CONSISTENCY IN TRANSPORTATION DEMAND AND EVALUATION MODELS

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This paper is addressed to the evaluation of traveler benefits associated with transportation system alternatives. It is asserted that trip-generation, trip-distribution, modal-split, and traffic-assignment steps, which are carried out by individual mathematical models, in the transportation planning process are frequently not consistent with one another. The inconsistencies arise because, while each is intended to represent travelers' behavior, its mathematical form can imply inconsistent behavior. It is further asserted that a formal evaluation of traveler benefits, which is normally the last step in the modeling process, may provide further inconsistency. These inconsistencies may lead to erroneous conclusions regarding the relative desirability of one system over another. An earlier paper on this subject dealt with achieving modal-split model and evaluation-model consistency. The current paper covers 2 additional aspects of demand modeling: the use of a trip-distribution model and the use of a total-demand model. Procedures for making consistent traveler-benefit calculations with each model are suggested.

• THE PURPOSE of this paper is to attempt to provide a consistent and logical bridge between the methods used to conduct evaluations of alternative transportation systems and the methods used in other phases of the transportation planning process.

An earlier paper (1) dealt with specific problems and inconsistencies that result in the evaluation of multimodal alternatives when the modal-split procedure is not closely coordinated with the evaluation procedure. That paper compared conventional methods of calculation of traveler benefits with recommended methods designed from different modal-split models. It was found that a suitably adapted consumers' surplus approach to benefit calculations provided correct results, whereas the more conventional traveler-expenditure methods were erroneous. A procedure for structuring the analysis method and for making the calculations was presented.

The reader is referred to this paper for background and discussion of the theory behind the results derived here. The presentation in this paper assumes that the reader is familiar with the earlier paper.

The present paper offers suggestions for tying evaluation methods more consistently to the earlier demand-modeling phases in the planning process. Separate sections of the paper deal with recommended procedures applicable to the following 2 approaches to demand estimation:

1. The use of a trip-distribution model, in which different distributions of trips are estimated for different transportation system alternatives; and
2. The use of a total-demand model, in which trip generation, trip distribution, and modal split are accomplished in a single model.

Specific examples of each approach are described; however, the results are generally applicable to other formulations of demand.

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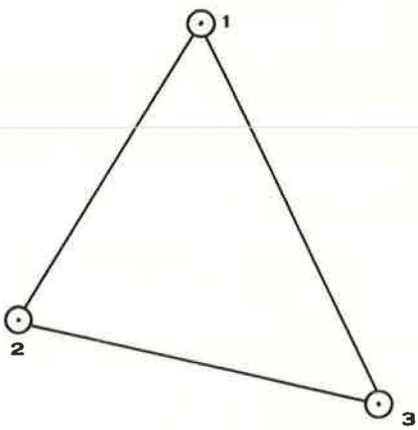
TRIP-DISTRIBUTION MODELS

Figure 1. A simple network.



As different transportation system alternatives are postulated and analyzed in a planning process, the most common method of dealing with demand is to make a single estimate of total trip-interchange volumes (a trip table) and to consider that demand as fixed over all alternatives. This procedure has appeal; with demand fixed, a search can be undertaken to find the alternative that produces the given transportation service at minimum direct cost, and no thought need be given to whether different amounts of service are being provided.

However, such a procedure would seem to violate logical inferences as to travel behavior. A reasonable hypothesis of travel behavior is that, as transportation impedances are selectively altered in a study area, persons will change their travel patterns. As particular areas (zones) become more accessible, there will be greater demand for travel to those areas. The analyst may wish to attempt to incorporate such change in travel behavior in the planning process.

If the planning process has been designed along conventional lines, with trip generation, trip distribution, and modal split being accomplished in 3 separate steps, the analyst may adopt a procedure of running the trip-distribution model separately for each transportation system alternative. If this is done under a fixed set of trip ends, redistribution will simply rearrange the trip patterns. The estimate will show some person trips lengthened along paths whose travel times or costs are reduced by a new alternative. Others will be shortened because the model compensates for the farther trips.

