A Criterion Designed to Aid Highway Expenditure Programming

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● THE GOAL of the research project reported in this paper was the development of a criterion which might help to systematize the problem faced by those charged with the responsibility of programming the expenditure of funds available for construction of highways.

The plan of the paper will be to outline the logic behind the choice of travel time as the one criterion. A detailed demonstration of how this criterion of time might be employed in programming construction expenditures for a typical highway system is giver In conclusion some comments relative to the benefits claimed for this criterion are offered.

DEVELOPMENT OF THE CRITERION

As this is an economic study, it must be assumed that existing engineering decisions regarding design and construction are optimal. It is further assumed that there is a definite relation between presently used design features and maintenance costs as affected by design. This paper, however, will emphasize the criterion as related to con struction projects and their selection on a priority basis.

Highway systems are designed to offer transport service (utility) to highway users. The expenditure of highway funds for construction can be defined as a continuing incremental investmant in existing capital facilities. The "return" on this highway investment will be maximized when the total of the utility enjoyed by all of the users of all road segments in the system is maximized. Thus, optimum highway expenditure programming requires that the maximum possible user utility be obtained from each dollai spent — the familiar "equi-marginal principle."

The problem is now defined; a method of measuring this user utility must be designed. Highway engineers are presently able to estimate the total cost of any proposed construction project; they can also specify the levels of the various user services that these projects will offer to given volumes of traffic. The question remaining is that of devis ing a criterion which is capable of measuring the value of this user utility which constitutes the "return" to be obtained from any propsed improvement project. Once this criterion is designed, it will be a simple matter to rank all proposed construction projects according to the "return" they offer for each dollar of expenditure — the well-knowi benefit-cost ratio method of ranking alternatives.

Variables Relating to User Utility

The ultimate goal of all types of transport, including highways, is movement from one location to another at minimum cost. Several aspects of this cost include: The number of travelers served, travel time, risk of accident, certainty of use of the facility, comfort, esthetic pleasure, and vehicle operating cost. The criterion to be designed should take some account of these cost variables which must be minimized if user utility is to be maximized.

A. Travel Time, has been selected as the most important variable affecting user utility. It is the only variable for which a system of measurement will be developed here.

B. Risk of Accident, which is assumed to be the next most important variable will not be measured in terms of its utility. Instead, it will be treated as a constant, with the specification that arbitrary levels of safety must be provided by all road segments, perhaps divided into classes. A separate study might develop a system of measurement for this variable by applying the insurance principle.

C. Traffic Volume, obviously the utility enjoyed by the user of an individual vehicle must be multiplied by the number of vehicles using a given road segment to arrive at a valuation of the total utility which would be made possible by each improvement project considered.

D. Risk of Unavailability for Use, is a minor variable relating to the expense involved in combating adverse weather conditions, such as snow, ice, and flood, closing of the facility for repairs, and other events. This variable will also be treated as a constant by specification of arbitrary levels of weather maintenance and design features for all road classes in the system. A separate study might develop a criterion for this variable also, again utilizing the insurance principle.

E. Comfort and Beauty, are minor subjective variables difficult to measure objectively. They are disposed of here with the comment that the judgment of highway design engineers must be relied on for determination of adequate levels of these variables.

F. Vehicle Operating Cost, is conventionally included in this list but it will be disregarded here because it is only indirectly related to the quality of highway facilities. This aspect of transport cost is a function of operating traffic volume, speed, grades and alignment. Over observable ranges highway users prefer speed to operating economy, a clear indication that travel time savings offer much greater user utility than operating cost savings.

With the less important variables reduced to constants of specified value for all road segments, the task remaining is to devise a satisfactory measure of the value of travel time. Since highway expenditure is measured in money terms, it seems only reasonable that this measure of travel time value also be stated in money terms.

A. For vehicles carrying passengers this measure must be the opportunity cost of passenger travel time (average hourly income) (1), plus the time cost of hired drivers of commercial vehicles.

B. For cargo vehicles the measure must employ an appropriate interest rate in computing a money valuation of the time element in cargo travel (1), plus the time cost of hired drivers.

These two cost factors will be the only ones included in the computation of travel time cost, because they are the only ones directly related to travel time. All other user costs relate either to vehicle quality, which has no relation to highway facilities, or to vehicle operating cost, which has already been eliminated as a pertinent variable.

APPLICATION OF THE CRITERION

Here, a complete definition of all measurements which will be needed is presented, then a numerical demonstration of the application of the criterion will be given using data relative to a sample of actual projects considered by the Virginia Department of Highways.

