The Evaluation of Benefits From Measures to Increase Urban Transport Efficiency

Gabriel J. Roth, International Bank for Reconstruction and Development, Washington, D.C., and Y. Zahavi, Transportation Consultant, Bethesda, Maryland

Although everybody is in favor of more efficiency in urban transport, not much attention has been paid to evaluating the expected benefits in a comprehensive manner. It is not difficult to postulate a change in the urban transport system, e.g., a time-saving investment, and to calculate the consequent savings in time and money related to a given number of trips made before and after the improvement. However, this approach ignores the newly generated travel that invariably follows urban transport improvements and thus conceals many of their likely consequences.

The purpose of this paper is to take a closer and more comprehensive look at the phenomena of urban transport improvement and to calculate estimates of the order of magnitude of the benefits that might reasonably be expected to accrue from the relaxation of economic regulation in the Washington, D.C., area. Specifically, calculations are made to indicate the effects of

1. Reduction of the number of private automobiles by 10 percent, due to an increase in car pooling, with a consequent increase in traffic speed due to a reduction in congestion;
2. Substitution of subscription bus services for conventional ones, with consequent increases in public transport speeds and a reduction in operating costs; and
3. Substitution of subscription bus services for 10 percent of private automobile trips, with a consequent increase in traffic speeds due to the reduction in the number of automobiles but a decline in the speed of trips transferred from automobiles to subscription bus services.

The calculations are based on the conditions that were present in the Washington, D.C., area in 1968, the latest year for which comprehensive travel data are available. The area considered is shown in Figure 1. The population considered consists of residents of districts 1 through 14, while their travel covers districts 1 through 20. The basic population and automobile data for each district were obtained from unpublished survey material collected for the 1968 Transportation System Findings Report by the Metropolitan Council of Governments (COG) and are summarized below.

District	Population	Households	Automobiles	Trip Makers/ Household
1	76 803	37 133	20 613	1.37
2	17 060	8 070	5 476	1.62
3	96 519	36 143	20 890	1.60
4	82 365	27 377	18 125	1.58
5	61 005	28 772	31 714	1.59
6	46 681	20 287	21 216	1.75
7	116 054	37 770	38 258	1.84
8	184 256	58 180	42 658	1.73
9	110 760	38 270	48 349	1.90
10	98 999	36 049	48 451	1.93
11	277 901	85 981	135 468	2.18
12	190 630	64 552	90 699	1.98
13	143 599	42 688	56 679	2.13
14	89 966	25 950	41 934	2.35
Total	1 592 599	547 224	620 531	1.87

A comparison of the basic travel characteristics for 1955 and 1968 is shown below (1 km = 0.6 mile).

Item	Trip Makers: Automobile Only 1955	Automobile Only 1968	Transit Only 1958	Transit Only 1968
Daily door-to-door travel time, h	1.09	1.11	1.27	1.43
Time/trip, h	0.35	0.35	0.55	0.67
Trips/weekday	3.07	3.16	2.31	2.12
Distance traveled/d, km	20.48	25.91	13.60	14.35
Distance/trip, km	6.68	8.21	5.89	6.24
Door-to-door speed, km/h	18.83	23.33	10.70	10.04

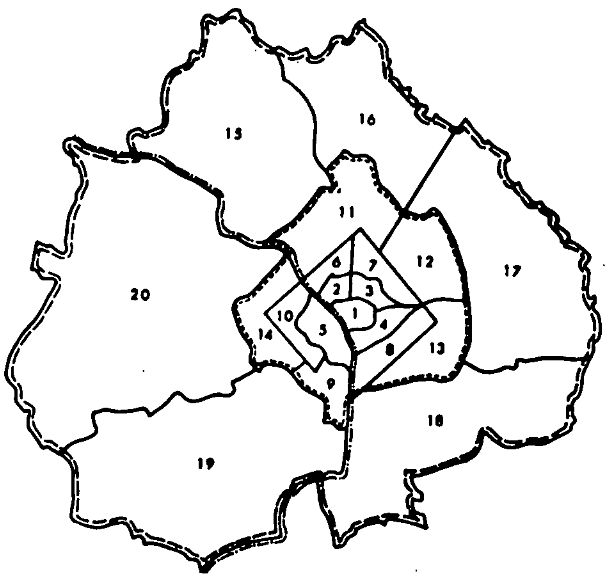
Automobile-only trip makers are those from households in which all trips are made by private automobile. Transit-only trip makers belong to households in which all trips are made by transit, including those made by taxi and school bus. A third group, from households that used mixed modes, is not shown; its travel characteristics are intermediate between the first two groups.

