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Stability of Travel Components over Time

Yacov Zahavi and James M. Ryan

A critical assumption underlying the application of transportation models to forecasting is that their base-year relationships, developed on the basis of cross-sectional data, will hold over time. This assumption is based on studies that have tested selected components of travel and have indicated, for example, that trip rates and trip times to work in a given city tend to remain stable over time. It has not been clear, however, how travel components that do change over time interact with one another. This paper summarizes the results of a study that analyzed the entire range of characteristics of motorized personal travel by private and public modes and their interactions in two U.S. cities: Washington, D.C., 1968 versus 1955; and Twin Cities (Minneapolis-St. Paul), 1970 versus 1958. The main findings are that (a) the time and money spent on travel per traveler and per household display regularities that can be attributed to such factors as household characteristics and transportation system supply and may be regarded as travel budgets and (b) all travel components, such as trip rate, trip time, trip distance, and proportions of trips by purpose, are products of the interactions among travel demand, system supply, and urban structure as constrained by the two principal travel budgets. These findings, if verified in additional cities and on a disaggregate level, may allow travel demand, system supply, and urban structure to be integrated within one modeling framework that would be more readily transferred between cities and over time.

Studies of urban travel behavior typically rely on the support of cross-sectional data. These data are further used to estimate models that are applied in a variety of transportation analyses. Many of these applications attempt to predict behavior under conditions that are significantly different from those observed in the base data. As a result, a recurring issue in transportation planning is transferability: the validity of model forecasts in settings that are beyond the range of base-year cross-sectional data.

Past research on this issue generally focused on specific travel demand models. For example, a number of efforts examined the transferability of coefficients in logit mode-choice models for work trips (1-3). These investigations produced mixed results. Other work examined the stability of trip rates, average trip distance, and travel times for households in an urban corridor undergoing a significant transportation improvement (4). The results indicated that speed increases were correlated with increases in trip distance, while changes in trip rates appeared unrelated to system improvements. However, other investigations of time-series data rejected hypotheses on the time stability of trip-generation models (5). Unexplained variations of 10-20 percent were found in trip rates over a 12-year interval.

A different approach to the problem is a recent handbook for transportation planners that provides travel characteristics from a large number of urban travel studies in American cities (6). Data are provided on such characteristics as trips per household, vehicle-kilometers of travel per person, average trip distances, and mode shares. This handbook is useful in checking the reasonableness of model forecasts against observed travel characteristics in similar urban areas. For longer-range forecasts in particular, these checks are important in ensuring that relationships developed from cross-sectional data do not produce misleading forecasts.

Potential problems remain, however. One is that the analysis in question may deal with conditions that have not been observed in any existing travel data. Consequently, no information exists on "reasonable" travel behavior under these conditions. Prolonged limitations on the availability of gasoline or severe increases in its price are prime examples. A second problem is that the characteristics of travel data eventually become less than representative. Changes in tastes, life-style,

Table 1. Household and travel characteristics in Washington, D.C., and Twin Cities.

