Shortcut Modal Split Formula

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A shortcut modal split formula has been devised to measure the number of car drivers in large and middle-sized cities who would be diverted to travel on public transit if transit fares were reduced and/or if door-to-door travel times on transit were shortened by specified amounts. The shortcut formula applies only to car owners who work in central business districts since they often constitute the only significant concentration of tripmakers who can exercise a practical choice between driving and riding transit. The shortcut formula can be applied when two items of information are known: (a) the number of CBD workers who have their own cars, and (b) the proportion of car-owning workers who presently arrive at work on transit. Data may be evaluated for an entire city or for specific zones and zone clusters.

•IN the summer of 1965, Wilbur Smith and Associates was authorized by the U.S. Department of Transportation, Bureau of Public Roads, to undertake research entitled "Evaluation of Bus Transit Demand in Middle-Sized Urban Areas," with one aspect of this study to be the development of a "shortcut" method for quickly estimating the general magnitudes of change in the modal split when specific changes in cost or travel time requirements were introduced into a known situation. The "shortcut modal split formula" was prepared from data that represent trip-making behavior in large urban areas, but the formula is intended to indicate the general impact of trip cost or travel-time modifications in any community.

The shortcut formula relates only to travel performed by persons as they go to and from work and was developed from data on worker travel to the central business district (CBD) in the urbanized areas listed in Tables 1 and 2. (Although the shortcut formula has been prepared for a rather small and specialized segment of the traveling public, the principal reason for this restriction is based on the fact that there are very few transit riders in other trip-making populations who have regular access to a car, so that statistically stable information for analytical investigation is hard to find except for work trips to the CBD. There does not seem to be any basic reason, however, why the shortcut formula cannot be applied to workers traveling to any concentration of urban employment for which appropriate input data are available.)

The shortcut formula is designed to measure only the change in travel mode that can be expected to occur when the relative quality or cost of trip-making by car and public transit is modified, and is not intended to predict wholly new or induced trip-making that might result if the general level of mobility within an urban environment were improved. Because the formula relates only to the reapportionment of given amounts of travel, it is concerned with tripmakers who have the freedom to choose between private and public modes of travel.

Car owners will voluntarily travel by transit to very few employment centers in most urbanized areas. In searching for data to use in this study, it was soon found that the CBD is almost the only work place where a substantial number of car owners

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Paper sponsored by Committee on Origin and Destination and presented at the 48th Annual Meeting.

TABLE 1

SEVEN URBANIZED AREAS SELECTED FOR STUDY OF BUS TRANSIT DEMAND

Urbanized Area	Year of Survey	Population (thousands)	Dwellings (thousands)	No. of Cars (thousands)	Cars per Household	Thousands of Trips by Population		
						All	Transit	Percent Transit
Philadelphia, Pa.	1960	4,007	1,299	1,088	0.84	8,144	1,283	15.8
Boston, Mass.	1963	3,541	1,089	1,066	0.98	7,997	1,055	13.2
Baltimore, Md.	1962	1,608	481	446	0.93	2,675	322	12.4
Seattle, Wash.	1962	1,347	445	487	1.09	2,368	116	4.9
Milwaukee, Wis.	1963	1,221	366	373	1.02	2,555	268	10.5
Springfield, Mass.	1964	531	170	170	1.00	1,195	42	3.6
Columbia, S.C.	1964	196	62	69	1.12	581	14	2.5

TABLE 2

CBD WORKER POPULATIONS IN SEVEN URBANIZED AREAS (PERCENTAGES)

Urbanized Area	Population (thousands)	All CBD Trips (percent)	Percent Transit Riders	Percent Car Owners	Percent With Cars Ride Transit	Percent Transit Riders Have Cars	Transit Riders With Cars as Percent All Workers
Philadelphia	4,007	100	69.0	48.0	49.7	34.6	23.9
Boston	3,541	100	63.0	52.9	47.8	40.0	25.3
Baltimore	1,608	100	40.6	51.1	20.7	26.0	10.6
Seattle[a]	1,347	100	29.2	66.5	16.0	36.5	10.6
Milwaukee[b]	1,221	100	31.6	68.8	12.0	25.8	8.2
Springfield	531	100	21.8	65.2	7.6	22.8	5.0
Columbia	196	100	11.0	72.1	1.9	12.3	1.4