METHOD

The calculation of benefits uses a methodology developed recently by Zahavi (1). It depends on the empirical finding in a number of cities, including Washington, D.C., that both the time and the money allocated by groups of trip makers for urban travel tend to be stable and therefore predictable. The basic indications, which will be discussed later, may be summarized as follows:

1. Daily travel demand is constrained by two main travel budgets, that of money and that of time;
2. The travel-money budget of the individual trip maker depends on his or her household income;
3. The travel-time budget for trip makers is stable both between cities and over time within the speed ranges normally found in U.S. cities; and
4. Trip makers strive to maximize their daily travel distance within the above constraints of money and of time.

Figure 1. The Washington, D.C., study area.



Travel-Money Budget

The cost of travel is recognized to be a major constraint on travel, since people must allocate a proportion of their disposable income to transportation. The proportion of income allocated to travel seems to be stable both over time and between countries (in developed countries). The average percentage of total personal expenditure devoted to travel in the United States between 1963 and 1973 (2) is shown below.

Year	Expenditure on Travel as a Percentage of Total Expenditure	Year	Expenditure on Travel as a Percentage of Total Expenditure
1963	13.1	1969	13.4
1964	12.9	1970	12.6
1965	13.4	1971	13.6
1966	13.0	1972	13.7
1967	12.7	1973	13.6
1968	13.4		

As indicated, expenditures on travel tend to be a relatively stable proportion of the total expenditure—about 13.2 percent. Since total personal expenditure in this period was about 86 percent of total income, it follows that the average expenditure on travel during 1963 to 1973 was about 11.4 percent of total income. (Disposable incomes are most difficult to define and, therefore, all data in this section are based on total income.) The same trend is also found in other countries and cities (1, 3, 4), as shown below.

Place	Year	Percentage of Expenditure on Travel
United Kingdom	1972	11.7
London	1972	12.3
Federal Republic of Germany	1971	12.0
	1972	11.3
	1973	11.1
	1974	10.7
Washington, D.C.	1968	11.2

Hence, it may be inferred that expenditures on travel tend to be a stable proportion of income, within the range of about 11 to 12 percent.

It was further noted that households in which the members make all their trips by automobile tend to allocate a stable proportion of their income to travel—about 11 to 13 percent, at all income levels. However, households in which the members make all their trips by transit tend to allocate only 3 to 5 percent of their income to travel, again at all income levels. Since the proportion of households that own an automobile increases with income, it follows that the total average expenditure on travel by income group increases from about 3 percent at low income levels to a saturation level of just more than 13 percent at high income levels.

Travel-Time Budget

It has already been noted that the average daily travel time per automobile tends to be stable—about 0.8 h, in cities of developed countries (5). Recent analysis of four traffic studies in Washington, D.C., and Minneapolis-St. Paul showed that the same phenomenon applies to trip makers and that the average daily door-to-door travel time remained about 1.1 h for automobile-only trip makers over a 12 to 13-year period; this was also the average daily travel time per automobile trip maker for the whole United States in 1970 (6). A comparison of the average travel time and trip speed of trip makers who used automobiles and those who used only transit in Washington, D.C., and Minneapolis-St. Paul is shown below (1 km = 0.6 mile).