	Car Only										Transit Only			
	Household Size										Household Size			
Item	1		2		3-4		5 or More		Total		1		2	
Washington, D.C.	1955	1968	1955	1968	1955	1968	1955	1968	1955	1968	1955	1968	1955	1968
Households	31 012	77 372	61 057	99 746	88 151	108 581	34 685	46 563	214 905	332 262	29 177	34 518	27 955	25 186
Cars per household	0.68	0.87	1.07	1.36	1.20	1.59	1.28	1.66	1.10	1.36	0.12	0.13	0.28	0.27
Travelers per household	1.00	1.00	1.57	1.62	1.85	2.01	2.23	2.65	1.71	1.75	1.00	1.00	1.43	1.38
Trips														
Per household	3.09	3.12	4.81	5.11	5.72	6.39	6.76	8.37	5.25	5.52	2.40	2.13	3.26	2.94
Per traveler	3.09	3.12	3.06	3.15	3.09	3.18	3.03	3.16	3.07	3.16	2.40	2.13	2.28	2.13
Distance (km)														
Per household	18.36	24.09	33.53	43.97	38.60	53.56	43.68	64.25	35.06	45.33	12.23	13.40	20.29	19.97
Per traveler	18.36	24.09	21.36	27.14	20.86	26.65	19.59	24.25	20.50	25.90	12.23	13.40	14.19	14.47
Per trip	5.95	7.72	6.98	8.61	6.74	8.38	6.47	7.67	6.68	8.21	5.08	6.29	6.23	6.79
Travel time (h)														
Per household	1.07	1.08	1.80	1.90	1.99	2.25	2.34	2.73	1.86	1.94	1.14	1.25	1.81	1.93
Per traveler	1.07	1.08	1.15	1.17	1.00	1.12	1.05	1.03	1.09	1.11	1.14	1.25	1.26	1.40
Per person	1.07	1.08	0.90	0.95	0.57	0.66	0.41	0.47	0.61	0.70	1.14	1.25	0.90	0.96
Trip time (h)	0.35	0.35	0.38	0.37	0.35	0.35	0.35	0.33	0.35	0.35	0.47	0.59	0.55	0.66
Speed (km/h)	17.2	22.2	18.6	23.1	19.4	23.8	18.7	23.5	18.8	23.3	10.7	10.7	11.2	10.4
Twin Cities	1958	1970	1958	1970	1958	1970	1958	1970	1958	1970	1958	1970	1958	1970
Households	14 644	38 872	70 566	96 725	92 758	117 425	57 505	72 293	235 473	325 315	8957	10 180	11 729	7302
Cars per household	0.73	0.86	1.13	1.31	1.32	1.58	1.33	1.65	1.23	1.43	0.10	0.06	0.32	0.27
Travelers per household	1.00	1.00	1.59	1.62	2.00	2.11	2.48	3.05	1.93	2.04	1.00	1.00	1.30	1.16
Trips														
Per household	3.21	3.50	5.59	6.04	7.37	8.18	9.10	12.09	7.00	7.85	2.15	2.07	2.67	2.50
Per traveler	3.21	3.50	3.52	3.73	3.69	3.88	3.67	3.96	3.63	3.85	2.15	2.07	2.05	2.16
Distance (km)														
Per household	19.69	28.32	39.16	52.60	50.38	71.76	59.60	94.35	47.35	65.89	12.07	16.23	16.06	16.25
Per traveler	19.69	28.32	24.63	32.47	25.19	34.01	24.03	30.94	24.54	32.30	12.07	16.23	12.35	14.01
Per trip	6.15	8.11	7.00	8.72	6.84	8.77	6.55	7.80	6.76	8.40	5.62	7.85	6.02	6.52
Travel time (h)														
Per household	1.04	1.09	1.85	1.90	2.36	2.41	2.69	3.35	2.21	2.31	1.05	1.08	1.35	1.35
Per traveler	1.04	1.09	1.16	1.17	1.18	1.14	1.08	1.10	1.14	1.13	1.05	1.08	1.04	1.17
Per person	1.04	1.09	0.93	0.95	0.68	0.69	0.46	0.57	0.64	0.70	1.05	1.08	0.67	0.68
Trip time (h)	0.32	0.31	0.33	0.32	0.32	0.29	0.30	0.28	0.32	0.29	0.49	0.52	0.50	0.54
Speed (km/h)	19.0	26.0	21.1	27.6	21.3	29.8	22.1	28.1	21.5	28.5	11.5	15.0	11.9	12.0

or technology, for example, can produce significant shifts in travel demand characteristics.

To address these issues, the research reported here examines a comprehensive set of travel data from two urban areas, each studied in two different years. The analysis is a preliminary attempt to identify changes in travel parameters or interrelations over time. Of particular interest are those parameters or relationships that remain stable even with significant changes in other characteristics of the urban areas (7).

DATA

The data sets used in this effort contain traditional origin-destination and household information collected in large-scale home interview surveys in Washington, D.C. (1955 and 1968), and Minneapolis-St. Paul (1958 and 1970). In the interval between the surveys, both cities had expanded sufficiently to require enlargement of their cordon lines. Consistent bases for analysis are established by examining, in both study years for each city, only the travel within the enlarged cordon lines that was produced by households that reside within the original cordon lines. To reduce costs, all travel data are aggregated to a superdistrict level: 14 districts in Washington, D.C. (DC), and 18 in Twin Cities (TC). The data include characteristics of households making at least one vehicle trip during the survey day. The data are stratified by mode: (a) households making car trips only, (b) households making transit trips only, and (c) households using both modes during the travel day. Further stratifications are by household size and car ownership.

TRAVEL CHARACTERISTICS

Table 1 presents a variety of travel data for the two urban areas, stratified by mode and household size. Travelers are defined as persons above the age of five years who made at least one motorized trip during the survey day. Travel times are the door-to-door times as reported by the respondents, and speeds are the derived door-to-door speeds.

It is important to note that a number of significant changes occurred in both cities over the time intervals in question. Average travel speed reported by car users increased 24 percent in DC and 33 percent in TC. These large increases in travel speeds can be attributed to additional highway capacity and a general reduction in density of development. Several techniques from urban geography have been employed to identify strong dispersion trends in both cities.

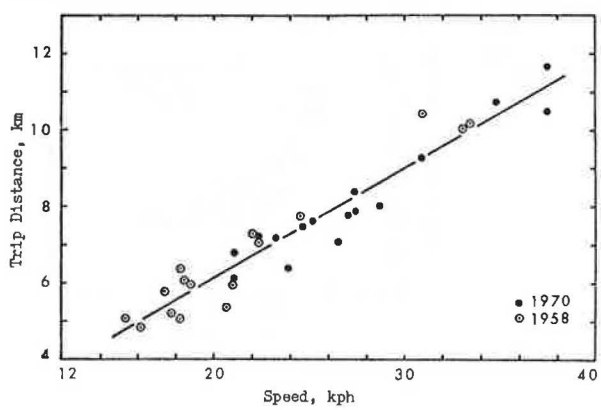
While car travelers enjoyed a marked increase in travel speeds, transit travelers experienced no such improvements. Households using transit exclusively reported a 7 percent decrease in average travel speed in DC and a 1 percent improvement in TC.