Measurements to Be Used

In order to provide for computation of the congestion allowance, which will be defined later, all costs will be calculated in hourly terms. Also, to assure comparability between proposed projects of different lengths all highway costs will be stated in per mile terms.

A. The time valuation for users of passenger vehicles will be computed by adding the time cost for users of passenger vehicles to the time cost of hired drivers, where applicable.

1. The money value of travel time to individuals will be the opportunity cost of time to the average individual. This opportunity cost is assumed to be their average hourly income. Employed persons in Virginia have an average hourly wage of $2.74[1]. This

[1] Data obtained from Bureau of Population and Economic Research at University of Virginia.

average time value figure will be applied to all users of the Virginia highway system, even though the value of time does vary greatly individual to individual and through the day and the year.

2. The average number of passengers in the various types of passenger vehicles is assumed to be:

Cars	— Urban	- 1.75 Passengers[2]
	Rural	- 1.50 Passengers
Taxis	— No data available	
Busses	— Urban	- 30 Passengers[3]
	Rural	- 21 Passengers

3. The hourly value of bus driver time is $2.50.[3]

B. The time valuation for owners of the cargo carried by trucks is computed by adding the time cost of investment in truck cargoes to the driver time cost.

1. The opportunity cost of travel time to owners of truck cargo will be the average cost of money they would have to pay for the money invested in these cargoes. The assumption here is that this rate is 6 percent per year, a representative interest rate for business loans.

2. The average investment in the cargo carried by the four conventional classes of trucks is as follows:[4]

Class I	— light trucks	$ 200
Class II	— medium trucks	1,000
Class III	— heavy trucks	9,000
Class IV	— trailer trucks	33,000

3. The hourly value of driver time for the four classes of trucks follows:

Class I	$1.50
Class II	1.75
Class III	2.00
Class IV	4.13

C. Traffic volumes for the six proposed improvement projects used later as an example were supplied by the Virginia Department of Highways. The average daily traffic customarily used in highway statistics were accepted as representative of the single figure which is necessary for this user time cost computation. The ADT figure will be divided by 24 to give an average hourly traffic.

Traffic volumes are projected to increase for all road segments to 1975, but the rate of this increase is not constant for all road segments in the system. Thus, to obtain a true value for the average user costs, and average user savings resulting from the various improvement projects, it was necessary to calculate user costs for the 1958 traffic volumes and for the increased traffic at the mid-year 1958 to 1975. This amount of increased travel time cost is then discounted back to a present value so that the project benefits would be comparable to the present improvement cost estimates.

D. It is well-known that the existence of traffic congestion creates a social time cost which is an addition to the normal travel time cost imposed on users of any given road segment which is not overloaded. The proposal here is that where congestion exists on any road segment the social cost of user time lost because of this congestion should be included in the analysis. However, it is omitted in the analysis to follow because applicable information on the proposed projects was not available.

This computation can be illustrated as follows:

Assumed data:

$3.75 = value of time per vehicle-hour

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[2] Data from Virginia Department of Highways.

[3] Data from Richmond City Bus Line and Trailways Bus Line.

[4] Data from American Truckers Association.

0.5 min. = social cost (time) per mi of congested road, per vehicle
1,000 = average traffic volume during congested hours
800 = number of hours of congestion per yr

Social cost per yr:
(1,000 vehicles x 800 hr ÷ 60/0.5 cost) ($3.75) = $25,000

E. Total construction project costs, which were obtained from the Virginia Department of Highways, are converted into hourly cost figures so that they can be directly compared with the hourly user cost figures already defined. This will be a three-step operation.

1. Total project cost is converted into a cost per mi figure to facilitate comparison between projects.
2. Total cost must be amortized over the life of the road segment or a suitable period of years assumed for the analysis. This amortization cost will be calculated at 6 percent interest rate, a rate representative of the value of money to the road user. Maintenance costs per mi of the road segments is shown along with the construction costs for each project. Also, given there is the number of years of service used in the analysis. This period of years is somewhat arbitrary, but representative of the relative service of the six projects considered. Maintenance and operating cost per yr per mi are given in the same listing.
3. The cost per yr is divided by the number of hours in a yr — 8,760.

