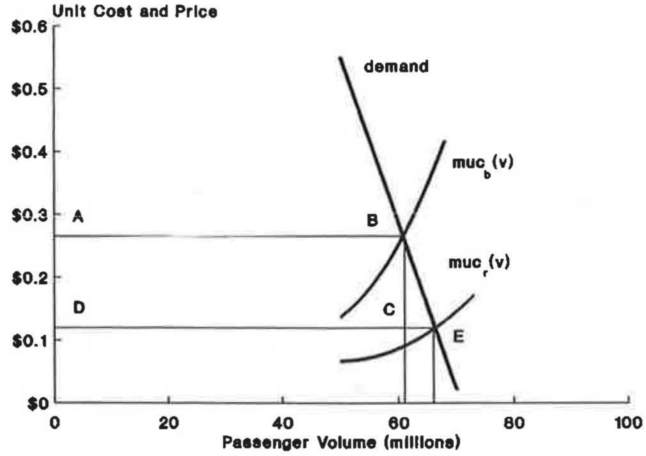

FIGURE 2 User benefits.

Calculating Cost-Effectiveness

The discussion that follows makes use of the variables already introduced plus the following nomenclature:

$TC_m(v)$ = the sum of the annualized capital, operating, maintenance, and user costs for a corridor public transportation investment ($m = r$ for rail and $m = b$ for bus) designed for volume v;

$TUC_m(v)$ = total user cost, obtained by subtracting capital, operating, and maintenance costs from total costs;

$TB_m(v)$ = the sum of the annualized benefits to patrons of the all-bus alternatives, $B(v_b)$, benefits to new riders, $B(v_r - v_b)$, and benefits to nonusers, $NB\ (v_r - v_b)$; and

$muc_m(v)$ = marginal user cost.

Equation 6 expresses Assumption 7 as a linear function of new rider benefits:

$$NB(v_r - v_b) = n[B(v_r - v_b)] \qquad (6)$$

where n is a multiplier that links new rider and nonuser benefits.

Project 3 in Table 1 and the investment environment depicted in Figures 1 and 2 illustrate how UMTA computes cost-effectiveness. To be consistent with UMTA definitions, all costs in Table 1 and Figures 1 and 2 are 1-year annualized values and include a 10 percent return on investment. Because scale economies are assumed, only the portions of the curves in which average costs are falling are germane to the analysis. Two alternative investments are shown in Figures 1 and 2; one, an improved bus option and the other, a rail investment. All three projects in Table 1 were derived from the cost curves in Figures 1 and 2; note that the capital cost is the same for all project combinations, implying that all regions have the same construction and operating cost functions.

In Figure 1, $TC_r(v)$ is a flatter curve than $TC_b(v)$, reflecting the greater productivity of rail transit at high passenger volumes (*12–14*). The capital cost of the rail option is higher than the bus investment, as indicated by the larger y-intercept of the rail alternative. Total user costs, which are a component of total cost, are also shown.

Figure 2 is derived from Figure 1. Marginal user costs are the first derivatives of the total user cost functions in Figure 1. If demand is taken to represent marginal benefit, benefits to existing users $[B(v_b)]$ are the dollar value of the travel time savings resulting from the rail investment realized by patrons of the TSM option. For Project 3, Figure 2 depicts benefits to existing users as the rectangular area $ABCD$, which is equal to the marginal user cost savings per trip, resulting from the investment multiplied by the number of bus riders.

Although marginal user cost will not ordinarily be known, the difference between marginal user cost for the rail and bus alternatives can be derived from benefits to existing riders, which is known. Planning agencies estimate benefits to existing riders by summing the product of the number of TSM patrons and the travel time savings for each zone pair in which a change in travel time has occurred as a result of the proposed rail investment. These time savings are converted to dollar equivalent values by multiplying by the value of time for various trip purposes. Dividing the benefits to bus riders computed in this manner by the number of bus riders yields the difference in marginal user cost. In Figure 2, this value is equivalent to dividing the rectangular area $ABCD$ by volume $v_b = 61.79$ million annual bus passengers.

The dollar value of benefits to new riders is the triangular area BCE in Figure 2, computed according to Equation 7.

$$B(v_r - v_b) = 0.5\,(v_r - v_b)\,[muc(v_b) - muc(v_r)] \tag{7}$$

The UMTA index is derived according to Equation 1. For Project 3, the calculation is

$$CEI = \frac{(40.00 - 10.00) - (20.50 - 35.97) - [(0.27 - 0.12)(61.79)]}{67.29 - 61.79}$$

After allowing for rounding, all of the projects in Table 1 have UMTA cost-effectiveness indexes equal to 1.0. On the basis of these indexes, UMTA should be indifferent about which of the projects to fund; all of the projects involve the same capital cost.

Incorporating Nonuser Benefits

Most interpretation problems with the UMTA index can be traced to the peculiar manner in which costs and benefits are commingled. To demonstrate this point, consider that the following inequality is a criterion for economic efficiency:

$$\Delta\$CAP + \Delta\$O\&M < B(v_b) + B(v_r - v_b) + NB(v_r - v_b) \tag{8}$$

Substituting Equation 6 into Equation 8 and solving for n yields

$$n > \frac{\Delta\$CAP + \Delta\$O\&M - B(v_b) - B(v_r - v_b)}{B(v_r - v_b)} \tag{9}$$

Assumption 1 establishes that there are economically efficient investments. Of these economically efficient investments, the minimally acceptable project has total benefits just equal to incremental cost. Assigning the value n^* to the multiplier for the minimally acceptable project, any other project that has a lower value of n would be preferable to a project whose multiplier is n^*, if to the nine assumptions already made a tenth is added:

10. The ratio of nonuser benefits to new rider benefits is the same for all rail projects.

For projects with $n < n^*$, the nonuser benefits that must be generated from new user benefits are fewer than the minimum necessary to make a project economically efficient. Stated differently, total benefits will exceed the incremental cost for projects with values of $n < n^*$.