[a]Seattle data relate to only those portions of the Puget Sound Regional Transportation Study Area that lies east of Puget Sound.
[b]Milwaukee data have been compiled from the home interview survey conducted in the Milwaukee urbanized area, which is only a portion of the Southeastern Wisconsin Regional Planning Commission's Seven County Study Area.

regularly arrive at work by transit. Even in very large urban areas, such as Philadelphia and Boston, relatively few car owners use transit to get to work destinations that are not located in the CBD. Because this is the case, the basis for the shortcut formula is travel by car-owning workers who are employed in the CBD. While there are reasons to believe that the formula can probably be applied to workers at other large generators served by transit, empirical data are not available to prove it.

THE SHORTCUT MODAL SPLIT FORMULA

The shortcut formula is illustrated in Figure 1. The use of public transit for travel to work in the CBD is expressed as a percentage of any particular trip movement according to calculated cost differences for travel by transit and private car. When costs are equal (zero cost difference), half of the car-owning CBD workers would be expected to use their cars, while the other half would use transit. If transit costs are higher than those by car, less than half of the movement would take place in transit vehicles.

The following items cover most of the areas of cost subject to measurable manipulation:

1. Changes in transit fare structure;
2. Changes in toll charges and/or CBD parking rates; and
3. Changes in door-to-door travel time by car or transit (reduced to cost equivalents).

