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TRAVELTIME BUDGETS AND MOBILITY IN URBAN AREAS

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16. Abstract

This study tests by empirical comparative analysis the concept that tripmakers have a stable daily traveltime budget and discusses the implication of such a budget to transportation modeling techniques and the evaluation of alternative transportation systems.

After varifying the stability of the traveltime budget for both macro and micro conditions, the responsiveness of travel damand to system supply is developed and formulated. Many known travel factors, such as the levels of mobility, modal choice and trip purpose splits, are then explained by a unified behavioral mechanism.

One of the many conclusions that are presented in this study is that extreme care should be exercised in evaluating policy decisions such as speed reductions and pricing policies without first establishing the sensitivity and responsiveness of mobility to such restrictions. This conclusion is of special significance at this time when fuel shortages threaten mobility.

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TRAVELTIME BUDGETS AND MOBILITY IN URBAN AREAS

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SYNOPSIS

The concept that an average household or a tripmaker has a stable traveltime budget is well known. However, it has never been thoroughly tested, nor have its implications to traffic modeling techniques and economic evaluation procedures been explored. This study, therefore, discusses both of these aspects.

The methodology is exploratory in nature and scope. It is based on empirical comparative analysis of travel behavior, in relationship to the traveltime budget on three different levels--Nationwide averages, a macro study of 21 urban areas with population ranging from over 16 million to 70 thousand, and a detailed micro study of Washington, D.C.

The results of this study may be summarized as follows:

		Report Section	Page
(1)	The average daily auto traveltime is stable in all urban areas, with a slight tendency to increase with the size of the area.	1.3	8
(2)	Autodrivers appear to trade traveltime savings for more trips.	1.2	6
(3)	Tripmakers have specific daily traveltime budgets, which can be related to their location of residence and modes of travel used during the day.	1.5-1.6	12-14
(4)	Tripmakers of both private and public transport rank their trips by purpose, resulting in different trip purpose splits at different levels of mobility.	2.4-2.5	24-28
(5)	A diversion from private to public transport results in a net loss of total trips when the latter speed is lower.	2.4	24
(6)	The daily auto trip rate would seem to be a good indicator for the total mobility in an urban area.	3.4	42
(7)	The average auto trip distance can be related to population size.	3.7	48
(8)	The auto trip rate is responsive to the average trip distance and speed.	3.8	50
(9)	Total mobility is responsive to population size and the road network speed.	3.9	52
(10)	The road network performance can be expressed by its ability to carry a certain amount of traffic kinetic energy, namely the product of flow and its speed.	4.2	58
(11)	The total number of person trips in an urban area, as well as their modal choice and trip purpose splits, can be related to the road network level of traffic performance.	4.5	68
(12)	A unified formulation for the responsiveness of travel demand to transportation system supply may be defined.	4.5	68

The report concludes with several recommendations, where the principal theme is the need for more conclusive verification of the above results. However, even at this preliminary stage, it seems imperative that a thorough review of the current standard travel modeling and economic evaluation techniques is warranted.

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NOTATIONS

Chapter 1

TT - Traveltime.
R - Auto trip rate: the daily internal autodriver trips divided by the number of autos stationed in the study area.
t - Trip time: the daily average trip time, in minutes, for internal trips, by mode.
r - Coefficient of correlation.
h - Traveltime: the daily total traveltime per tripmaker or auto, in hours.
d - Trip distance: the daily total average trip distance, in miles.
v - Velocity: the daily average travel speed, in miles per hour.
F - Tripmaker trip rate: the daily internal person trips divided by the number of tripmakers, total or by mode.

Chapter 2

R_i - Auto trip rate by purpose.
E - Index of Elasticity: the change in percent of the dependent variable by a 1 percent change in the independent variable.
M - Mobility: the daily total number of internal person trips by residents in the study area, by all modes, per 100 residents.
M_p - The mobility of private transport.
M_t - The mobility of transit transport.
Z - Tripmaker rate: the number of people making trips, by a particular mode, per 100 population.

Chapter 3

Mot. - Motorization: the number of autos stationed in the study area per 100 residents.
P - Population: the total number of residents in the study area.

Chapter 4

I - Traffic intensity: internal daily vehicle-miles of travel divided by the land area; total, district, or zone.
D - Road density: the road network length, total or by category, divided by the land area, in miles per square mile.
α - Alpha: traffic performance index, expresses the dynamic capacity of a road network to carry flows at certain speeds.
b - Exponent: an exponent in the formulation of Alpha.
q - Traffic flow: the daily VMT divided by the road network length.
C - Traffic concentration: the daily average number of vehicles occupying a unit-length of 1 mile of the road network.
K - The total daily internal VMT on the road network.
L - Road length: the road network length, in miles.
H - Total traveltime: the total TT in the study area by all tripmakers (VHT).
N - The total number of vehicles stationed in the study area.

INTRODUCTION

Preliminary Remarks

* This study is exploratory in nature and scope, being constrained by a time budget. All results, therefore, should be considered as indicative only, even when the author could not sometimes resist the temptation of putting forward some conclusions with full conviction.

* The subject of mobility is so broad, and the relevant previous studies so numerous, that most of the space in this report would have been taken up by their listing. That is why only a few references are mentioned in this report, namely only the recent ones which have a direct bearing on the text.

* The structure of the report is centered around tables and graphical presentation, with a minimum of supporting text, based on the belief that one diagram is worth a thousand words. It is recognized though, that a two-dimensional diagram may severely restrict the comprehension of a complex subject, where many factors interact with each other in very complicated, and sometimes even devious, patterns.

  It is hoped, however, that the brevity and simplicity of this presentation will compensate and mollify the reader, as well as assist him in appreciating how complex the subject could really become by introducing additional factors to the few that are presented here.

* It should be noted that this study is a purely empirical one, based on comparative analysis of available data. No pre-conceived hypotheses are put forward and no effort is made to prove assumed theories. This report is rather a collection of tests, in order to verify or reject a well-known concept, namely the existence of a behavioral constraint in the response mechanism of travel demand to transportation system supply. The empirical results, therefore, should speak for themselves, although their interpretation will, of course, depend entirely on the reader.

Aggregate Versus Disaggregate Traffic Models

Traffic models are presently classified under two major headings: aggregate models, which describe the influence of areawide or average socio-economic variables on travel demand; and disaggregate models, which describe the influence of personal characteristics and transportation system supply on the behavioral choice mechanism of tripmakers.

Lately, however, much effort has been directed at defining the responsiveness of aggregate models to system supply, but as yet with no conclusive results.[1/]

1/ "A System Sensitive Approach for Forecasting Urbanized Area Travel Demand," prepared for the U.S. Department of Transportation by Alan M. Voorhees and Associates, Inc., 1971.

The main difficulty in trying to obtain sensitivity to system supply using aggregate models is the correlative or descriptive qualities of aggregate models, where the relationships are open ended, with no constraining factors. Thus, this group of models tends to propagate the base year conditions and the effects of the transportation system characteristics on travel demand into any future design year.

Disaggregate models, on the other hand, are usually considered to be constrained, so that the tripmakers' choice probabilities lie between zero and one. The difficulty, however, in analyzing and developing such models at the present time is the lack of data in the required form. For instance, a recent development and calibration of a disaggregate model had to rely on the extremely limited information from only about 200 households in one city.2/

It is somewhat difficult to decide in which of the two groups this study belongs, since it analyzes both aggregate and disaggregate data under a common behavioral constraint. The surprising result is that both aggregate and disaggregate travel characteristics may be explained by introducing such a common constraint, namely the constraint of a traveltime budget of tripmakers.

The Traveltime Budget

The traveltime budget is an old and well known concept. Basically it is also a very simple concept, since it postulates that, within the recurring and competing activities of people during a closed cycle of 24 hours, only a certain--and quite stable--period of time will be allocated to travel.

This concept was already introduced in Geography about a century ago, when the influence area of settlements and their interaction were explored on the basis of a daily traveltime budget and the speed of the available modes of transport. Thus, the expansion of the influence areas of settlements, from the historical agricultural villages up to the modern megalopolitan urban areas, have been explained by the ever increasing speed of transport modes, within a stable daily traveltime budget (henceforth TT budget).

Even in the transportation field, the stableness of the weekly TT budget of households has been known for a decade at least.

It may, therefore, seem somewhat odd that most standard traffic models disregard this fundamental concept. Moreover, they are based on a diametrically opposed concept, namely that the increase in travel speed will result in traveltime savings which, when valued in monetary units, are then regarded as "benefits" against which the costs of providing the improved transportation system are compared. On the other hand, if it is proven that the traveltime remains stable for a given population under all transportation systems, then the present foundation of standard traffic models will have to be reviewed and probably revised.

2/ "A Disaggregated Behavioral Model of Urban Travel Demand," prepared for the Federal Highway Administration by Charles River Associates, Inc., 1972.

CHAPTER 1: THE TRAVELTIME (TT) BUDGET

1.1. INTRODUCTION

The Concept

The concept of a traveltime budget is well known, although its appearance in the technical literature has been somewhat sporadic. The need for a more energetic treatment of the concept dawned on several researchers more or less simultaneously and culminated with this study.

The following references discuss the subject from various viewpoints, all of which appeared in 1973: Velona has argued that the structure and growth of cities may be explained on the basis of a stable TT budget and on the speeds of the available modes of transport;[1/] Goodwin hypothesized that the generalized expenditure for all travel in time and cost, measured in units of time, is constant for all income groups;[2/] Zahavi showed that the auto TT budget seems to be stable for all cities with a motorization level of over 10 autos per 100 residents and discussed the probable influence of such a traveltime budget on planning;[3/][4/] Hagerstrand discussed the probable interaction between a TT budget and the quality of life in urban areas;[5/] and a study conducted by the Delphi technique has indicated that the TT budgets of both husband and wife in an average suburban household are considered to be identical.[6/]

This study tests the hypothesis that tripmakers in urban areas tend to have a stable TT budget during an average weekday and discusses the implications of such a concept to the transportation planning process.

The Data

The data analyzed in this report were derived from several sources as detailed in Appendix D. Severe difficulties, however, were encountered while trying to derive the necessary data from published urban transportation planning study reports. Only a few reports presented the average trip time, the total vehicle hours of travel (VHT) or the average speed of travel together with the total vehicle-miles of travel (VMT) in the study areas. Thus, after carefully reviewing 85 studies (from 1,200 study reports covering over 230 urban areas), only 21 studies could be selected for a detailed analysis.

Another severe limitation was the lack of standardized definitions for many of the factors and variables used in the studies. These problems included: (1) Study Area Definition--although all studies were considered as urban, many were regional in scope with base year surveys covering substantial parts of rural areas; (2) Traffic Zoning--a wide range of the size of the zones

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1/ "The Role of Traveltime Limits in Urban Growth: A Postulated Urban Area Definition," W. D. Velona, FHWA, April 1973.

2/ "A Hypothesis of Constant Time Outlay on Travel," P. B. Goodwin, Proc. PTRC Summer Meeting, University of Sussex, United Kingdom, June 1973.

3/ "Testing Alternative Road Networks by the IN Procedure," Y. Zahavi, Proc. PTRC Summer Meeting, University of Sussex, United Kingdom, June 1973.

4/ "The TT-Relationships: A Unified Approach to Transportation Planning," Y. Zahavi, Traffic Engineering and Control, August/September 1973.

5/ "The Impact of Transport on the Quality of Life," T. Hagerstrand, Fifth International Symposium on Theory and Practice in Transport Economics, Greece, October 1973.

6/ "Transportation Issues in Consumer Motivation," K. Balkus, Highway Research Record No. 439, HRB, U.S.A., 1973.

affects the proportions between inter- and intrazonal trips; (3) Trip Linking--affects the number of trips and may therefore change the trip rates and the modal and purpose splits; (4) Trip Purpose--definitions vary to a large extent between studies; and (5) Road Network--many diversified groupings of road categories for the assignments. When such factors are combined with the variety of sampling techniques used in the basic surveys, modeling procedures, as well as the inconsistencies in the presentation of results in the study reports, it may be realized how difficult it can be to uncover the basic relationships within the data. It is surprising and gratifying, therefore, to have found basic behavioral travel relationships emerging from these data.

The Analysis

Both macro and micro analyses have been conducted in this study. In Chapters 1 to 3, a macro analysis is defined as a comparative analysis between different cities, while a micro analysis refers to the analysis within the same city. It should, therefore, be recognized that macro and micro analyses are at two different levels, and even if they do not produce identical results, one cannot conclude that the results are inconsistent or conflicting, but rather complementary.

A second point to note is that a comparative analysis is wholly dependent on the available data. When considering the limitations of the available data as mentioned above, it becomes evident that a purely statistical evaluation of the significance level of a relationship is inadequate, since the dominant part of the variability may not necessarily be statistical in nature, but rather result from the various definitions. On the other hand, it must also be assumed that all the data are from the same analysis population, namely urban tripmakers. Thus, although several basic statistical techniques (such as deriving the best fit by the least squares technique) were applied in this study, they had been chosen because they had been considered preferable to hand-drawn average tendencies. The coefficients of correlation are indicative only, useful for second level comparisons.

The Relationships

Difficulties were encountered while trying to derive the necessary data from the transportation study reports for the macro analysis of traveltimes. Three different methods had to be used: (1) when the auto average trip time was detailed, it was multiplied by the average daily auto trip rate for establishing the average daily auto TT budget. Since the average trip time referred to internal interzonal travel by the autos stationed in the area (in all cases but the Tri-State study), the resulting TT budget is for the average auto stationed in the area. (2) In some cases, only the total vehicle hours of travel (VHT) was given, including internal and external auto and commercial vehicles' travel within the study area as derived from the assignment model. In such cases, the total daily VHT was divided by the total number of vehicles stationed in the area, although part of the VHT had been produced within the area by vehicles stationed outside. The result is referred to as the vehicle TT budget. (3) In other cases, the total VHT was detailed in the study report but no information was given as to the total number of vehicles stationed in the area. In such cases, the total VHT was divided by the number of autos stationed in the area, and referred to as the vehicle per auto TT budget.

Significant variations should be expected in the analysis of data using such diversified methods. The TT budget should consistently increase from method (1) through method (3). Moreover, method (1) should result in a slight underestimation of the auto TT budget, while method (2) should result in an overestimation of the vehicle TT budget.

Table 1.1 summarizes the results for the 21 cities (with the addition of Washington, D.C., as will be explained later) according to the above three methods. As can indeed be seen, the average TT budget tends to increase with increasing population. The same tendency is exhibited when two methods could be applied to the same city. However, the most surprising result is that all results are within a very narrow range, despite the variations in the data. This tendency will be further analyzed in the following sections.

The complete set of data for the analysis of the auto TT budget is detailed in Table 1.2, while the data for the vehicle and vehicle/auto TT budgets are detailed in Appendix A.

TABLE 1.1

SUMMARY OF DAILY TRAVELTIMES

No.	Study Area	Study Year	Population	Traveltime (Hours)		
				Auto	Vehicle	Vehicle/ Auto
1	Tri-State	64	16,303,000	0.97		1.10
2	Los Angeles	60	7,595,834	0.80	0.89	0.98
3	Baltimore	62	1,607,980	0.67	0.90	
4	Cincinnati	65	1,391,869	0.83		
5	Kansas City	57	960,568	0.87		
6	Indianapolis	64	762,900	0.95		
7	S.E. Virginia	62	602,018	0.84		
8	Oklahoma City	65	574,013	0.77		
9	Springfield	65	532,188			0.92
10	Salt Lake City	60	394,286	0.74		
11	Orlando	65	355,619	0.70		0.78
12	St. Petersburg	62	261,933	0.76		
13	Peoria	64	260,826		0.93	
14	Baton Rouge	65	245,076		0.76	0.84
15	Knoxville	62	241,810	0.63		
16	Pulaski	64	222,652	0.78	0.80	
17	South Bend	67	222,110	1.02		
18	Columbia	65	195,173	0.67		
19	Monroe	65	96,530	0.71		1.04
20	Fort Smith	65	80,119	0.88		
21	Rapid City	63	73,459	0.57		
W	Washington, D.C.	68	2,562,025	0.85		
Average Traveltime				0.79	0.86	0.94

1.2. DAILY AUTO TRAVELTIME (TT) - A MACRO-ANALYSIS

Purpose

To analyze traveltime through the components of average auto trip rate, R, and average trip time, t.

Data

The data for analysis were derived from the transportation study reports detailed in Tables 1.1 and 1.2. The auto trip rate, R, was established as the ratio between the daily internal autodriver trips and the number of autos stationed in the study area, while the average trip time, t, in minutes, was found from a specific reference in the report or from the trip time frequency distribution data. The point for Washington, D.C., W, in Figure 1.1, was added for comparison purposes as will be explained later in this report.

Analysis

The total daily auto traveltime (TT) results from the product of R x t. Table 1.2 details the results, where it can be seen that the daily auto TT seems to be quite stable with an average value of 0.79 hours with a standard deviation of ± 0.12 hours, or ± 15 percent.

The next step was to check the dependency between R and t--to test whether R x t is actually a constant. The test is presented in Figure 1.1, where R is related to t. After several tests, the best fit was found to be in the form of an exponential equation:

$$R = 17.065\ t^{-0.583} \qquad \text{(Equation 1.1)}$$

It should be noted that R was considered to be the dependent variable according to the concept that the trip rate may be affected by the trip time within the constraint of a total daily TT budget.

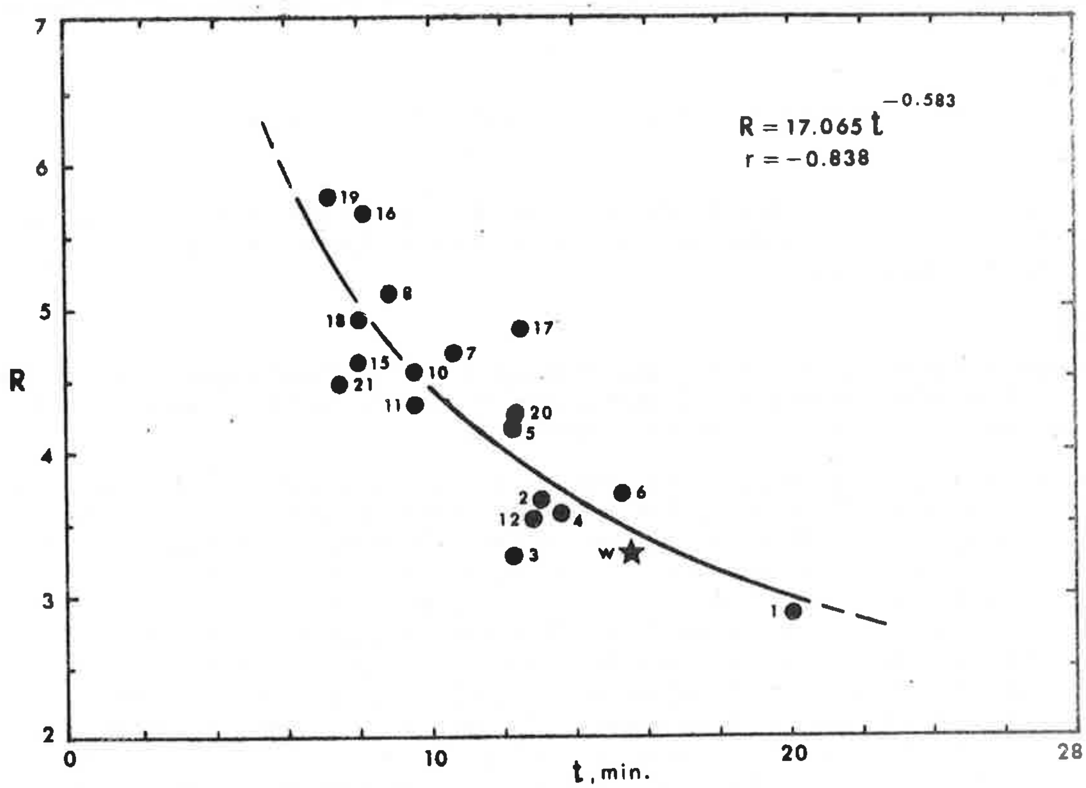
Discussion

The shape of the relationship in Figure 1.1 is very similar to a demand curve, where t may be considered to be the price of a trip and R the quantity of trips purchased at that price. It may then be concluded that a reduction in the price of trips, in time units, will increase the quantity of trips purchased, and vice-versa.

Of particular interest is the exponent of t which is less than unity. By recognizing the exponent as the index of elasticity, it may be concluded that the incremental satisfaction of auto drivers is declining with a reduction in the price t. Namely, there may be a saturation level for the amount of trips per auto per day, an increase in the average trip distance, a partial saving in the total daily traveltime, or a combination of these.

The above results raise some basic questions, such as: (1) is the daily auto traveltime constant for all cities, or does it vary as a function of some factor; (2) will the daily auto traveltime on a micro scale, within a city, be the same as on a macro scale between cities?

In the following sections these, as well as other issues, will be evaluated as to their possible effects on the daily TT budgets of tripmakers.



AUTO TRIP RATE vs. TRIP TIME

Fig. 1.1

Table 1.2

DAILY AUTOMOBILE TRAVELTIME (TT)

Study Area No.	Population	Autos	Motorization Percent	Internal Auto Trips	Trip Rate	Avg. Trip Length Min.	Daily Traveltime	
							Min.	Hours
1	16,303,000	4,186,000	25.7	12,108,350	2.89	20.1	58.0	0.97
2	7,595,834	3,123,319	41.1	11,439,455	3.66	13.1	48.0	0.80
3	1,607,980	437,540	27.2	1,425,470	3.26	12.3	40.0	0.67
4.	1,391,869	484,770	34.8	1,759,078	3.63	13.7	49.7	0.83
5	960,568	264,448	30.8	1,107,579	4.19	12.4	52.0	0.87
6	762,900	273,000	35.8	1,010,664	3.70	15.4	57.0	0.95
7	602,018	169,997	28.2	798,726	4.70	10.7	50.3	0.84
8	574,013	230,100	40.1	1,178,533	5.12	9.0	46.1	0.77
10	394,286	136,707	34.7	624,345	4.57	9.7	44.5	0.74
11	355,619	137,255	38.6	594,227	4.33	9.7	42.0	0.70
12	261,933	102,000	38.6	360,370	3.53	12.9	45.5	0.76
15	241,810	78,374	32.4	362,887	4.63	8.1	37.5	0.63
16	222,652	76,337	34.3	432,084	5.66	8.3	47.0	0.78
17	222,110	90,512	40.8	441,208	4.87	12.6	61.4	1.02
18	195,173	69,314	35.5	341,154	4.92	8.2	40.3	0.67
19	96,530	31,648	32.8	183,196	5.79	7.3	42.4	0.71
20	80,119	28,189	35.2	119,868	4.25	12.4	52.7	0.88
21	73,459	26,680	36.3	118,992	4.46	7.6	33.9	0.57

1.3. EFFECT OF THE AVERAGE TRIP TIME ON THE DAILY AUTOMOBILE TRAVELTIME (TT) BUDGET - MACRO

Purpose

To test whether the auto TT budget is a constant or a variable value.

Data

The data are the same as detailed in Table 1.2, but this time it is the total daily TT per auto, h, in hours, that is related to the trip time, t, as presented in Figure 1.2.

Analysis

The average curve in the figure was derived directly from Equation 1.1. The shape of the relationship is of particular interest, as it shows a slight increase in the TT budget with an increase in t.

An increase in h on a macro scale, namely while comparing cities, should be expected, since as the size of the area increases, a greater part of the daily TT budget would then be expended within the area. The same would be expected of t, since the average trip distance tends to increase with the size of the area. Thus, h should tend to increase with t, where the smaller values of both h and t would be in small areas, and greater in large areas. Although this general tendency can be found in Figure 1.2, the wide dispersion of the data would indicate the influence of additional factors that are yet undefined, such as speed. It has been decided, therefore, to test the tendency of h to increase on a micro scale, within a city, where a wide range in values of travel parameters is to be expected. Such a test will be detailed in the following section.

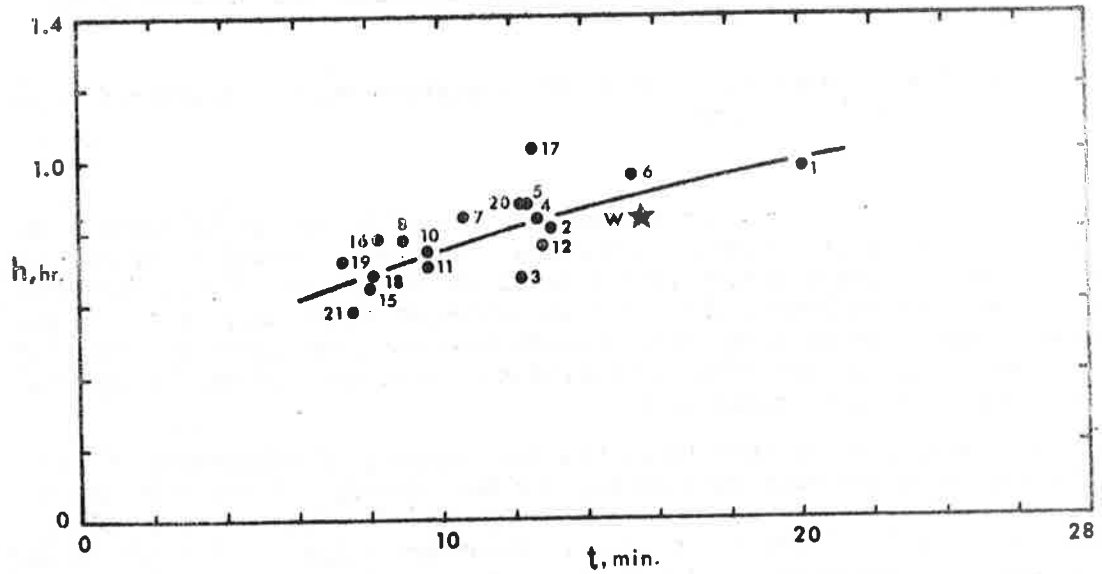
Discussion

Until now, the traveltime of autos has been discussed as an areawide daily average. From now on, however, the discussion will center on the traveltime of individual tripmakers.

At this stage, a few words of explanation would seem to be desirable. In most standard transportation models, the trip generation submodel is based on the concept that households at different socio-economic levels will generate different amounts of trips. Thus, the submodel considers the population by many representative characteristics, such as household size, income, motorization, and sometimes even by an indicator for the spatial location within the study area. Then, by the techniques of either multiple regression or category analyses, the number of generated trips, by purpose, are calibrated for base year conditions and later estimated for any assumed future design year.