TABLE 1

HOURLY MONEY VALUATION OF USER TRAVEL TIME COST FOR ALL TYPES OF VEHICLES

(A) Passenger Vehicles

Type	Average No. of Passengers		Average Hourly Earnings ($)		Hourly Passenger Time Cost ($)
Car, Urban	1.75	x	2.74	=	4.80
Rural	1.50	x	2.74	=	4.11
Bus, Urban	30.00	x	2.74	=	82.20
Rural	21.00	x	2.74	=	57.54

Type	Average Hourly Driver Cost ($)		Hourly Passenger Time Cost ($)		Total Hourly Time Cost ($)
Car, Urban	-	+	4.80	=	4.80
Rural	-	+	4.11	=	4.11
Bus, Urban	2.50	+	82.20	=	84.70
Rural	2.50	+	57.54	=	60.04

(B) Cargo Vehicles

Type	Average Cargo Value ($)		Interest Rate (%)		Hours in Year		Hourly Int. Cost ($)
Class I	200	x	6	÷	8,760	=	0.0013
Class II	1,000	x	6	÷	8,760	=	0.0068
Class III	9,000	x	6	÷	8,760	=	0.0616
Class IV	33,000	x	6	÷	8,760	=	0.2260

Type	Average Hourly Driver Cost ($)		Hourly Interest Cost ($)		Total Hourly Time Cost ($)
Class I	1.50	+	0.0013	=	1.5013
Class II	1.75	+	0.0068	=	1.7568
Class III	2.00	+	0.0616	=	2.0616
Class IV	4.13	+	0.2260	=	4.3560

TABLE 2

COMPUTATION OF MONEY VALUE OF 1958 HOURLY TRAVEL TIME

Vehicle Type	Hourly Count[1]	Hourly Vehicle Time Cost ($)	Total Hourly Time Cost ($)
(A) High-Cost High-Volume Urban Road			
Cars	593.6	4.80	2,862.24
Busses	2.5	84.70	211.75
Trucks			
Class I	83.3	1.5013	125.06
Class II	52.1	1.7568	92.53
Class III	31.3	2.0616	64.53
Class IV	10.4	4.3560	45.30
Total			3,401.41
(B) Low-Cost High-Volume Urban Road			
Cars	671.3	4.80	3,222.24
Busses	19.6	84.70	1,660.12
Trucks			
Class I	55.9	1.5013	83.92
Class II	68.9	1.7568	121.04
Class III	2.1	2.0616	4.33
Class IV	27.3	4.3560	118.92
Total			5,210.57
(C) Low-Cost Low-Volume Urban Road			
Cars	79.1	4.11	325.10
Busses	0.9	60.04	54.04
Trucks			
Class I	11.1	1.5013	16.66
Class II	9.5	1.7568	16.69
Class III	0.3	2.0616	0.62
Class IV	2.1	4.3560	9.15
Total			422.26
(D) High-Cost High-Volume Rural Road			
Cars	384.5	4.11	1,580.30
Busses	1.3	60.04	78.05
Trucks			
Class I	18.8	1.5013	28.22
Class II	11.0	1.7568	19.32
Class III	0.5	2.0616	1.03
Class IV	1.6	4.3560	6.97
Total			1,713.89
(E) Low-Cost High-Volume Rural Road			
Cars	334.3	4.11	1,373.97
Busses	1.0	60.04	60.04
Trucks			
Class I	18.4	1.5013	27.62
Class II	11.3	1.7568	19.85
Class III	0.6	2.0616	1.24
Class IV	0.8	4.3560	3.48
Total			1,486.20

TABLE 2 (continued)

COMPUTATION OF MONEY VALUE OF 1958 HOURLY TRAVEL TIME

Vehicle Type	Hourly Count[1]	Hourly Vehicle Time Cost ($)	Total Hourly Time Cost ($)
	(F) Low-Cost Low-Volume Rural Road		
Cars	7.2	4.11	29.59
Busses	0.1	60.04	6.00
Trucks			
Class I	1.8	1.5013	2.70
Class II	1.2	1.7568	2.11
Class III	-	2.0616	-
Class IV	0.1	4.3560	0.44
Total			40.84

[1]Average daily traffic count by each type of vehicle divided by 24; all hourly counts in the following data were secured this way.

NUMERICAL DEMONSTRATION

A demonstration is given here of the application of the proposed criterion to a sample of construction projects actually considered by the Virginia Department of Highways.

Basic Hourly User Time-Cost Computation

Data from the preceding section are employed in computations (Tables 1 and 2) leading to a money valuation of the cost of 1 hr of travel time for users of each of the types of vehicles for which traffic counts are available.