Socioeconomic characteristics of the households can also be observed to have changed over time. Average car ownership for all households rose significantly: in DC, from 0.87 car per household to 1.13; in TC, from 1.15 to 1.36. At the same time, average household size decreased: in DC, from 3.16 to 2.91 persons per household; in TC, from 3.53 to 3.37. Unfortunately, neither the 1955 DC nor the 1958 TC data include information on household income. As a result, income trends can only be surmised from national trends and through correlations with average car ownership.

The significance of these regional changes is that they provide a setting in which major sociodemographic and transportation system changes are occurring. This setting provides an excellent test for stability of the various travel parameters and interrelationships, some of which are detailed below.

						Mixed Modes									
						Household Size									
3-4		5 or More		Total		1		2		3-4		5 or More		Total	
1955	1968	1955	1968	1955	1968	1955	1968	1955	1968	1955	1968	1955	1968	1955	1968
24 927	18 958	13 540	10 777	95 598	89 439	8792	9934	34 223	29 470	59 954	52 254	37 207	33 866	140 177	125 523
0.30	0.28	0.19	0.23	0.22	0.22	0.26	0.39	0.82	1.02	1.02	1.29	1.14	1.42	0.96	1.19
1.74	1.59	1.98	1.73	1.46	1.32	1.00	1.00	1.93	1.92	2.60	2.64	3.43	3.61	2.56	2.60
4.02	3.33	4.49	3.64	3.37	2.80	5.05	3.45	6.18	5.72	7.69	7.84	9.28	10.32	7.58	7.67
2.31	2.09	2.27	2.11	2.31	2.12	5.05	3.45	3.20	2.99	2.96	2.97	2.71	2.86	2.96	2.95
24.51	23.70	26.81	25.90	19.86	18.94	26.89	23.81	41.14	45.71	49.93	60.58	57.83	74.90	48.43	58.04
14.08	14.91	13.54	14.97	13.60	14.35	26.89	23.81	21.32	23.81	19.20	22.95	16.86	20.75	18.92	22.32
6.10	7.11	5.97	7.11	5.89	6.77	5.33	6.90	6.66	7.98	6.50	7.72	6.23	7.26	6.39	7.58
2.32	2.45	2.65	2.83	1.86	1.89	1.87	1.68	2.80	2.73	3.28	3.52	3.91	4.27	3.25	3.39
1.33	1.54	1.34	1.64	1.27	1.43	1.87	1.68	1.45	1.43	1.26	1.33	1.14	1.18	1.27	1.30
0.68	0.72	0.42	0.46	0.69	0.78	1.87	1.68	1.40	1.37	0.94	1.01	0.65	0.71	0.89	0.94
0.58	0.73	0.59	0.78	0.55	0.67	0.40	0.49	0.45	0.48	0.43	0.45	0.42	0.41	0.43	0.44
10.6	9.7	10.1	9.1	10.7	10.0	13.2	14.2	14.7	16.7	15.2	17.2	14.8	17.5	14.9	17.1
1958	1970	1958	1970	1958	1970	1958	1970	1958	1970	1958	1970	1958	1970	1958	1970
7125	4603	2937	1497	30 748	23 582	2675	4660	19 494	17 753	42 269	30 433	35 852	31 717	100 290	84 563
0.48	0.40	0.69	0.78	0.33	0.23	0.15	0.36	0.87	1.00	0.82	1.49	1.42	1.70	1.19	1.41
1.64	1.41	1.89	1.82	1.35	1.18	1.00	1.03	1.89	1.90	2.77	2.88	3.83	4.40	2.99	3.14
3.55	2.95	4.03	3.63	2.85	2.47	3.10	3.29	6.10	6.28	9.14	10.29	12.31	15.08	9.52	10.86
2.16	2.09	2.13	1.99	2.11	2.09	3.10	3.19	3.23	3.31	3.30	3.57	3.21	3.43	3.18	3.46
21.98	16.67	23.30	16.85	16.96	16.36	17.91	22.75	40.03	48.62	59.39	79.57	79.89	112.42	61.85	82.27
13.40	11.82	12.33	9.26	12.56	13.87	17.91	22.09	21.18	25.59	21.44	27.63	20.86	25.55	20.69	26.20
6.19	5.65	5.79	4.63	5.95	6.61	5.76	6.92	6.56	7.74	6.50	7.74	6.48	7.45	6.50	7.58
1.77	1.92	1.94	1.50	1.41	1.35	1.31	1.36	2.35	2.44	3.26	3.33	4.12	4.68	3.34	3.54
1.08	1.36	1.02	0.83	1.05	1.15	1.31	1.32	1.24	1.28	1.18	1.16	1.07	1.06	1.14	1.13
0.52	0.59	0.30	0.22	0.58	0.64	1.31	1.36	1.18	1.22	0.92	0.94	0.69	0.76	0.83	0.87
0.50	0.65	0.48	0.41	0.50	0.55	0.42	0.41	0.39	0.39	0.36	0.32	0.33	0.31	0.35	0.33
12.4	8.67	12.0	11.2	12.0	12.1	13.6	16.7	17.0	20.0	18.2	23.9	19.4	24.0	18.5	23.2

Figure 1. Average trip distance of car travelers for TC.