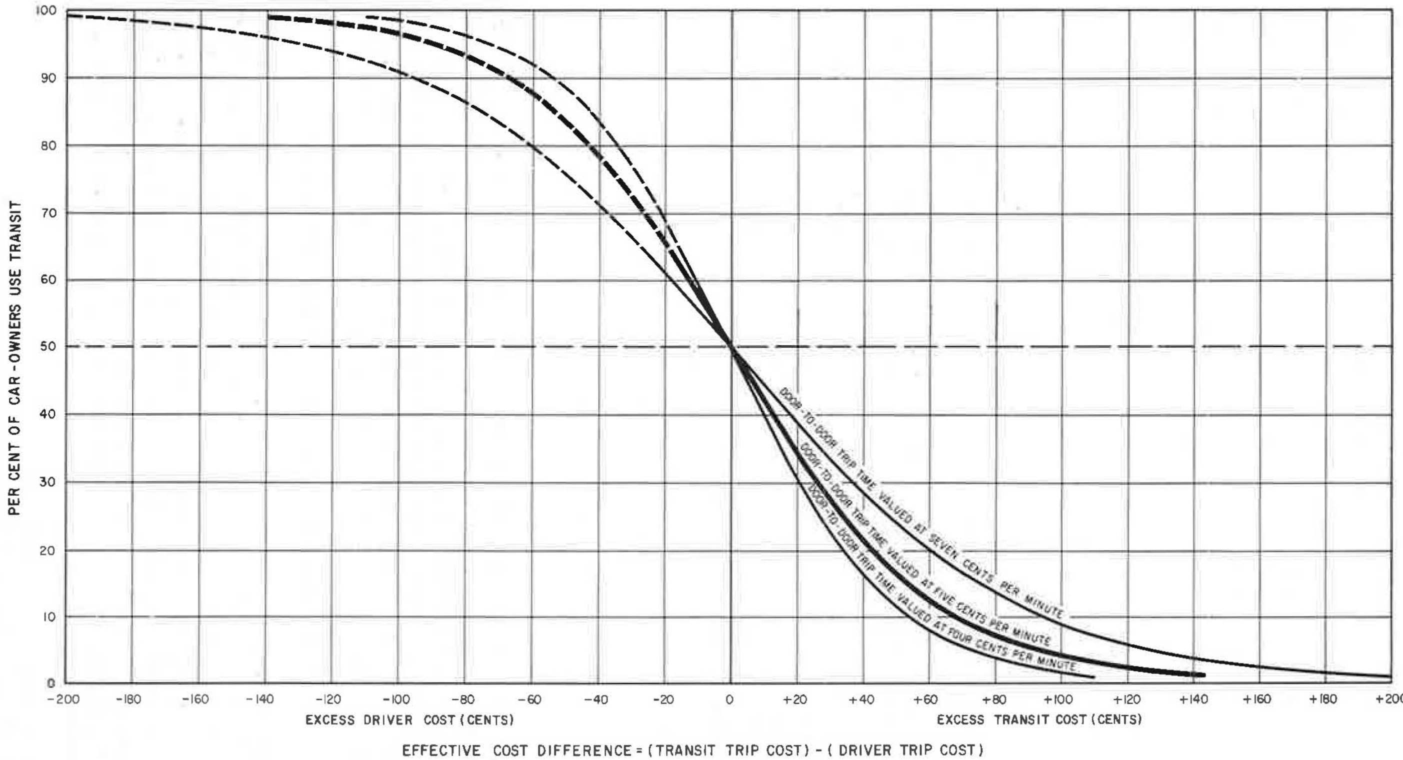

Figure 1. Shortcut formula to estimate effect of change in trip cost or travel time on the use of transit for CBD work trips by persons with cars.

Fares charged to transit riders may be modified by an overall increase or decrease in the cost of a ride; selective changes may be made, such as zone-fares, that affect only parts of the study area; or fares may be reduced or increased on some routes and not on others.

Average all-day parking costs tend to rise generally in most CBD's; it may be found feasible to accelerate an increase in rates, or even to reduce or eliminate charges. Toll charges usually apply to specific corridors (ferries, bridges, tunnels).

Travel-time may be modified for transit riders by increasing or decreasing service frequency (affects waiting time, or headway, between successive vehicles on a route); by adding or subtracting transit routes in a system that may change spacing between routes (affecting distance and walking time to bus stops); by reducing or increasing the number of loading and unloading stations (skip-stop technique may increase average running speed but also will result in longer waiting times at skipped stops); by introducing or abandoning express (nonstop) service between specific neighborhoods and the CBD; or by utilizing express highways, exclusive transit lanes, or exclusive transit rights-of-way for a portion of the trips. Driver trip time tends to become longer as traffic volumes (congestion) increase, but may be reduced when a new freeway or other street improvement is opened to use.

Some analyses of the value of travel time have differentiated between time spent in the vehicle and time spent waiting for the bus. These studies find that reduction of waiting time results in larger amounts of new transit travel than identical amounts of time saving achieved by improving vehicle speeds. The difference attributed to the value of a unit of time spent waiting, as opposed to time spent riding, would seem to be owing to the discomforts associated with waiting at transit stops, rather than to the time loss itself. These discomforts, such as adverse weather and fatigue of standing are among the "intangible" costs of travel that have not yet been defined and evaluated in mathematical terms. If it is proposed that time savings be achieved through reduction of waiting time, it would be appropriate to add the value of these intangibles, as found in controlled experiments and studies, to the cost savings attributed to the reduction in trip time.

APPLYING THE SHORTCUT FORMULA

The shortcut formula consists of a logarithmic growth curve which has been calibrated to show the proportion of CBD workers with cars who are likely to use public transit for their work trips under a complete range of relative cost conditions.

The following equation has been developed from the relationships shown in Figure 1 (this equation was developed by Herbert S. Levinson and Bruno Wildermuth, based on curves that had been hand-fitted to the data used in the study; earlier versions consisted of separate equations for each value of time-cost (2)):

$$P = \frac{1}{1 + \exp(16x/c)} \tag{1}$$

where

P = percent of car owners who use public transit to travel to work in CBD;
e = base of natural logarithms = 2.71828;
c = cost of time in cents per minute; and
x = net trip cost difference = (transit trip cost) - (driver trip cost).

Three curves have been calculated and drawn in Figure 1, based on different rates of cost for travel time. At present, a rate of 5 cents per minute provides an appropriate weighting for travel time when combined with other costs of travel. Rates of 4 cents and 7 cents per minute were used to develop the lightly drawn lines that flank the 5-cent curve and that are shown to illustrate a range within which an estimate might fall. The curves show how different assumptions on the worth of travel time affect estimates of transit use, ranging from low (7-cent curve) to high (4-cent curve) transit-use potentials. If the value of commuters' time continues to increase, the 7-cent curve should gradually become more suitable than the 5-cent curve, because per-mile direct costs will probably increase with the passage of time owing to the forces of inflation. Under conditions where differences in trip cost relate only to travel time, however, the equation will develop nearly identical estimates for any time value used (within the range shown).