However, once the total number of generated person trips for the various socio-economic groups of population have been derived, they are considered as a constant pool of trips within the area.

The next step in the current standard procedures of transportation modeling is to divide this constant amount of person trips between the private and the public modes of transport as well as their distribution between the multitude of origins and destinations. Finally, the trips are assigned to the transportation networks.



DRIVER'S DAILY TT vs. TRIP TIME

Fig.1.2

A factor that should be noted at this stage is that the total number of person trips is assumed to remain constant under all alternative transportation systems.

This assumption, however, has recently been questioned, since it has been realized that the behavior of tripmakers and their travel demand should be sensitive to the transportation system supply.

The following sections, therefore, will also deal with these aspects, with the aim of defining the sensitivity of and responsiveness between travel demand and system supply.

1.4. EFFECT OF AN AUTODRIVER'S LOCATION ON HIS DAILY TT BUDGET - MICRO

Purpose

To test whether the spatial location of tripmakers within an urban area may affect their daily TT budgets.

Data

Of particular interest was the notion that the TT budget of tripmakers may change by location and income. A fortunate source of data for testing such factors was the comprehensive trip file of the Washington, D.C., Metropolitan Area Transportation Study, where a full record of all trips, by all modes, was available. The original trip records have been tabulated in this research in two basic tables, the first by location of residence of the tripmaker, and the second by his income level.

The second dimension in each table was the grouping of tripmakers by the combination of modes they used during the day, namely all who made their trips as: (1) Drivers - an autodriver only; (2) Passenger - an auto passenger only; (3) Transit - a transit passenger only; (4) D + P - an auto-driver and auto passenger, whether in the same trip from origin to destination or in different trips during the day; (5) T + D - transit passenger and auto-driver; (6) T + P - a transit and auto passenger: and (7) T + D + P - tripmakers who used all three modes during the day (since the last group was a small one, 0.4 percent of all tripmakers, it is not included in this report, although available in the original tables).

The third dimension in the two basic tables was the trip purpose. The fourth dimension was a detailed list of travel data, such as the number of tripmakers, trips, trip rate, daily travel distance, daily net and total (including excess) traveltime, and net and total daily average speed.

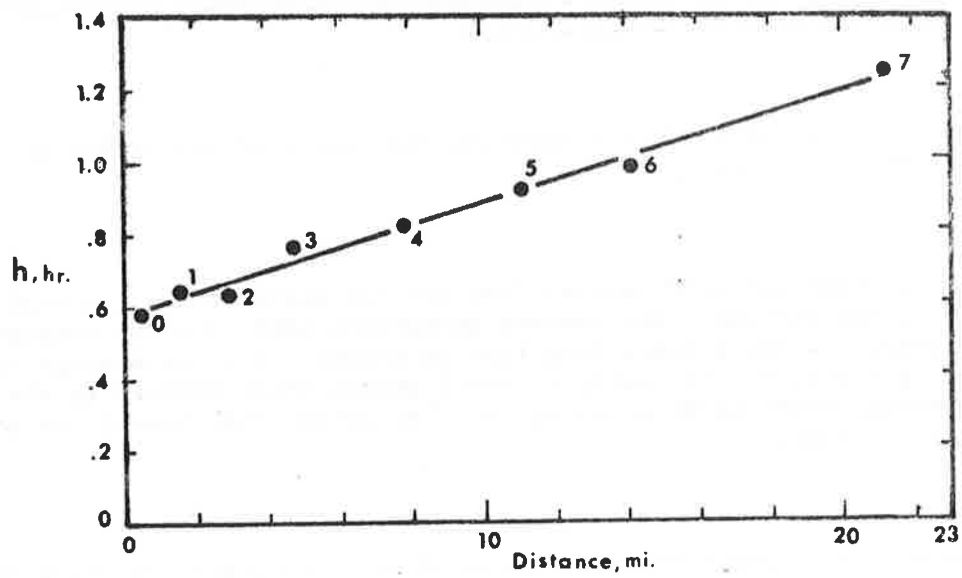
Analysis

Table 1.3 and Figure 1.3 present the daily traveltime of autodrivers only, measured in hours, h, versus the aerial distance in miles between their residence and the core of the Washington Metropolitan Area. The locations were grouped by rings, 8 in number, beginning from the center.

Discussion

As can clearly be seen in Figure 1.3, there is a strong relationship between the daily TT of autodrivers and their location of residence, where the TT varies by a factor of two within the area, namely from less than 0.6 hours to over 1.2 hours per day. Thus, it may be inferred that although the total areawide average TT tends to be stable for all urban areas, with only a slight increase with population size, the variations within an urban area are somewhat more significant and may be clearly explained through a relationship with distance to the city center.

Therefore, a more thorough micro-analysis was conducted with additional travel parameters in the Washington metropolitan area, as discussed in the following section.



DRIVER'S DAILY TT vs. LOCATION
Washington Metro. Area, by Ring

Fig. 1.3

Table 1.3

Ring	Auto Driver Traveltime h, Hours	Dist. From City Center
0	0.58	0.58
1	0.64	1.59
2	0.64	2.95
3	0.77	4.77
4	0.82	7.90
5	0.91	11.11
6	0.98	15.20
7	1.24	21.28
Average	0.85	-

1.5. AUTODRIVER'S DAILY TRAVELTIME (TT) AND OTHER RELATED TRAVEL PARAMETERS BY LOCATION AND BY INCOME - MICRO

Purpose

To test the effect of residence location and income of tripmakers on their travel characteristics.

Data

The data in Table 1.4 were derived from the two basic tables, as explained in the previous section. The various parameters are: v - the average travel speed; t - the average trip time in minutes; d - the average trip distance in miles; F - the daily internal person trips divided by the number of tripmakers, total or by mode; and h - the daily total traveltime per tripmaker, in hours.

Analysis

The various travel parameters for autodrivers were compared by both distance of location from the core and by income level, as shown graphically in Figure 1.4.

It should be mentioned again that the data include the trips that were made by tripmakers who made all their trips during the day as autodrivers only. In other words, the data include only part of all internal auto trips, since many other auto trips are summarized under other mode combinations, namely D + P, T + D, and T + D + P.

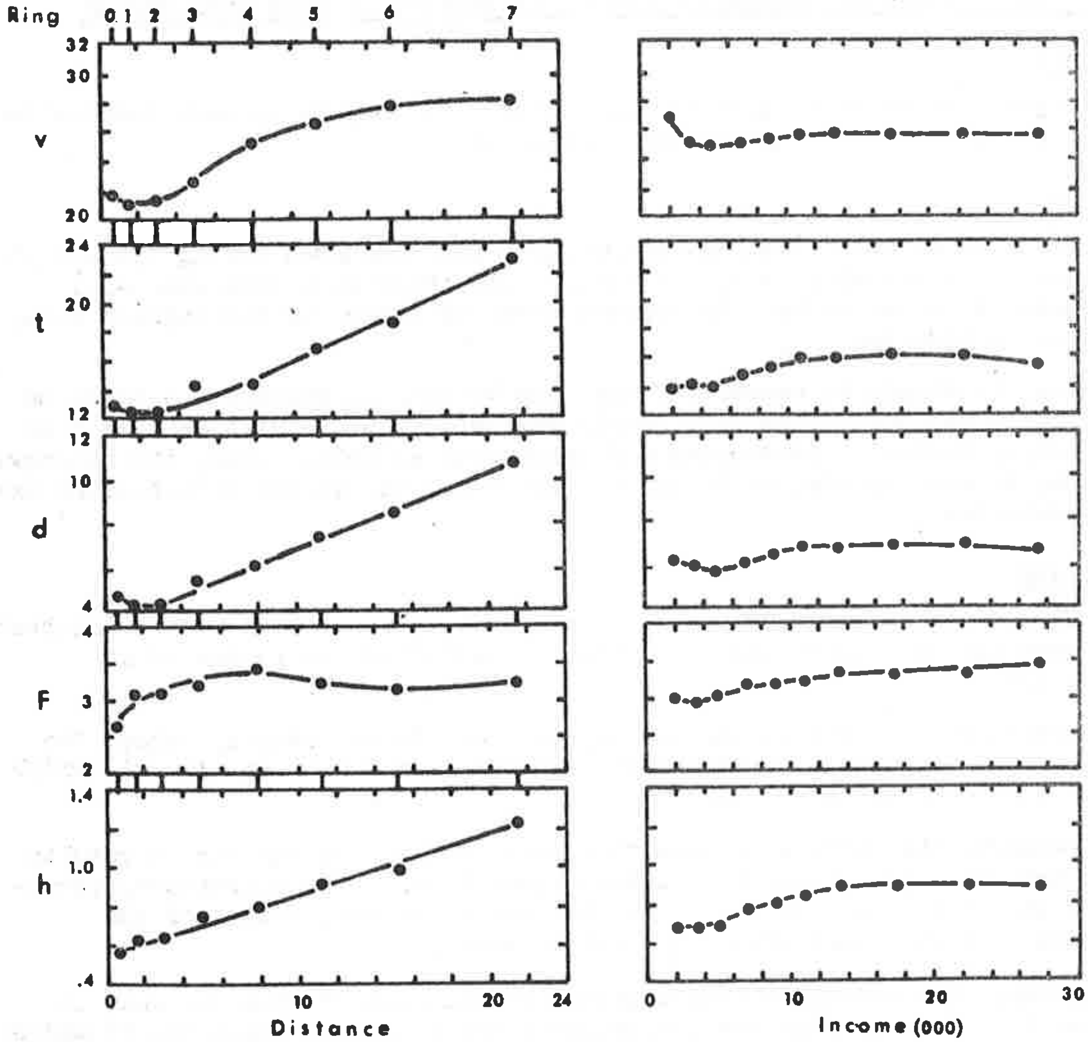
Discussion

The first notable result is that the travel parameters seem to be much more sensitive to location of residence than to income. The same result was found for all other mode combinations (Appendix C, page 78) where location was found time and again to be a much stronger indicator than income for all travel parameters.

One possible explanation for this phenomenon is that, by grouping population by income, households from different locations are put together, thus averaging distinctly different travel behaviors. Indeed, the figure in Appendix B-1, page 76, clearly shows that the same average household incomes may be found at various distances from the center.

It may be inferred, therefore, that location may be a much better indicator for travel behavior than income. Namely, it would be preferable to have the first stratification of population data by location, while the second stratification, within each location, would then follow by income and other relevant parameters.

A second noteworthy result is that not only h but also d and t increase linearly with increasing distance of residence from the city center. The implications of such a trend will be evaluated later.



AUTO DRIVER'S BASIC TRAVEL PARAMETERS BY LOCATION & INCOME

Washington Metro. Area

Fig. 1.4

Table 1.4

Income ($000)	h Hours	F Trip Rate	t Min.	d Miles	v Speed
0 - 3	0.70	3.03	13.9	6.2	26.7
3 - 4	0.69	2.95	14.1	5.9	25.1
4 - 6	0.71	3.06	13.8	5.7	24.8
6 - 8	0.79	3.20	14.8	6.1	24.9
8 - 10	0.82	3.21	15.3	6.4	25.1
10 - 12	0.87	3.26	16.0	6.8	25.5
12 - 15	0.90	3.39	15.9	6.8	25.6
15 - 20	0.91	3.37	16.2	6.9	25.5
20 - 25	0.91	3.36	16.3	6.9	25.5
25 - +	0.90	3.45	15.6	6.6	25.4
Average	0.85	3.28	15.6	6.6	25.4

Ring	h Hours	F Trip Rate	t Min.	d Miles	v Speed
0	0.58	2.66	13.0	4.7	21.6
1	0.64	3.12	12.3	4.3	21.1
2	0.64	3.12	12.3	4.3	21.2
3	0.77	3.23	14.3	5.4	22.6
4	0.82	3.42	14.4	6.1	25.2
5	0.91	3.25	16.8	7.4	26.6
6	0.98	3.16	18.6	8.6	27.7
7	1.24	3.22	23.1	10.8	28.1
Avg.	0.85	3.28	15.6	6.6	25.4

1.6. NATIONWIDE AND WASHINGTON, D.C., TT BUDGETS BY MODE COMBINATION

Purpose

To compare the micro results of Washington's TT budgets by mode combination with the macro nationwide average TT budgets.

Data

A Nationwide Personal Transportation Study was conducted during 1969-70 in a sample of households in all States.3/ The basic data were specially tabulated in order to have it conform with the tables of Washington, D.C., by mode combination.

However, it should be emphasized that the Washington results are based on internal interzonal trips only, while the nationwide results are based on all trips, including interurban and intrazonal as well. Thus, the nationwide TT budgets are expected to be higher than those within the metropolitan area of Washington.

Analysis

The TT budgets by mode combinations have been ranked from lowest to highest for both the Washington and the nationwide averages, as presented in Table 1.5.

Of particular interest is the gradual increase in the ranking, where the single mode tripmakers of passenger, transit, and driver are lowest, while their combinations are highest.

Furthermore, the nationwide results closely follow the Washington results although--as expected--at a somewhat higher level. The difference, therefore, should account for the interurban and intrazonal travel of the residents of the Washington metropolitan area.

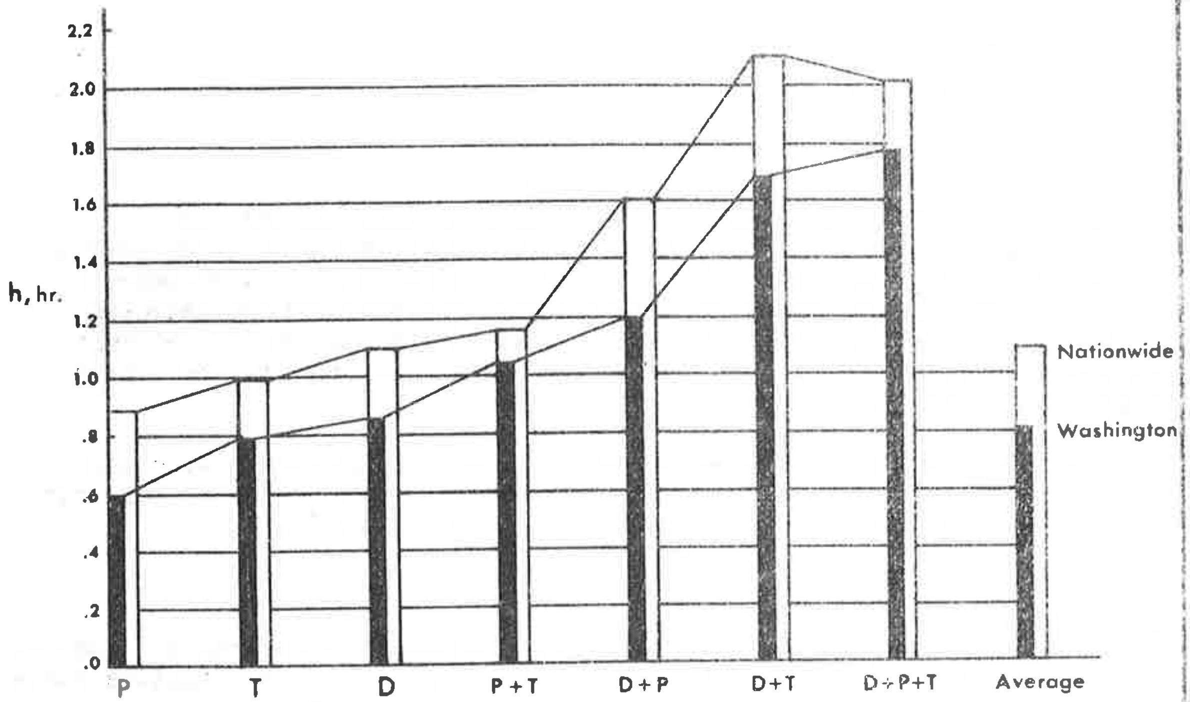
Altogether, the correspondence between the two sets of data, as seen in Figure 1.5, is very high and corroborates the indication that the TT budget is an inherent and stable behavioral characteristic of tripmakers.

Discussion

Although tripmakers seem to have a stable TT budget, there are significant differences between them by the combination of modes used. Autodrivers only and transit passengers only have similar TT budgets and it would be reasonable to regard each group as basically captive. The auto passengers, on the other hand, have a lower TT budget and they may be regarded as tripmakers who may be served by either the private or the public mode.

When a combination of modes is considered, the situation becomes more intricate, since the tripmakers' motivations for using a combination of modes are unknown. Furthermore, since their TT budgets seem to increase significantly over single mode users, their share in the total population's TT should be considered with special care.

3/ "Nationwide Personal Transportation," Federal Highway Administration, 9 separate reports, 1972-73.



TT-BUDGETS BY MODE COMBINATIONS
Nationwide & Washington D.C.

Fig. 1.5

Table 1.5

TRAVELTIME BUDGETS		
Mode	Washington, D.C.	Nation-wide
Driver	0.85 hr.	1.10 hrs.
Passenger	0.59	0.89
Transit	0.79	0.99
D + P	1.19	1.60
D + T	1.67	2.10
P + T	1.04	1.15
D + P + T	1.76	2.01
Average	0.81	1.08

1.7. NET VERSUS TOTAL TRAVELTIME (TT) BY LOCATION AND BY INCOME - MICRO

Purpose

To test the effects of excess time on the TT budget.

Data

The data in Table 1.6 were derived from the same basic tables for Washington, D.C., as mentioned earlier. The original trip records included the estimated net traveltimes (exclusive of excess time) between pairs of origin and destination zones, as derived from the road and bus networks. Excess times were then added to the net times, to represent the relevant walking and waiting times that one usually associates with either private or public transport.

Table 1.6 and Figure 1.6 detail the total TT budget for autodrivers and transit passengers only, although the full set of data, for all other mode combinations, is available in the original computer printouts.

Analysis

The aim of the analysis was to test whether the excess times may be regarded by tripmakers as an integral part of their daily TT and thus influence their travel behavior.

The excess times were estimated in the Washington study by a novel procedure--different values were assumed a-priori and the ones finally chosen were those that had resulted in the best calibration of the traffic model for the area. Thus, it was argued, the resulting excess times would represent the actual subjective times as perceived by the tripmakers.

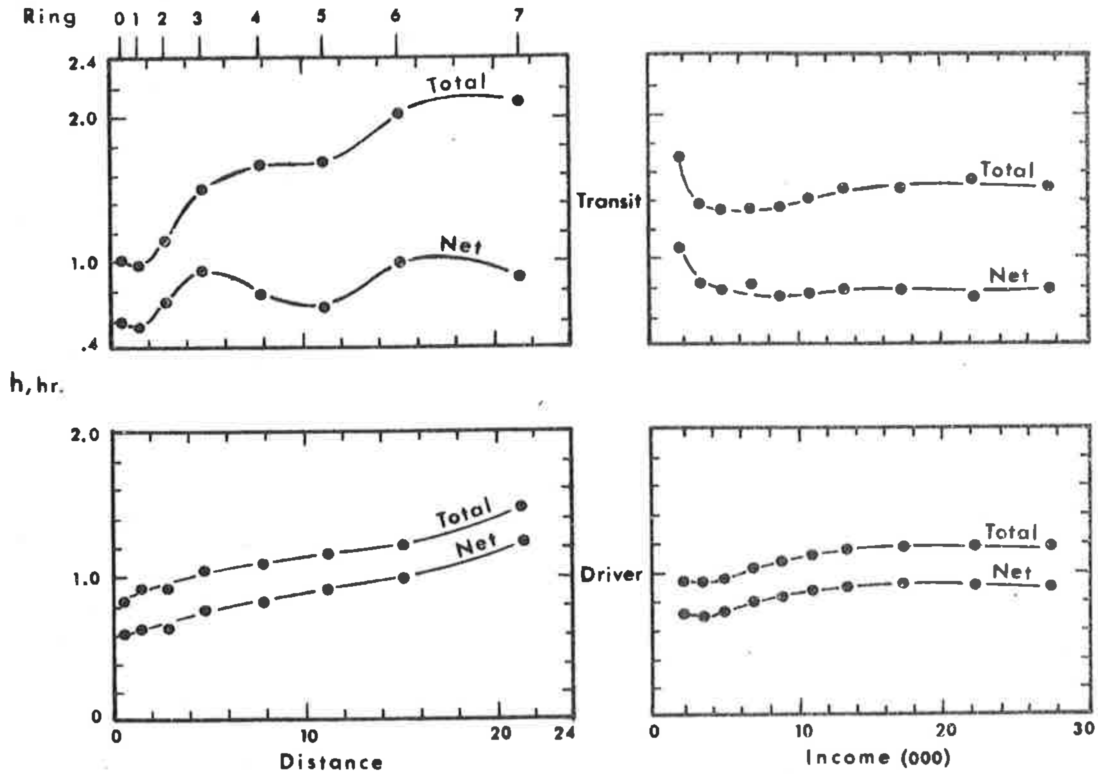
Discussion

When the comparison is made between autodriver TT by location and by income, it may be inferred that the excess time is a relatively constant value which was added automatically to all auto trips. Thus, either the net or the total TT may be considered for autodrivers with equal preference.

When a comparison is made between transit passengers' net and total TT by location, it may be concluded that excess times increase substantially with distance, presumably because of increasing waiting times for buses as their network and frequency become diluted with distance from the center.

The significant double hump that appears only in the transit passengers' TT versus distance was found to be attributed to the performance of the bus network and it would merit a detailed analysis of that network.

In summarizing this section, it has been concluded that since the subjective excess time seems to be relatively stable in all mode combinations except for transit versus distance, and since net times are more objective and easily defined by observations, it is suggested to use the latter at this stage of analysis.



NET vs. TOTAL TT BY LOCATION & INCOME
Washington Metro. Area

Fig. 1.6

Table 1.6

Ring	Driver (TT)		Transit (TT)	
	Net	Total	Net	Total
0	.59	.82	.58	1.01
1	.64	.92	.56	.98
2	.64	.92	.73	1.16
3	.77	1.05	.94	1.51
4	.82	1.09	.77	1.66
5	.91	1.16	.69	1.69
6	.99	1.21	.99	2.01
7	1.24	1.47	.89	2.10
Avg.	.85	1.11	.79	1.42

Income ($000)	Driver (TT)		Transit (TT)	
	Net	Total	Net	Total
0 - 3	0.70	0.94	1.07	1.70
3 - 4	0.69	0.93	0.82	1.37
4 - 6	0.71	0.95	0.78	1.33
6 - 8	0.79	1.04	0.81	1.34
8 - 10	0.82	1.08	0.74	1.35
10 - 12	0.87	1.13	0.77	1.41
12 - 15	0.90	1.17	0.79	1.47
15 - 20	0.91	1.18	0.77	1.48
20 - 25	0.91	1.19	0.72	1.53
25 - +	0.90	1.18	0.78	1.49
Avg.	0.85	1.11	0.79	1.42

CHAPTER 2: THE TRIP PURPOSE PREFERENCE LADDER

2.1. INTRODUCTION

The Concept

Based on the indication that tripmakers may have a stable daily TT budget, it can be argued that as speeds decrease, or trip times increase, tripmakers will have to value and rank their trips by purpose, so as to maximize their mobility within the constraint of a limited TT budget per day. Thus, if such a trip purpose preference ladder will emerge out of this analysis, it would serve as additional proof, although indirectly, to the constraining effect of a TT budget. An additional bonus of such an analysis would be a better understanding of the interdependency between the trip purposes under various exogenous factors.

Methodology

The methodology of analysis is based on an empirical comparative analysis of the rates of tripmaking by purpose for the cities detailed in Table 1.1. The first test was conducted for the preference ladder of autodrivers, while the second test was widened to encompass both private and public transport passengers.

In only a few studies, however, could a common denominator for the comparative analysis be found, since each area had its own scale and definition of trip purposes. Of great help was the monumental publication "Urban Transportation Planning Data,"4/ which detailed the required information for 8 out of the 21 cities with a wide range of population size.

From a purely analytical point of view, all the forthcoming relationships are doubious, since the dependent variable is part of, or closely related to, the independent variable. Thus, the relationships are self-evident and should be expected even before the start of the analysis. The aim of the analysis, however, was not to define each individual relationship as such, but to compare the relative trends between them, namely on a second level of evaluation. Indeed, it will be shown later that the results are illuminating since they define the interaction of and the interdependency between the various trip purposes within each given level of mobility.

Results

The results of the analysis were most encouraging, when the sensitivity and elasticity between trip purposes and the road network could be defined in a relatively simple and straightforward formulation.

Of particular interest are the several "bonuses" that were implied by the analysis, such as a simplified procedure for a rapid estimation of the level of mobility and modal split, as well as a better understanding of the behavioral process that affects the proportions of purpose in different urban areas.

4/ "Urban Transportation Planning Data," Federal Highway Administration, 1969.

2.2. AUTODRIVER PREFERENCE LADDER BY TRIP PURPOSE

Purpose

To analyze the interaction of and interdependency between the various trip purposes within given levels of autodriver mobility.

Data

The data have been derived from the publication "Urban Transportation Planning Data," where autodriver trips are detailed by purpose for 8 cities, as presented in Table 2.1. Although only 8 cities out of 21 could be included in this table, because of problems of data availability, they cover a wide range of population size from over 16 million to less than 200,000.

The number of autodriver trips by each purpose was divided by the number of autos in each area for deriving the trip rate by purpose. Table 2.1 and Figure 2.1 present, therefore, the trip rates by purpose versus total trip rate for each one of the 8 cities.

The original data were stratified into 10 different purposes, but since 4 were minor ones, with only a few trips, they have been combined into a new purpose--Other. Thus, 7 major purposes are shown in Figure 2.1.

Analysis

As previously mentioned, each individual relationship is quite meaningless from a statistical point of view since each trip rate by trip purpose, R_i, is part of the total trip rate, R, for that city, namely:

$$R = \sum R_i$$

Nonetheless, when a second level analysis is conducted, by comparing the slopes of the lines, a meaningful result begins to emerge, indicating that there is a clear tendency for each purpose to increase at a different rate with an increase in the total trip rate.