HOUSEHOLDS MAKING CAR TRIPS ONLY

Table 1 indicates that households using cars exclusively increased their average daily travel distance substantially. These data are summarized below. In both cities there is close agreement between the changes in speed and distance per traveler.

		Change Over Time (%)		
City	Years	Speed	Distance per Household	Distance per Traveler
DC	1955-1968	+24	+29	+26
TC	1958-1970	+33	+39	+32

Further reference to Table 1 indicates that the larger growth in distance per household is caused by an increase in the number of travelers per household. It is clear, then, that travelers have used the increase in highway travel speeds to travel farther rather than to maintain their original travel distance and reduce their expenditure of travel time. This trend is most clearly seen in the travel-time-per-traveler statistics. In both cities in both survey years and across all household sizes, an average of approximately 1.1 h can be observed.

Given that travelers have increased their total travel distance, the next question is the mechanism of this increase. Reference to Table 1 indicates that average trip distance increased, whereas trip rates rose marginally. For all households in DC using car travel only, 88 percent of the travel distance increase arises from a longer trip distance, with 12 percent due to increased trip rates. Similarly, in TC, 79 percent of the travel distance increase was due to trip distance changes and 21 percent to higher trip rates.

These results can also be observed at the district level. Figure 1 shows the generally linear relationship between average trip distance and travel speed in TC. No significant relationship can be found between trip rate and travel speed, however. Furthermore, although there is a consistent increase in average travel speed with distance from the center of either city, no systematic variation can be identified in the travel time per car traveler as a stable parameter of urban travel, at an aggregate level, within the range of reported door-to-door speeds.

HOUSEHOLDS MAKING TRANSIT TRIPS ONLY

It is most illuminating to compare the changes exhibited by transit travelers with those found for car travelers. As both cities expanded and became less dense, average trip distance increased for both car and transit trips.

However, while higher car speeds permitted car travelers to increase their total travel, transit speeds remained unchanged in TC (+1 percent) and declined in DC (-7 percent). The combination of more dispersed activities and slow travel speeds thrust transit travelers in a different direction from car users. Trips per household declined, whereas total travel time per traveler increased significantly.

These results are consistent with those observed for car travelers. Car travelers used higher travel speeds to expand both trip rate and trip distance within a stable travel time expenditure of approximately 1.1 h. Transit travelers, however, could not preserve their earlier travel time expenditure, even by making fewer trips: Total travel time per traveler increased to 1.43 h in DC and 1.15 h in TC, while trip rates declined to 2.12 trips/traveler in DC and 2.09 trips/traveler in TC. Transit travelers appear to illustrate the trade-offs between travel time, trip rate, and trip distance under more adverse conditions.

The apparent stability of total travel time per traveler means that trip rates and average trip times are inversely related. This interaction, however, is discussed in only a few studies, e.g., those by Zahavi (8, 9) and by Horowitz (10). At a subarea level, Figure 2 illustrates the relationship between trip rate and trip time per traveler by car and transit modes in DC and TC in both study years. The elasticity of trip rate with respect to trip time is found to be approximately -1.0 within the range of 15-35 min. This indicates that the trip rate is inversely proportional to the door-to-door trip time until a minimum trip rate of about 2 trips/traveler is reached; travelers then have to spend as much time as necessary to make only two daily trips between their necessary pairs of origins and destinations. Not unexpectedly, this area is dominated by transit travelers. These results suggest that modal shifts are not necessarily a one-to-one transfer. Where car disincentives are used to shift travel to transit, the lower level of service typical of transit can cause trips to be foregone rather than shifted.

The interrelationship between trip rate and trip time can also be observed with regional data. Table 2 summarizes the average car-only daily trip rate versus the

Figure 2. Trip rate versus door-to-door trip time per traveler by mode, district averages for DC and TC.

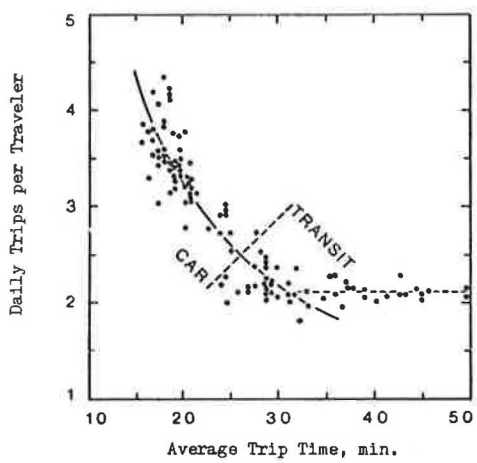


Table 2. Car daily trip rate versus trip time in selected cities.