To use the shortcut formula, it is necessary to know the number of car owners attracted to an employment center from each of the residential neighborhoods in an urban area, and to determine, either by direct measurement or informed estimate, the proportion of these car owners who arrive at work on a transit vehicle. Transit riders would include any persons who started their trips by car and transferred to transit, such as railroad commuters. When the percentage of transit riders has been found for a particular population of car-owning CBD workers, this information may be projected to the modal-split curves shown in Figure 1.

Figure 2 shows how the modal split curve can be used to estimate the effect of a reduction in transit trip costs relative to costs by car. In the example shown, it has been assumed that 15 percent of the car-owning CBD workers residing in a particular traffic zone are presently using transit for the trip to work. This value has been scaled on the vertical axis of the chart and carried horizontally (A) to intersect the 5-cent curve. The approximate value for excess transit cost has been noted on the scale at the bottom of the chart (B). It was next assumed that a saving of 10 cents in the average cost of the transit ride from the traffic zone of residence to the CBD can be anticipated; this reduction in the excess cost of transit has been subtracted from the "effective cost difference" by moving an appropriate distance to the left (C). A vertical projection (D) intersects the diversion curve again, and a new estimate of the proportion of car owners using transit has been obtained (E) from the vertical scale on the left margin of the chart. Under the revised condition, about 20 percent of the car-owning CBD workers in this residential zone would be expected to arrive at work by transit, or about a one-third increase in transit use by this particular sector of the traveling public.

The cost reduction assumed for transit can be realized in various ways. The 10-cent saving might result from a fare reduction, from introduction of express service that reduces trip time by two minutes, from an increase in service frequency that reduces average headways at the bus stop by four minutes, and thereby saves the average rider about 2 minutes per trip, by an increase in motorist parking costs, or by any combination of these. If the analyst believes that he can establish a realistic estimate of the value of such intangibles as air conditioning, protected bus stops, prohibition of standees, and other conditions that do not directly affect travel time or out-of-pocket costs, he can assume such savings and estimate the increased patronage resulting from such inducements.

The information needed to enter the shortcut formula consists of one item for each traffic zone; that is, the proportion of car-owning CBD workers who ride transit to work. When this is known or assumed for a base condition, the effect of trip cost savings or increases can be quantified for tripmakers in each traffic zone in the study area.

DEVELOPING THE SHORTCUT FORMULA

Only the CBD worker population was examined in this study, with special attention given to workers defined as car owners. This definition was applied only to CBD workers who had exclusive use of a car during the working day and, according to definition, the car was either used by the owner in making his trip to work or it remained idle throughout the time the worker was away at his job. In spite of this strict interpretation of car availability, almost half of all CBD workers interviewed in the Philadelphia survey, more than half of those in Boston and Baltimore, about two-thirds of the workers in Seattle, Milwaukee and Springfield, and nearly three-quarters of those in Columbia were classified as car owners.

Nearly half of the CBD car owners in Philadelphia and Boston arrived in the CBD on transit, but only a fifth came by bus in Baltimore, a sixth in Seattle, and an eighth in Milwaukee. The proportions were so small in Springfield and Columbia (less than 8