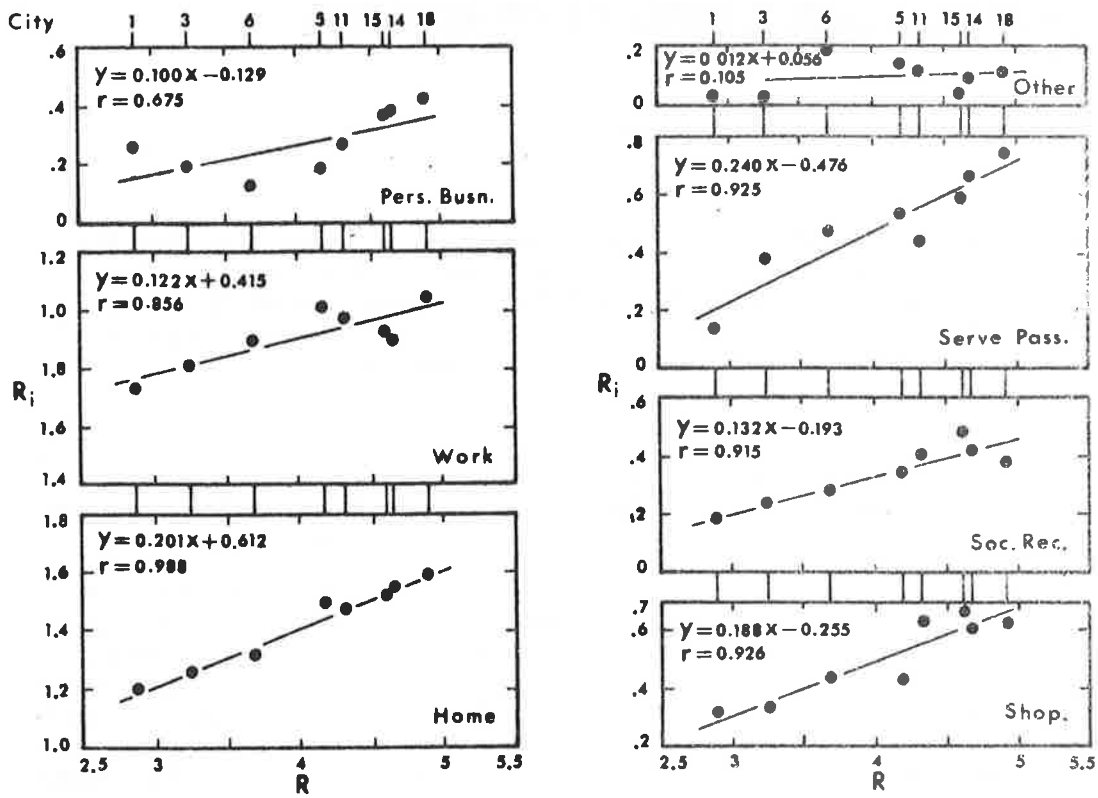
Thus, it can be concluded that a change in the total trip rate will result in different proportions of trips by purpose, and at some critical levels even changes in their ranking.

Discussion

The above result would indicate, therefore, that autodrivers may be conscious of their total trip rate and within its value would have to choose individual trip rates by purpose for their daily activities. Thus, a preference ladder by trip purpose would emerge.

It already has been shown in Figure 1.1 that the total average auto trip rate in an urban area may be related to the total average trip time. Thus, the rate of mobility of autodrivers, as well as their purpose split, may be related to and affected by the trip time, where a decrease in trip time will increase the trip rate, and vice-versa.

The sensitivity of the purpose split to changes in the trip rate will be analyzed in the next section.



AUTO DRIVER TRIP RATE BY PURPOSE VERSUS TOTAL TRIP RATE

Fig. 2.1

Table 2.1

AUTO DRIVER TRIP RATE

Purpose	CITY							
	1	3	5	6	11	14	15	18
Home	1.20	1.26	1.50	1.33	1.48	1.55	1.52	1.60
Work	0.73	0.81	1.01	0.89	0.97	0.90	0.93	1.04
Pers. Busn.	0.27	0.19	0.19	0.13	0.27	0.39	0.38	0.42
Medical	-	-	0.03	0.02	0.03	-	-	-
School	0.02	0.02	0.02	0.03	0.02	0.09	0.03	0.09
Soc. Rec.	0.18	0.24	0.35	0.28	0.41	0.43	0.49	0.38
Chg. Mode	0.04	0.01	0.01	-	-	-	0.01	0.01
Eat Meal	-	-	0.09	0.10	0.07	-	-	-
Shopping	0.31	0.34	0.44	0.44	0.64	0.62	0.68	0.63
Serve Pass.	0.14	0.39	0.54	0.48	0.45	0.67	0.59	0.75
Total Trip Rate Per Auto	2.89	3.26	4.19	3.70	4.33	4.66	4.63	4.92

2.3. ELASTICITY OF TRIPS BY PURPOSE FOR AUTODRIVER TRIPS

Purpose

To define the autodriver demand elasticity by trip purposes.

Data

The data in Table 2.2 are based on those presented in Table 2.1, for the same 8 cities. In this case, however, the Index of Elasticity (or Demand Elasticity) has been calculated for each trip purpose separately, namely the rate of change of R_i, in percent, that is associated with a change of 1 percent in the total average autodriver trip rate, R.

Analysis

By measuring the Index of Elasticity, the sensitivity of each separate purpose can be defined quantitatively and compared with all other purposes for each change in the total average trip rate in the area.

As can be seen in Figure 2.2, the various purposes group themselves into three distinctly different groups. The first group includes the purposes Work and Other (Home purpose trips are also in this category. However, this purpose represents a return trip for many other purposes rather than a purpose itself), where their elasticity is less than one. That is, these purposes are inelastic to changes in the total auto trip rate, R, and their relative importance will always be high at any auto trip rate. This result is, of course, quite expected, since the first priority of autodrivers would be given to trips to work and back home.

The surprising result, though, is the inclusion of the combined purpose Other in the above group. It would indicate the high preference given by drivers to the individual purposes of Medical, School, and Change Mode. In other words, although the relative number of trips is quite low, their importance to the individual driver who makes them is high.

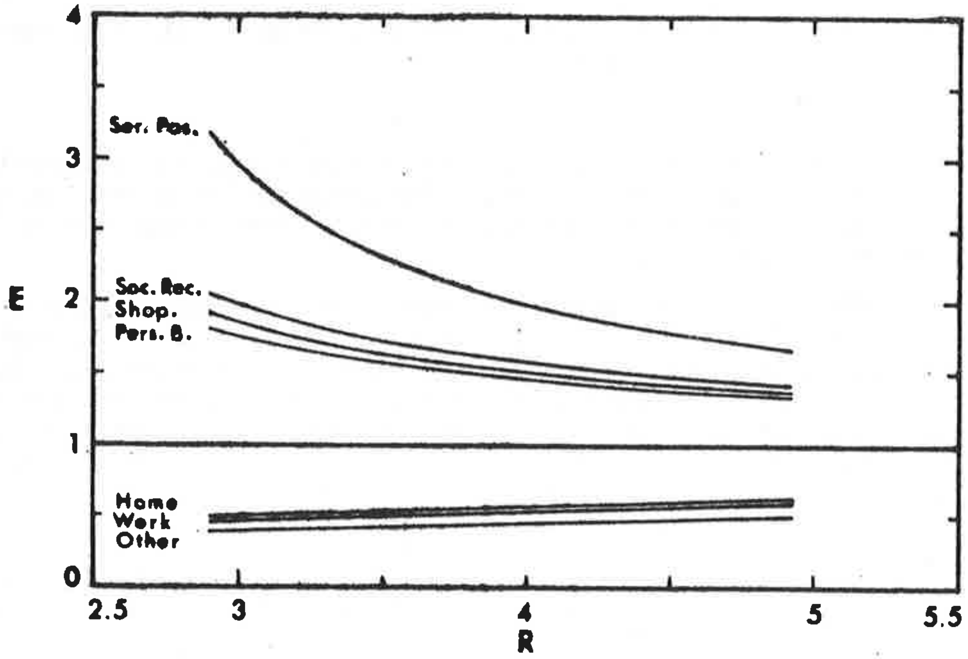
The second group, with a demand elasticity that reaches two, includes the trip purposes Social-Recreation, Shopping, and Personal Business. Namely, these purposes are ranked in importance by the autodriver below the first group, and a decrease in the total trip rate will result in an accelerated decrease in this group until their decrease will reach double the decrease in R (within the observed data).

The third and lowest rank is given to the purpose Serve Passenger, which may reach a demand elasticity of over three.

Discussion

Of particular interest is the trip purpose Serve Passenger since it is the most sensitive to a change in the total auto trip rate, R. Thus, a decrease in the total trip rate will first and foremost affect the auto passengers since they will no longer be "served" by an autodriver.

At this stage, the question of modal split should be raised. Namely, will the loss of auto passengers from private transportation be a gain to public transportation? This question, as well as other closely related subjects of modal choice, will be discussed in the following sections.



AUTO DRIVER'S INDEX OF ELASTICITY BY TRIP PURPOSE vs. AUTO TRIP RATE

Fig. 2.2

INDEX OF ELASTICITY

Table 2.2

Auto Trip Rate	2.89	3.0	3.5	4.0	4.5	4.92
Trip Purpose						
Home	0.49	0.49	0.53	0.56	0.60	0.62
Work	0.46	0.47	0.51	0.54	0.57	0.59
Pers. Busn.	1.81	1.74	1.58	1.47	1.40	1.35
Soc. Rec.	2.03	1.95	1.72	1.58	1.48	1.42
Shopping	1.89	1.85	1.63	1.51	1.43	1.38
Serve. Pass.	3.20	2.95	2.31	1.98	1.79	1.68
Other	0.39	0.39	0.43	0.46	0.49	0.52

2.4. MOBILITY OF PRIVATE AND PUBLIC TRANSPORT BY PURPOSE

Purpose

To analyze the trip purpose split of Private versus Public Transport as affected by the level of mobility.

Data

The data presented in Table 2.3 have been derived from the publication "Urban Transportation Planning Data." The necessary data could be defined, on the basis of common denominators, for only 6 urban areas out of the 21 areas listed in Table 1.1.

Table 2.3 details the mobility for 6 study areas, by purpose, for private and public transport. Mobility by mode is defined as the total number of internal person trips by the mode in question per 100 residents. Thus, the mobility of private transport is the number of both autodriver and auto passenger trips per 100 residents, while the mobility of public transport is the number of rapid transit and bus passengers per 100 residents. Total mobility, then, is the grand total of all internal person trips in the area per 100 residents, excluding taxi and school bus trips.

Figures 2.3 and 2.4 present the data in a graphical form, where 4 minor purposes (as detailed in the preceding section) have been combined from the table into the purpose Other in the figures.

Figure 2.3 relates the mobility of private transport, M_p, by trip purpose versus the daily average auto trip rate R in the study area. Figure 2.4 relates the mobility of transit transport, M_t, by purpose versus the same R.

Analysis

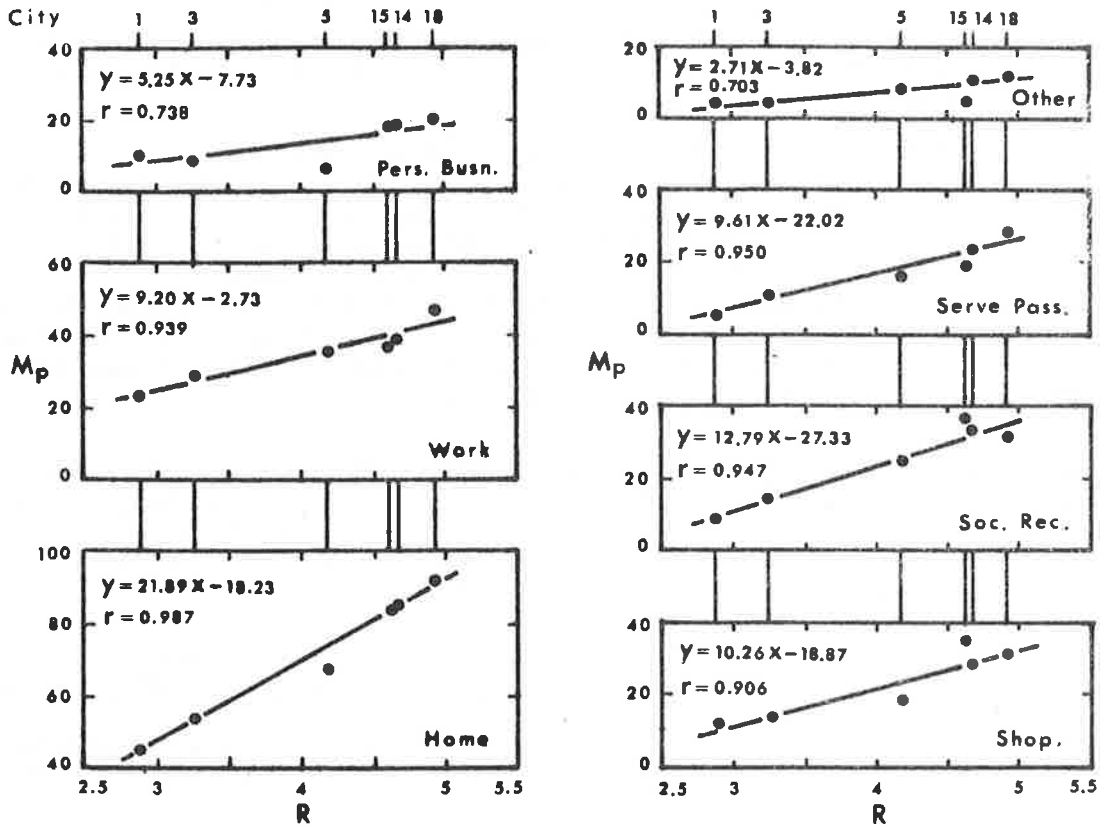
It should be noted again that each individual relationship in Figures 2.3 and 2.4 is of doubtful value when considered by itself since mobility, especially for the private transport, is related directly to the auto trip rate, R. It is the second level analysis, however, that is of particular interest, namely the relative demand elasticity of the various trip purposes, as well as the interaction between M_p and M_t. A few conclusions that can be drawn from this analysis are that: (1) all relationships for M_p show the expected linearity with R, since they are directly related; (2) all relationships for M_t, however, show the unexpected nonlinear shapes, similar to a demand curve; and (3) when both M_p and M_t are added together, for the total M in each urban area, a surprising phenomenon appears, as shown in Figure 2.5--as the auto trip rate R decreases, the corresponding decrease in M_p cannot be compensated for by the opposite increase in M_t, with the result that the total mobility decreases.

It may be concluded, therefore, that a diversion of trips from private transport to transit is incomplete, namely that part of the trips is lost in the process.

The best-fit equations for mobility were found to be:

$$M_p = 72.39\ R - 103.48; \qquad \text{(Equation 2.1)}$$

$$M_t = 1{,}119.4\ R^{-2.934} \qquad \text{(Equation 2.2)}$$



AUTO DRIVER AND PASSENGER MOBILITY BY PURPOSE vs. AUTO TRIP RATE

Fig. 2.3

MOBILITY BY TRIP PURPOSE & MODE

Table 2.3

PURPOSE	Driver	Pass.	D + P	Transit	Total	Driver	Pass.	D + P	Transit	Total	Driver	Pass.	D + P	Transit	Total
	1 - TRI-STATE					3 - BALTIMORE					5 - KANSAS CITY				
Home	30.7	14.8	45.5	23.1	68.6	34.6	19.6	54.2	13.3	67.5	41.3	26.2	[illegible]	8.8	76.3
Work	18.8	4.3	23.1	14.3	37.4	22.0	6.9	28.9	6.1	35.0	27.9	7.2	[illegible]	5.0	40.1
Pers. Busn.	6.8	3.7	10.5	2.3	12.8	5.2	2.9	8.1	0.9	9.0	5.2	1.5	6.7	0.4	7.1
Medical	-	-	-	-	-	-	-	-	-	-	0.7	0.8	1.5	0.3	1.8
School	0.5	1.8	2.3	6.7	9.0	0.5	2.8	3.3	5.6	8.9	0.6	1.7	2.3	2.6	4.9
Soc. Rec.	4.7	4.2	8.9	1.5	10.4	6.7	7.6	14.3	0.9	15.2	9.6	15.0	24.6	0.7	25.3
Change Mode	1.0	1.3	2.3	4.3	6.6	0.3	0.6	0.9	0.4	1.3	0.3	0.5	0.8	0.5	1.3
Eat Meal	-	-	-	-	-	-	-	-	-	-	2.4	1.5	3.9	0.1	4.0
Shopping	8.0	4.0	12.0	1.8	13.8	9.2	4.9	14.1	1.1	15.2	12.2	6.1	18.3	1.0	19.3
Serve Pass.	3.6	1.9	5.5	-	5.5	10.6	-	10.6	-	10.6	15.0	0.5	15.5	-	15.5
Total	74.1	36.0	110.1	54.0	164.1	89.1	45.3	134.4	28.3	162.7	115.2	61.0	176.2	19.4	195.6
PURPOSE	14 - BATON ROUGE					15 - KNOXVILLE					18 - COLUMBIA				
Home	54.5	30.5	85.0	9.3	94.3	49.3	34.6	83.9	4.8	88.7	56.9	34.7	91.6	3.5	95.1
Work	31.8	6.9	38.7	1.2	39.9	30.3	6.6	36.9	2.9	39.8	37.0	9.9	46.9	2.2	49.1
Pers. Busn.	13.8	4.8	18.6	0.3	18.9	12.3	6.0	18.3	0.6	18.9	14.9	5.3	20.2	0.4	20.6
Medical	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
School	3.1	7.3	10.4	7.6	18.0	0.9	2.8	3.7	0.5	4.2	3.1	7.5	10.6	0.5	11.1
Soc. Rec.	15.1	18.1	33.2	0.2	33.4	15.9	21.8	37.7	0.6	38.3	13.6	17.7	31.3	0.2	31.5
Change Mode	0.1	0.1	0.2	0.1	0.3	0.4	0.4	0.8	0.3	1.1	0.3	0.3	0.6	0.1	0.7
Eat Meal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Shopping	21.7	7.0	28.7	0.4	29.1	21.9	12.8	34.7	1.2	35.9	22.2	8.5	30.7	0.5	31.2
Serve Pass.	23.6	0.8	24.4	-	24.4	19.2	0.4	19.6	-	19.6	26.7	1.4	28.1	-	28.1
Total	163.7	75.5	239.2	19.1	258.3	150.2	85.4	235.6	10.9	246.5	174.7	85.3	260.0	7.4	267.4

Discussion

The above conclusion could, of course, be arguable since a macro-analysis between different cities does not constitute by itself a proof for micro conditions within each study area.

Two factors, however, should be considered at this stage: (1) if it is assumed that people do have an individual TT budget, as has been indicated in Chapter 1 for both macro and micro conditions, then any reduction in the speed of travel will automatically be accompanied with a reduction in mobility, and (2) if the transfer or diversion of passengers from private to public transport would have been a complete one, then the indices of elasticity, by purpose, should be ranked in the same order, though with a reversal of sign. Namely, the purpose with the greatest loss to private transport should then be the greatest gain to transit, and vice versa. But is this really the case?

To test this possibility, the Index of Elasticity has been calculated by mode for each purpose. These indices for transit are the exponents in the equations of best-fit, as detailed in Figure 2.4. For the linear relationships of the private transport, the elasticities had to be calculated separately as detailed in the next section and shown graphically in Figure 2.6.

When the elasticities by trip purpose for the two modes are ranked and compared with each other, it is found that the above assumption is not proven.

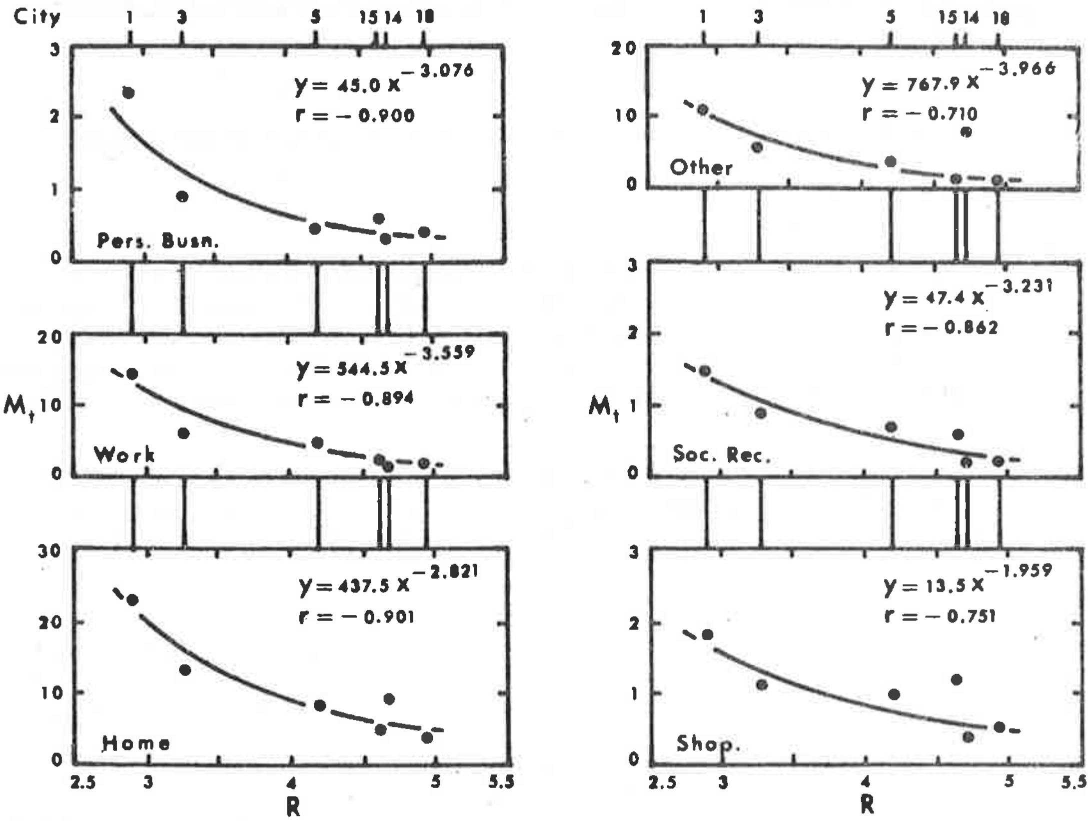
It is true that the purpose Serve Passenger in the private mode introduces some uncertainty but, nevertheless, there is not even a remote similarity between the two rankings.

It can be concluded, therefore, that a reduction in trips made by private transport for whatever reason cannot be considered as an automatic gain in transit trips.

The above conclusion raises a basic issue--the currently applied modal split procedures are based on the assumption that varying the transportation systems will divert person trips from one mode to another within a constant total number of person trips in the area. It may, therefore, be concluded that this assumption should now be reviewed in light of the above results in order to develop a better and more sensitive modal choice process.

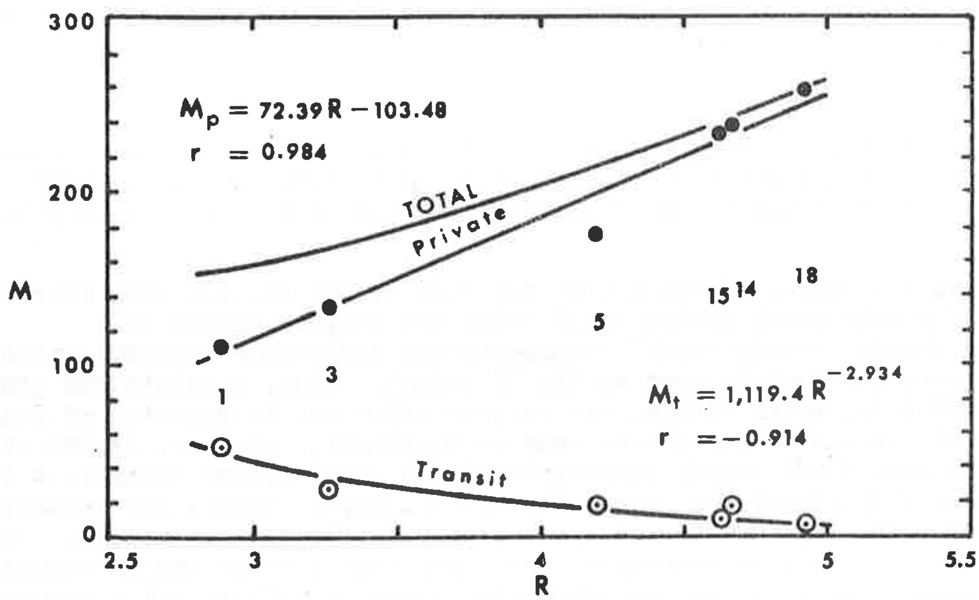
An additional unexpected finding from the above analysis was the possibility to estimate rapidly, and within acceptable first approximation levels of accuracy, the total mobility for urban areas if only the auto trip rate, R, is known. Namely, the relationships for mobility for the two modes, which had been developed on the basis of only 6 urban areas, were applied for all 21 study areas in Table 1.1, as well as for Washington, D.C. The public transport trips in this case, however, include taxi and school bus trips as well.

The results are detailed and explained in Section 2.6. Let it be said here that the results have been most encouraging.



TRANSIT PASSENGER MOBILITY BY PURPOSE vs. AUTO TRIP RATE

Fig. 2.4



TOTAL PRIVATE AND TOTAL TRANSIT MOBILITY vs. AUTO TRIP RATE

Fig. 2.5

2.5. ELASTICITY OF TRAVEL DEMAND BY TRIP PURPOSE FOR PRIVATE AND PUBLIC TRANSPORT

Purpose

To define the demand elasticity by trip purposes for private and public transport.

Data

The data in Table 2.4 were derived from the equations developed for the private mode in the preceding section and the indices of elasticity, by trip purpose, were calculated within the observed values in the 6 urban areas. The elasticity indices in the table are related for both the auto trip rate, R, and the mobility, M, while Figure 2.6 depicts the relationships for the mobility, M.

As mentioned earlier, the elasticity indices for the transit mode are the exponents in the equations shown in Figure 2.4, and since they remain constant for all values of either R or M, they are not shown graphically.

Analysis

When the elasticity indices of the private mode, for both autodrivers and auto passengers as seen in Figure 2.6, are compared with the corresponding indices for autodrivers only, in Figure 2.2, a major change can be noted. While only selected trip purposes for autodrivers are elastic, all purposes become so when the total private mode is considered.