No.	City	Year	Population	Trip Rate	Trip Time (min)
1	Hull, U.K.	1967	344 890	6.25	6.9
2	Monroe, U.S.	1965	96 530	5.79	7.3
3	Belfast, U.K.	1966	504 620	5.63	8.6
4	Orlando, U.S.	1965	355 620	4.33	9.7
5	West Midlands, U.K.	1964	2 529 010	3.59	10.3
6	Copenhagen, Denmark	1967	1 707 000	4.21	10.5
7	Baltimore, U.S.	1962	1 607 980	3.26	12.3
8	Los Angeles, U.S.	1960	7 595 830	3.66	13.1
9	Cincinnati, U.S.	1965	1 391 870	3.63	13.7
10	London, U.K.	1961	8 826 620	3.27	13.7
11	Washington, D.C., U.S.	1968	2 562 030	3.28	15.6[a]
12	New York, U.S.	1964	16 303 000	2.89	20.1[b]

[a] Total metropolitan area.
[b] Including intrazonal time.

Figure 3. Car daily trip rate versus trip time in selected cities.

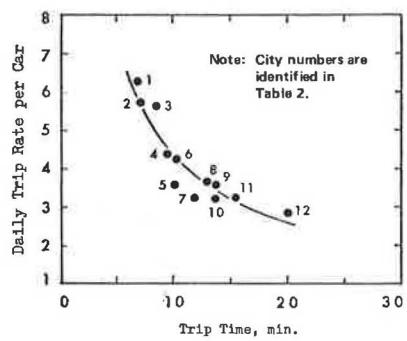
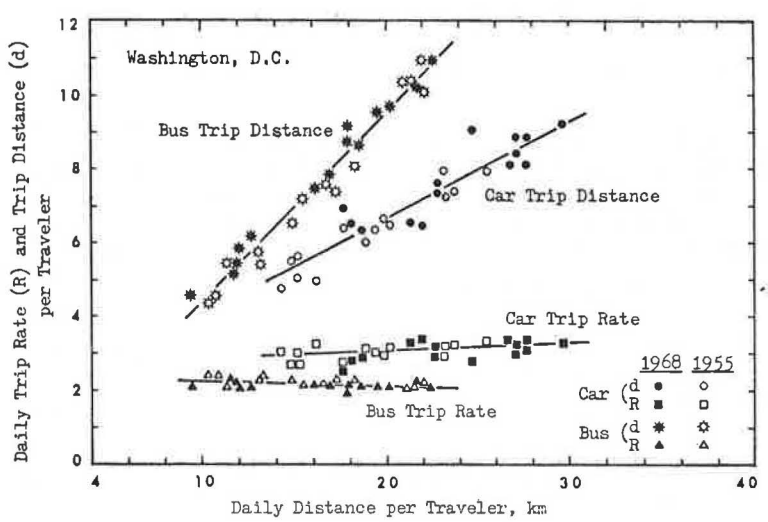


Figure 4. Trip rate versus trip distance within total daily travel distance per traveler for DC, district averages.



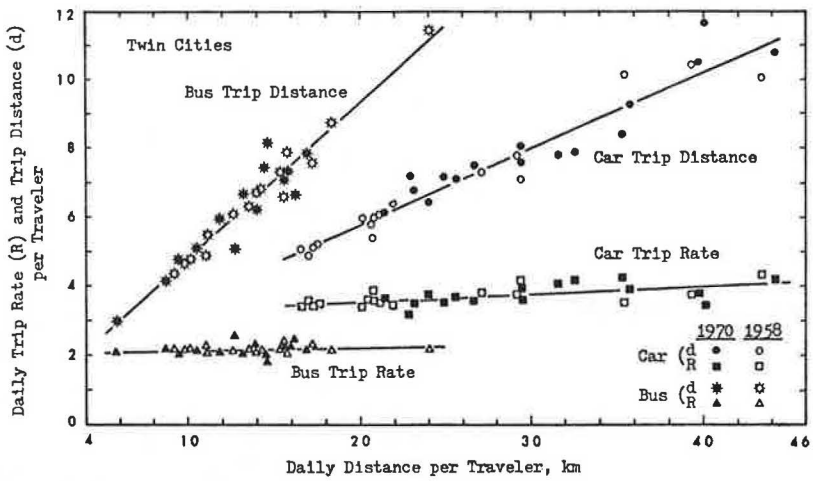


Figure 5. Trip rate versus trip distance within total daily travel distance per traveler for TC, district averages.

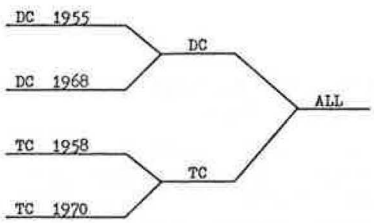


Figure 6. Structure of procedure for testing equality between sets of coefficients in linear regressions.

interzonal highway network trip time in a selection of cities, and the results are shown graphically in Figure 3.

Trade-offs between average trip rate and average trip distance within the total distance per traveler are summarized in Figures 4 and 5 for DC and TC. In both cities, trip rates are largely invariant with respect to total travel distance. Trip distances, however, are strongly correlated with total distance.

The travel characteristics of households that use mixed modes, both car and transit, usually fall between those displayed by car-only and transit-only households.

TRAVELERS PER HOUSEHOLD

The discussions above identify travel time per traveler as a key component of urban travel. For this to be a useful parameter in analysis of travel demand, however, it is necessary to understand the generation of travelers per household. A series of linear regression equations was estimated. A similar series was also estimated for trips per household, a more conventional parameter of urban travel.