		Automobile		Transit	
City	Year	Travel Time (h)	Speed (km/h)	Travel Time (h)	Speed (km/h)
Washington, D.C.	1955	1.09	18.8	1.27	10.7
	1968	1.11	23.3	1.42	10.0
Minneapolis-St. Paul	1958	1.14	21.5	1.05	11.9
	1970	1.13	28.5	1.15	12.1

It indicates that, although in Minneapolis-St. Paul the transit-only trip makers had roughly the same travel-time budget as the automobile-only trip makers, the travel time of transit-only trip makers in Washington, D.C., in 1955 was 1.27 h/d, significantly higher than the travel-time budget for automobile-only trip makers, and by 1968 the travel time of transit-only trip makers had increased even more, while the travel time of automobile-only trip makers remained virtually the same. In addition, the daily travel times show a significant rise when the travel speed falls below about 11 km/h (7.5 mph).

It was noted above that, while the trip rates of automobile-only trip makers in Washington increased from 3.07 to 3.16 between 1955 and 1968, the trip rate of the transit-only trip makers decreased from 2.31 to 2.12, coming close to the minimum trip rate of 2.0/d (virtually all urban trips involve outward and return journeys on the same day). The increase in the travel time of this group was therefore not accompanied by an increase in the trip rate but reflected the fact that transit-only trip makers had no other way of carrying out the minimum number of trips that they considered necessary.

For the purpose of predicting travel behavior, it will therefore be assumed that, in all cases in which trip makers travel more than the preferred daily travel time of 1.1 h, an increase in speed will result in a reduction in daily travel time to the preferred figure of 1.1 h, as long as the base-year trip rate is not reduced. However, for trip makers who already travel within this limit, it

Table 1. Characteristics of average weekday travel by case and by trip maker.

Category	Distance Traveled (km)	Number of Trips	Travel Time (h)	Expenditure ($)	Mobility (trips/100 people)	Cost/ Trip ($)
Base case						
Automobile trip maker	19 676 650	2 397 866	528 460	1 422 000	150.6	0.59
Transit trip maker	3 675 150	543 838	197 660	137 047	34.1	0.25
Total	23 351 800	2 941 704	726 120	1 559 047	184.7	0.53
Case 1						
Automobile trip maker	20 734 990	2 526 840	528 460	1 296 317	158.7	0.51
Transit trip maker	3 675 150	543 838	187 684	137 047	34.1	0.25
Total	24 410 140	3 070 678	716 144	1 433 364	192.8	0.47
Case 2						
Automobile trip maker	19 676 650	2 397 866	528 460	1 422 000	150.6	0.59
Transit trip maker	3 740 380	553 490	147 687	139 480	34.8	0.25
Total	23 417 030	2 951 356	676 147	1 561 480	185.4	0.53
Case 3						
Automobile trip maker	20 734 990	2 526 840	528 460	1 296 317	158.7	0.51
Transit trip maker	3 938 620	582 825	147 687	146 872	36.6	0.25
Total	24 673 610	3 109 665	676 147	1 443 189	195.3	0.46
Case 4						
Automobile trip maker	18 631 980	2 270 559	474 885	1 296 317	142.6	0.57
Transit trip maker	5 534 820	819 027	201 986	206 395	51.4	0.25
Total	24 166 800	3 089 586	676 871	1 502 712	194.0	0.49

Note: 1 km = 0.6 mile.

Table 2. Characteristics of average weekday travel by case.

Case	Percentage Using Transit as a Function of			Avg Expenditure/ Household on Travel ($)	Travel Expenditure as Percentage of Income	Daily Distance/ Trip Maker (km)	Daily Expenditure/ Trip Maker ($)
	Distance	Number of Trips	Travel Time				
Base case	15.7	18.5	27.2	2.85	10.5	22.53	1.50
Case 1	15.1	17.7	26.2	2.62	9.6	23.56	1.38
Case 2	16.0	18.7	21.8	2.85	10.5	22.59	1.51
Case 3	16.0	18.7	21.8	2.64	9.7	23.81	1.39
Case 4	22.9	26.5	29.8	2.75	10.1	23.31	1.45

Note: 1 km = 0.6 mile.

will be assumed that increases in speed will result in more travel: either more trips or longer trips or a combination of both.

For Washington, D.C., in 1968, it is assumed that the structure of the city will not be altered by the relaxation of transport regulation and that the average trip distance will remain unchanged at 8.2 km (5.1 miles) for automobile trip makers and 6.8 km (4.2 miles) for transit trip makers. Any increase in daily travel distance will therefore be reflected in additional trips. The computational methodology is based on equilibrium conditions between travel demand and system supply for automobile trip makers, i.e., it is assumed that money and time budgets are fully expended and not exceeded for each of seven income groups. The resulting travel characteristics are within a few percentage points of those observed in the 1968 study.