These vehicle user travel time costs can now be multiplied by the hourly number of each of the types of vehicles using a given road segment to arrive at a total user travel time cost, by types of vehicles, for that road segment.

Road Segments Used in Sample

The road segments used in this sample were chosen to represent examples of the types of improvement projects listed below. The reader is warned however, that because of the many items influencing costs including the requirements for safety, maintenance, and comfort and beauty, no generalizations can be drawn regarding the cost per mi to construct other specific segments of highway in these general classes.

These projects are described in general terms below:

1. A high-cost, high-volume urban project. Cost — $820,538 per mi; 1958 and 1975 ADT — 18,560 and 42,000 vehicles; annual maintenance cost — $5,000; analysis period — 50 yr.
2. A low-cost, high-volume urban project. Cost — $494,074 per mi; 1958 and 1975 ADT — 20,280 and 49,080 vehicles; annual maintenance cost — $4,500; analysis period — 40 yr.
3. A low-cost, low-volume urban project. Cost — $253,103 per mi; 1958 and 1975 ADT — 2,470 and 4,000 vehicles; annual maintenance cost — 4,000; analysis period — 30 yr.
4. A high-cost, high-volume rural project. Cost — $521,145 per mi; 1958 and 1975 ADT — 10,030 and 16,250 vehicles; annual maintenance cost — $1,500; analysis period — 40 yr.
5. A low-cost, high-volume rural project. Cost — $195,930 per mi; 1958 and 1975 ADT — 8,800 and 14,250 vehicles; annual maintenance cost — $1,200; analysis period — 30 yr.
6. A low-cost, low-volume rural project. Cost — $34,656 per mi; 1958 and 1975 ADT — 250 and 330 vehicles; annual maintenance cost — $1,000; analysis period — 15 yr.

TABLE 3

COMPUTATION OF COST INCURRED BY USERS ON ROAD SEGMENTS

1. Total User Time Cost Before Improvement

Road Segment	Old Average Speed	Vehicle Travel Time on This Road Segment, Minutes		Travel Time as % of Hr.		Total Hourly Time Cost [1]		Old Total User Time Cost-Per Hr. Per Segment
No. 1	13	4.62 ÷ 60	=	7.70%	X	$3,401.41	=	$261.91
No. 2	35	1.71 ÷ 60	=	2.85%	X	5,210.57	=	148.50
No. 3	30	2.00 ÷ 60	=	3.33%	X	422.26	=	14.06
No. 4	35	1.71 ÷ 60	=	2.85%	X	1,713.89	=	48.85
No. 5	35	1.71 ÷ 60	=	2.85%	X	1,486.20	=	42.36
No. 6	10	6.00 ÷ 60	=	10.00%	X	40.84	=	4.08

2. Total User Time Cost After Improvement

Road Segment	New Average Speed	Vehicle Travel Time on This Road Segment, Minutes		Travel Time as % of Hr.		Total Hourly Time Cost [1]		New Total User Time Cost-Per Hr. Per Segment
No. 1	25	2.40 ÷ 60	=	4.00%	X	$3,401.41	=	$136.06
No. 2	40	1.50 ÷ 60	=	2.50%	X	5,210.57	=	130.26
No. 3	35	1.71 ÷ 60	=	2.85%	X	422.26	=	12.03
No. 4	50	1.20 ÷ 60	=	2.00%	X	1,713.89	=	34.28
No. 5	45	1.33 ÷ 60	=	2.22%	X	1,486.20	=	32.99
No. 6	30	2.00 ÷ 60	=	3.33%	X	40.84	=	1.36

3. Benefits to Traffic After Improvement

Road Segment	Old User Time Cost Per Hour Per Segment		New User Time Cost Per Hour Per Segment		Hourly User Time Cost Savings	Factor for Increase in Traffic [2]	Time Cost Savings of Traffic Increase	Present Worth of Increase [3]	Total Benefits
1	$261.91	-	$136.06	=	$125.85	0.63	$79.29	$46.93	172.78
2	148.50	-	130.26	=	18.47	0.71	13.11	7.76	26.23
3	14.06	-	12.03	=	2.03	0.31	0.63	0.37	2.40
4	48.85	-	34.28	=	14.57	0.31	4.52	2.68	17.25
5	42.36	-	32.99	=	9.37	0.31	2.90	1.72	11.09
6	4.08	-	1.36	=	2.72	0.16	0.44	0.26	2.98

[1] These figures represent an average of the 1958 and 1975 Total Hourly Time Cost figures calculated in the preceding section.