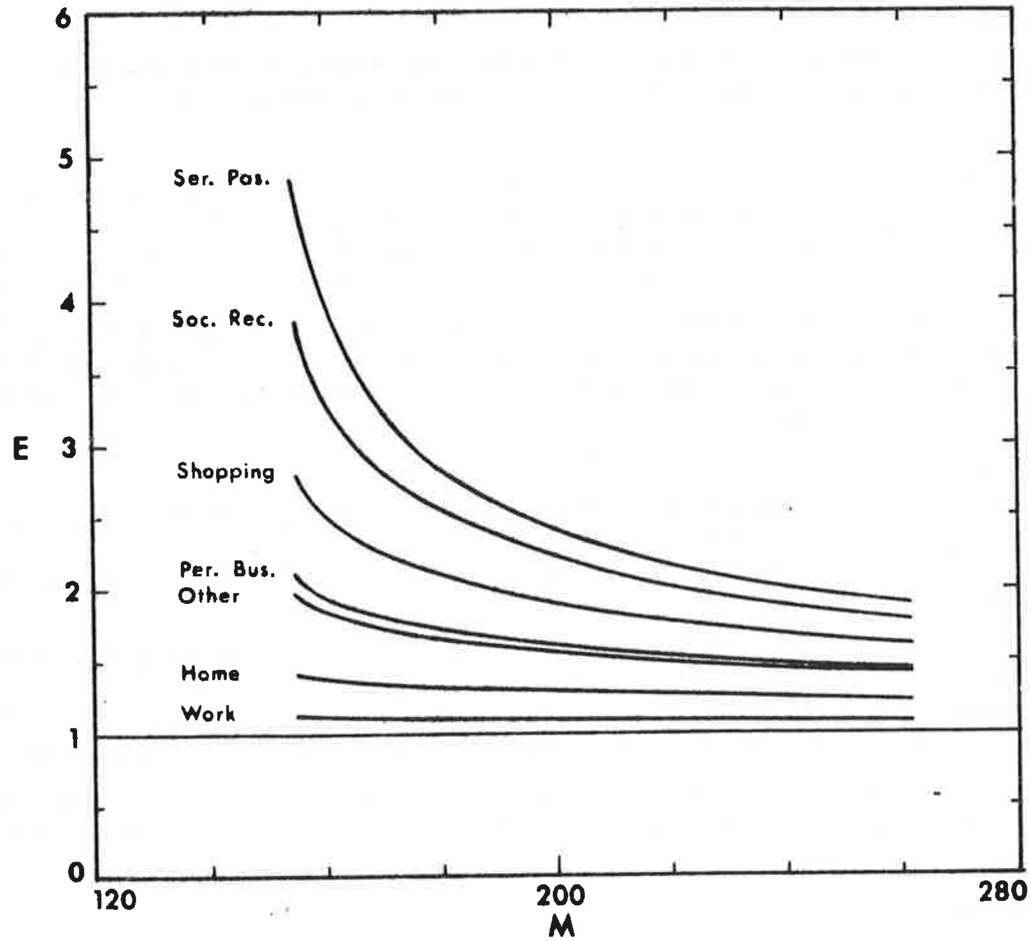
Therefore, when estimating the total mobility in an urban area, 3 components of modal split become available: autodriver trips, total private mode trips, and transit trips. Thus, the three components may be evaluated both separately and when they interact together, for a better estimation of the modal and purpose splits at different levels of mobility.

Discussion

The above relationships may explain in a simple and consistent way a well established, although not always understood, phenomenon in transportation studies, where the proportions of trips by purposes may vary from city to city.

Now there is a strong indication that all such variations are only external symptoms of a behavioral mechanism of modal and purpose choice in a relatively stable "steady state" transportation condition, enclosed within several strong constraints such as the TT budget. Thus, a relatively stable range of mobility, modal choice, and purpose split may be expected as long as the total transportation system remains unchanged. However, if one or both of the demand and supply components of the total system changes, a feed-back process will adjust the level of mobility, modal choice, and purpose split until stability is achieved again within the basic constraints. Such a unified formulation, if developed, would probably provide better results than the present trip generation submodels, since it will be fully responsive to changes in the transportation system.

As will be seen later on, even a rudimentary formulation of travel, as developed in this exploratory study, can already be useful for a better understanding of travel behavior and patterns in urban areas.



AUTO DRIVER AND PASSENGER'S INDEX OF ELASTICITY
BY TRIP PURPOSE vs. MOBILITY

Fig. 2.6

Table 2.4

Auto Trip Rate R	2.89	3.00	3.50	4.00	4.50	4.92
Mobility	155.4	158.3	178.2	205.3	235.9	262.9
Trip Purpose						
Home	1.40	1.38	1.51	1.26	1.23	1.20
Work	1.11	1.11	1.09	1.08	1.07	1.07
Pers. Busn.	2.04	1.96	1.73	1.58	1.49	1.43
Shopping	2.76	2.59	2.11	1.85	1.69	1.60
Soc. Rec.	3.85	3.48	2.57	2.15	1.90	1.77
Serve. Pass.	4.84	4.23	2.90	2.34	2.03	1.87
Other	1.95	1.88	1.67	1.54	1.46	1.40

2.6. A PROCEDURE FOR THE RAPID ESTIMATION OF TOTAL MOBILITY

Purpose

To test whether the formulation of mobility developed from the data of 6 urban areas can be applied to other areas with equal accuracy.

Data

The elementary equation of private transport mobility as developed in Section 2.4, and a more generalized equation of public transport (including taxi and school bus passengers) have been applied to the given auto trip rates, R, for all 21 urban areas detailed in Table 1.1, as well as to Washington.

The results are given in Table 2.5, where the M_p and M_t for each area have been calculated, added to arrive at the total mobility, M, and then compared with the given total M. The differences between the estimated and given M are shown in percent.

Analysis

The results of the rapid estimation procedure are quite surprising, since in no case does the difference between the estimated and given M reach ± 17 percent, while 50 percent of the cases have a difference of less than ± 7.5 percent.

The results are even more outstanding if it is remembered that the procedure is based on one simple variable, the auto trip rate, R; the given mobilities are based on a wide range of local definitions of zones, linked trips; and that the procedure itself is based on an analysis of only 6 urban areas.

It may be inferred that the relationships are strong enough to emerge above all possible local variations and express some fundamental behavior of travel in urban areas.

Discussion

It may be argued again that M is directly related to R and, therefore, the strong correlation is self-evident and expected.

However, two factors should be considered in this specific case: (1) the auto trip rate can be obtained with a smaller sample than would be necessary for developing information for such factors as modal and trip purpose splits. Thus, the procedure may be applied when the knowledge of the total mobility and its approximate modal and purpose splits are urgently required. Namely, the procedure may be considered as relatively reliable because of, and not in spite of, the close interdependence between M and R; and (2) it already has been shown that the auto trip rate is responsive to the road network. It can, thus, be inferred that the total mobility will also be responsive to the road network.

Therefore, this stage should be considered as an intermediate one since both M and R will be further analyzed in light of additional factors, as detailed later in Chapter 3.

In the meantime, the next section will be devoted to a micro-analysis of modal choice, and a new definition will be proposed.

TABLE 2.5

ESTIMATION OF MOBILITY

City	Trip Rate	M_p Esti.	M_t Esti.	M_{Total} Esti.	M Given	Diff. ± Percent
1	2.89	105.7	51.8	157.5	165.1	- 4.6
3	3.26	132.5	39.8	172.3	172.4	- 0.1
4	3.63	159.3	31.4	190.7	217.3	- 12.2
5	4.19	199.8	22.8	222.6	199.7	+ 11.5
6	3.70	164.4	30.1	194.5	213.5	- 8.9
7	4.70	236.8	17.7	254.5	224.8	+ 13.2
8	5.12	267.2	14.7	281.9	317.7	- 11.3
9	4.30	207.8	21.6	229.4	216.6	+ 5.9
10	4.57	227.3	18.9	246.2	247.9	- 0.7
11	4.33	210.0	21.2	231.2	257.6	- 10.2
12	3.53	152.1	33.4	185.5	216.9	- 14.5
13	5.10	265.7	14.8	280.5	303.2	- 7.5
14	4.66	233.9	18.1	252.0	251.0	+ 0.4
15	4.63	231.7	18.4	250.1	249.3	+ 0.3
16	5.66	306.2	11.8	318.0	309.1	+ 2.9
17	5.10	265.7	14.8	280.5	303.5	- 7.6
18	4.92	252.7	16.0	268.7	279.4	- 3.8
19	5.79	315.7	11.2	326.9	298.8	+ 9.4
20	4.25	204.2	22.1	226.3	226.2	± 0.0
21	4.46	219.4	19.9	239.3	249.0	- 3.9
W	3.28	134.0	39.3	173.3	206.7	- 16.2

$M_p = 72.39\ R - 103.48$

$M_t = 540.14\ R^{-2.207}$

2.7. MODAL CHOICE OF TRIPMAKERS BY MODE COMBINATION - MICRO

Purpose

To define the modal choice of tripmakers.

Data

The data in Table 2.6 were derived from the basic tabulations of the Washington, D.C., study, as mentioned earlier.

In most transportation studies, the modal choice is applied to the total number of person trips. However, since it already has been indicated that the number of trips may vary in response to the transportation system, the modal choice in this case has been applied to the tripmakers themselves. Thus, the tripmakers' rate, Z, is the number of persons making trips, by a particular mode, per 100 population, as detailed in Table 2.6 in percent and presented graphically in Figure 2.7.

Analysis

The first surprising result is that the Z rate in the city center is the highest. This result would seem to contradict the established belief that the vehicular mobility of population residing in the center should be the lowest because of the high density of opportunities in the center, within walking distances. The contradiction can be explained by referring back to Figure 1.4, where the trip rate per tripmaker, F, in the center is indeed lowest. Thus, while the trip rate per tripmaker, F, is the lowest in the city center, the proportion of persons making trips, Z, is the highest.

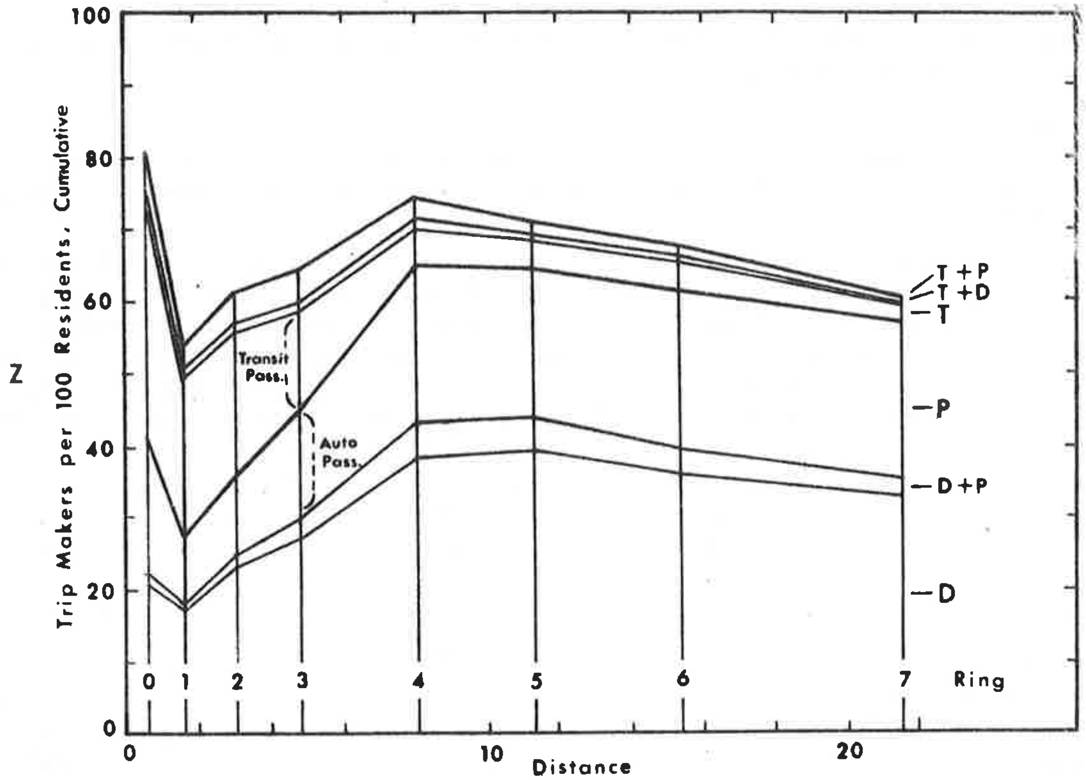
Another test was then conducted by deriving the Z rates for the labor force instead of the population, since the household structure in the center may differ from other parts in the area. Indeed, the Z rate decreased somewhat in this case, although it was still higher than in ring 1, and very near to the Z rates in other parts in the area.

A second interesting result in Figure 2.7 is the interchangeability between transit passengers and auto passengers with increasing distance from the center, although their total percentage from ring 1 outwards remains quite stable. This tendency is notable only between those two modes.

Discussion

It may be concluded from the above that the first and foremost source for the diversion of passengers to transit can be found in the auto passenger group. This conclusion is corroborated by the previous result, in Section 2.5, where it has been found that when the auto trip rate is reduced, the highest reduction in demand elasticity is in the purpose Serve Passenger. Namely, auto passengers may be considered as the best potential source of passengers for diversion to transit, since they are the first to be lost to auto travel.

The above conclusion is of particular interest since it may have an effect not only on transit network planning but also on transit publicity campaigns--they may have to be directed toward specific groups of tripmakers at certain localities rather than toward the public in general.



TRIP MAKERS' RATE BY MODAL CHOICE vs. LOCATION
Washington Metro. Area

Fig. 2.7

PERCENTAGE OF TRIP MAKERS BY MODE

Table 2.6

Ring	MODE							Total Trip Makers*	Total Population
	D	P	D + P	T	T + D	T + P	Total.		
0	20.7	18.9	1.5	34.1	1.3	4.4	80.9	12,784	15,795
1	17.2	9.0	0.5	23.1	0.6	3.3	53.7	46,282	86,118
2	23.5	10.5	1.9	20.1	1.0	4.4	61.4	200,524	326,616
3	27.3	15.2	2.4	13.7	1.1	4.5	64.2	320,587	499,052
4	38.5	21.6	4.8	5.1	1.1	3.0	74.0	560,336	757,629
5	39.0	20.8	4.6	3.6	0.8	2.0	70.8	324,127	458,067
6	35.7	22.1	3.6	3.9	0.4	1.9	67.5	197,282	292,303
7	32.8	21.4	2.7	2.2	0.3	0.9	60.3	73,832	122,511
Total	33.0	18.4	3.5	8.9	0.9	3.1	67.9	1,735,754	2,558,092

*Does not include D + P + T or unknown modes

2.8. THE STAR MODAL SPLIT

Purpose

To define the relative interaction between all mode combinations at each ring in the Washington, D.C., area.

Data

The data in Table 2.7 were derived from the basic tabulations of the Washington study, as mentioned earlier. All person trips are by location of residence.

The applicability and usefulness of the star modal split to modal choice analysis is based on the standard concept and procedures of trip modal split instead of tripmakers' modal split, although the latter has been found in this study to be more representative of and responsive to the transportation system. In other words, a better approach to modal split analysis may be to deal with total tripmakers in the modal split model rather than total person trips.

The trips, by mode combination, are in percent and Figure 2.8 presents the results in a graphical form. The three major axes are the single modes D, P, and T, while their mode combinations are in between, along the minor axes. It should be noted that the stars, by ring, are two-dimensional, where each axis depicts only one single mode or mode combination.

Analysis

The stars clearly express how the modes interact and change from ring to ring. In ring 0, for instance, the dominant mode is transit, but from then on, ring by ring, the weight shifts to the autodriver mode, D, as well as to the auto passenger mode P.

Of particular interest is the significant increase in the modes of P and D + P in rings 3 to 5, which surpasses the relative increase in D. Furthermore, ring 4 becomes the critical one for transit, where it suddenly drops down to only a third of its previous value. Such drastic changes are possibly caused by the beltway that encircles the area within ring 4.

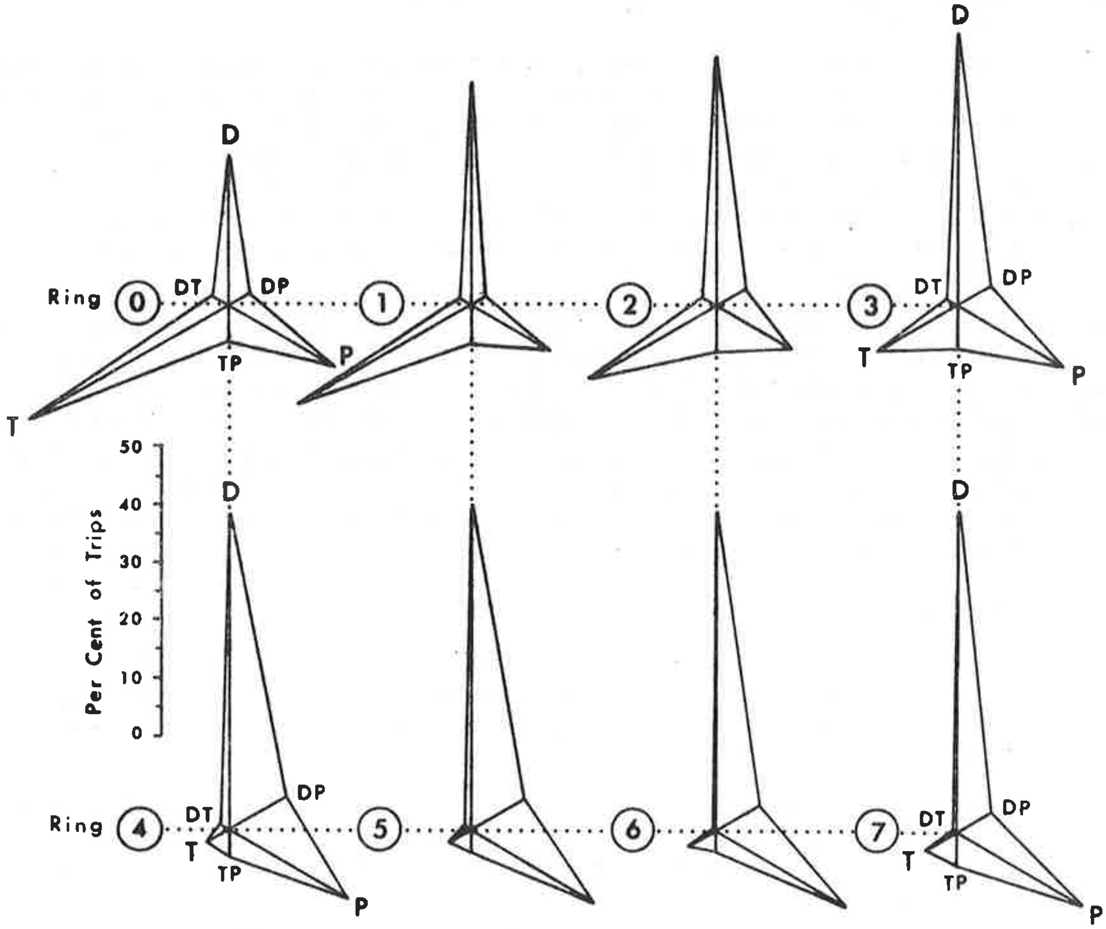
Discussion

The purpose of detailing the above trends is not to delve into the specific travel characteristics in the Washington area, but rather to present a quick example of the kind of information and conclusions that can be derived from the mode combination analysis.

Most of the current procedures of modal choice deal with a total pool of person trips and the split of trips is carried out into the two major groups of private and public modes (with a possible subdivision within each one, such as autodriver and auto passenger, or bus, rail, and rapid transit), while disregarding the real-life conditions, where tripmakers actually use various combinations of modes during the day, for different purposes at different locations in the area.

It would seem desirable, therefore, to revert back to the tripmaker himself for a more thorough and real-life analysis of modal choice, but even if only the trips are considered, even then a mode combination analysis would seem to be preferable to the single-mode analysis.

These suggestions and other related subjects are discussed again in the next section.



STAR MODAL SPLIT OF PERSON TRIPS BY LOCATION
Washington Metro. Area

Fig. 2.8

Table 2.7

Ring	Total Person Trips	Percent of Trips by Mode					
		Driver	Pass.	Transit	D+P	D+T	P+T
0	30,487	28.6	23.7	34.3	3.5	3.7	6.2
1	118,032	39.4	15.6	34.5	2.2	2.1	6.2
2	548,267	43.6	15.3	25.1	5.5	2.6	7.9
3	920,962	47.8	20.4	15.5	6.8	2.4	7.1
4	1,811,568	55.0	23.9	4.3	10.9	1.7	4.2
5	1,021,620	56.8	25.0	3.2	10.6	1.2	3.2
6	583,205	56.5	27.5	3.9	8.7	0.7	2.7
7	220,725	58.6	29.5	2.3	7.2	0.6	1.8
Total	5,254,866	52.7	23.1	8.9	8.9	1.7	4.7

2.9. IN CONCLUSION

While trying to summarize the results of the report, it becomes evident that no subject is new or novel. For example, it has been known for a long time that households seem to have a stable weekly traveltime budget; it has been well known that the proportion of trips by trip purpose varies according to an approximately predictable scale which can be related to the size of the urban area; and it has already been recognized that a truly behavioral traffic model should be based on the tripmakers themselves rather than on their resultant trips.

When all these known subjects are grouped together under a unified approach, however, a basic conflict with the current standard modeling procedures comes into light, since the results of most--if not all--of the present established models are diametrically opposed to the above known tendencies.

For instance, the prevailing assumption in the standard models is that the total number of person trips (as well as their trip purpose ratios) at a given socio-economic condition in an urban area is a constant number for all system alternatives. The result of such an assumption is that the traveltimes of tripmakers must vary from system to system--which is in contradiction with the indication that tripmakers have a stable TT budget.

Moreover, the traveltimes saved by providing an improved transportation system have been given a monetary value--based on the readiness of tripmakers to pay for achieving such savings in time--without really defining what might be the alternative uses of the saved times.

If, however, it could be proven that the saved times will mostly be used for making additional trips--as is indicated in this study, then the basic assumption in the standard models, namely that the total number of person trips is constant, might collapse.

While reviewing the results of this study up to this stage, it can be concluded that the whole subject of mobility should be raised anew, since there are indications that the amount of travel, by modes and purposes, is sensitive and responsive to the transportation system, and a feedback process is at work within a few but stable constraints, such as the TT budget.

Indeed, it has been indicated that tripmakers seem to have a trip purpose preference ladder which is sensitive to the level of mobility; that their modal choice is sensitive to the auto trip rate; and that a diversion of trips from private to public modes--or rather from fast to slow modes--may result in a loss of trips and mobility. Therefore, it might be expected that iniatives relating to energy conservation and air quality, which tend to divert travel from private to public transport, may result in a significant decrease in total mobility.

The next chapter will, therefore, be devoted to a review of the well known subject of mobility, where some established beliefs will be tested again, and an empirical and simple (at this stage) formulation of mobility will be developed. Special attention will be given to the interaction of and interdependence between the level of mobility and the transportation system, so that a better understanding of the responsiveness of travel demand to system supply can be achieved.

CHAPTER 3: MOBILITY

3.1 INTRODUCTION

The Concept

Mobility is recognized to be a complex subject. This is one of the main reasons for the ever increasing complexity and sophistication of traffic models, where additional variables and factors are being added to the formulation of mobility year by year.

It is somewhat surprising that, although techniques in transportation analysis have progressed a long way, some fundamental questions have remained unanswered until now. For instance, as yet it is not known explicity whether mobility is the cause or effect of economic development and, if it is both, what is the value of an increase or decrease in mobility, in monetary units, to the economy? Such questions are of prime importance, especially now when the fuel shortage threatens mobility.

Some of the difficulties and uncertainties in these and similar issues are believed to have been caused by the established concepts of traffic models, where it has time and again been assumed that mobility is a direct derivation of only the socio-economic characteristics of the population and, therefore, will remain a constant value as long as these characteristics remain stable.

Lately, it has been recognized that some changes in the basic concepts and assumptions are required, since it is realized that mobility should be sensitive and responsive to the transportation system supply. Thus, several studies have recently been conducted, with the purpose of defining the interaction between travel demand and system supply. Several different approaches have been tried, but as yet with inconclusive results. This study will try to add to the total pool of knowledge, and indicate an additional approach, which may be useful for enhancing a better understanding of the mobility process.

Methodology

Special attention will be given in testing some of the factors that have been known to affect the amount of mobility on both macro and micro levels. The methodology is basically empirical in nature, where the available information and observations for the 21 urban areas will be evaluated by comparative analysis.

To simplify this complex subject and in order to derive the dominant factors, the analysis will test only single factors at a time. The limitations of such an analysis are well recognized; nevertheless, it will be shown that even within this limited frame, several seemingly unrelated travel characteristics may be united under one unified explanation.

The Relationships

At first a few factors that are believed to affect mobility will be tested on a macro level. It should be noted that such relationships have appeared time and again in the technical literature, but are repeated here only for the specific 21 urban areas that are the basis for this study. Then the trip rate will be tested again, on both macro and micro levels. The chapter will end with a formulation of mobility.

3.2. MOBILITY VERSUS POPULATION DENSITY

Purpose

To test the effect of population density on mobility.

Data

The data were derived from the transportation study reports of the 21 urban areas detailed in Table 1.1. Mobility, M, is defined as the total internal person trips by both private and public transport per 100 residents. (It should be noted that some study reports have presented the data by including truck passenger trips as well.) Population density is the total average for the area, in residents per square mile.