RESULTS

The methodology described above was used to examine four alternatives to the Washington, D.C., travel situation in 1968.

Case 1. Shift from automobiles to car pools—It is assumed that, as a result of automobile users being allowed to give each other trips for money, there would be an increase in car pooling that would bring about a 10 percent reduction in automobile traffic and a resulting increase in speed for both automobiles and transit.

Case 2. Replacement of peak-period regular bus services by subscription bus services—It is assumed that the bus services provided by the 1000 conventional buses that in 1968 were used only in the peak periods were replaced by subscription bus services of the kind used in the Peoria-Decatur demonstration project in 1966 to 1970 (7). On the basis of the results obtained in Peoria, it is assumed that average transit speeds would rise from the 1968 level of 55 percent of automobile speeds to 75 percent of automobile speeds but that fares would remain at 3.7 cents/km (6 cents/mile).

Case 3. Cases 1 and 2 combined—It is assumed that automobile traffic is reduced by 10 percent at the same time that bus speeds are increased, so that transit speeds are 75 percent of automobile speeds.

Case 4. Shift from automobiles to subscription buses—It is assumed that, as a result of the introduction of subscription bus services, 10 percent of automobile trip makers (drivers and passengers) would shift to the speeded-up bus services and that the consequent reduction of 10 percent in automobile traffic would result in a further reduction in automobile and transit travel times, as in case 1.

Tables 1 and 2 are based on the data from the COG study, on known speed-flow relationships, and on the 1968 money- and time-travel budgets established for the Washington, D.C., area. These tables show, for the base case and the four alternatives and for automobiles and transit separately, the following characteristics:

Distance: The total daily in-vehicle kilometers of travel by automobile and transit trip makers;

Trips: The total number of daily trips by automobile and transit trip makers;

Hours: The total daily hours (in-vehicle time) of travel by automobile and by transit;

Expenditure: Daily expenditure by trip makers on automobile or on transit (since increases in travel speed allow trip makers to increase their daily travel distance within their daily travel-time budgets and since the unit cost of automobile travel decreases with an increase in speed within the speed range found in cities, automobile trip makers can increase their daily travel distance considerably for comparatively slight additional expenditures);

Mobility: The number of weekday trips per 100 people (since trip length is assumed to remain unchanged, any change in the daily distance traveled is reflected in a pro rata change in the number of trips and hence in mobility);

Cost/trip: In the case of transit, this was 25 cents—3.7 cents/km (6 cents/mile)—and, in the case of automobile trips, the costs fall as traffic speed is improved, in accordance with the formula

$$c = 1.494v^{-0.75}$$

where c = travel costs in dollars per kilometer and v = automobile speed in kilometers per hour (within a stable automobile travel-time budget, both standing and operating costs vary with speed);

Expenditure/household: The figures given are for a household income of $8500/year, the weighted average of the population in the study area in 1968;

Daily distance traveled/trip maker: The total distance traveled per day divided by the number of trip makers.

Daily travel cost/trip maker: The total expenditure by trip makers in the area divided by their number.

The average network speed was calculated for automobiles and for transit by dividing the sum of the in-vehicle person-kilometers by the sum of the in-vehicle person-hours. These speeds and the weighted averages for each case are shown below (1 km = 0.6 mile).

Case	Automobile Speed (km/h)	Transit Speed (km/h)	Weighted Avg (km/h)
Base case	37.23	18.59	32.16
Case 1	39.24	19.58	34.09
Case 2	37.23	25.33	34.63
Case 3	39.24	26.67	36.49
Case 4	39.23	27.40	35.70

Case 1

A reduction of the private automobile fleet by 10 percent, due to an increase in car pooling, would increase the travel speeds and reduce the costs of both automobile and transit trips. Automobile trip makers would be able to travel additional kilometers within their travel-time budget and would increase their daily travel while their costs per trip (due to higher speeds and higher rates of vehicle utilization) would fall from 59 to 51 cents. As a group, their expenditure on travel would fall, although the payments for car pooling would bring about money transfers within the group, the effects of which have been ignored.