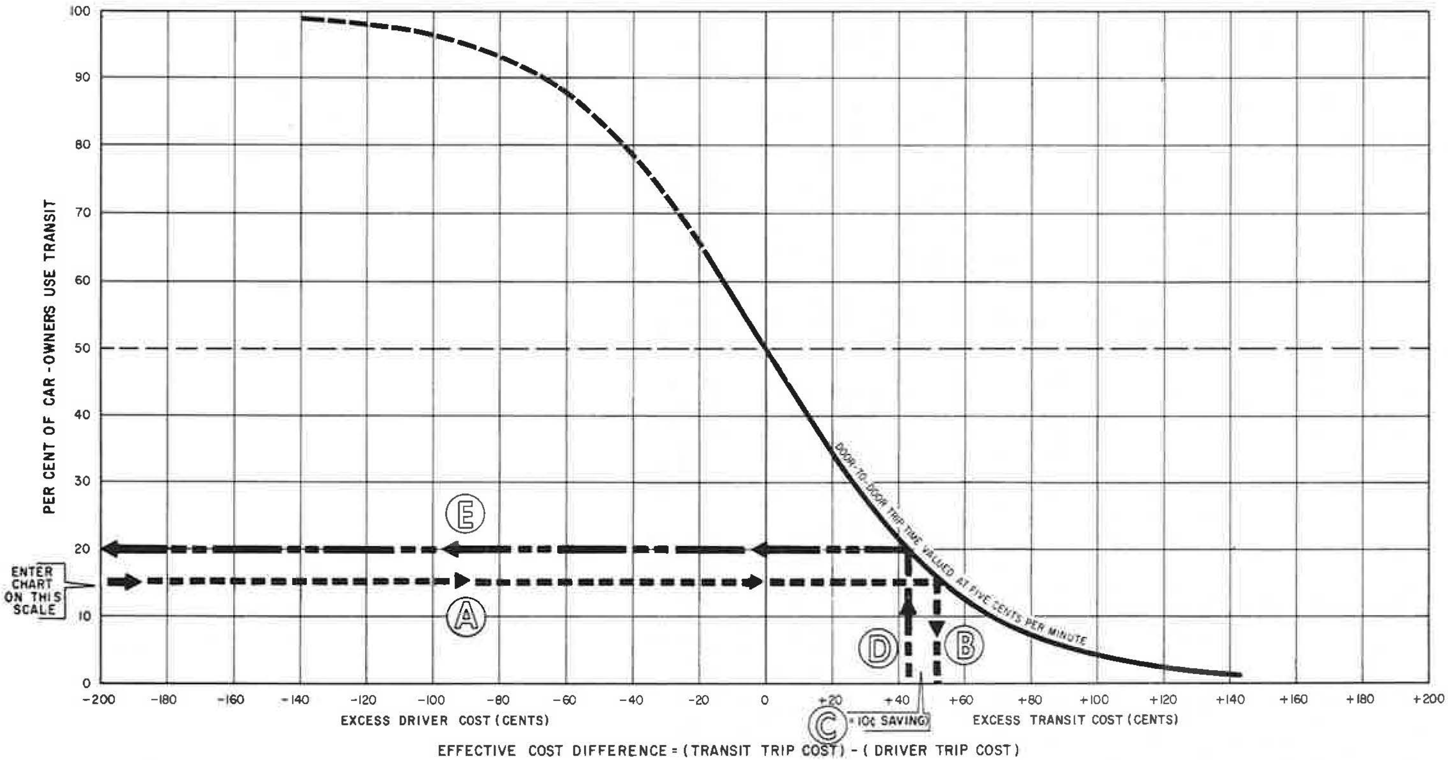

Figure 2. Shortcut formula: example of use to estimate effect of change in trip cost or travel time on the use of transit for CBD work trips by persons with cars.

and 2 percent, respectively) that data from these areas were dropped from further analyses. Both Boston and Philadelphia have extensive rail commuter services, with up to three-fourths of the car-owning CBD commuters in some outlying communities going to work by train each day.

Data for each study area were organized in a few concentric "rings" or "belts" of traffic zones centered on the CBD. All home-based worker trips to the CBD were assembled by rings and summarized by mode of arrival at work. Door-to-door elapsed trip times were compiled and average time values computed for travel from each ring according to mode.

The basis for the shortcut formula is the assumption that the use of transit by car owners who work in the CBD is a function of the relative costs of travel by car and transit. Although the cost of travel is an exceedingly complex subject, means were sought to simplify the situation and base the estimating formula on a few relatively uncontroversial cost items. Four categories of cost were defined for consideration:

1. Out-of-pocket costs of travel (fares on transit; vehicle operating costs for drivers);
2. Nonoperating costs to drivers (parking and tolls);
3. Travel time (minutes of trip-time, converted to appropriate cost values); and
4. Intangible costs (comfort, convenience, privacy, etc.).

Out-of-pocket costs are highly variable within each mode but, after careful consideration, it seems feasible to regard them as approximately equal, or near enough so that no reliable distinction could easily be developed. Intangible costs do not easily yield to quantification. After considering these points, estimated cost differences for travel by car and transit were prepared, based on door-to-door times (in cents per minute) and average all-day parking costs paid by drivers. Recent studies of the value of time to persons commuting to work suggest that a range of 4 to 5 cents per minute is appropriate (3, 4). It was convenient to apply these rates to the time-difference between car and transit trips.