As an example, consider a very simple network and zonal system consisting of 3 links and 3 centroids as shown in Figure 1. Assume that the trip ends are to be held constant, as follows: $O_1 = D_1 = 570$, $O_2 = D_2 = 540$, and $O_3 = D_3 = 420$. Assume that the interzonal travel costs of alternative 0 are as follows:

	Destinations		
Origins	Zone 1	Zone 2	Zone 3
Zone 1	6	12	15
Zone 2	12	5	11
Zone 3	15	11	8

If a simple gravity model with a cost exponent (cost being used in a general sense) of 2.0 is used, the resulting travel volumes are as follows:

	Destinations			
Origins	Zone 1	Zone 2	Zone 3	Total
Zone 1	420	82	68	570
Zone 2	82	357	101	540
Zone 3	68	101	251	420
Total	570	540	420	

Now, assume that the travel cost under alternative 1 between zone 1 and zone 3 is reduced by 2 units. The new cost matrix is as follows:

Origins	Destinations Zone 1	Zone 2	Zone 3
Zone 1	6	12	13
Zone 2	12	5	11
Zone 3	13	11	8

The resulting trip distribution, using the same gravity model, is as follows:

Origins	Destinations Zone 1	Zone 2	Zone 3	Total
Zone 1	402	81	87	570
Zone 2	81	365	94	540
Zone 3	87	94	239	420
Total	570	540	420	

Looking at the results in detail, we infer that the changes in behavior can be described in terms of 6 groups:

1. Eighteen persons previously traveling internal to zone 1 now choose to travel to zone 3,
2. One person previously traveling from zone 1 to zone 2 now chooses to travel to zone 3,
3. One person previously traveling from zone 2 to zone 1 now chooses to travel within zone 2,
4. Seven persons previously traveling from zone 2 to zone 3 now choose to travel within zone 2,
5. Seven persons previously traveling from zone 3 to zone 2 now choose to travel from zone 3 to zone 1, and
6. Twelve persons previously traveling within zone 3 now choose to travel to zone 1.

The changes in behavior must be carefully understood. While 2 groups (groups 3 and 4) are saving travel costs by their changes in behavior, the other 4 are incurring higher costs of travel.

Conventional Benefit Calculation

Unless that fact is recognized, a conventional approach of comparing travel costs for the 2 alternatives would simply multiply the travel cost times the travel volume for each zone pair and sum these products over all zone pairs. The most attractive alternative, in terms of travel cost, would be the one with the lower cost. Alternative 1 is preferred if

$$\sum_{ij} C^0_{ij} D^0_{ij} > \sum_{ij} C^1_{ij} D^1_{ij}$$

Alternative 0 is preferred otherwise. The variables given above signify that C^k_{ij} = travel cost between zones i and j for alternative k, and D^k_{ij} = travel volume between zones i and j for alternative k. In the example the total unit costs are 12,543 for alternative 0 and 12,423 for alternative 1. Thus, alternative 1 would appear to be favored by 120 cost units. This net difference is the result of both some cost decreases and some cost increases.

Improved Benefit Calculation

Another way of viewing the changed behavior is to hypothesize that persons choose their travel destination in relation to 2 factors: the value of being at a destination and the cost of getting there. Looking at all possible destinations that are available, each person assigns his particular value to each and assesses the travel cost. The destination that has the highest excess of value less cost will be chosen.

For persons in 4 of the groups given above, the following perceptions should explain their changes in behavior:

Group	Alternative 0	Alternative 1
1	$\text{value}_1 - \text{cost}_1 > \text{value}_3 - \text{cost}_3$	$\text{value}_1 - \text{cost}_1 < \text{value}_3 - \text{cost}_3$
2	$\text{value}_2 - \text{cost}_2 > \text{value}_3 - \text{cost}_3$	$\text{value}_2 - \text{cost}_2 < \text{value}_3 - \text{cost}_3$
5	$\text{value}_2 - \text{cost}_2 > \text{value}_1 - \text{cost}_1$	$\text{value}_2 - \text{cost}_2 < \text{value}_1 - \text{cost}_1$
6	$\text{value}_3 - \text{cost}_3 > \text{value}_1 - \text{cost}_1$	$\text{value}_3 - \text{cost}_3 < \text{value}_1 - \text{cost}_1$

where value_x is the value of being at zone x, and cost_x is the cost of getting to zone x. Because it can be argued that the value of an individual's being at a destination does not change, the benefits for persons in each of the 4 groups must be directly related to the change in travel cost to the new destinations. Some people in the group will have rather high preferences for their selected destinations, while others will feel less strongly. Therefore, depending on the improvement in travel, different amounts of travel will shift. The maximum individual traveler benefit will accrue to the traveler who was previously on the margin between the 2 destinations. As an example, the group 1 marginal traveler will perceive benefits as follows:

$$\text{Benefit} = (\text{value}_1 - 6) - (\text{value}_3 - 15) - (\text{value}_1 - 6) - (\text{value}_3 - 13)$$
$$= 2 \text{ cost units}$$

At the other extreme, the minimum benefit will accrue to the traveler who is just barely induced to change destinations by the change in travel cost. His benefit is slightly greater than zero.