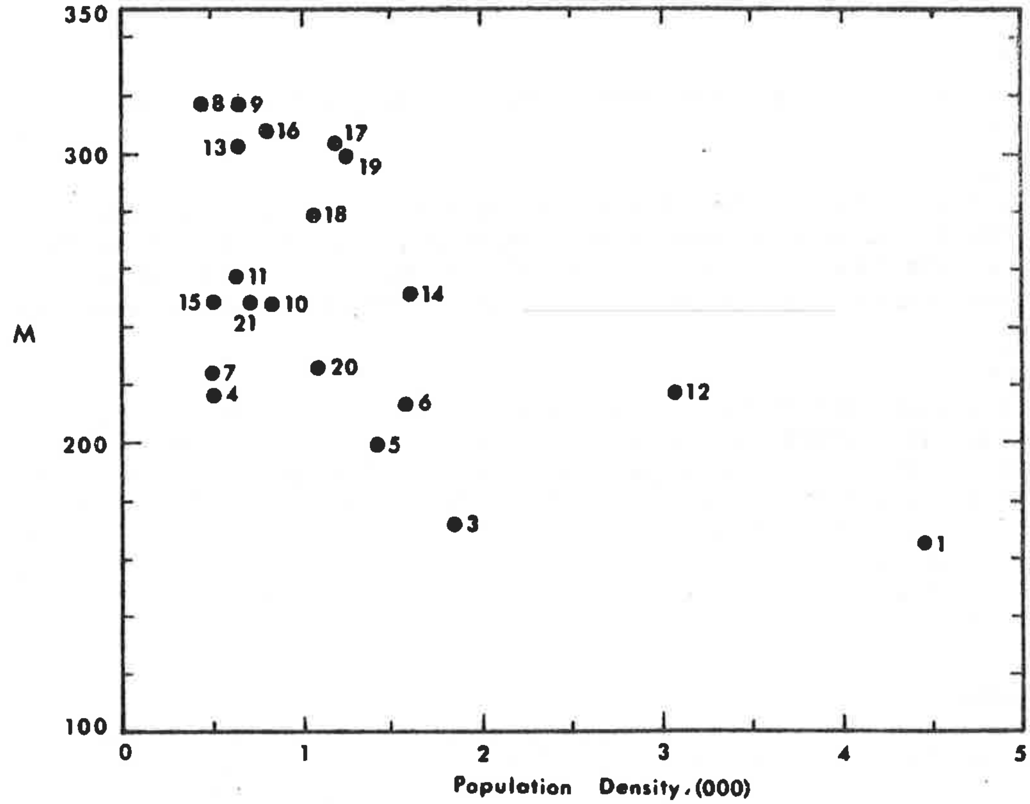
Analysis

ᴜ ing the above definition, it can be assumed that high population densities will be associated with low levels of mobility, and vice versa. The reason being that the density of land use opportunities will increase with increasing population density and, thus, many urban activities of the population could be fulfilled within walking distances. Figure 3.1, however, shows only a slight relationship between mobility and population density with a wide scatter of points. Further tests were carried out by separating regional from urban studies and by separating studies which included truck passenger trips in the data from those which did not include truck passenger trips, but the wide dispersion remained wide in all cases. It can be concluded that although population density has some effect on mobility, it is not a dominant factor in defining or explaining the level of mobility.

An additional possible test is to differentiate between various parts of the urban area, such as the center and the suburbs, and conduct the above analysis for each part separately. Since this portion of the study is to deal with macro analysis, this possibility has been rejected at this stage of the study.

Discussion

Many previous studies have strongly indicated that mobility does decrease with an increase in population density. However, when discussing mobility, one has to be very careful with the various possible definitions of mobility, since different definitions may result in different conclusions. Moreover, when the analysis is conducted by the multiple regression technique, many of the assumed independent variables are usually inherently and closely dependent. Furthermore, in most cases it is very difficult to disengage cause from effect and the analysis portrays a "still" photograph only of a dynamic process. For instance, if mobility is defined by the F rate, the trip rate per tripmaker (see Figure 1.4), it may then be concluded that mobility is indeed lower in the center than elsewhere. If, on the other hand, it is defined by the Z rate, the number of persons making trips, by mode, per 100 population (see Figure 2.7), then mobility is highest in the center.



MOBILITY vs. POPULATION DENSITY

Fig. 3.1

Table 3.1

Study Area	Population	Area	Pop. Density	Total Person Trips	Total Mobility
1	16,303,000	3,660	4,454	26,908,635	165.1
3	1,600,800	860	1,861	2,759,220	172.4
4	1,391,869	2,700	516	3,024,336	217.3*
5	960,568	676	1,421	1,917,818	199.7
6	762,900	490	1,557	1,628,764	213.5*
7	602,018	1,195	504	1,353,660	224.8*
8	574,013	1,250	459	1,823,669	317.7*
9	532,188	830	641	1,152,539	216.6
10	394,286	462	853	977,361	247.9*
11	355,619	540	659	915,949	257.6
12	261,933	86	3,046	568,210	216.9*
13	260,826	396	659	790,879	303.2
14	245,076	152	1,612	615,157	251.0*
15	241,810	461	525	602,843	249.3
16	222,652	278	801	688,290	309.1*
17	222,110	188	1,181	674,169	303.5
18	195,173	182	1,072	545,336	279.4
19	96,530	77	1,254	288,413	298.8
20	80,119	72	1,113	181,229	226.2*

*Including Person Trips by Commerical Vehicles

3.3. MOBILITY VERSUS MOTORIZATION

Purpose

To test the effect of motorization (automobile ownership) on mobility.

Data

The data were derived from the study reports of the 21 urban areas mentioned in Table 1.1. Motorization or automobile ownership is defined as the number of autos stationed in the area per 100 residents. Mobility is the total internal person trips by private and public transport per 100 residents.

Analysis

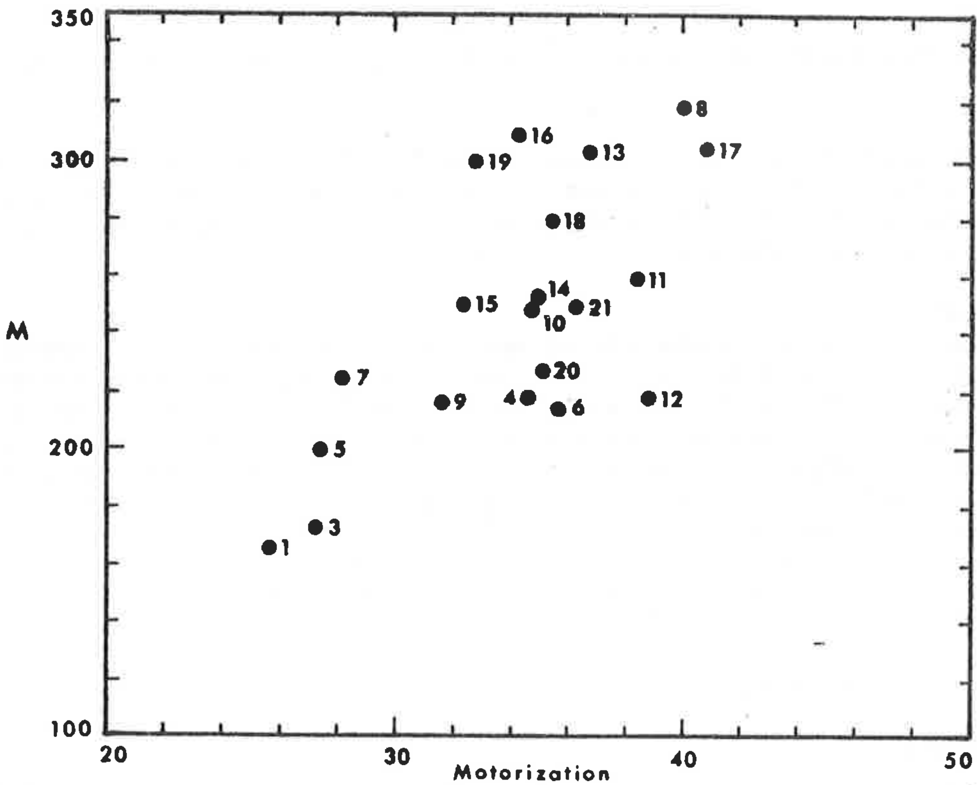
It has always been recognized that mobility is closely related to motorization, namely the higher the motorization, the higher is the mobility. However, Figure 3.2 shows a peculiar result. Although there is a general tendency for mobility to increase with motorization, the dispersion is too wide for a definite conclusion. Motorization is one of the factors that may affect mobility, but it does not seem to be the dominant one. That is, a given level of motorization does not necessarily ensure a certain level of mobility.

Discussion

At this stage, the confusion that may arise from a macro versus a micro analysis should be considered again. Within an urban area, the interdependence between income, residence location, and motorization is usually very strong, when all are found to be related when considered at the same time in the same area. Thus, an increase in the distance of the residence from the center (up to a certain limit) is usually coupled with increasing income, motorization, and mobility of the household. On a micro scale at a certain time it can, therefore, be inferred that it is the level of motorization that strongly affects the mobility.

If motorization usually increases with income, while income increases with distance, what then is the dominant factor that affects mobility--is it income, location of residence, or motorization? This question is usually analyzed by applying the multiple regression or category analyses techniques in the trip generation submodel, where many such factors are considered simultaneously and their individual influences are weighed against each other. These techniques, on the other hand, have been critized in the technical literature because their fundamental assumption--that the independent variables are truly independent of each other--cannot be proven beyond a doubt. Indeed, the socio-economic characteristics, such as income, location of residence, and motorization, are usually found to be closely interlinked and dependent on each other. Thus, it cannot be concluded from this type of analysis what is the cause and what is the effect within the variables.

Moreover, even when each characteristic is analyzed separately, their macro comparison in Figures 3.1 and 3.2 indicates that they cannot represent or explain mobility with a high level of confidence. Therefore, it has been decided to test an additional factor, which has already been found to be sensitive to the transportation system, namely the auto trip rate, R. This test is detailed in the next section.



MOBILITY vs. MOTORIZATION

Fig. 3.2

Table 3.2

Study Area	Population	Autos	Mot. Percent	Mobility
1	16,303,000	4,186,000	25.7	165.1
3	1,600,800	437,540	27.3	172.4
4	1,391,869	484,770	34.8	217.3
5	960,568	264,448	27.5	199.7
6	762,900	273,000	35.8	213.5
7	602,018	169,997	28.2	224.8
8	574,013	230,100	40.1	317.7
9	532,188	168,634	31.7	216.6
10	394,286	136,707	34.7	247.9
11	355,619	137,255	38.6	257.6
12	261,933	102,000	38.9	216.9
13	260,826	95,923	36.8	303.2
14	245,076	86,116	35.1	251.0
15	241,810	78,374	32.4	249.3
16	222,652	76,337	34.3	309.1
17	222,110	90,512	40.8	303.5
18	195,173	69,314	35.5	279.4
19	96,530	31,648	32.8	298.8
20	80,119	28,189	35.2	226.2

3.4. MOBILITY VERSUS AUTO TRIP RATE

Purpose

To test the relationship between mobility, M, and the auto trip rate, R.

Data

The data were derived from the study reports of the 21 urban areas detailed previously. In this case, however, 6 additional areas, which had some partial information, have been included in the analysis (see Chapter 4). The data are detailed in Table 3.3.

Analysis

The analysis in this section is of particular interest since it tests mobility versus a factor which was found to be sensitive to the transportation system. Figure 3.3 presents the total mobility versus the daily auto trip rate. An indication of the general trend of the relationship has already been shown in Figure 2.5, but in this case an additional phenomenon comes into light--there seems to be a saturation level for mobility, at about 310 trips per 100 residents. Therefore, the representative average curve has been derived for the range of data up to the saturation level, while excluding the data for the study areas a, 16 and 19. The best-fit equation was found to be in the form of:

$$M = \frac{110}{1 - 0.121\,R} \qquad \text{(Equation 3.1)}$$

Discussion

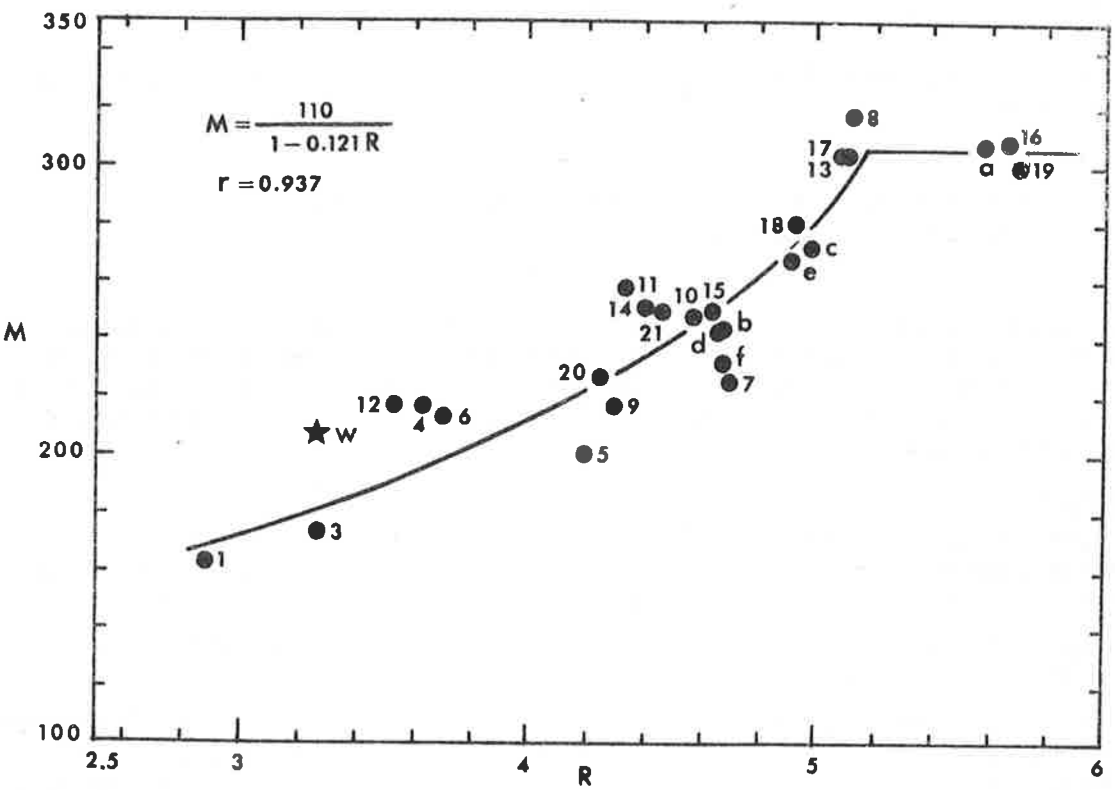
The relationship in Figure 3.3 is of particular interest in spite of the argument that M is inherently dependent on R; it is the nonlinear shape of the relationship which is of importance for the understanding and formulation of mobility.

Moreover, it is the first time where a direct link could be established between the total mobility and its responsiveness to the transportation system rather than to socio-economic characteristics of the population. Since the auto trip rate has been found to be sensitive to the trip time (Figure 1.1), and now the total mobility can be shown to be sensitive to the auto trip rate, it can be inferred that mobility should also be sensitive to the trip time.

As will be seen later on, this simple interdependence between mobility and trip time is a fundamental behavioral phenomenon when considered within the constraint of the daily TT budget.

At this stage, another question has to be clarified--namely, whether the auto trip rate is indeed sensitive to the transportation system, or is it dependent on some other factor? While reviewing many factors that may affect R, it became evident that the most probable one is the level of motorization. That is, when the level of motorization increases, with a corresponding increase in the proportion of multi-auto households, the average daily trip rate per auto should be expected to decrease.

This concept is usually considered to be true not only because it is logical but also because the average auto occupancy rates seem to decrease with increasing motorization; namely, the availability of autos to more people should decrease the trip rate per auto. This assumption is tested in the next section.



MOBILITY vs. AUTO TRIP RATE

Fig. 3.3

Table 3.3

Study Area	Internal Auto Driver Trips	Autos	Trip Rate	Mobility
1	12,108,350	4,186,000	2.89	165.1
3	1,425,470	437,540	3.26	172.4
4	1,759,078	484,770	3.63	217.3
5	1,107,579	264,448	4.19	199.7
6	1,010,664	273,000	3.70	213.5
7	798,726	169,997	4.70	224.8
8	1,178,533	230,100	5.12	317.7
9	725,299	168,634	4.30	216.6
10	624,345	136,707	4.57	247.9
11	594,227	137,255	4.33	257.6
12	360,370	102,000	3.53	216.9
13	489,047	95,923	5.10	303.2
14	379,600	86,116	4.41	251.0
15	362,887	78,374	4.63	249.3
16	432,084	76,337	5.66	309.1
17	461,803	90,512	5.10	303.5
18	341,154	69,314	4.92	279.4
19	183,196	31,648	5.79	298.8
20	119,868	28,189	4.25	226.2
21	118,992	26,680	4.46	249.0
a	365,948	65,478	5.59	306.9
b	437,464	93,859	4.66	242.6
c	657,707	132,198	4.98	272.1
d	795,724	171,636	4.64	243.0
e	972,076	197,837	4.91	268.1
f	1,626,338	349,364	4.66	230.8

a Binghamton
b Utica
c Syracuse
d Albany
e Rochester
f Buffalo

3.5. AUTO TRIP RATE VERSUS MOTORIZATION

Purpose

To test the assumption that the auto trip rate is affected by the level of motorization.

Data

The data were derived from the same study reports of the 21 urban areas that were detailed previously.

Analysis

Table 3.4 and Figure 3.4 present the data and relationship between the auto trip rate, R, and motorization, MOT. (The trip rate is presented along the x axis in order to keep the place and scale of R consistent with the previous diagram.) As can be seen in Figure 3.4, no relationship is evident between R and motorization.

Discussion

The above result is quite surprising since it seems to contradict a well known phenomenon in developing countries, where an increase in motorization results in a significant drop in the auto trip rate.

Following are quotations from three studies in this country, which will illustrate the complexity of the problem:

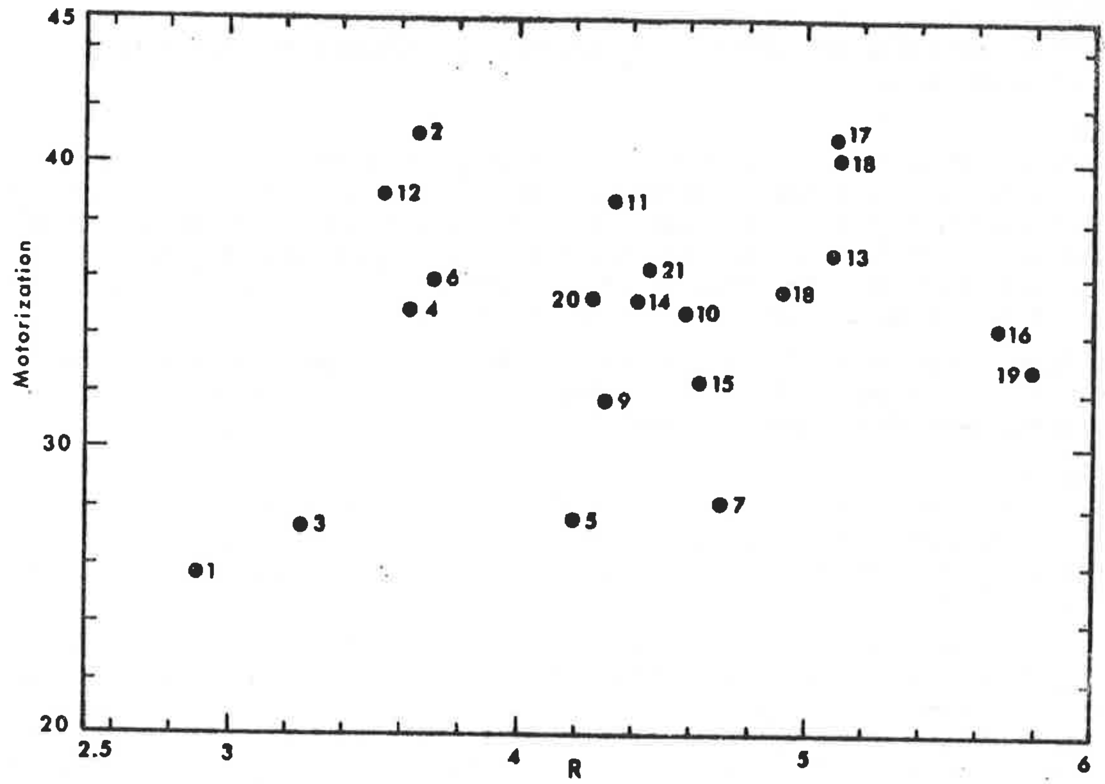
(a) Figure 36 in the publication "Future Highways and Urban Growth"[1] presents the driver trip rates for the first, second, and third auto in multi-car households in Chicago, 1956, versus their location distance from the center. Indeed, the trip rate decreases successively for the second and third autos at each distance, and the quotation is "The use of successive cars in multi-car families is generally less than the use made of the car owned by a one-car family." However, when the trip rates in the above mentioned figure are compared by distance, it immediately becomes evident that the trip rate of even a third car in a multi-car family far from the center is much higher than that of the first car when the multi-car family is near the center. Thus, the increasing effect of distance from the center on the trip rate is stronger than the decreasing effect of adding a second and a third car to a family.

(b) The addition of one auto to a single-auto-owning household in the Tri-State area produced an increase in the auto trip rate of about 9 percent.[2]

(c) A recent nationwide study reported that "Cars operated from single-car households have lower average annual miles than cars operated from multi-car households."[3]

These three examples are sufficient to show how confusing the results of studies can be when they lack a common denominator within a unified formulation of travel. For instance, how should the average usage of an auto be defined: by the daily trip rate, by the daily mileage, or by the daily traveltime? Furthermore, how will location affect the travel behavior of single versus multi-car households? How can the trip rate be related to the mileage of travel for each successive car?

Before embarking on the task of developing a unified formulation, one last test will be conducted in the next section, where mobility will again be related to the auto trip rate, but this time on a micro scale.



AUTO TRIP RATE vs. MOTORIZATION

Fig. 3.4

Table 3.4

Study Area	Population	Autos	Mot. Percent	Internal Auto Trips	Trip Rate
1	16,303,000	4,186,000	25.7	12,108,350	2.89
2	7,595,834	3,123,319	41.1	11,439,455	3.66
3	1,600,800	437,540	27.3	1,425,470	3.26
4	1,391,869	484,770	34.8	1,759,078	3.63
5	960,568	264,448	27.5	1,107,579	4.19
6	762,900	273,000	35.8	1,010,664	3.70
7	602,018	169,997	28.2	798,726	4.70
8	574,013	230,100	40.1	1,178,533	5.12
9	532,188	168,634	31.7	725,299	4.30
10	394,286	136,707	34.7	624,345	4.57
11	355,619	137,255	38.6	594,227	4.33
12	261,933	102,000	38.9	360,370	3.53
13	260,826	95,923	36.8	489,047	5.10
14	245,076	86,116	35.1	379,600	4.41
15	241,810	78,374	32.4	362,887	4.63
16	222,652	76,337	34.3	432,084	5.66
17	222,110	90,512	40.8	461,803	5.10
18	195,173	69,314	35.5	341,154	4.92
19	96,530	31,648	32.8	183,196	5.79
20	80,119	28,189	35.2	119,868	4.25
21	73,459	26,680	36.3	118,992	4.46

1/ "Future Highways and Urban Growth," Wilbur Smith and Associates, 1961.

2/ Internal Technical Report "Automobile Usage in the Tri-State Region," Tri-State Transportation Commission, 1970, page 10.

3/ "Nationwide Personal Transportation Study," U.S. Department of Transportation, Report No. 2, "Annual Miles of Automobile Travel," 1972, page 23.

3.6. MOBILITY BY LOCATION VERSUS AUTODRIVER TRIP RATE - MICRO

Purpose

To relate mobility by location of residence of tripmakers versus their driver trip rate.

Data

The data were derived from the basic tabulations prepared for the Washington, D.C., area, as described previously. The definition of mobility is the same as before, while that of the trip rate, F, is limited to the daily person trips per tripmaker who made all his trips as an auto driver only. Thus, R and F are quite similar, since R is the auto trip rate related to the auto while F is the auto trip rate related to the driver.

The data, detailed in Table 3.5, are summarized by rings, namely by the location of residence of the tripmaker, and Figure 3.5 presents the data in a graphical form for rings 1 through 7.

Analysis

It should be noted that the range of F in Figure 3.5 is quite narrow, 3.12 to 3.43. Thus, the dispersion of the points is not unexpected. In spite of the dispersion, the trend is quite clear--the mobility increases with an increase in the trip rate, F.

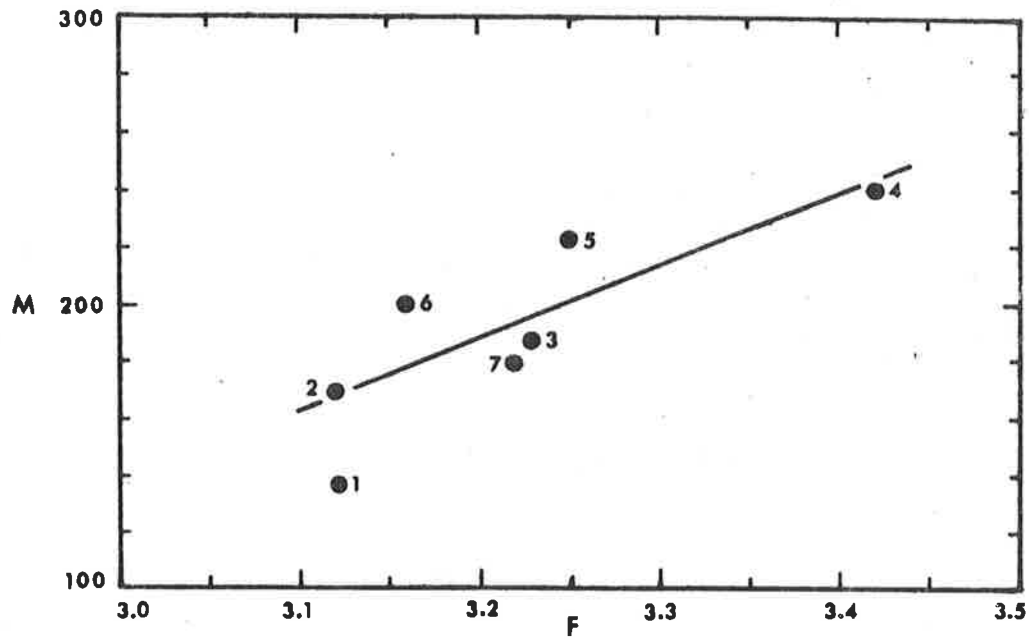
Of particular interest is the sequence of rings in the figure, where both F and M increase up to ring 4, after which there is a reversal of direction for both. Namely, M follows F in a characteristic way. As can be seen in Appendix B-1, ring 5 typifies the edge of the urban area, while rings 6 and 7 show a gradual shift into rural characteristics. In Figure 3.5, mobility increases with F until ring 4; in Figure 1.4, the trip rate, F, increases with distance until ring 4; while all other travel characteristics in Figure 1.4 increase continuously. It may be concluded that the total mobility is closely related to the trip rate, F, which is basically similar to the trip rate, R.

It may be concluded from the above comparison that the best indicator for mobility, whether on macro or micro scales, seems to be either the auto trip rate, R, or the autodriver trip rate, F. Moreover, the autodriver trip rate, F, seems to increase with distance from the center within the urban area.