Figure 3 was prepared to show the basic costs of all-day parking to those persons who pay for parking in the CBD, based on parking survey data for cities ranging widely in size. Curve B on the chart represents the actual rates paid by persons who had to

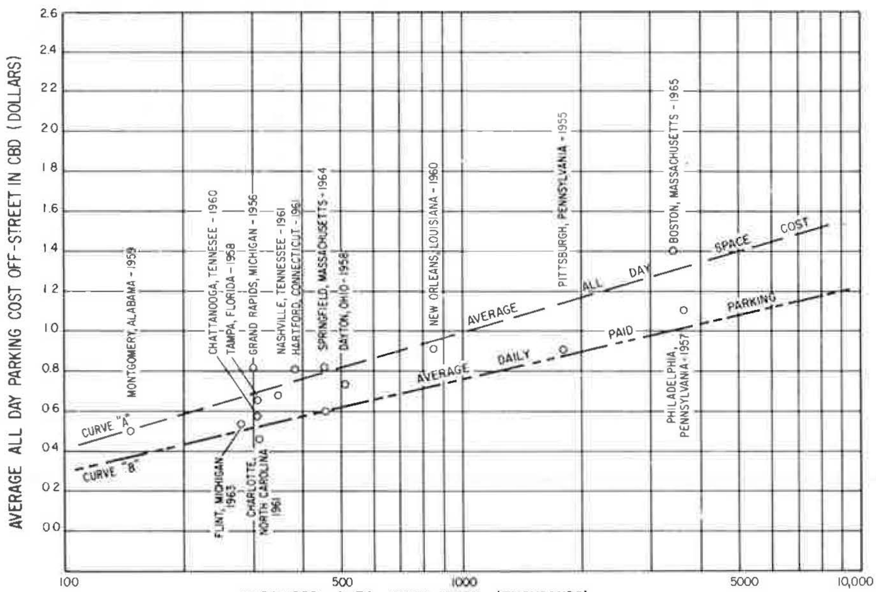

Figure 3. Average all-day, off-street parking rates in CBD.

bear the cost for storing their cars. Daily rates are shown to vary according to city size.

An amount equal to half of the daily parking cost represents a fair charge against the one-way trip to work; this value was factored by the percentage of drivers who paid to park to find an average parking cost for all CBD drivers. Parking costs were added to time cost of driver trips and the effective cost differences computed for car and transit travel to the CBD in each study area. Figure 4 shows these data, summarized by a ring, plotted against the proportion of car owners using transit. Figure 4 was plotted from data showing the percentage of car owners in each ring who use transit related to excess trip costs at 5 cents per minute. Points for the series of rings in each study area have been joined.

The logarithmic growth curve shown in Figures 1 and 2 has also been plotted in Figure 4. The general shape of the curve was worked out from inspection of the data-points, with consideration for the shape that the curve might be expected to take. The most evident relationship is the grouping of points for Philadelphia and Boston. A straight line drawn freehand to fit the Philadelphia points would cross the line of equal cost at a point where 50 percent of the CBD car owners use transit for the trip to work. Data for the most important rings in Boston, while dispersed more widely, tend to average out at about the same point. The data plotted in Figure 4 thus confirm the relationship that would be expected, assuming that all trip costs had been taken into account. It can be argued that this is true in the case of Philadelphia and Boston.