Four data sets were developed for estimation of coefficients. These represented travel by all households in both cities in the two survey years. Because the data are aggregated to the district level, DC data sets contain 14 observations, whereas TC data sets consist of 16. Independent variables are available for seven district-level measures: distance from district to center of region (km), area of district (km^2), gross household density (HH/km^2), number of households in the district, household annual income, cars per household, and door-to-door travel speed (km/h). The final linear models estimated are of the form:

Travelers/HH = f_1 (HH size, car ownership)
Trips/HH = f_2 (HH size, car ownership)

A procedure developed by Chow (11) was then employed to test hypotheses on the transferability of the relationships between the two cities and over time. In this test, the null hypothesis is that $B_1 = B_2$, where B_1 and B_2 are the vectors of coefficient estimates obtained from two separate regressions. B_1 is estimated with the first data set of m observations, and SS_{reg1}, the sum of squared errors, is obtained. The second data set of n observations is then pooled with the first, and B_2 is estimated with SS_{reg2}, the corresponding sum of squared residuals. The null hypothesis is that $B_1 = B_2$; the alternative hypothesis is $B_1 \neq B_2$.

If the null hypothesis is true, the statistic

$$F = [(SS_{reg2} - SS_{reg1})/n]/[SS_{reg1}/(m-k)] \quad (1)$$

has an F distribution with n and (m - k) degrees of freedom. Rejection of the null hypothesis leads to the conclusion that the same relationship does not hold for both data sets. This test is most discerning when SS_{reg1} is small, that is, when the model estimated on the first m observations explains a large part of the variance. As the goodness of fit of this first model decreases, the ability of the above test to identify differences in the models decreases. The structure of the testing procedure is illustrated in Figure 6.

The estimated equations and Chow tests are summarized in Tables 3 and 4. In Table 3, the 1955-1968 combined F value for DC is 2.28, that for 1958-1970 for TC is 1.64, and that for all data is 2.30. The F values from Table 4 are 1.96 for 1955-1968 for DC combined and 1.57 for 1958-1970 for TC combined; that for all data is 2.88, which is significant at the 0.01 level. In general, the estimated parameters are statistically significant and yield acceptable goodness-of-fit statistics. The Chow tests provide some preliminary observations on the question of transferability. The hypothesis of equivalent coefficient estimates is accepted for all within-city tests. However, the hypothesis is rejected for the between-city test for trips per household, but it is accepted for travelers per household.

These results are at best only preliminary indications. The limited number of observations and high level of aggregation in the data restrict the usefulness of the tests. However, they do indicate potential directions for further work. Specifically, it may be possible to develop models of travelers per household that are as valid as conventional trip-generation models. Estimates of travelers per household can then be used with travel time per traveler to estimate total vehicle hours of travel (VHT) available. Travel speed estimates and

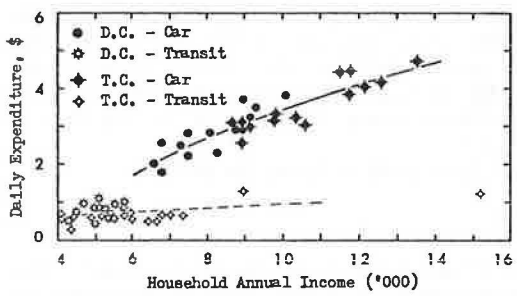
Table 3. Travelers per household.

City	Year	Constant	Household Size Value	Household Size t	Cars per Household Value	Cars per Household t	R^2	F	Σe_j^2
DC	1955	0.9169	0.1921	3.23	0.4712	3.79	0.81	20.75	0.0810
	1968	0.643	0.2309	4.50	0.5031	7.62	0.94	81.93	0.0607
TC	1958	0.024	0.3248	5.28	0.8701	5.74	0.95	128.51	0.0502
	1970	0.210	0.2791	5.23	0.7764	6.35	0.95	133.36	0.0621
DC	Both	0.6487	0.2771	6.96	0.4176	6.46	0.85	69.06	0.2243
TC	Both	0.1186	0.3677	11.07	0.6339	8.50	0.94	214.03	0.1514
Both	All	0.4029	0.3366	12.90	0.4896	9.69	0.91	279.77	0.4750

Table 4. Trips per household.

City	Year	Constant	Household Size Value	Household Size t	Cars per Household Value	Cars per Household t	R^2	F	Σe_j^2
DC	1955	1.9307	0.383	1.40	2.769	4.85	0.79	18.49	1.7090
	1968	1.582	0.1563	0.50	3.093	7.70	0.89	45.23	2.2443
TC	1958	-3.214	1.450	3.11	4.776	4.16	0.90	55.97	2.8800
	1970	-1.473	0.842	1.755	4.972	4.52	0.86	40.16	5.0260
DC	Both	1.0829	0.6432	3.02	2.5094	7.27	0.79	43.89	6.4074
TC	Both	-2.147	1.219	4.90	4.546	8.14	0.87	96.46	8.4701
Both	All	-1.66	1.356	6.46	3.505	8.59	0.82	123.67	30.9912

Figure 7. Daily expenditure on travel versus household annual income for DC and TC.