Transit trip makers would save time but not enough time to bring them within the preferred daily travel-time budget of 1.1 h. They would therefore not increase their travel distance. The percentage of people using transit would decline from 15.7 to 15.1 percent by distance and from 18.5 to 17.7 percent by trips. However, the increased speed of transit would benefit transit operators by $3 million/year by reducing their capital and operating costs, as is discussed below.

Case 2

The rise in transit speeds would make no difference to automobile trip makers, and the vital statistics of their trips would remain the same as in the base case. Transit trip makers would enjoy a large saving in travel time, so that their original trips would take less than the preferred daily travel time of 1.1 h. They would therefore increase their daily trip distance. The savings to the transit operators would be $16 million/year. The increased transit travel would raise the percentage of people using transit from 15.7 to 16.0 percent by distance and from 18.5 to 18.7 percent by trips.

Case 3

This combines the most favorable features of cases 1 and 2. It produces the highest mobility of all the cases tested: 195.3 trips/100 persons/d, compared with 184.7 in the base case.

Case 4

It is assumed that the effect of raising transit speeds to 75 percent of automobile speeds would be to transfer 10 percent of automobile trip makers to transit. This would reduce by 2.1 million the 20.8 million person·km/d that would otherwise have been traveled by automobile trip makers. However, since transit speed remains below automobile speed and there are constraints on the travel-time budget, only 1.8 million would shift to transit; 0.3 million person·km/d would be lost.

This transfer to transit would save about $55 000/d and lose about 19 000 h/d, so that the transfer would only take place if this exchange seemed attractive to a sufficient number of trip makers. Since no evidence is available as to the substitutability of money for travel time in Washington, D.C., in 1968, the methodology used here is unable to predict how many trips, if any, would shift from automobile to transit under the assumed conditions. In the Peoria demonstration project, 72 percent of the subscription bus users were attracted from automobiles, but in that case the subscription services were reported to have enabled 67 percent of the users to travel as fast as, or faster than, before (7). In Washington, D.C., it is assumed that door-to-door transit trip speeds would remain well below automobile trip speeds. Case 4 results in the most favorable percentage of people using transit—22.9 percent by distance and 26.5 percent by trips—but in terms of both output and cost savings it is inferior to cases 1 and 3.

ECONOMIC EVALUATION OF BENEFITS

Benefits to trip makers result from savings in vehicle operating costs, time savings on the distance traveled before the improvement, and additional distance traveled as a result of the improvements. The average benefits per additional kilometer traveled are assumed to equal half the difference between the costs of travel before and those after the assumed improvement. Benefits consist of gains in money and in time; these are shown separately.

Benefits to the providers of public transport—mainly bus operators—are calculated on the basis of savings in capital and operating costs to be expected from speeding up 1500 buses. The figures related to 1968 conditions

Table 3. Summary of economic benefits accruing from each case.

Category	Vehicle Costs ($, millions/year)				Time (h, millions/year)			
	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
Benefits to automobile trip makers								
Savings on original distance	59.9	–	59.9	33.6	8.4	–	8.4	2.6[a]
Benefits from new distance	1.6	–	1.6	2.3	0.2	–	0.2	-0.4
Total	61.5	–	61.5	35.9	8.6	–	8.6	2.2
Benefits to transit trip makers								
Savings on original distance	–	–	–	–	3.1	16.4	18.7	19.8
Benefits from new distance	–	–	–	–	–	0.2	0.7	0.4
Total	–	–	–	–	3.1	16.6	19.4	20.2
Benefits to transit providers								
Savings on capital costs	0.7	3.6	4.1	4.3	–	–	–	–
Savings on operating costs	2.3	12.4	14.1	15.0	–	–	–	–
Total	3.0	16.0	18.2	19.3	–	–	–	–
Total benefits	64.5	16.0	79.7	55.2	11.7	16.6	28.0	22.4