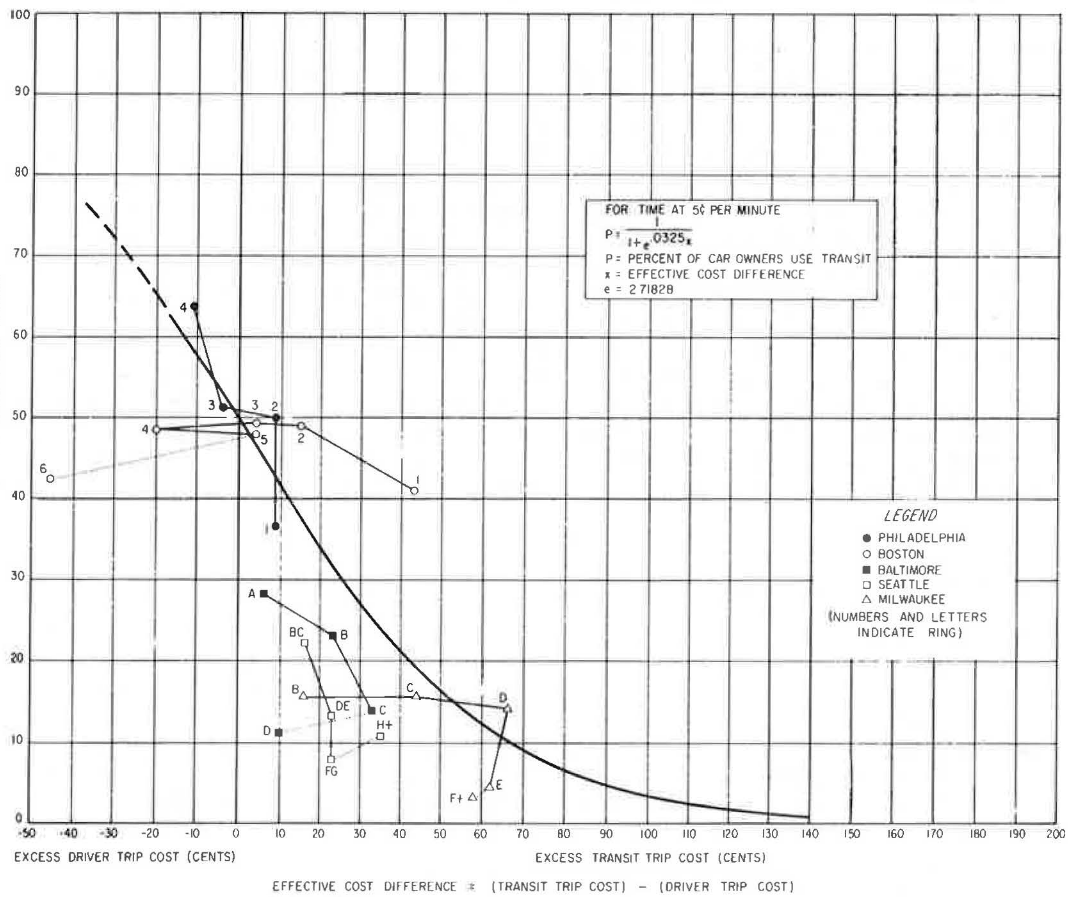

Figure 4. Transit use vs trip cost difference.

Data for the smaller cities do not lie on, or even near, the curve projected through the Philadelphia and Boston data. It is significant, though, that lines connecting the points representing rings in Baltimore and Seattle develop slopes that are generally similar to the curve. Thus, it could be argued that the lateral displacement of the curve represents cost differences that relate to intangible conditions. But, in any case, it is the slope of the curve that determines the added proportion of car owners affected when transit trip costs are reduced. The curve representing the shortcut formula has a reasonable slope in relation to these data.

TYPICAL APPLICATIONS

The shortcut formula pertains only to populations that have freedom of choice in the selection of a travel mode for work trips. These are the tripmakers who have their own cars and who are not likely to use transit for a trip unless it meets their needs better than the car.

In a typical situation, the shortcut formula might be used to estimate potential diversion of additional workers to transit because of an improvement in the effective cost-difference for transit travel between the CBD and a number of residential neighborhoods (zone clusters). The total of car-owning CBD workers in each neighborhood, and the percentage of them who presently use transit for the work trip, would be determined, and the effective cost-difference between car and transit would be established for each movement as illustrated in Figure 2. A 5-cent value of time can be expected to develop a good estimate of the cost-use relationships in most current situations, but the analyst may pick a cost value at his own discretion.

Taking this approach, the effect of a change in the relative costs or performance levels of car and transit work trips can be estimated. The average amount of cost change would be calculated for travel attracted to work places in CBD from each neighborhood and this amount would be subtracted from the effective cost-difference based on present levels of transit use. The new cost-difference value would be projected to the diversion curve to find the corresponding percentage of transit users.

A variety of costs can be considered in developing the estimate of change. Direct out-of-pocket cost-changes may relate to transit fares, parking charges, toll rates, and possibly other cost elements. Time changes, which must be converted to cost values according to a rate specific to the diversion curve used, can be realized in various ways, such as improved transit running speeds (owing to express service, skip-stop operation, exclusive bus lanes on freeways), more frequent headways (saving up to half of the difference in headway time-changes), closer spacing of transit routes (resulting in less walking time), and similar measures.

When a new percentage of transit riders is found, it may be applied to the base number of car-owning workers who travel to the CBD to derive an estimate of transit diversion and thus find the number of new riders. If these are estimates of 24-hour diversions of trips to work, an appropriate percentage factor may be used to estimate the number of new transit riders in peak-hour travel to work.

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