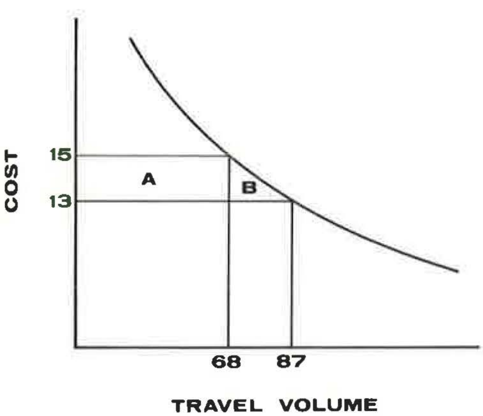
The consumers' surplus concept can again be used to assess benefits. In this case we consider the zone pairs that have experienced a reduction in travel cost. Using the conventional demand curve diagram as shown in Figure 2, we have the following situation for zone 1 to zone 3 travel: The benefits accruing to the travelers in groups 1 and 2 are shown in the triangle labeled B. In addition, the travelers who traveled between zones 1 and 3 under both alternatives will perceive a benefit, represented by the rectangle A. Using the consumers' surplus formula, we find that the benefits for the persons traveling from zone 1 are

$$\text{Consumers' surplus} = \tfrac{1}{2}(C_0 - C_1)(V_0 + V_1)$$
$$= \tfrac{1}{2}(2)(68 + 87)$$
$$= 155 \text{ cost units}$$

A similar argument and calculation can be made for persons traveling from zone 3. The 2 calculations will account for groups 1, 2, 5, and 6, plus the benefits to travelers who continue to travel between the same zones as before.

But what about groups 3 and 4? They have changed their travel behavior, but neither the values of being at the before-and-after locations nor the costs of getting to those locations have changed. In the normalizing process, the gravity model has forced them out of their preferred destinations to less preferred locations. We can, however, observe that, for group 3,

Figure 2. Travel demand between zone 1 and zone 3.



$$\text{Value}_1 - \text{cost}_1 > \text{value}_2 - \text{cost}_2$$

$$\text{Value}_1 - \text{value}_2 > \text{cost}_1 - \text{cost}_2$$

$$> 12 - 5$$

$$> 7$$

This group would be prepared to spend 7 additional cost units in order to travel to zone 1 rather than zone 2, but, by the formulation and operation of the gravity model, they are forced to travel to destinations in zone 2 and thus must be incurring a disbenefit of at least 7 cost units.

$$\text{Disbenefit} > \text{cost}_2 - \text{cost}_1$$

Not having information as to the actual values of being at the 2 destinations, we can understate the disbenefit by the calculation

$$\text{Disbenefit} = \text{cost}_2 - \text{cost}_1$$

$$\text{Disbenefit} = 5 - 12 = -7$$

and, for group 4,

$$\text{Disbenefit} = 5 - 11 = -6$$

Suggested Procedure

In summary, the total procedure for analyses of benefits and disbenefits is as follows:

1. Determine which zone pairs would have reduced travel cost when compared with the base case. In the example, zone 1 to 3 travel and zone 3 to 1 travel would be identified.
2. Identify the costs of travel and the travel volumes for those zone pairs. In the example, the following data would apply:

Item	Alternative 0	Alternative 1
Zone 1 to 3		
Cost	15	13
Volume	68	87
Zone 3 to 1		
Cost	15	13
Volume	68	87

3. Make the consumers' surplus calculation for each of the zone pairs given above. In the example, the following calculations would be made:

$$\text{Consumers' surplus for zone 1 to 3} = \tfrac{1}{2}(15 - 13)(68 + 87) = 155$$

$$\text{Consumers' surplus for zone 3 to 1} = 155$$

4. Identify all other zone pairs that would have increased travel. In the example, zone 2 to zone 2 would have increased travel.
5. Determine the travel cost and volumes for those zone pairs for the alternative being studied and for the base case. In the example, for zone 2 to 2 cost = 5, and volume for alternative 0 = 357 and for alternative 1 = 365.
6. Determine the number of trips that are reduced from the origins of the zone pairs given above to each destination and the original costs of the trips. In the example, the cost for zone 2 to 1 is 12 and for zone 2 to 3 is 11. The volumes are as follows:

Zone	Alternative 0	Alternative 1	Difference
2 to 1	82	81	1
2 to 3	101	94	7

7. Calculate the estimated disbenefit for each change in volume.

$$\text{Disbenefit} = (\text{cost}_0 - \text{cost}_1)(\text{volume change})$$

or

$$\text{Benefit} = (\text{cost}_1 - \text{cost}_0)(\text{volume change})$$

In the example, the following calculation would be made:

Benefit for zone 2 to 1 = (1 - 12)(1) = -7

Benefit for zone 2 to 3 = (5 - 11)(7) = -42

8. Add the results of steps 3 and 8 to obtain the total benefit. In the example, the total benefit is

Consumers' surplus for zone 1 to 3	155
Consumers' surplus for zone 3 to 1	155
Benefit for zone 2 to 1	-7
Benefit for zone 2 to 3	-42
Net benefit	261

Such a benefit calculation produces an overestimate of benefits because the place-value losses of some travelers are not known. One can suppose that the overestimate is not large because the travelers who compete and win for the smaller number of trip destinations—in the example at zone destinations 3 and 1—probably have higher excess of values than those who compete and lose. It is the losers who are included in the disbenefit calculation.

It is significant to compare the benefits by the 2 methods of calculation:

Conventional method = 120 cost units
Suggested method = 261 cost units

If the theoretical approach of the suggested method is accepted, it appears to present significantly greater benefits than the conventional method.

Another comparison is also of interest. If the analyst chooses not to redistribute travel for each new alternative and thereby to deal with a fixed trip table, only the travel from zone 1 to zone 3 and from zone 3 to zone 1 would be included. The net benefits here would be 2 cost units per traveler × 68 travelers × 2 zone pairs = 272 cost units, which is much closer to the benefits calculated by the suggested method. However, it appears that not many significant observations can be drawn from the relative similarity of the values in this case. The methods are simply different from each other. However, the suggested method total of 261 cost units is composed of 272 units of benefit to those who do not change destinations at zone 1 and 3, 38 units of consumers' surplus benefits to those who do change destinations [which is shown by the triangle labeled B, in Figure 3: $(2)(\frac{1}{2})(15 - 13)(87 - 68)$], and 49 units of disbenefit for those travelers from zone 2.

Further Observations

Following the procedure described above may not correct all of the inconsistencies between trip distribution and evaluation models. Most frequently, trips are distributed by using a friction factor relation or some other function of one variable, travel time. On the other hand, the evaluation model may use travel time differences multiplied by a value of travel time to estimate the time benefits and may also include other cost variables. One approach that might be taken to avoid this inconsistency would be to accomplish the trip-distribution process by using a number of combinations of time and cost variables, selecting the one that produces the best fit to the observed data, and finding an equivalent price by manipulation of the equations. This price would then be used in a consumers' surplus formulation such as the one presented in the previous section.

Also, even if trip distribution and evaluation were conducted consistently, a multimodal planning problem may not be able to also resolve the modal-split and evaluation problem discussed in the earlier paper. Efforts to attain consistency in demand models are discussed next.

TOTAL-DEMAND MODELS

Within the past 5 years or so, a number of investigators, recognizing the inconsistencies in the various demand models and the fundamental commonality of travelers' decision-making, have attempted to develop overall demand models for transportation planning. Those models place trip generation, trip distribution, and modal split into a single estimation process. Although the successful implementation of such approaches must solve a myriad of problems, it appears that future research may produce promising results that will make the total-demand model more attractive than the currently popular sequence of models.

As an example of the total-demand model, consider the one developed in the Northeast Corridor Project (2, 3, 4). In the context of this paper, the model can be presented as

$$D = (K)\left(\alpha_t C_t^{\beta_t} T_t^{\gamma_t} + \alpha_a C_a^{\beta_a} T_a^{\gamma_a}\right)^{\delta}$$

where

- D = total demand between 2 zones, in number of persons;
- K = variable representing a combination of economic, demographic, and travel characteristic variables plus a constant term, all of which do not change with changes in the transportation system;
- C_t = cost of travel by transit;
- C_a = cost of travel by automobile;
- T_t = time of travel by transit; and
- T_a = time of travel by automobile.

The variables α, β, γ, and δ are constants determined in calibration.

The demand for the transit mode is computed as follows:

$$D_t = (D)\left[\alpha_t C_t^{\beta_t} T_t^{\gamma_t} / \left(\alpha_t C_t^{\beta_t} T_t^{\gamma_t} + \alpha_a C_a^{\beta_a} T_a^{\gamma_a}\right)\right]$$

and similarly for the automobile mode.

After demand is estimated for each transportation system alternative by using a model such as that shown above, the planner needs to compare alternatives and to provide information that can be used in selecting the one deemed most desirable. Among the comparisons usually made are comparisons of traveler benefits, in which travel cost, travel time, and other effects are assessed.