VHT per household then produce estimates of total vehicle kilometers per household directly from stable characteristics of urban travel.

TRAVEL MONEY EXPENDITURES

Since no direct information on travel money expenditures per household was available in the data, this had to be derived indirectly, as a product of observed travel distance per household and cost per unit distance by mode. Furthermore, information on household income was available only for the later study in each city, namely, 1968 in DC and 1970 in TC. Figure 7 shows the estimated travel money expenditures per household for car-traveling households and for transit-traveling households aggregated by district in the two cities.

Relating the travel money expenditures to income per household suggests that the former are a stable proportion of income, at about 10.5 percent for car-traveling households and about 3-5 percent for transit-traveling households, at all income levels. Similar results were observed in the United Kingdom and West Germany (12).

While additional analyses at disaggregate levels and by household location are required before final conclusions are reached, it appears that the daily travel money expenditure, like the travel time expenditure, is related to the socioeconomic characteristics of the households. Of particular interest is the significant gap between the two household types in Figure 7, suggesting that the household's decision to own a car is a major one, affecting all other money budgets.

REPORTED VERSUS NETWORK TRAVEL TIMES

It is important to note that the travel time data used in the above analyses are the reported times provided by home interview survey respondents. To investigate the impact of coded network travel time data on these results, several comparisons were made.

Figure 8 illustrates the comparison between reported and network trip time frequency distributions in DC in 1968. (Since travelers tend to estimate their trip times in rounded figures, the reported times cluster around 30, 60, and 90 min. Adjustment of the clustering to smooth hand-drawn curves was done by interpolating the curves of the accumulated trip time frequency distributions, as shown in Figure 9.) It is to be noted that the reported times, on the left-hand side of Figure 8, represent door-to-door times, including access, in-vehicle, and egress times, whereas the diagrams on the right-hand side represent computed network times. Therefore, it is not unexpected that the two sets of distributions are markedly different.

Figure 9 shows one way of expressing these differences: The time differences between the two distributions, measured horizontally on the accumulated distributions at each trip time, are shown in the upper diagrams as relationships between the reported and the network trip times by mode. These diagrams suggest that the two time sets are linearly related within the range of trip times that includes more than 90 percent of all trips. If such relationships are verified in other cities as well, it would then be possible to derive the network frequency distributions from the door-to-door trip times as reported in the home interview forms.

It is interesting to compare also the reported and network travel times on a per-traveler basis. The computed values are derived from the network trip times plus the estimated access and egress times. Such a comparison by distance of residence from the city center is shown in Figure 10 for car travelers in DC in 1968. It may be inferred from this figure that the network times, with the addition of estimated access and egress times, do not necessarily express the travel times as perceived by the travelers, with possible implications to mode-choice models based on computed trip times.

CONCLUSIONS

The research reported here is a preliminary examination

Figure 8. Door-to-door versus network trip time frequency distributions for DC.

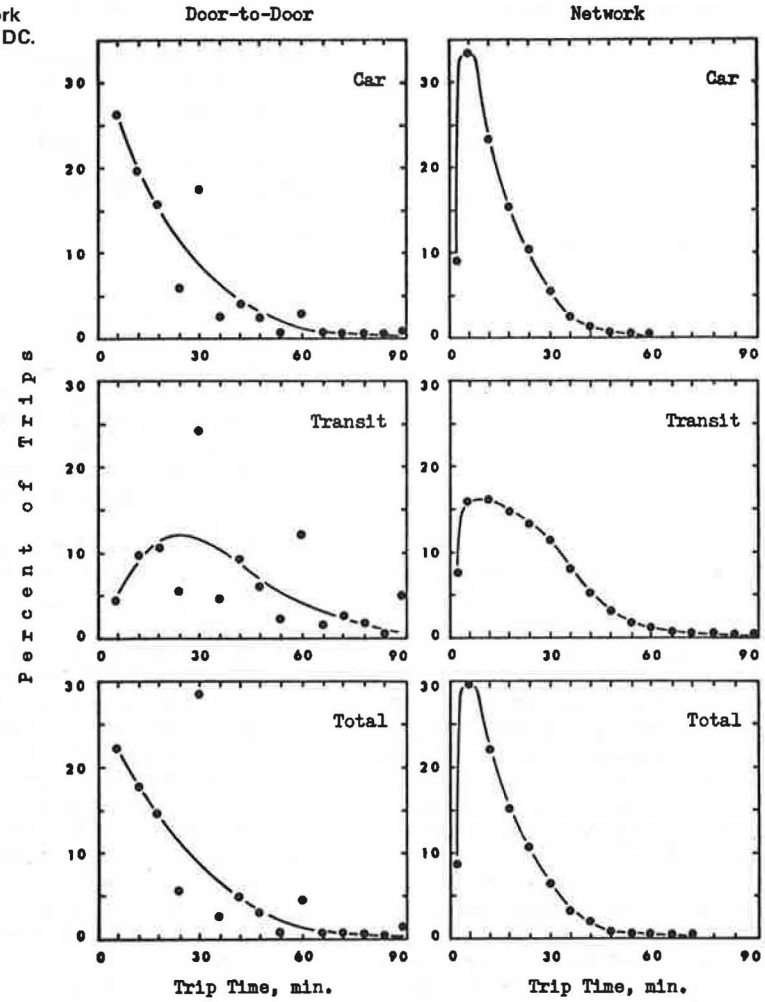


Figure 9. Cumulative door-to-door versus network trip time frequency distributions and adjusted relationship between them for DC.