Discussion

The analysis in this chapter up to now would seem to be fragmented, confused, jumping from subject to subject, and without a central concept. This typifies, in a way, the present situation in the basic analysis--and understanding--of mobility, where many components of mobility are evaluated separately, in an unrelated way. Even when a few of the components are integrated within one formulation, such as in the trip generation submodel, they are only a small part of the complex subject and usually in the form of open-ended relationships. Using constraining factors in an open-ended relationship is of particular importance since it would then be possible to achieve the desired sensitivity and responsiveness of travel demand to system supply.

An experiment to develop a formulation of travel which is sensitive to the transportation system will be presented in the following sections.



MOBILITY BY LOCATION vs. AUTO TRIP RATE PER DRIVER
Washington Area

Fig. 3.5
Table 3.5

Ring	Population	Total Person Trips	Mobility	F Trip Rate
0	15,795	30,547	193.4	2.66
1	86,118	118,512	137.6	3.13
2	326,616	554,135	169.7	3.12
3	499,052	928,719	186.1	3.23
4	757,629	1,824,208	240.8	3.42
5	458,067	1,026,594	224.1	3.25
6	292,303	585,144	200.2	3.16
7	122,511	220,919	180.3	3.22
Total	2,558,092	5,288,778	206.7	3.28

3.7. TRIP DISTANCE VERSUS POPULATION

Purpose

To test the relationship between the average trip distance, d, and population, P.

Data

The data were derived from 10 of the 21 urban area study reports that contained the necessary information. The trip distance, d, is the average vehicle trip distance, for both autos and commercial vehicles, as well as for internal and external trips within the study area.

Table 3.6 details the available data. In the case of Washington, D.C., d is for tripmakers who made all their internal trips as auto drivers. However, the difference between the average vehicle and the average auto trip distance is usually found to be marginal.

Analysis

Figure 3.6 repeats a well known relationship, between d and population, on log-log scales. The best-fit equation is in the form of:

$$d = 0.245\ P^{0.220} \qquad \text{(Equation 3.2)}$$

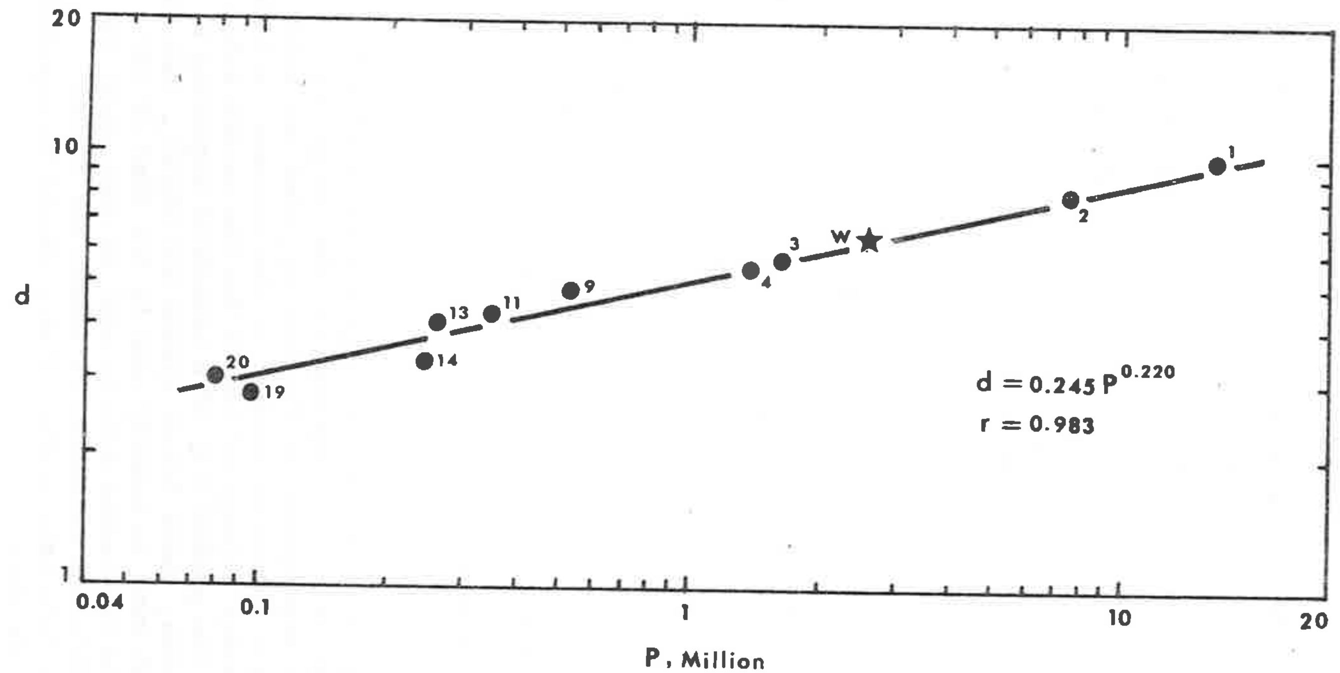
This relationship, and its variations by population density, area size, and their combinations, is a well established one, and it is recognized that d is usually a function of the size of the study area and the spatial distribution of land uses within it.

Discussion

Traffic models are normally based on a cross-sectional approach, where an instantaneous situation in the life of a city is analyzed. Therefore, at the trip distribution and traffic assignment phases, it has been established that traveltime is dominant over travel distance, since a tripmaker will try to minimize his traveltimes (and costs, in time units), whether by selecting part of his destinations, or routes to them, or a combination of both. In a long range or time series approach, other factors should be considered as well. When a resident has to choose his location of residence, he will certainly consider the traveltime between home and work, and other similar stable destinations, among the factors in the decision process. Once he has decided, however, a major part of his daily trips will become stable in the spatial sense and distance-wise, although he may change his daily routes between the stable origins and destinations in order to save traveltime.

It can be asserted that, while the trip time may be dominant in explaining an instantaneous condition, the trip distance is dominant in explaining a long range stable condition. For instance, if the saving in traveltime, by an increase in speed, would have been just for the sake of saving, or for the sake of making longer trips, then the trip rate, R, in Figure 1.1, would have remained constant for all trip times. However, this is not the case. It would seem, therefore, that within a relatively stable average trip distance, which can be related to population size, a tripmaker will try to decrease his trip time in order to increase his trip rate within his traveltime budget.

In conclusion, the average trip distance was considered to be the dominant factor in the formulation of travel, as detailed in the next section.



AVERAGE TRIP DISTANCE vs. POPULATION SIZE

Fig. 3.6

Table 3.6

Study Area	1	2	3	4	9	11	13	14	19	20	W
Population	16,303,000	7,595,834	1,607,980	1,391,869	532,188	355,619	260,826	245,076	96,608	80,119	2,558,092
VMT	119,940,000	102,082,084	-	12,791,908	4,599,000	3,230,000	2,504,054	1,882,100	714,741	596,230	18,231,480
Vehicle Trips	12,097,540	12,476,957	-	2,311,177	933,824	752,033	605,719	563,206	256,993	194,337	2,768,723
d	9.9	8.2	5.8	5.5	4.9	4.3	4.1	3.3	2.8	3.1	6.58

3.8. AUTO TRIP RATE VERSUS POPULATION SIZE AND SPEED

Purpose

To define the responsiveness of the auto trip rate to changes in population size and speed on the road network.

Data

Based on the data for the urban areas mentioned earlier.

Analysis

It was already shown that: $R = 17.065\ t^{-0.583}$ (Equation 1.1)

And that: $d = 0.245\ P^{0.220}$ (Equation 3.2)

Since $t = (d/v)60$ substituting for d using Equation 3.2 results in: $t = \frac{14.70\ P^{0.220}}{v}$ (Equation 3.3)

Then, substituting Equation 3.3 for t in Equation 1.1: $R = 3.565\ v^{0.583} P^{-0.128}$ (Equation 3.4)

It may be concluded that the auto trip rate is directly responsive to the speed of travel and reciprocally responsive to the population size in the study area. Moreover, as indicated by the exponents of Equation 3.4, the auto trip rate, R, is more sensitive to changes in speed than in population size. Figure 3.7 presents the responsiveness of R to different values of v and P.

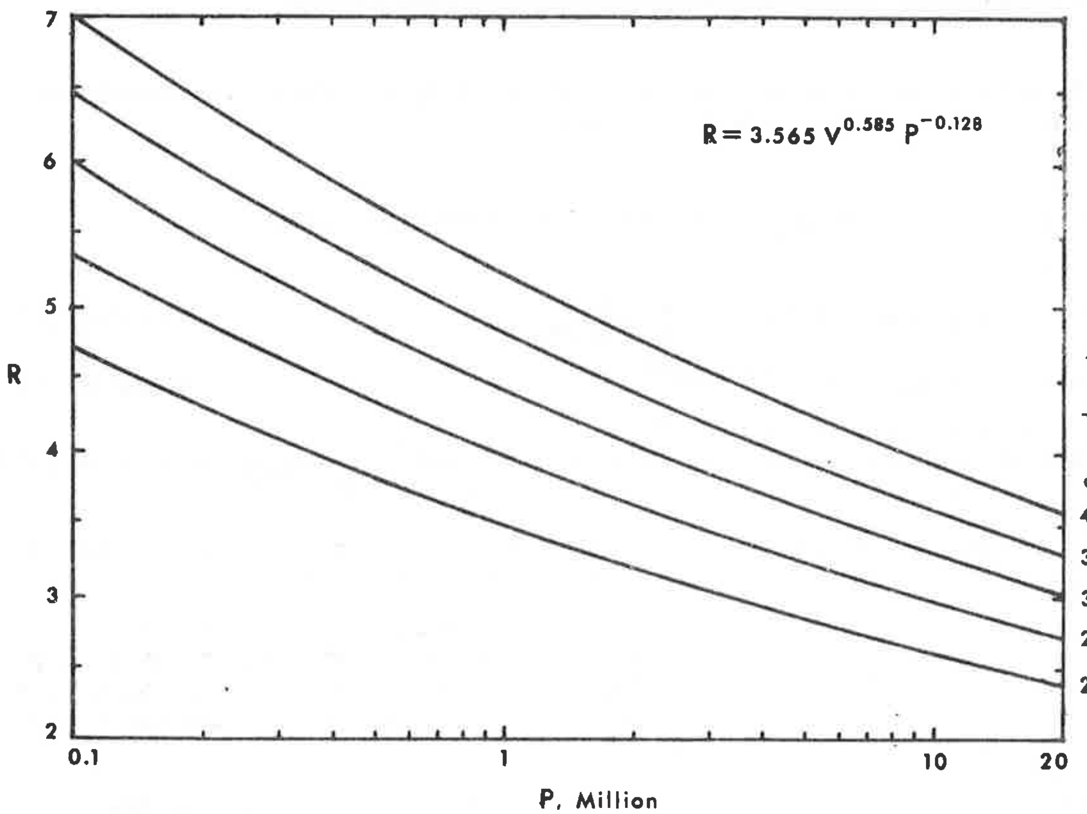
The formulation of R versus v and P was tested for the few studies which had detailed the necessary information, including Washington, D.C. The variability is quite noticeable in Table 3.7, where differences between estimated and given values of R reach and surpass 20 percent. Nevertheless, even such differences are surprisingly low when one considers the variability in the definitions, techniques, and presentation of results in the original reports, or the coarse formulation of R. It is believed that further refinements in the formulation, such as the inclusion of population density, level of motorization, and ground area, may produce better results.

Discussion

One important conclusion from Figure 3.7 is that an increase in speed will increase the auto trip rate. This conclusion may explain the unexpected results of previous studies which were quoted in Section 3.5, that the addition of a second auto to a one-auto household results in the increase in both the average trip rate and the average mileage of travel for the second auto. The reasons for this being: (a) the probability of a household acquiring a second auto is higher in the suburbs, where travel speeds are higher, than in the city center; and (b) the first auto is usually used by the head of the household to travel to work, while the second auto is used in most cases to travel in the suburbs. Thus, within the allocated TT budget and higher speeds, an increase in either the trip rate and/or mileage should be expected for the second auto over that of the first.

This result also explains the process of induced travel, where an increase in speed within the TT budget will generate more trips.

Total mobility has been shown to be related to the auto trip rate. Its responsiveness to the travel speed and population size will be analyzed in the next section.



AUTO TRIP RATE BY SPEED vs. POPULATION

Fig. 3.7

ESTIMATION OF THE AUTO TRIP RATE

Table 3.7

Study Area	Population	Speed m.p.h.	R Estimated	R Given	Diff. ± %
1	16,303,000	26.0	2.84	2.89	- 1.7
2	7,595,834	32.8	3.59	3.66	- 1.9
3	1,607,980	28.0	3.99	3.26	+ 22.4
9	532,188	30.1	4.79	4.30	+ 11.4
11	355,619	30.2	5.06	4.33	+ 16.9
13	260,826	24.6	4.67	5.10	- 8.4
14	245,076	26.0	4.86	4.41	+ 10.2
19	96,530	21.8	4.95	5.79	- 14.5
W	2,558,092	25.4	3.56	3.28*	+ 8.5

*For tripmakers who made all their daily trips as drivers only.

3.9. FORMULATION OF A SYSTEM SENSITIVE MODEL OF MOBILITY

Purpose

To formulate a system sensitive model of mobility and test its responsiveness to changes in the transportation system.

Data

Based on the data for the urban areas mentioned previously.

Analysis

It was already shown that: $$M = \frac{110}{1 - 0.121\ R} \quad \text{(Equation 3.1)}$$

And that: $$R = 3.565\ v^{0.583} P^{-0.128} \quad \text{(Equation 3.4)}$$

Thus, substituting Equation 3.4 for R in Equation 3.1 will result in: $$M = \frac{110}{1 - 0.431\ v^{0.583} P^{-0.128}} \quad \text{(Equation 3.5)}$$

The formulation of M versus v and P was tested for the few studies which had detailed the necessary information, as presented in Table 3.8.

As in the previous test of R, there is a noticeable variability where differences between estimated and given values of M reach and surpass 20 percent. It is believed that the inclusion of several additional parameters in the ultimate formulation of mobility will significantly increase the accuracy level of the estimation procedure.

One possible way to increase the accuracy level is by introducing the specific TT budget into the formulation, according to the following steps:

(a) If the trip time t in Equation 3.3 is defined in hours, then:

$$t_{hr} = \frac{d}{v} = \frac{0.245\ P^{0.220}}{v} \quad \text{(Equation 3.6)}$$

(b) The TT budget should be equal to:

$$h = R \times t_{hr} \text{ or } R = \frac{h}{t_{hr}} \quad \text{(Equation 3.7)}$$

(c) Substituting Equation 3.6 in Equation 3.7 will result in:

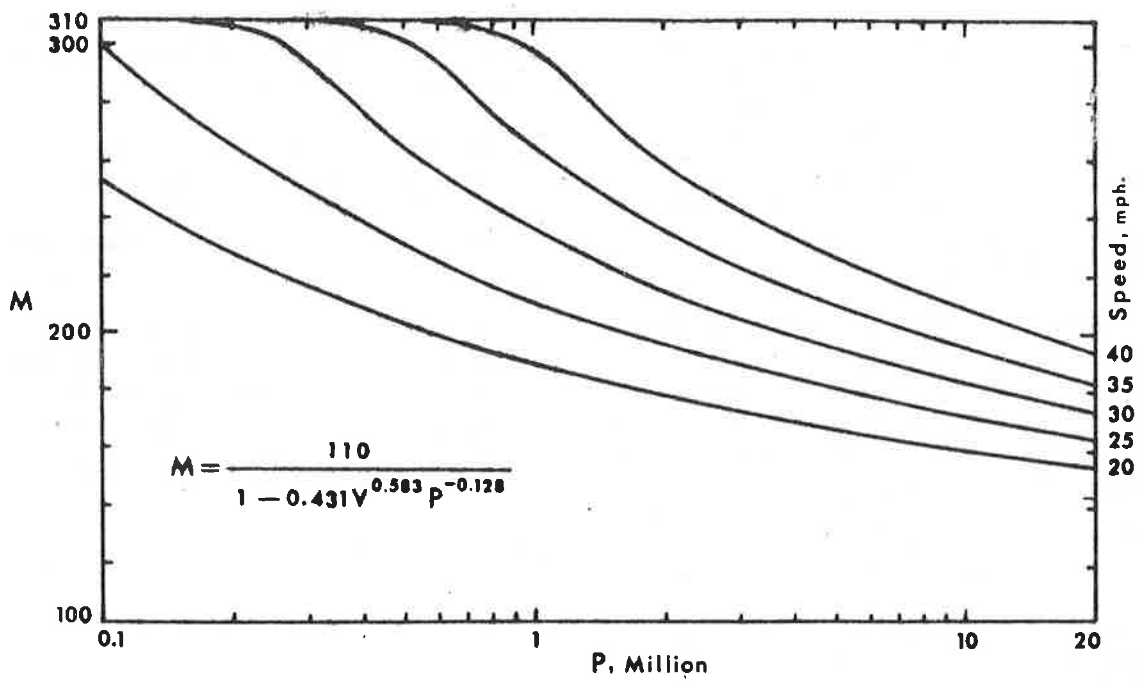
$$R = \frac{h}{t_{hr}} = 4.08\ h\ v\ P^{-0.220} \quad \text{(Equation 3.8)}$$

(d) Therefore, substituting Equation 3.8 for R in Equation 3.1 results in:

$$M = \frac{110}{1 - 0.494\ h\ v\ P^{-0.220}} \quad \text{(Equation 3.9)}$$

Thus, mobility will also be sensitive to the specific TT budget of autodrivers in the given urban area.

This is just one example of the many additional factors that can be introduced into the formulation of mobility by a stepwise empirical analysis, where each additional factor would be tested for its influence on increasing the accuracy of the formulation.



MOBILITY BY SPEED vs. POPULATION

Fig. 3.8

ESTIMATION OF MOBILITY

Table 3.8

Study Area	Population	Speed m.p.h.	M Estimated	M Given	Diff. ± %
1	16,303,000	26.0	167.6	165.1	+ 1.5
3	1,607,980	28.0	212.7	172.4	+ 23.4
9	532,188	30.1	262.0	216.6	+ 21.0
11	355,619	30.2	283.5	257.6	+ 10.1
13	260,826	24.6	252.9	303.2	- 16.6
14	245,076	26.0	267.2	251.0	+ 6.5
19	96,530	21.8	273.7	298.8	- 8.4
W	2,558,092	25.4	192.9	206.7	- 6.7

Discussion

The formulation of mobility, even in its coarse form as given in Equation 3.5 or Figure 3.8, can be very useful for a better understanding of mobility and its responsiveness to the transportation system.

It can be concluded that mobility is very sensitive to the road network speed in urban areas below 1 million population, but the sensitivity decreases rapidly above 1-2 million population. Moreover, it becomes evident that there is a practical limit for road improvements in smaller urban areas when mobility reaches saturation.

Of even more interest is the situation in urban areas of over 1-2 million population, since it can be inferred from Figure 3.8 that the importance and effect of the road network speed decreases rapidly and, therefore, the ability of rapid transport to compete with private transport may increase appreciably. However, within the constraint of the TT budget, the importance of a rapid transit system becomes evident since it is the speed that will decide the level of mobility. Namely, as long as the speed of public transport will be much lower than that of private transport, any diversion of trips from auto to transit may suffer a substantial loss of mobility.

Figure 3.8 presents the complex interaction between travel demand and one measure of the transportation system performance, speed. It is recognized that many additional performance measures might well be considered and tested before a full understanding of mobility is achieved. Nontheless, Figure 3.8 is quite illuminating even in its rudimentary form, when it explains several seemingly unrelated travel phenomena under a simple and consistent framework. For example, from past experience rapid transit systems are usually considered only for urban areas with over 1-2 million population. It now becomes evident that it is not just the minimum potential number of passengers that affects such a consideration, but also the relatively sudden reduction in the effect of the road network speed on mobility at that population size. Namely, from that size of urban areas upwards, the relative impact of road improvements on mobility becomes less obvious and the natural substitute for private transport, in the wish to meet the minimum required level of mobility, then seems to be the rapid transit system.

A further development of the travel formulation, including mode combinations of tripmakers and their specific TT budgets, as well as their spatial distribution in the urban area, would then enable a better evaluation of the interaction between corridors of rapid transit and the more dispersed distribution of auto travel. Moreover, a balanced and coordinated planning effort between private and public transport would then compare not the savings in traveltime as is done today but rather the levels of mobility and their value to and impacts on the area. This subject will be further discussed in the next section.

3.10. IN CONCLUSION

Responsiveness of Mobility to System Supply

It has been shown in Chapter 3 how mobility can be defined in terms of speed and population size in an urban area, and why it is responsive to the transportation system.

While reviewing Chapter 3, it becomes evident that each of the subjects discussed is rather well known. It is the integration of the various components under one empirical formulation that unifies and explains the various travel phenomena within a simple travel process. Moreover, since Equation 3.5 and Figure 3.8 define the sensitivity of mobility to speed, they also corroborate once again the constraining effect of the traveltime budget.

The next possible phase in the development of a unified formulation of travel, in the future, would be the integration of the various tripmakers--by their mode combinations and specific TT budgets--within the formulation, for a better understanding and prediction of the total mobility and the behavioral process of modal choice.

The following macro and micro example may best illustrate the wide possibilities of such a unified formulation. Table 3.9 summarizes the relevant data for the Washington, D.C., and the nationwide studies for the auto and transit passengers.

Table 3.9: Travel Characteristics of Auto and Transit Passengers in Washington, D.C., and Nationwide Averages

Mode	Nationwide				Washington			
	h	R	d	v	h	R	d	v
Auto Passenger	0.89	2.63	10.99	32.40	0.59	2.58	5.97	26.2
Transit Passenger	0.99	2.03	7.44	15.28	0.79	2.06	4.41	11.4

Although the TT budget, h, of transit passengers is greater than for auto passengers while their trip distance is shorter, their trip rate is significantly lower than for auto passengers. The reason for this becomes immediately evident when the speeds of travel are compared--the speed of transit is only about one-half of the auto speed. Thus, the mobility level of transit passengers is forced down to the minimum trip rate of 2.03-2.06, namely, to about one trip from home and one trip back home for the average transit tripmaker before his TT budget is exhausted.

Thus, a diversion of auto passengers to transit will result in a loss of mobility even if the same number of tripmakers will transfer--as long as the auto is significantly faster than transit. The loss may even be greater if the number of tripmakers decreases during the process of diversion. This, then, emphasizes the importance of the relative speed of transit versus private transport, within the constraints of a daily TT budget, whether on a microscale or a nationwide scale.

The above example illustrates the responsiveness of mobility to an important measure of the transportation system, as well as the importance of considering the tripmakers by their mode combination and not their resultant trips in the process of modal choice.

In a way, the problem of the tripmaker is a peculiar one. Many transportation studies discuss the average auto trip rate in terms of the daily average number of trips per auto unit. However, when person trips are discussed, no attention is given to the person unit of tripmakers. Although the level of mobility or modal choice is a personal decision process, the standard procedures usually deal with either the household unit or the total pool of person trips.

It is strongly recommended, therefore, to consider the tripmaker and his mode combination rather than trips as the basic unit for analysis of mobility, mode choice, and trip purpose split.

The Value of Mobility

At this stage, one may wonder what is the importance and value of mobility and why should a reduction in mobility be of such a concern.

Mobility may be both the cause for and the effect of economic development. The main function of mobility in developing countries is to enhance economic development; while in developed countries, the main function of mobility is to keep economic activities rolling. Therefore, a reduction in mobility in developed countries may affect the level of economic activity, whether in an urban area or the whole country. The problem, then, is how to measure the monetary value of mobility. This problem is very complex and is beyond the scope of this study. However, one indication of the minimum subjective value of mobility might be obtained by utilizing the monetary values that already have been established for saved traveltime. By this procedure, the perceived monetary values that tripmakers have been found to trade off for "saved" traveltime could be applied to the differences in mobility that would result from those "saving time." Needless to say, the objective values to the economy of the area would probably be much higher than the subjective values that are perceived by the tripmakers.

It would seem to be quite essential and urgent to establish the values of mobility, both direct and indirect, especially at the present time, when the shortage of fuel threatens mobility with possible repercussions spreading to the whole spectrum of economic activities.

Measuring the Performance Level of a Transportation System

The full attention of this report, until now, has been concentrated on the subject of mobility and its responsiveness to the transportation system. At this stage, the interest will be shifted to the transportation system itself and special attention will be given to the problem of how to define its performance by quantified measures, so that alternative systems may be compared on the basis of objective criteria.

The next chapter will deal with the road network within the transportation system, since it has already been shown that mobility can be expressed by the road network levels of supply and performance.

CHAPTER 4: TRAFFIC PERFORMANCE OF A ROAD NETWORK

4.1. INTRODUCTION

Traffic performance of a road network is recognized as a complex subject. One may realize its complexity by leafing through the booklet "Measures of the Quality of Traffic Service,"1/ where about 30 different methods of measurements are discussed without coming to a conclusion which one may be the most indicative. The reason being that "no single measure of the quality of traffic service can describe the performance of a highway system adequately for all operating and engineering goals" (Ibid).

The study of traffic performance can be divided into micro and macro analyses, where in this case micro deals with a road section or intersection, while macro deals with a road network. This chapter deals with the road network in 6 urban and regional areas.

The analysis is based on a performance index termed the alpha relationship. The alpha relationship describes the interaction between the traffic intensity, road density, and speed, as detailed in the next section. This relationship, which was developed by empirical analysis, was found to be very similar to the energy concept of traffic performance, namely by explaining the interaction of traffic with the road network in terms of the kinetic energy of the moving vehicles.

The alpha relationship was found to be very useful, since it is a practical tool for a variety of purposes, such as defining the borders of an urban area or its central core in terms of traffic characteristics; defining in quantified indices the traffic performance of road sections or the complete road network, as a common denominator for comparison purposes; establishing an equivalence scale of values for the various road categories; raising the accuracy of a capacity restraint assignment; developing a simplified procedure for rapid estimation of the amount and spatial distribution of vehicular travel in an urban area; and for developing a procedure for the evaluation of alternative road networks.

Within the framework of this study, however, the first and foremost objective was to test and verify the alpha relationship for U.S. traffic conditions. In Section 4.5, a unified concept of mobility will be presented, where both the mobility and the road network will be integrated within a first-approximation formulation.

1/ "Measures of the Quality of Traffic Service," Special Report 130, Highway Research Board, U.S.A., 1972.