A method of evaluating traveler benefits that is consistent with the travel behavior implied by the total-demand model is illustrated by considering 2 alternative transportation systems having costs and times as follows:

Alternative 0	Alternative 1
C_{0t}	C_{1t}
C_{0a}	C_{1a}
T_{0t}	T_{1t}
T_{0a}	T_{1a}

then

$$D_0 = (K)\left(\alpha_t C_{0t}^{\beta_t} T_{0t}^{\gamma_t} + \alpha_a C_{0a}^{\beta_a} T_{0a}^{\gamma_a}\right)^{\delta}$$

and

$$D_1 = (K)\left(\alpha_t C_{1t}^{\beta_t} T_{1t}^{\gamma_t} + \alpha_a C_{1a}^{\beta_a} T_{1a}^{\gamma_a}\right)^{\delta}$$

The benefits that accrue to travelers between 2 alternative transportation systems can be found by using the concept of equivalent price (1). The equivalent price is, as defined in the earlier paper, the price that would have resulted in the same new demand if only the cost had changed. In other words, a demand D_1 for a new alternative might result from an improvement in both time and cost. The equivalent price would produce the same new demand but only with a cost (price) change. The equivalent price (if an improvement in the transit system is being analyzed) is found by solving the following equation for C_{1t}^e:

$$D_1 = (K)\left(\alpha_t C_{1t}^{e\,\beta_t} T_{0t}^{\gamma_t} + \alpha_a C_{0a}^{\beta_a} T_{0a}^{\gamma_a}\right)^{\delta}$$

If rearranged,

$$C_{1t}^e = \left\{\left[(D_1/K)^{1/\delta} - \left(\alpha_a C_{0a}^{\beta_a} T_{0a}^{\gamma_a}\right)\right] / \alpha_t T_{0t}^{\gamma_t}\right\}^{1/\beta_t}$$

In words, the demand on the new alternative is first found by using the demand equation and the values of cost and time for both modes under the new alternative; then, the equivalent price is found by using the values of the new demand and the old automobile time, automobile cost, and transit time.

An alternative method of finding the equivalent price would be to use the modal-split formula. Here, C_{1t}^e is as follows:

$$C_{1t}^e = \left(\left\{\left[(D_1/D_{1t}) - 1\right]\left(\alpha_a C_{0a}^{\beta_a} T_{0a}^{\gamma_t}\right)\right\} / \alpha_t T_{0t}^{\gamma_t}\right)^{1/\beta_t}$$

The choice among such alternatives will depend on the mathematics. In some cases, one method may not be reducible to an analytical expression, whereas another may be.

In the operation of the demand model, an improvement in the cost or time of 1 mode will cause not only a diversion of trips from the previous mode to the improved mode but also an increase in the total number of trips—which is referred to as induced traffic.

The total traffic on the improved transit mode results from a combination of the original traffic, the diverted traffic, and the induced traffic. The diverted and induced traffic are as follows:

$$D_{1t} - D_{0t} = D_{diverted} + D_{induced}$$

$$D_{diverted} = D_{0a} - D_{1a}$$

$$D_{induced} = (D_{1t} - D_{0t}) - (D_{0a} - D_{1a})$$

The traveler-benefit calculations can be separated into the 3 groups described in the following subsections.

Original Traffic—For the previous transit travelers who experienced reduced costs, the net benefits are easily calculated.

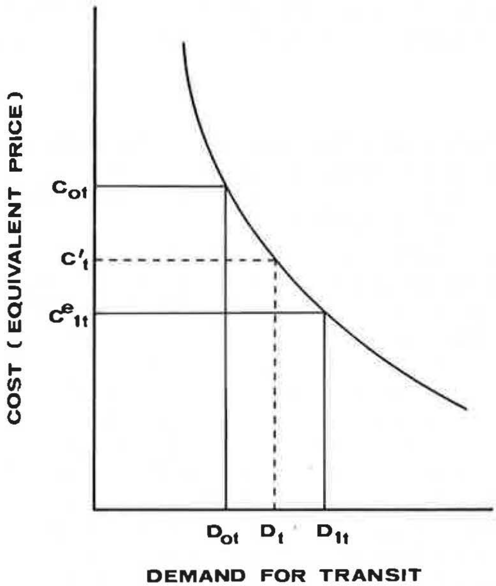
$$NB_{transit\ travelers} = (C_{0t} - C_{1t}^e)(D_{0t})$$

Induced Traffic—For the induced travel, arguments similar to those presented in the earlier paper can be made regarding the demand for travel, the willingness to pay, and the cost of travel. These arguments result in a consumers' surplus approach to demand estimation.