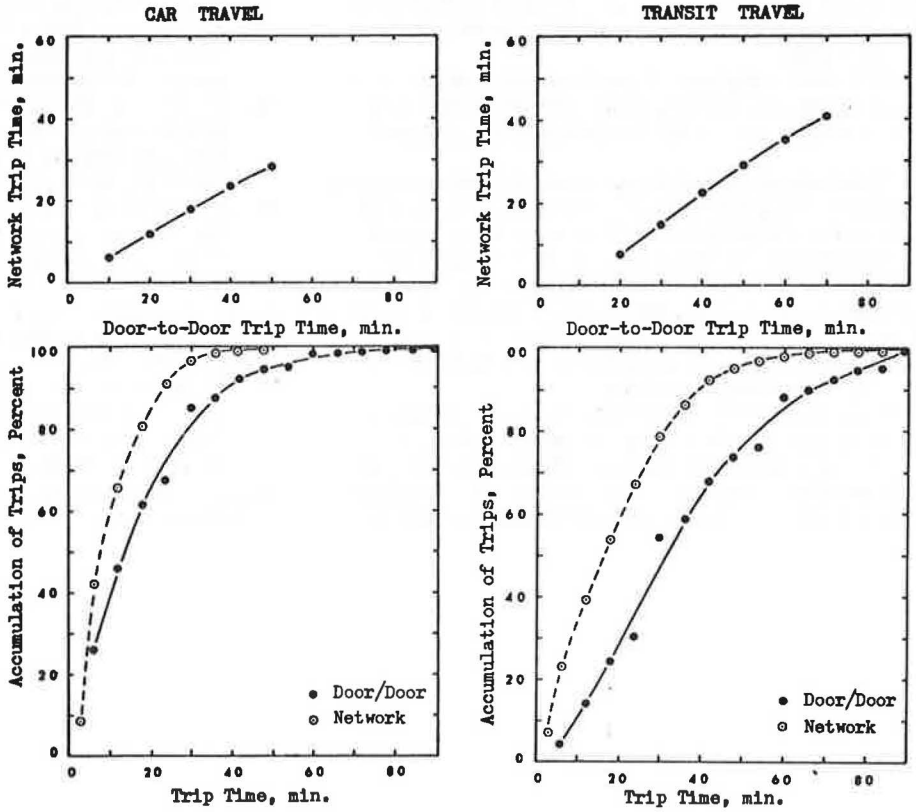
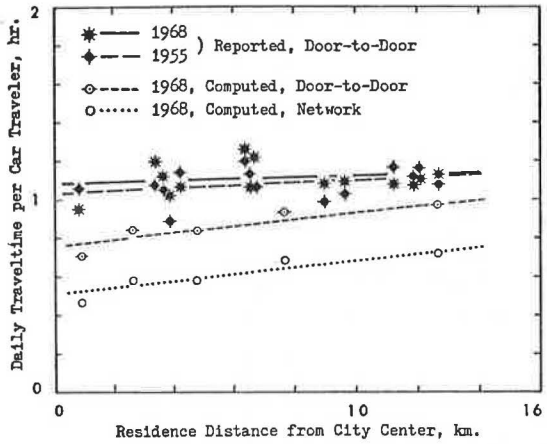


Figure 10. Daily travel time per car traveler versus distance of residence from the city center for DC.



of a variety of travel components and their interactions in two cities at two times. The following conclusions, therefore, are tentative and subject to further analysis on a disaggregate level in additional cities.

1. There are strong indications that, at least at an aggregate level, daily travel times per traveler display consistent regularities. At reasonably good speeds, the daily travel time per traveler is about 1.1 h and remains so even when speeds increase appreciably. However, as speeds deteriorate, travelers have to spend more daily travel time for fewer trips.
2. Regularities are also observed in travel money expenditures, which are found to be strongly related to the household income level and similar socioeconomic characteristics. For example, the daily average money expenditure on travel per car-owning household is about 10.5 percent of income at all income levels. A carless household, on the other hand, spends about 3-5 percent of its income on travel, again a stable proportion at all income levels.
3. All travel components, such as trip rate by purpose, trip distance, and trip time, are determined by trade-offs within these total expenditures of time and money.
4. These results suggest that more attention be given to the observed regularities of travel expenditures per traveler and per household, in time and money terms. Such expenditures are found to be more transferable both between cities and over time than isolated travel components, such as trip rates. All the isolated travel components can then be integrated within one travel system, controlled by the available travel budgets, system supply, and urban structure.
5. More research is necessary to verify the above indications. Such a new line of research is deemed to be of extreme importance because, if the above results are fully verified, they may have far-reaching implications for the conventional travel-modeling procedures.

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