[2] Ratio of one-half the increase 1958 to 1975 to 1958 ADT.

[3] Present worth of savings of traffic increase at 6% for 9 years; factor is 0.5919.

Total Hourly Time-Cost Computation

Now data are available for the computation of a money valuation for one hr of travel time for all of the users of each road segment. This computation is based on actual 1958 traffic and later the dollar time savings are adjusted for the average of 1958 and 1975 estimated traffic.

Time Cost to the Hourly Users of These Road Segments

From the basic hourly user time-cost figures calculated above it will now be possible to compute the cost incurred by users while actually traversing the road segments in question. This actual travel time cost will of course be a function of the old and new speeds

TABLE 4

Road Segment	Cost per Mile ($)[1]	Capital Recovery Factor	Capital Cost per Yr ($)	Maintenance Cost ($)	Total Annual Road Cost ($)	Cost per Hr[2]
No. 1	820,538	0.06344	52,055	5,000	57,055	6.51
No. 2	494,074	0.06646	32,836	4,500	37,336	4.26
No. 3	253,103	0.07265	18,388	4,000	22,388	2.56
No. 4	521,145	0.06646	34,635	1,500	36,135	4.12
No. 5	195,930	0.07265	14,234	1,200	15,434	1.76
No. 6	34,635	0.10296	3,568	1,000	4,568	0.52

[1] Total project cost adjusted to a 1-mi basis.
[2] Annual figure divided by 8,760, the number of hr in a yr.

at which users can travel on the road in question. Obviously the difference between the actual travel time cost for users of the unimproved road and the cost on the improved road will provide a money valuation of the improved user utility made possible by this particular improvement expenditure. (Construction design standards must already have provided adequate levels of those variables bearing on user utility which are specified as constants under the proposed criterion, for the entire road system.)

Hourly Costs of Proposed Expenditure Projects

Now that computations have been made which can give the hourly user time-cost savings which will be made possible by the various improvement projects considered, a similar computation must be made for the expenditure costs of these projects. This will make possible a direct comparison of the user savings and the highway costs resulting from each project considered, the conventional benefit-cost ratio.

This project cost computation is given in Table 4.

TABLE 5

DEVELOPMENT OF BENEFIT-COST RATIOS

(A) Benefit Related to Cost

Road Segment	Hourly User Time-Cost Savings ($)	Project Cost per Hr ($)	Benefit-Cost Ratio ($)
No. 1	172.78	6.51	26.54
No. 2	26.23	4.26	6.16
No. 3	2.40	2.56	0.94
No. 4	17.25	4.12	4.19
No. 5	11.09	1.76	6.30
No. 6	2.98	0.52	5.73

(B) Benefit-Cost Ratios Ranked

Road Segment	Benefit-Cost Ratio ($)
No. 1	26.54
No. 5	6.30
No. 2	6.16
No. 6	5.73
No. 4	4.19
No. 3	0.94

Computation of Benefit-Cost Ratios

Data are now available for the computation of both the hourly user time-cost savings made possible by the various projects and the hourly cost of the projects themselves. The ratio between the user utility (in terms of time-cost savings) and the project cost now gives a measure of the dollar value of the benefits offered, per dollar of expenditure, by the different projects under consideration (Table 5).

CONCLUSIONS

From the mixture of road types used it is impossible to generalize about the desirability of rural or urban expenditure or even about expenditure as related to traffic volumes. Instead it is claimed that the rather involved calculation made here offers an objective comparison of the relative attractiveness of the user benefits to be obtained from the many alternative expenditures available to any highway department.

Some generalizations, however, can be drawn from the results obtained in this demonstration, as follows:

1. Even allowing for errors where estimated data were required, the wide range of benefit-cost ratios obtained would seem to indicate that existing programming decisions do not give adequate consideration to all of the variables used in this criterion.
2. If one accepts the implicit assumption that expenditures with benefit-cost ratios of more than 1.00 are profitable investments of public funds, the preponderance of ratios in the sample greater than this minimum value must be interpreted as sound evidence that more money should be spent on roads. Presumably the public would gladly pay higher highway use taxes where the dollar value of the benefit they receive exceeds the cost they must pay.
3. A complete application of the proposed system would give a complete ranking of benefit-cost ratios for as full a list of proposed projects as the highway department in question wanted to process. Thus, funds for a considerable period of years could be programmed for expenditure well in advance (data used would have to be kept current over the programmed period). The length of the planning period, for both revenues and expenditures, could now be chosen by the highway department in question.

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REFERENCE

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