Figure 3 shows a typical demand-curve relation between price and demand. Because the following arguments assume a transit system improvement, a transit-demand curve is shown. (Similar arguments regarding highway improvements could be pursued by using an automobile-demand curve.)

Those persons having a willingness to pay greater than the cost C_{0t} are the transit travelers under alternative 0 and are represented by points on the demand curve to the left of D_{0t}. Those persons represented by points on the demand curve to the right of D_{0t} have a willingness to pay for transit less than C_{0t}. It is important to recognize that these persons really consist of 2 groups because some are traveling by automobile and some are not traveling at all under alternative 0. Thus, they are those that may be diverted to transit and those that may be induced to travel (by transit).

Figure 3. Transit-demand curve.



If improvement alternative 1 were installed, at an equivalent price of C^e_{1t}, the total demand for transit would increase to D_{1t}. The increase is made up of members of each of the 2 groups identified above. Even a very small reduction in cost would result in an increase in travel traceable to both groups. Therefore, members of both groups lie at all points along the demand curve. This is an important characteristic of the model.

The group of persons who would be induced to travel would, in theory, have considered both automobile and transit under alternative 0 and decided that they were not willing to pay either price. If transit improves and highways do not, such as in alternative 1, the crucial choice of this group is between transit and not traveling.

Suppose a tiny fraction of the latter group is at the margin under the original conditions. Because they are at the margin, they perceive no difference in benefit between using transit or not traveling. However, if the transit price is reduced, they would choose to travel by transit, and their benefit is indicated by the difference between their willingness to pay and the price of transit. For the assumed improvement, this difference is $C_{0t} - C^e_{1t}$. Another tiny fraction of the latter group will be at the margin between travel by transit and not traveling if the transit price is C'_t. They lie at the D'_t point on the curve, and if the improved transit system were installed, the difference between their willingness to pay and the price is $C'_t - C^e_{1t}$. Similar reasoning can be applied to each traveler regardless of where he is represented on the demand curve.

For all of the persons who would choose to use transit rather than not traveling, the total benefits can be derived. If the induced travelers are divided into small m-increments depending on their location on the demand curve, the net benefits could be estimated by summing the benefits that accrue to each increment as follows:

$$NB_1 = \sum_{j=1}^{m} (\hat{C}^e_{1tj} - C^e_{1t}) n_j$$

where

NB_i = net benefits from the induced travel for alternative i,
$\hat{C}^e_{1tj}$ = average equivalent cost at a point on the demand curve representing the j th increment,
C^e_{1t} = equivalent price of alternative 1, and
n_j = number of induced travelers in the j th increment.

If the procedure described in the earlier paper is followed, the sizes of the increments could be reduced and the number of increments increased until their number approached infinity. Then, methods of calculus could be used to produce a more exact calculation. However, these net benefits can be approximated, following arguments similar to those presented in the earlier paper, by a consumer's surplus formulation.

$$NB_{induced} = \frac{1}{2}[C_{0t} - C^e_{1t}][(D_{1t} - D_{0t}) - (D_{0a} - D_{1a})]$$

This formulation depends on the earlier recognition that members of both groups lie at all points along the demand curve.

Diverted Traffic—For the diverted travelers, similar arguments on the willingness to pay can be made; these travelers also consider automobile travel, transit travel, and no travel. Under the alternative 0 conditions, the members of the group lying along the demand curve between D_{0t} and D_{1t} choose to travel by automobile. As transit improves from C_{0t} to C^e_{1t}, their crucial comparison is between automobile travel and transit travel.

Under alternative 0, a tiny group of those travelers who lie at D_{0t} on the demand curve are indifferent between transit and automobile. They are willing to pay C_{0t} to use transit and no more. Similarly, they are willing to pay C_{0a} to use automobile and no more. However, if the transit price were reduced, they would choose to travel by transit. Their benefit would be indicated by the difference between their willingness to pay for transit and the cost of transit. For the assumed improvement, this difference is $C_{0t} - C^e_{1t}$. Another tiny fraction of previous automobile travelers will choose to use transit only if the transit price is less than C'_t. They lie at the D'_t point on the curve shown in Figure 3; and, if the alternative 1 transit systems were installed, the difference between their willingness to pay and the cost is their perceived benefit, $C'_t - C^e_{1t}$.

Thus, the total benefits can be derived for the group of persons who would choose to use transit under alternative 1, those being diverted from automobile. The argument is similar to that presented earlier, which displayed summation of benefits over a number of traveler increments for the induced travel. Now, the m-increments are increments of travelers in the diverted category.