4.2. THE ALPHA RELATIONSHIP

The alpha relationship was originally developed from an empirical comparative analysis of traffic conditions in 9 United Kingdom towns.1/2/

It was shown that Traffic Intensity, I (daily vehicle-miles of travel per unit land area, A), could be related to Road Density, D (unit length of road network, L, per unit land area, A), and the space mean speed, v, through the relationship:

$$I = \alpha (D/v)^b \quad \text{(Equation 4.1)}$$

Where b is an exponent and α is a constant in units of daily or hourly vehicle-miles per hour.

It could also be shown that since b is approximately unity in many cases, the relationship may be approximated by:

$$I = \alpha \ (D/v) \quad \text{(Equation 4.2)}$$

Thus, α can be expressed as:

$$\alpha = (I \ v)/D \quad \text{(Equation 4.3)}$$

This relationship was verified using both traffic districts and traffic zones based on peak and off-peak hours as well as total daily traffic.

Dividing I by D in Equation 4.3 results in:

$$\alpha = q \ v \quad \text{(Equation 4.4)}$$

where q is the average traffic flow in units of vehicles per unit length of road network, in miles.

The flow of traffic equals the Concentration of Traffic, C, multiplied by its space mean speed, v, so that:

$$q = C \ v \quad \text{(Equation 4.5)}$$

Thus, it follows that Equation 4.4 may be written in the form of:

$$\alpha = q \ v = Cv^2 \quad \text{(Equation 4.6)}$$

By considering the concentration C as representative of the mass of the vehicles, it can be concluded that α may represent the kinetic energy of the moving traffic, similar in form to $\frac{1}{2}mv^2$, where m is the physical mass. The α value would represent, therefore, the interaction of flow and speed combined, by indicating the ability of a specific section or a complete road network to hold and pass through it a certain amount of traffic kinetic energy.

The concept of kinetic energy of traffic flow as a measure for a quantified level-of-service on a micro scale was already introduced in 1965.3/ The alpha relationship, however, is a macro measure that defines the end result of the interaction between the ever-changing micro conditions of flows and their speeds during an extended period of time in a wide area. Therefore, it can be used as an areawide measure of the dynamic capacity or level-of-service of a road network. Moreover, the exponent b changes somewhat the standard concept and form of kinetic energy as developed originally in 1965 upon theoretical considerations.

1/ "A Method for Rapid Estimation of Urban Transport Needs," Y. Zahavi, University College London, 1972-73, under a grant by the Science Research Council, United Kingdom.

2/ "Traffic Performance Evaluation of Road Networks by the Alpha Relationship," Traffic Engineering and Control, United Kingdom, September-October 1972.

3/ "Freeway Level-of-Service as Influenced by Volume and Capacity Characteristics," D. R. Drew and C. J. Keese, Highway Research Record No. 99, Highway Research Board, U.S., 1965.

4.3. VERIFYING THE ALPHA RELATIONSHIP

Purpose

To test and verify the alpha relationship under U.S. traffic conditions.

Data

The necessary micro data were received for six urban and regional areas in New York State, as detailed in Tables and Figures 4.1 to 4.6. The six areas represent a wide range of daily conditions and sizes, from a population of about 370,000 to over 1.6 million.

Analysis

The analysis was conducted by a specially developed computer program, and the tables and figures present the detailed relationships where each dot represents a traffic district. For practical reasons of presentation, the relationships are shown graphically on double logarithmic scales, in the form of:

$$I = \alpha \left(\frac{v}{D}\right)^{-b} \qquad \text{(Equation 4.7)}$$

so that data spread over several fields of magnitude could be shown with equal clarity. It should be noted that the dispersion of values in the figures is distorted because of the scales and does not signify the absolute scatter.

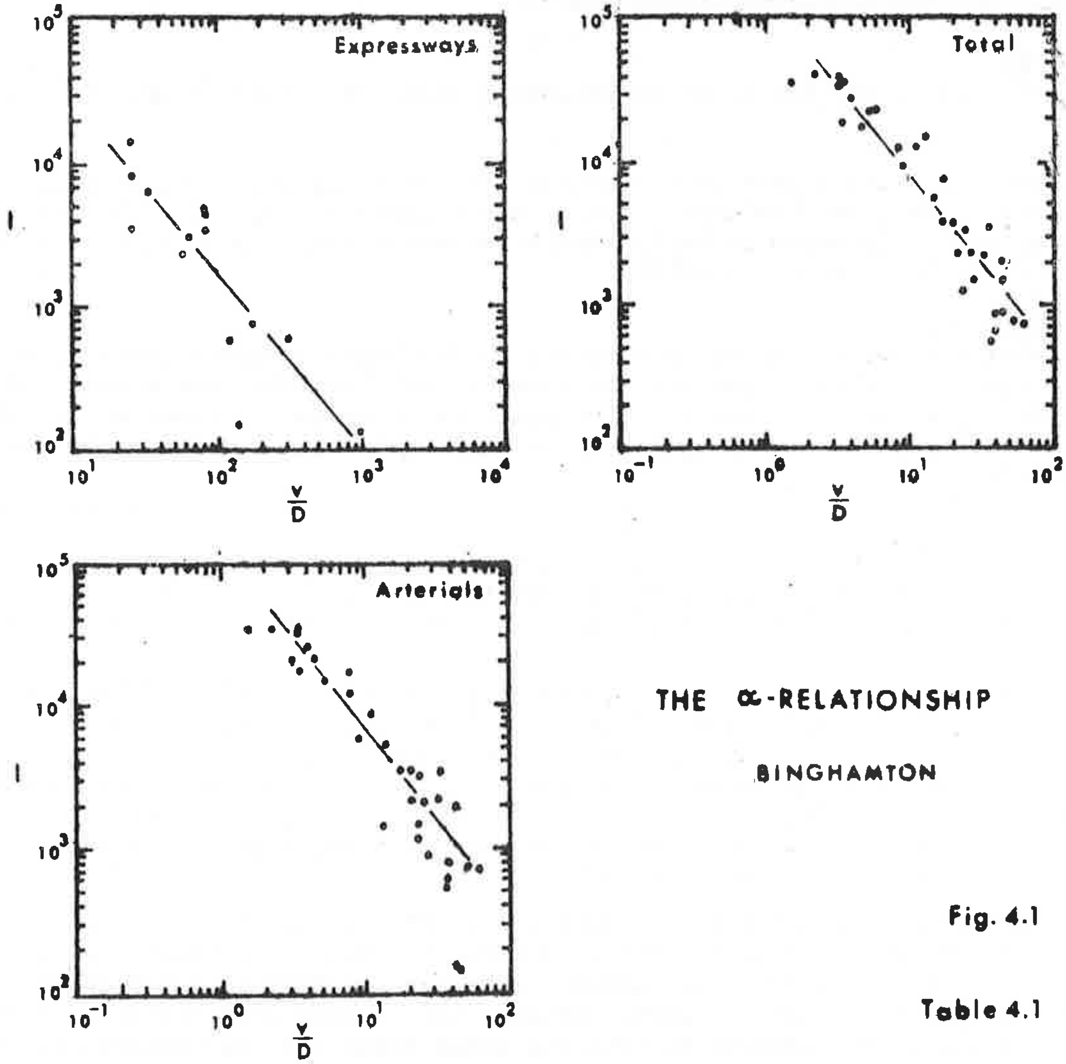
The results in Figures 4.1 to 4.6 indicate the validity of the alpha relationship under U.S. traffic conditions; in most cases, a clear linear relationship (on double logarithmic scales) emerges for both the arterial and the expressway networks as discussed in the next section. When comparing the above formulation with Figures 4.1 to 4.6, it becomes evident that the exponent b represents the slope of the average line, while alpha represents the intercept on the I axis for $v/D = 1$.

Of particular interest are the different slopes in Figure 4.1 to 4.6 of the two road categories, which represent the exponent b in the formulation. It can be inferred that the steeper the slope (or higher the exponent) the better is the quality of the road network. Namely, the traffic performance of a road network should be assessed by both its alpha value and the exponent b. As yet, however, it is not clear what components of the road network or the traffic characteristics (such as its composition by vehicle type) affect separately or together the alpha relationship and the exponent b.

Discussion

An additional test has shown that the total alpha value for an urban area may change with varying definitions of its land area. By expanding the boundary of an urban area, additional interurban roads of high capacity such as expressways will be included, thus raising the alpha value artificially. In order to prevent such a possibility, it is suggested to apply the alpha map procedure, as explained in the following section.

It should also be noted that some uncertainty was introduced into the analysis by the supplied data, since both the vehicle-miles (VMT) and the speeds had been derived from traffic assignments. In spite of these uncertainties, the results in Figures 4.1 to 4.6 are very encouraging and justify the application of the alpha relationship--after additional testing--in the unified formulation of mobility. This subject will be discussed in Section 4.5.



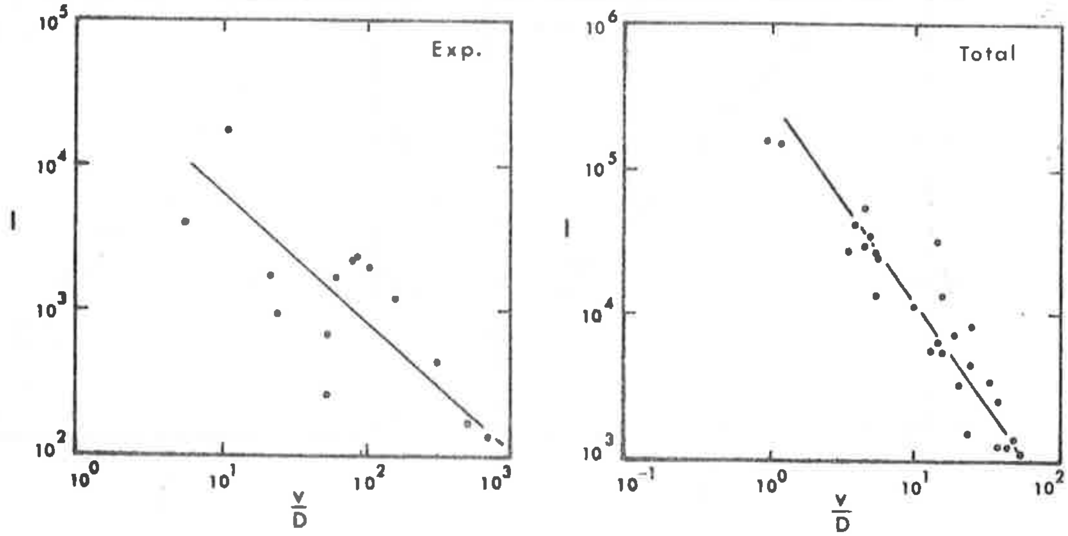
THE α-RELATIONSHIP

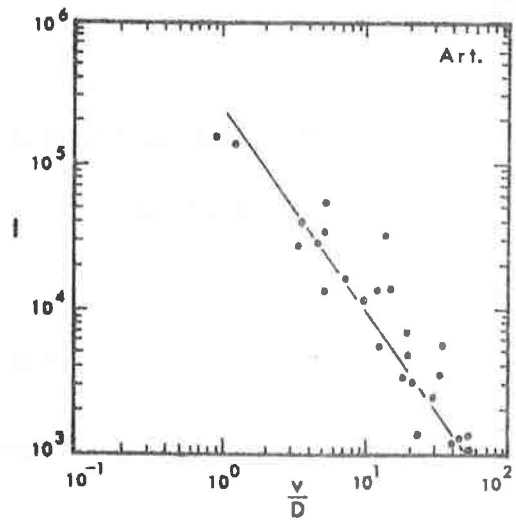
BINGHAMTON

Fig. 4.1

Table 4.1

		Arterials	Expressways	Total
Area	A			644.38
Road Length	L	860.7	75.9	936.6
Road Density	D	1.34	0.12	1.45
VMT		1,877,700	304,700	2,182,400
Traffic Intensity	I	2,914	473	3,387
Speed	v	20.7	43.2	22.3
v/D		15.45	360.00	15.40
Alpha		125,367	391,601	128,927
Exponent	b	1.264	1.201	1.227





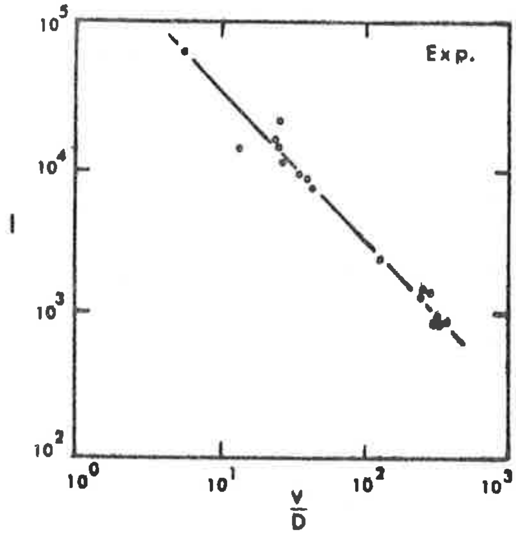
THE α-RELATIONSHIP

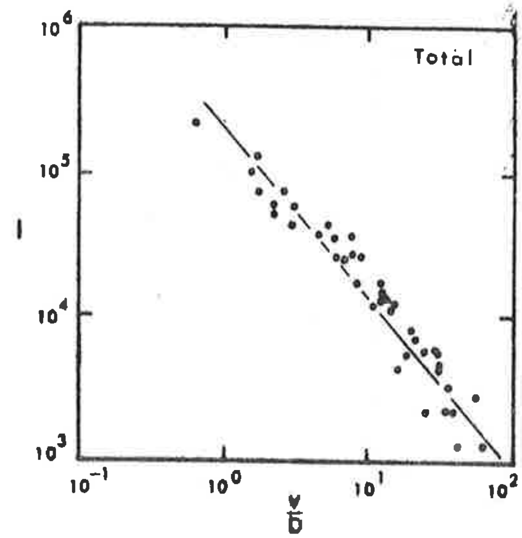
UTICA

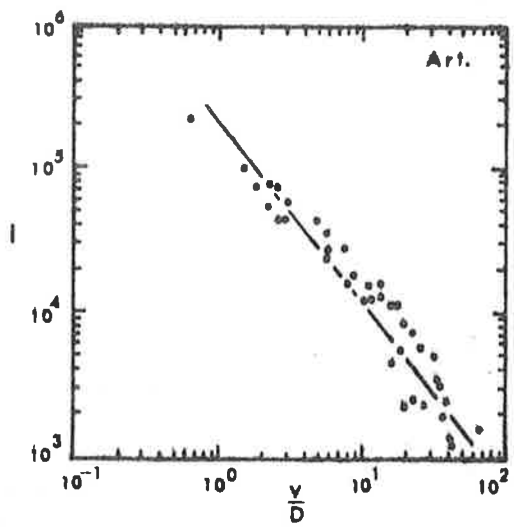
Fig. 4.2

Table 4.2

		Arterials	Expressways	Total
Area	A			2,744.29
Road Length	L	1,779.6	167.2	1,946.8
Road Density	D	0.65	0.06	0.71
VMT		2,344,960	527,200	2,872,100
Traffic Intensity	I	854	192	1,047
Speed	v	33.1	49.4	35.2
v/D		50.92	823.34	49.58
Alpha		278,730	51,021	262,761
Exponent	b	1.437	0.884	1.413







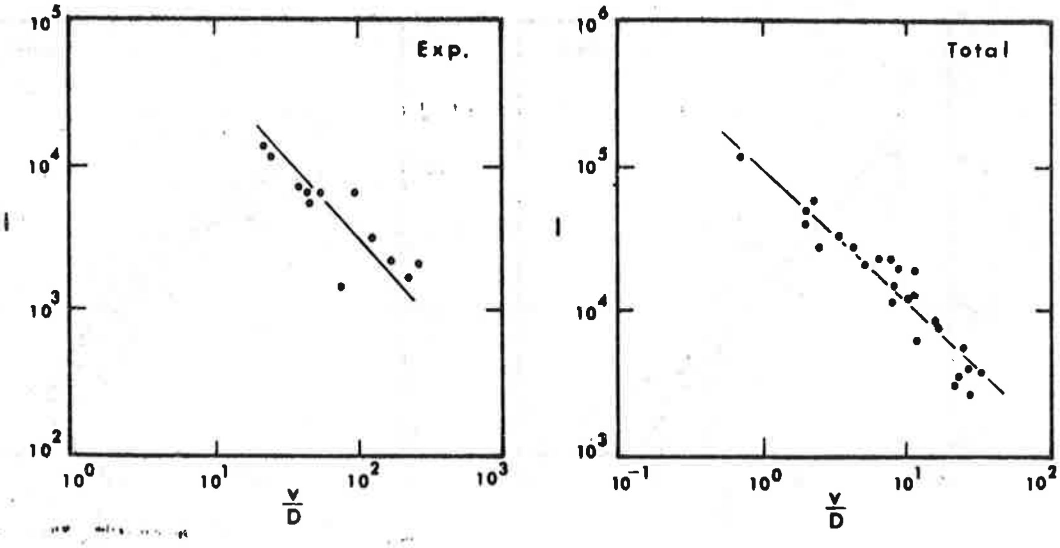
THE α-RELATIONSHIP

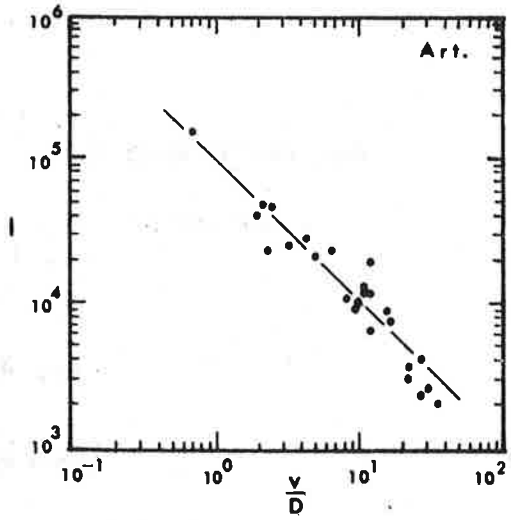
SYRACUSE

Fig. 4.3

Table 4.3

		Arterials	Expressways	Total
Area	A			802.50
Road Length	L	1,091.5	196.2	1,287.7
Road Density	D	1.36	0.24	1.60
VMT		3,389,000	1,275,800	4,664,800
Traffic Intensity	I	4,223	1,590	5,813
Speed	v	28.6	51.1	32.5
v/D		21.03	212.92	20.31
Alpha		233,748	369,904	228,443
Exponent	b	1.269	1.064	1.191





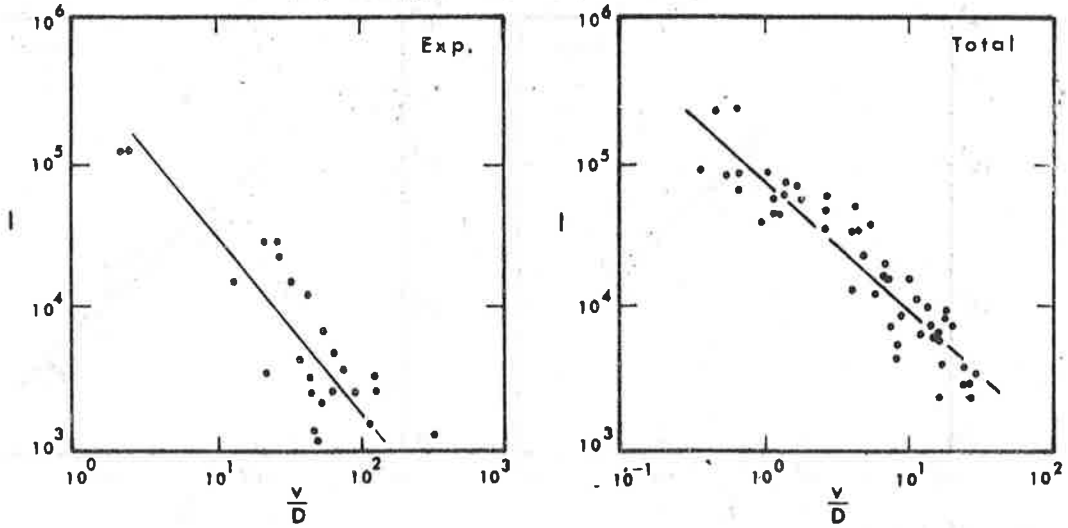
THE α-RELATIONSHIP

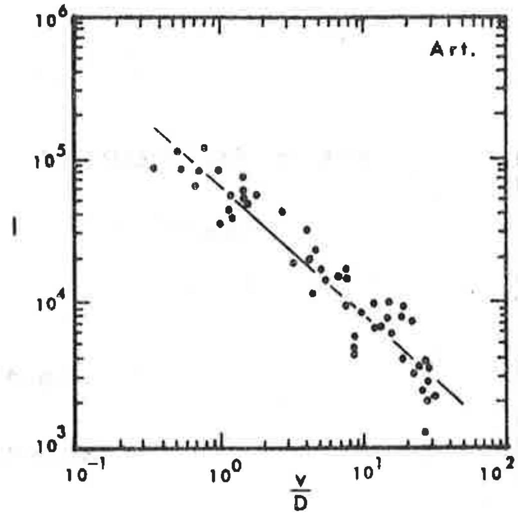
ALBANY

Fig. 4.4

Table 4.4

		Arterials	Expressways	Total
Area	A			468.37
Road Length	L	959.6	139.4	1,099.0
Road Density	D	2.05	0.30	2.35
VMT		3,563,000	989,500	4,552,500
Traffic Intensity	I	7,607	2,113	9,720
Speed	v	24.1	47.6	27.0
v/D		11.76	158.67	11.49
Alpha		94,372	534,453	100,509
Exponent	b	0.979	1.120	0.940





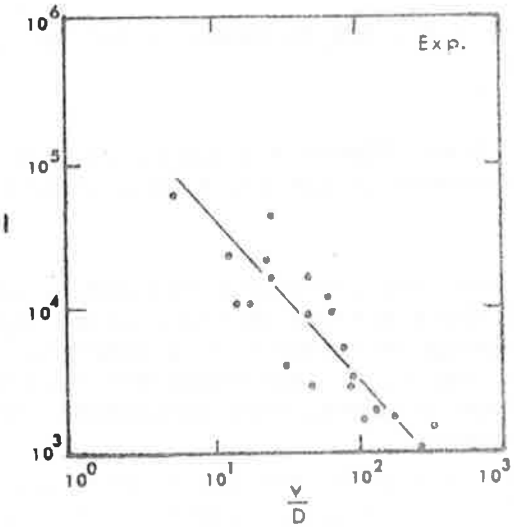
THE α-RELATIONSHIP

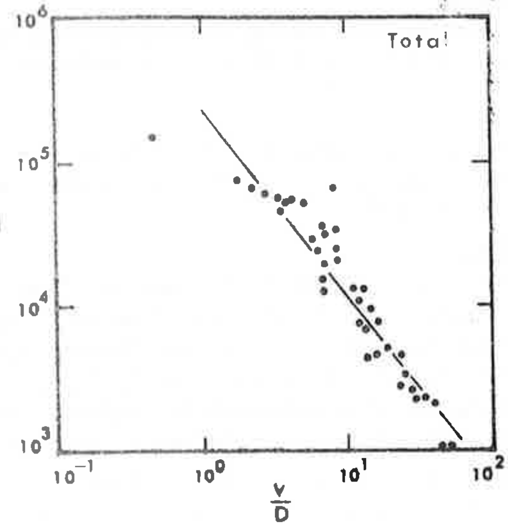
ROCHESTER

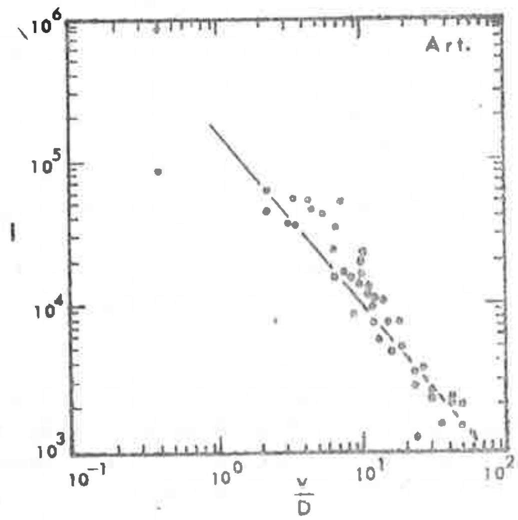
Fig. 4.5

Table 4.5

		Arterials	Expressways	Total
Area	A			692.03
Road Length	L	1,523.3	204.6	1,727.9
Road Density	D	2.20	0.30	2.50
VMT		4,644,200	1,157,900	5,802,100
Traffic Intensity	I	6,711	1,673	8,384
Speed	v	16.9	39.2	19.1
v/D		7.68	130.67	7.64
Alpha		66,436	538,746	79,459
Exponent	b	0.914	1.237	0.933







THE α-RELATIONSHIP

BUFFALO

Fig. 4.6

Table 4.6

		Arterials	Expressways	Total
Area	A			1,557.67
Road Length	L	2,286.6	199.9	2,486.5
Road Density	D	1.47	0.13	1.60
VMT		7,847,000	1,702,300	9,549,300
Traffic Intensity	I	5,038	1,093	6,131
Speed	v	23.0	43.1	25.1
v/D		15.65	331.54	15.69
Alpha		183,139	607,435	253,977
Exponent	b	1.228	1.149	1.300

4.4. COMPARING THE SIX CITIES

Purpose

To compare the alpha relationships of the six areas in order to define similarities or differences between them.

Data

The data are detailed in Tables 4.1 to 4.6 and Figure 4.7 summarizes the alpha relationships for the total road networks in the six areas, within the range of data.

Analysis

Significant differences can be found in both the levels and the slopes of the alpha relstionships. The ranking of the six areas by their alpha values (Tables 4.1 to 4.6) and by their relationship in Figure 4.7 is found to be, in descending order, areas 2, 6, 3, 1, 4, and 5. In all cases but one, the ranking of the exponent b follows the above sequence, thus indicating the close correspondence between the two parameters.