The last row of Table 1 shows the effect of evaluating the three projects using n as an indicator of project merit. As is evident, Project 1 is superior to the others. If the multiplier for the minimally acceptable project is 12.75 (Project 3), the present value of the annual net benefits for Project 1 is found by setting n equal to 12.75, computing nonuser benefits according to Equations 6 and 7, and solving the inequality in Equation 8, yielding an excess of benefits over costs of $25.44 million.

FUTURE RESEARCH

Many elements of UMTA's methodology warrant additional research. Alternative cost-effectiveness indexes, such as n, may be more valid indicators of project merit than UMTA's cost-effectiveness index and should be field-tested. In connection with these tests, the implications of relaxing UMTA's second assumption should be investigated. Because some rail projects are superior to all-bus systems involving smaller investments, it seems reasonable that only those rail projects demonstrated to be more cost-effective than their TSM benchmarks should compete for UMTA funding. The incremental value of n computed from a TSM benchmark could still be used to rank projects, but grant applications might be limited to those rail projects with values of n less than the TSM option computed from a no-build benchmark.

Assumptions 7 and 10 are critical to justifying rail transit investments using economic criteria; however, the relationship between benefits to new riders and those for nonusers is poorly understood. In this discussion, the relationship has been treated as linear and multiplicative. Other models might be more appropriate. The emotional debate over rail transit projects is largely a disagreement over the extent of positive and negative externalities. This is an area clearly in need of additional investigation.

Because Assumptions 8 and 9 may involve significant project biases, a consensus on assigning dollar values to travel time must be reached. Failing this consensus, a different philosophy of project evaluation will be necessary.

CONCLUSION

Viewed in the context of traditional measures of project benefit, the UMTA cost-effectiveness index cannot be readily interpreted. By measuring benefits in two different units, no estimate of total benefits can be obtained, preventing a finding of economic efficiency. The UMTA index also treats the benefits of one group as more important than another, inappropriately incorporating distributional impacts in the calculus. For existing riders, benefits are measured in travel time savings and offset sponsor costs in the numerator. For new riders, benefits are measured in terms of trips, making the UMTA index highly sensitive to changes in patronage, and encouraging the attraction of new riders, regardless of trip length, as the principal design goal.

This paper proposes an alternative cost-effectiveness measure that is more consistent with cost-benefit analysis theory and that explicitly and systematically incorporates nonuser benefits. The alternative cost-effectiveness index (n) represents the amount of nonuser benefit required to make rail investment benefits equal to cost. The index n can be calculated from data ordinarily produced in rail transit investment studies, and so it does not pose an additional data collection or computational burden. However, project rankings would be affected if n were substituted for UMTA's cost-effectiveness index as the design objective shifts from attracting new riders to generating benefits to new riders.

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REFERENCES

1. S. L. Zimmerman. UMTA and Major Investments: Evaluation Process and Results. In *Transportation Research Record 1209*, TRB, National Research Council, Washington, D.C., 1989, pp. 32–36.
2. J. Hoover. Cost-Effectiveness of Rail Transit. Presented at the American Public Transportation Association Western Education and Training Conference, Seattle, Wash., 1990.
3. R. A. Johnston and M. A. DeLuchi. Evaluation Methods for Rail Transit Projects. *Transportation Research* Vol. 24A, No. 4, 1989. pp. 322–323.
4. *Procedures and Technical Methods for Transit Project Planning.* UMTA, U.S. Department of Transportation, Sept. 1986.
5. D. H. Pickrell. *Urban Rail Transit Projects: Forecast Versus Actual Ridership and Costs.* UMTA, U.S. Department of Transportation, 1989.
6. M. Wohl and C Hendrickson. *Transportation Investment and Pricing Principles.* John Wiley and Sons, Inc., New York, N.Y. 1984, pp. 108–112.
7. UMTA. *Major Capital Investment Projects: Proposed Rulemaking.* 54 Fed. Reg. 17,891 (1989).
8. M. A. Bradley and H. F. Gunn. Stated Preference Analysis of Values of Travel Time in the Netherlands. In *Transportation Research Record 1258*, TRB, National Research Council, Washington, D.C., 1990, pp. 78–88.
9. *A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements.* AASHTO, Washington, D.C., 1977.
10. C. H. Sharp. Time in Transport Investment. In *The Practice of Transport Investment Appraisal* (K. J. Button and A. D. Pearman, Eds.). Gower, Aldershot, England, 1983, pp. 181–195.
11. E. J. Mishan. *Cost-Benefit Analysis.* Unwin Hyman, London, England, 1988, pp. 305–310.
12. B. Pushkarev. *Urban Rail in America.* Indiana University Press, Bloomington, 1983, pp. 77–83.
13. V. R. Vuchic. *Urban Public Transportation: Systems and Technology.* Prentice-Hall, Inc., Englewood Cliffs, N.J., 1981, pp. 83–86.
14. M. Pikarsky and D. Christensen. *Urban Transportation Policy and Management.* Lexington Books, Lexington, Mass., 1976, pp. 190–192.

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