The result is that the net benefits to the diverted traffic can also be approximated by a consumer's surplus formula.

$$NB_{diverted} = \frac{1}{2}(C_{0t} - C^e_{1t})(D_{0a} - D_{1a})$$

Total Benefits

The total net perceived traveler benefits for the improvement in the transit system is the sum of the net benefits to the 3 types of travelers.

$$\begin{aligned} NB &= NB_{original\ transit\ traffic} + NB_{diverted\ traffic} + NB_{induced\ traffic} \\ &= (C_{0t} - C^e_{1t})(D_{0t}) + \frac{1}{2}(C_{0t} - C^e_{1t})(D_{0a} - D_{1a}) \\ &\quad + \frac{1}{2}(C_{0t} - C^e_{1t})[(D_{1t} - D_{0t}) - (D_{0a} - D_{1a})] \end{aligned}$$

which simplified to the well-known consumers' surplus formula is

$$NB = \frac{1}{2}(C_{0t} - C^e_{1t})(D_{1t} + D_{0t})$$

Suggested Procedure

The procedure that has been followed in this example to calculate the traveler benefits can be applied to any transportation system in which a total-demand model is used. The following steps should be followed to compute net traveler benefits. The benefits should be computed for each zone pair.

1. Identify those zone pairs that, compared with the base case, have increased traffic under the alternative being studied.
2. Compute the equivalent price C^e for each zone pair.

3. Compute the consumer's surplus for each zone pair. The expression

$$NB = \frac{1}{2} (C_{0t} - C^e_{1t}) (D_{1t} + D_{0t})$$

would be used in the case of transit improvement.

4. Sum the net benefits over all improved zone pairs.

It has been recognized that one difficulty with the Northeast Corridor demand model is that it tends to reflect improvements in a given mode in much larger quantities of induced traffic and much smaller quantities of diverted traffic than are reasonable. Various steps have been taken to correct this problem.

Although this problem is very real and must be dealt with when the needed capacity on the various modes is considered, the resulting consumers' surplus formulation given above mitigates the problem somewhat. The formulation does not require separation of the 2 types of increase in travel—induced and diverted. In other words, the individual benefits to the travelers who elect to travel by the improved mode is the same regardless of whether they are induced or diverted travelers.

A NOTE ON THE INTERPRETATION OF THE ALPHA TERMS

In the total-demand and modal-split formulations presented in this and the earlier paper, the term α is used as a constant term in an expression describing either a difference in utility between modes or the utility of an individual mode.

Such models should normally be developed by experimentation with a number of formulations of the various independent variables in order to arrive at an expression that most nearly explains the observed behavior. Regardless of the amount of experimentation or the number of variables included, an unexplained difference invariably remains. This difference is represented by the α terms used in the formulations given in this and the earlier paper. Some investigators have referred to this unexplained difference as a comfort and convenience factor. The author would prefer to refer to it as the total unexplained difference, without theorizing any particular name or cause.

This difference is a difference between explicit modes of travel, between the modes against which travel decisions have been studied and the model developed. The explicit model should only be used to evaluate changes in the modes that were used in the calibration process.

We submit that there is no such thing as an "abstract modal model," in the sense that any technological mode can be studied in the context of a demand or modal-split model calibrated for 2 explicit modes. The new technological mode would produce a different α term that would stand for the preferences for that mode that are not explained by the independent variables. (Similarly, the significance of the independent variables under a new mode assumption may be different from that under the condition that existed for calibration of the model.)

This observation implies not only that considerable care should be used in applying demand and modal-split models to new modes but also that care should be used in conducting evaluations using these models.

REFERENCES

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DISCUSSION

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Haney points out the fallacy of judging the efficiency of a transport system on the basis of aggregate cost incurred in travel. The minimization of total cost is a reasonable objective when different systems achieve the same utility. But, because alternative transport systems lead to different origin and destination linkages (and level of trip generation), the condition of equal utility obviously is not fulfilled. Specifically, the paper argues that changes in the transportation system induce some travelers to reexamine their selections of origins or destinations. For those travelers, before-and-after cost comparisons are meaningless because not only did the cost of the trip change but so did its utility.

The logic of the argument presented is sound. Yet, the reader is left with the uncomfortable sensation that its practical consequences (increased net benefits to be used in justification of transport investment) point in the wrong direction. A stone is being added to the benefit side of the scales while society's finger tries to push the pointer in the opposite direction. To repeat a familiar argument: Transport investment leads to ease of travel, which is conducive to a footloose selection of place of residence and work, which in turn generates an apparent dependence of the society on travel and makes investment in transport system improvements easy to justify, and so on ad infinitum. The outcome of this self-perpetuating process is the present urban structure; its diffuse activities render automobile dependence absolute and the concept of "choice through mobility" questionable. For some years now, several communities dared to question the wisdom and expertise of planners and opposed their recommendations for transport investment. The dilemma is obvious: How is it possible that investments, which are justified on the basis of values and preferences of all members of a community (as calculated by the planner), are frequently opposed by vigorous political action of the very same group?