[a] This figure represents the difference between a gain of 8.4 million h to trip makers who remain in automobiles and a loss of 5.8 million h to those who shift to transit.

and may no longer be relevant. A bus is assumed here to cost $60 000 and to have a life of 10 years. At 10 percent interest, the annual capital cost of a bus is approximately $9000. Operating costs that vary in proportion to time (mainly wages) are assumed to be $100/bus/d, or $31 200/year. Benefits to transit providers resulting from newly generated traffic would be small and have been ignored. Extra revenues resulting from additional passenger travel do not constitute an economic benefit, since they are offset by the extra fares paid, which were not debited as a cost to the trip makers. On the basis of these considerations and the travel characteristics detailed above, the economic benefits were calculated in terms of the distance traveled before and after the change (Table 3).

The results suggest that a 10 percent reduction in the private vehicle fleet in the Washington, D.C., area in 1968 because of car pooling (case 1) could have saved automobile trip makers some $61 million/year in vehicle operating costs, as well as more than 9 million h, and that the resulting increases in transit speeds could have saved the bus operators $3 million/year. A substantial increase in transit speeds (case 2) would have saved transit trip makers some 17 million h and still allowed them to increase their travel distance within their budgetary constraints of time and money. Transit operators would have saved about $16 million/year. If both improvements were introduced simultaneously (case 3), total savings in 1968 could have been $80 million in automobile and transit costs and 28 million h. The 10 percent reduction in automobile trips and transfer to speeded-up transit (case 4) would have resulted in the same money and time savings for the remaining automobile trips as in case 3 while the trips transferred to transit would have saved $17 million/year in travel costs but have lost 6 million h. The total annual benefits would have been $55 million and 22 million h.

CONCLUSIONS

It should be emphasized that the changes assumed were necessarily arbitrary and were designed to indicate the benefits obtainable from substantial—but not implausible—changes in travel conditions. The method can of course be used to evaluate likely savings from other postulated changes in any transport system, given the information about the travel habits and the budgetary and time constraints of different population groups.

The most striking of the conclusions appears to be the indication that, in an area in which more than 80 percent of travel is by automobile, increased car pooling appears to offer greater promise for improving urban transport conditions than for inducing shifts from automobiles to transit. The first reason for this is that, under the conditions prevailing in Washington, D.C., in 1968, car pooling involves a smaller sacrifice of time to an automobile driver than does a shift to public transport. The second reason is that car pooling involves the more intensive use of existing equipment, while substantial shifts to public transport, particularly in the peak periods, would necessitate the use of additional equipment.

The exercise also illustrated the difficulty of inducing shifts from private to public transport, since any substantial shift would speed up automobile trips and increase the attractiveness of that mode. The analysis suggests that automobile trip makers are most likely to shift to transit if they can gain time—as they can on the Shirley Highway express bus lanes—or if they are subject to a financial penalty, such as paying for parking or road use.

Some of the main differences between the cases tested are brought out in a comparison of the daily travel expenditure per trip maker and his or her daily travel distance (Table 2). Cases 1 and 3 have obvious advantages over the others, since the former minimizes expenditures and the latter maximizes travel. Compared with the base case, all the cases tested result in increased travel, and all except case 2 result in reduced expenditure by trip makers.

REFERENCES

1. Y. Zahavi. The UMOT Model. Urban Projects Department, International Bank for Reconstruction and Development, Washington, D.C., Draft Rept., June 1976.
2. Summary of National Transportation Statistics. U.S. Department of Transportation, June 1975, Table 11.
3. Family Expenditure Survey. Her Majesty's Stationery Office, London, 1972.
4. Wirtshaft und Statistik. Statistische Bundesamt Wiesbaden, July 1975.
5. Y. Zahavi. Travel Characteristics in Cities of Developing and Developed Countries. International Bank for Reconstruction and Development, Washington, D.C., Staff Working Paper 230, March 1976.
6. Y. Zahavi. Travel Over Time. Federal Highway Administration, U.S. Department of Transportation, 1976.
7. M. Blurton. Report on Peoria-Decatur Subscription Bus Service. Mass Transportation Demonstration Project, Univ. of Illinois, Urbana, 1968.