The paradox may be easily explained in terms of vocal minorities, professional activists, irrationality and misinformation, uneven incidence of costs and benefits between groups, imperfections of the political process, or myopic decision-makers. The planners, however, must seriously consider whether the paradox stems, at least in part, from a professional bias. Specifically, has the planner not been systematically more diligent in searching for benefits than in scouting for "costs?" It is on this basis that Haney's paper may be found wanting.

Whether justification of public investment should proceed on the basis of the elusive "consumer surplus" while investment in the private sector can rarely do so is a moot question. But even if the legitimacy of incorporating the consumer's surplus into the benefits of investment is not questioned, the suggested evaluation scheme lacks in comprehensiveness.

It is well known that only a part of the cost associated with the performance of a trip is borne by the trip-maker himself. Some of the cost is imparted to his fellow travelers in the form of increased congestion, safety hazards, and the like. This component of the cost should not remain unaccounted for. Its neglect is particularly objectionable when, as a result of investment, new trips are being made. In this situation, it is the planner who is responsible for the incorporation of costs that the induced traveler is incapable of perceiving. The "congestion cost" is not merely academic hairsplitting relating to hypothetical situations. It may be seen at work in the common example of transport and other investment in the outer reaches of the cities, inducing new trip-makers into commuting to the downtown. Although the new travelers indicate by their decision to travel the receipt of a net benefit, the added plight of the original users remains anonymous and is not added to the accounting ledger. It is, however, present in a growing body of public sentiment that questions the desirability of "growth" because it usually means deterioration for those already in the system.

The second component of transport cost unaccounted for in Haney's accounting procedure is the cost imparted by trip-makers to nonusers of the transport system. Those are simply not present in the model. Yet, almost every major transportation investment in the past decade had to contend with relocation, air pollution, noise, visual obstruction, community disruption, and other impacts on nonusers.

In summary, Haney's method of calculating traveler benefits is certainly rational and consistent with currently used models. Lest consistency be construed to mean comprehensiveness, I find it necessary to point out that the benefits and costs accounted for in this procedure form but a part of the overall impact of transport investment. Under no circumstances can it be regarded as a "total procedure for analyses of benefits and disbenefits." And if used so, it will in all likelihood result in yet another confrontation of the public versus the "highway establishment."

AUTHOR'S CLOSURE

Hauer's principal concern is that transportation planners may become enamored with advancing the state of the art in the estimation of benefits from investments in transportation systems at the expense of advancing the art in estimating costs, as they are broadly defined. With this point I certainly agree, and I would hope that my earlier writings would testify to that philosophy.

The intent in the paper, perhaps more explicitly stated in the earlier paper (1), was to deal only with traveler benefits and costs. To treat isolated problems in methodology is appropriate within the format of professional papers, as I am sure Hauer will agree.

With regard to specific points in his comment, Hauer argues that a biased effort to find benefits can lead to diffused urban structure. Perhaps this is so when highway planners justify new highway projects. But what about transit planners? Do they search to find benefits so that they can counteract the urban-sprawl effect? I think not. I would hope that both the highway planner and the transit planner would search for 2 kinds of optimums: the optimal transportation system and the optimal effect of transportation in influencing land use. Neither of these is easy to define and measure, but I would hope that the procedures presented in this and the earlier paper would lead to improved solutions to the problem of finding optimal (balanced) transportation systems. At the present time, I would prefer not to argue as to the most attractive land use pattern, although a subsequent paper will address itself to a facet of that problem. Suffice it to say that the procedures described in the 2 papers could—or might—provide the planner with an improved way of assessing the potential of transit systems to condense patterns of land use as well as of highway systems to diffuse the patterns. Personally, I do not think that the effects of different technology cannot exclusively be labeled as producing, condensing, or diffusing land use changes.

Regarding Hauer's discussion of disbenefits to existing travelers, if both the demand and supply curves are specified and if the supply curve produces increased cost with increased usage, i.e., congestion cost, it is possible to estimate the magnitude of the increased cost to the original users. It can be estimated as the difference between the actual cost to the original users (as well as to the induced users) for the new system, less the cost to the original users for the new system had the induced travel not materialized. Thus, the disbenefits to original users can be added to the accounting ledger.