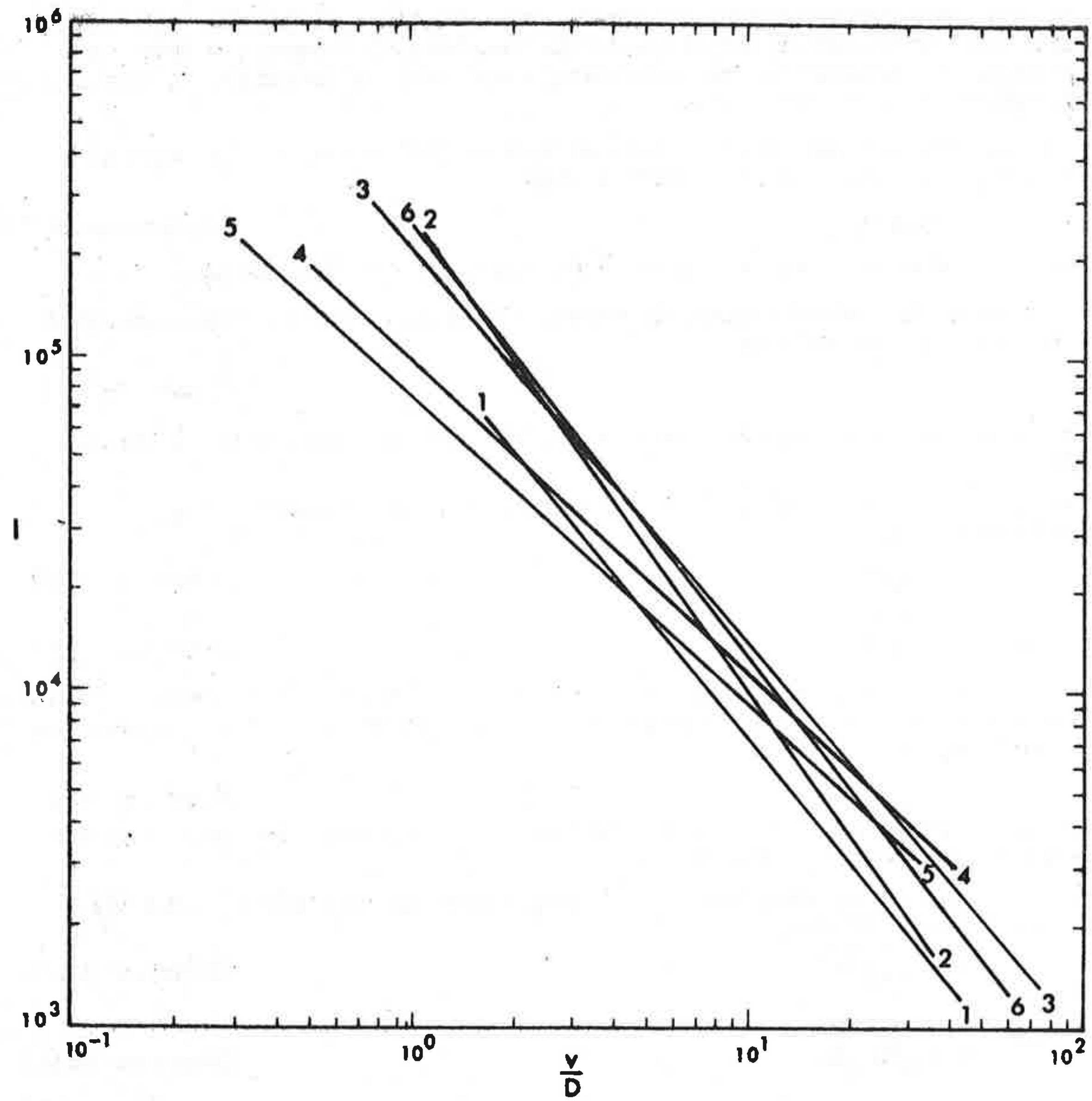
Of special interest is the tendency of the six relationships in Figure 4.7 to merge within a relatively narrow band along their middle parts. This tendency indicates that traffic districts with average traffic loads behave in a similar way (although their level of traffic performance may be quite different). Moreover, the relationship at their lower right-hand corners are somewhat questionable; when the traffic intensity is very low, speeds do not increase in a reciprocal manner but remain stable around the relevant legal speed limits. Thus, the dots in Figures 4.1 to 4.6 in the lower right-hand corner tend to deteriorate rapidly downwards, beyond the average line. A similar tendency may also be observed in the upper left-hand corner of the average lines where the flow in traffic districts with very high traffic intensities tends to diverge slightly from the average line. There is reason to believe that this specific tendency is the result of the assignment technique.

Therefore, within a wide range of traffic intensities and speeds, the six road networks behave in a basically similar way, although at different levels of traffic performance. This trend indicates the general applicability of the alpha relationship to different urban or regional areas, with a wide range of population size, land area, and road network characteristics.

Discussion

At this stage, however, some limitations should be recognized, for instance, the difficulty in defining the size of an urban area within which the traffic performance should be measured (if intercity comparisons are required). The solution to this problem is to use the alpha map procedure, according to the following steps: (1) the alpha value of each traffic district should be noted at the center of the district and a map of equivalue alpha lines be drawn for the whole area; (2) the gradient of the alpha lines usually increases from the center outwards until it reaches a maximum value, after which there will be a gradual decrease in values. The maximum ridge around the city signifies the border of the urban area, after which a decrease in traffic intensity will not increase the speed beyond the legal speed limit; and (3) the alpha relationship should then be applied to the traffic zones or districts enclosed within the ridge.

In conclusion, it can be stated that the testing of the alpha relationship under U.S. traffic conditions was very encouraging. Its integration within the unified formulation of travel will be detailed in the following section.



THE α-RELATIONSHIP

COMPARING THE SIX CITIES

Total Road Network

Fig. 4.7

4.5. A UNIFIED FORMULATION OF TRAVEL

A unified formulation of travel should, by definition, integrate both travel demand and system supply and explain the interaction between the two. One such possible formulation for vehicular travel will be presented in its most rudimentary form at this stage.

Referring back to Equation 4.2 and multiplying both sides by the relevant land area, A, results in the relationship:

$$K = \alpha \frac{L}{v} \qquad \text{(Equation 4.8)}$$

where K is vehicle-miles of travel (VMT) and L is the road length.

Furthermore, the vehicle-miles of travel, the speed, and the total amount of traveltime, are related by:

$$H = \frac{K}{v} \qquad \text{(Equation 4.9)}$$

where H is the total vehicle traveltime (VHT) in the study area, in vehicle hours.

Substituting K from Equation 4.8 in Equation 4.9 will result in the relationship:

$$L = \frac{v^2 H}{\alpha} \qquad \text{(Equation 4.10)}$$

or

$$v = \sqrt{\alpha \frac{L}{H}} \qquad \text{(Equation 4.11)}$$

Since it has already been shown that the daily TT budget is remarkably stable for an urban area, the total amount of vehicle traveltime can be derived from the relationship:

$$H = h\,N \qquad \text{(Equation 4.12)}$$

where N is the number of vehicles stationed in the urban area, and h is the average daily TT budget per vehicle.

The final unified formulation, in its most basic and simplified form will have the form of either:

$$L = \frac{v^2 N h}{\alpha} \qquad \text{(Equation 4.13)}$$

or

$$v = \sqrt{\alpha \frac{L}{N h}} \qquad \text{(Equation 4.14)}$$

Two remarks should be noted at this stage: (1) the same basic formulation can be applied to autos only, or to the total vehicles in the area, where N and h will change accordingly; and (2) the above formulation is approximate only, since it does not yet include the exponent b in the alpha relationship.

Nonetheless, several interesting conclusions may be drawn from the above formulation even at this preliminary stage, which explain some perplexing travel phenomena.

* There is an interdependency between the number of vehicles and the travel speed if all other factors remain constant. It can be deduced from Equation 4.14 that with a low number of vehicles in the urban

area the speed is very sensitive and decreases rapidly even for a small increase in the number of vehicles. However, when the number of vehicles in the urban area is high, the speed is insensitive and decreases slowly for even large increases in the number of vehicles. This relationship explains why travel speeds may deteriorate quite rapidly with an increase in the number of vehicles in small or medium urban areas, but will decrease very slowly, asympthotically to a minimum average speed of about 6-8 m.p.h., in large urban areas.

* When the decrease in speed approaches a minimum level, peak hours will tend to spread into peak periods. On the other hand, a decrease in speed will also decrease the trip rate, especially in the Serve Passenger, Social-Recreation, and Shopping purposes (see Figures 2.2 and 2.6). Thus, it can be expected that the greater the spread of peak periods during the day, mostly for the Work, Other, and Business purposes, the less travel will take place during the evening, since tripmakers would have used up their allocated TT budgets for the essential trip purposes during the day. Indeed, this is the trend in large urban areas.

The above are just two examples of the many conclusions that may be derived from the formulation. An additional interesting possibility is the development of a new planning procedure. In the current standard procedure, alternative transportation systems have first to be assumed, while the knowledge of their resultant levels of mobility, modal splits, and performance has to await the lengthy calibration and costly running of travel models. The new planning procedure, however, may begin from the present end-results, with much saving in time and effort. For instance: (1) first the planners and policy makers will decide on a range of desired levels of total mobility and trip purpose splits (Figures 2.3 to 2.6); (2) for each alternative the corresponding auto trip rate will be derived (Figure 3.3); (3) the required road network average speed will be estimated for the preferred mobilities and population projections (Figure 3.8); (4) based on the projected population and motorization, both the number of autos and their total VHT can then be estimated; (5) thus, by referring to Equation 4.11, after having established both v and H for various alternatives, the combined value of alpha and L will be derived; (6) various basic and practical road network alternatives can then be evaluated, where the product of their alpha and L will remain within the ranges mentioned above; and (7) a feedback process between the required system parameters and practical planning considerations within the area will thus ensure a first-approximation evaluation of numerous planning options and the responsiveness between the desired levels of mobility and the required levels of system supply. This macro-procedure may, therefore, rapidly and easily test numerous alternatives even before a comprehensive transportation/land use study is initiated.

In conclusion, it should be remembered that this study is exploratory in nature, where concepts have been tested and integrated within empirical first-approximation formulations. The important thing to note, though, is that a direct link was established by the above formulation between the travel demand and the transportation system supply. It is hoped that this study will initiate interest and further testing of the basic concepts and formulations developed above.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

This study has developed several first-approximation empirical relationships for urban areas. The results of this study may be summarized as follows:

(1) The average daily auto traveltime is stable in all urban areas, with a slight tendency to increase with the size of the area.
(2) Autodrivers appear to trade traveltime savings for more trips.
(3) Tripmakers have specific daily traveltime budgets, which can be related to their location of residence and modes of travel used during the day.
(4) Tripmakers of both private and public transport rank their trips by purpose, resulting in different trip purpose splits at different levels of mobility.
(5) A diversion from private to public transport results in a net loss of total trips when the latter speed is lower.
(6) The daily auto trip rate would seem to be a good indicator for the total mobility in an urban area.
(7) The average auto trip distance can be related to population size.
(8) The auto trip rate is responsive to the average trip distance and speed.
(9) Total mobility is responsive to population size and the road network speed.
(10) The road network performance can be expressed by its ability to carry a certain amount of traffic kinetic energy, namely the product of flow and its speed.
(11) The total number of person trips in an urban area, as well as their modal choice and trip purpose splits, can be related to the road network level of traffic performance.
(12) A unified formulation for the responsiveness of travel demand to transportation system supply may be defined.

It should be noted that this study is exploratory in nature and further verifications of the above results are needed before they can be regarded as conclusive.

Assuming that the above results are indicative enough of the general behavioral mechanism of travel, several additional conclusions may be derived from the above conclusions. Namely:

(a) A decrease in travel speed, whether by endogenous factors such as congestion or by exogenous policy decisions, may produce a decrease in mobility. A close relationship is known to exist between economic activity and mobility, ranging from a macro scale as between countries to a micro scale within one city. Since it is not yet clear if this relationship applies in both directions or is uni-directional (namely, whether or not economic activity and mobility both cause and affect each other), it may be concluded that special care should be exercised when policy decisions which may affect mobility are considered. This conclusion has a special meaning at the present time when the energy crisis and the fuel shortage threaten mobility.
(b) Both urban traffic congestion and the fuel shortage are now challenging the ability of public transport to meet travel demand. It is hoped, therefore, that a better understanding of the behavioral mechanism of travel within the constraining effect of a traveltime budget will give public transport the unique opportunity to meet the challenge with successful results. It appears that the crucial factor will be the ability of public transport to provide competitive travel speed, for if it cannot, a loss in total mobility will result.

5.2. RECOMMENDATIONS

Based on the results and conclusions detailed in this study, the following recommendations for further verification are presented for consideration.

(1) Test and establish whether a change in the daily combinations of modes a tripmaker will use during the day will affect his traveltime budget, trip rate, trip distance, and trip time. This is a crucial question for any policy decisions where changes in mode combination are considered, such as enforced diversion to public transport by gasoline rationing, speed reduction, or pricing policies. Such a survey should be initiated immediately, since the present situation offers a unique opportunity to test actual tripmakers' reactions to varying constraining measures.

(2) Although the subject of travel cost has not been discussed in this study--nor has it been necessitated by the analysis' results--it is recognized that the factors of travel cost and valuation of traveltime should be integrated within the mobility formulation, especially when the interaction and demand elasticities between the private and the public modes are considered.

(3) Special attention has been given to the responsiveness of both private and total mobility to the road network, since it had been indicated by the analysis that the auto trip rate is the most sensitive and representative parameter. The next phase of analysis should, however, test the sensitivity of mobility to transit system supply, especially when various competing or complementing modes of public transport are considered.

(4) It would be advisable to review the basic concepts of conventional travel forecasting models, especially the trip generation and modal choice submodels, and test whether adjusting and constraining them by the traveltime budget will increase their responsiveness to system supply and thus increase their consistency with travel behavior.

(5) The trip distribution and traffic assignment submodels may also be reviewed in light of the traveltime budget. For instance, most of the standard traffic assignment models assign a constant number of person trips on alternative transportation systems, thus the outcome is varying amounts of VMT and VHT. If, on the other hand, the procedure were based on the assignment of a constant amount of VHT on alternative systems, the outcome would be varying amounts of trips and VMT. Indeed, preliminary tests by the author have indicated that a direct assignment process may be feasible, since the spatial pattern and gradient of the VHT assignments, as produced by the standard procedures for various urban areas, have shown a remarkable similarity when compared by the relative values of VHT intensity and distance from the city center. It is recommended, therefore, that a more thorough analysis of this subject be conducted, where simplified and rapid procedures for direct assignments will be developed and evaluated.

(6) It is strongly recommended that standardized data be presented in transportation study reports. Such a pratice should include standarized definitions, so that future comparative analysis could be conducted on the basis of recognized common denominators.

As can be seen from the above list, a better understanding of one question may only raise many additional questions. It is believed, however, that by such a stepwise procedure we may gradually approach a much better understanding and formulation of travel behavior for the benefit of tripmakers.

APPENDICES

TABLE A-1

DAILY VEHICLE TRAVELTIME

Study Area	Vehicles	Vehicle Trips	VMT	VHT	Speed	h Hours
2	3,451,450	12,476,957	102,082,084	3,060,058	33.4	0.89
3	485,478	1,907,033	—	394,000	—	0.90
13	109,507	605,719	2,504,054	101,706	24.6	0.93
14	95,217	504,033	—	72,360	—	0.76
16	93,537	567,262	—	75,149	—	0.80

TABLE A-2

DAILY VEHICLE TRAVELTIME PER AUTOS

Study Area	Autos	VMT	VHT	Speed	h Hours
1	4,186,000	119,940,000	4,613,100	26.0	1.10
2	3,123,319	102,082,084	3,060,058	33.4	.98
9	168,634	4,599,000	155,022	29.7	.92
11	137,255	3,230,000	107,000	30.2	.78
14	86,116	1,882,100	72,360	26.0	.84

APPENDIX B: COMPARING THE URBAN CHARACTERISTICS OF WASHINGTON, D.C., AND BUFFALO, NEW YORK

Appendix B compares the basic urban parameters of the Washington, D.C., metropolitan area with another area, that of Buffalo, New York. Tables B-1 and B-2 detail the data, which Figures B-1 and B-2 present in a graphical form, separately by residence location from the center and by income.

Three points are of particular interest:

(1) The diagram of income versus distance in Figures B-1 and B-2 clearly shows that the same average income may be found for households at entirely different locations. Since it already has been indicated that travel behavior is strongly affected by residence location, it can be concluded that stratifying households by income only will mix together distinctly different travel behaviors.

(2) Regarding the diagram of population density versus income in Figures B-1 and B-2, there is a strong indication that the border of the typical urban strata within the metropolitan area can be defined in precise terms which shows a break and change of direction in the trend (ring 5 in Washington and ring 4 in Buffalo) typifying a change from urban to rural conditions. Two other diagrams that corroborate this trend are income and motorization versus distance, although they alone are much less indicative. Therefore, the diagram, population density versus income, may be useful for defining the border of the continuous urban area in quantified terms.

(3) Although Washington, D.C., is sometimes regarded as an atypical city for travel analysis, its comparison with other cities by the urban characteristics in Table B-1, as well as by the TT budgets, clearly show that people living in urban areas behave in basically similar and consistent patterns.

TABLE B-1

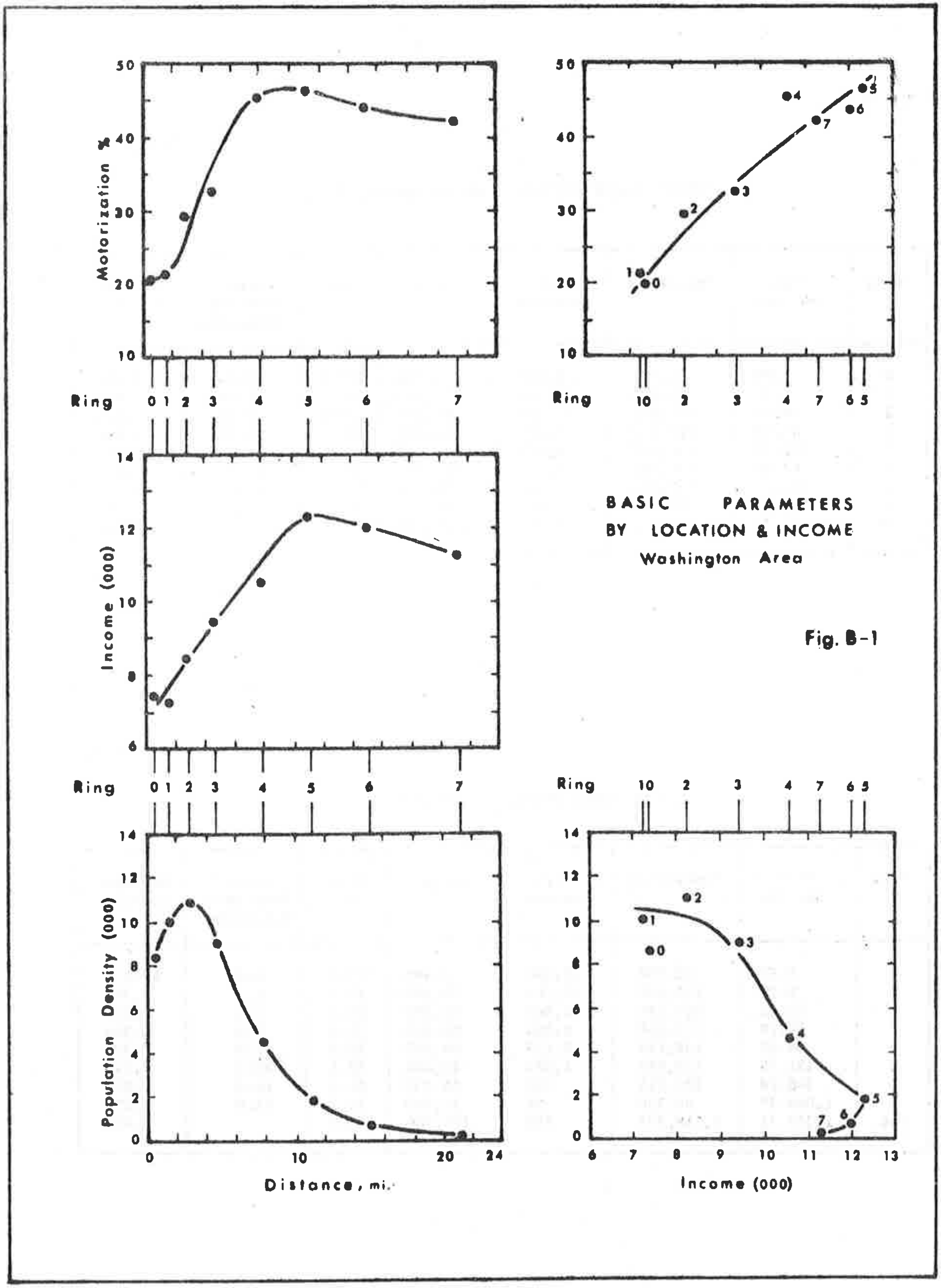
BASIC PARAMETERS - Washington, D.C.

Ring	Area sq. mi.	Population	Pop. Density	Autos	Mot. %	Dist. from zero Milestone	Average Income
0	1.86	15,795	8,492	3,269	20.7	0.58	$ 7,418
1	8.56	86,118	10,061	18,395	21.4	1.59	7,272
2	29.45	326,616	11,091	96,480	29.5	2.95	8,279
3	55.44	499,052	9,002	162,229	32.5	4.77	9,467
4	162.91	757,629	4,651	345,473	45.6	7.90	10,585
5	247.48	458,067	1,851	212,923	46.5	11.17	12,328
6	393.32	292,303	743	128,584	44.0	15.20	11,990
7	418.34	122,511	293	51,586	42.1	21.28	11,278
Tot.	1,317.36	2,558,092	1,942	1,018,939	39.8	-	10,232

TABLE B-2

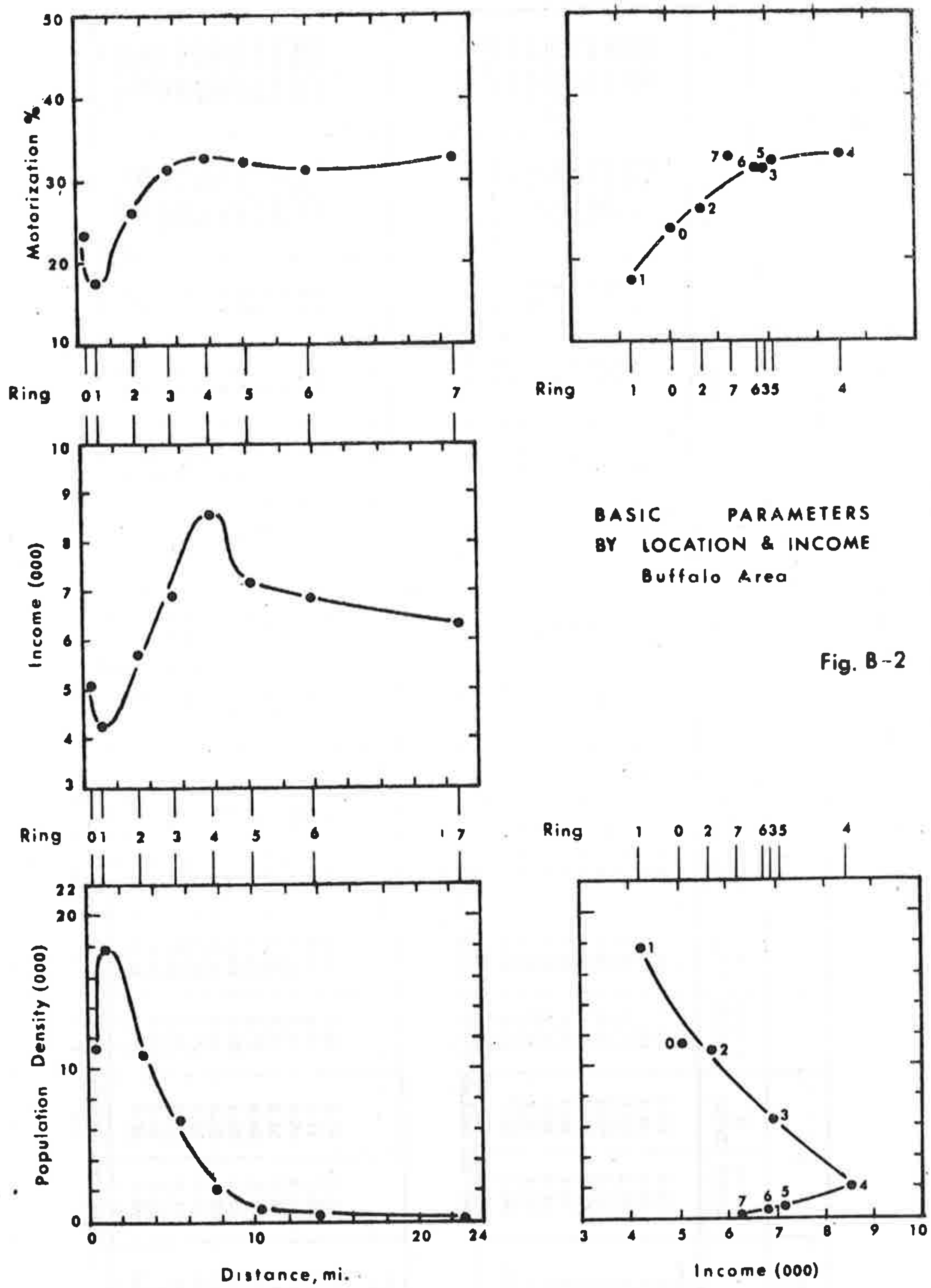
BASIC PARAMETERS - Buffalo, N.Y.

Ring	Area sq. mi.	Population	Pop. Density	Autos	Mot. %	Dist. from zero Milestone	Average Income
0	0.93	10,596	11,394	2,496	23.6	0.4	$5,131
1	9.29	165,030	17,764	29,181	17.7	1.1	4,300
2	23.02	253,294	11,003	66,087	26.1	3.4	5,727
3	40.78	275,660	6,760	86.338	31.1	5.6	6,941
4	64.33	139,729	2,172	46,025	32.9	7.9	8,533
5	121.79	125,881	1,034	40,444	32.1	10.4	7,125
6	248.78	181,215	728	56,933	31.4	14.0	6,834
7	1,048.79	66,930	64	21,860	32.7	22.9	6,294
Tot.	1,557.71	1,218,335	782	349,364	28.7	-	6,453



BASIC PARAMETERS
BY LOCATION & INCOME
Washington Area

Fig. B-1



BASIC PARAMETERS
BY LOCATION & INCOME
Buffalo Area

Fig. B-2

TABLE C-1

TRIP DATA BY MODE, LOCATION, AND INCOME

Washington Metropolitan Area

MODE	D		P		T		D + P		D + T		T + P		TOTAL*	
	% Trip Makers	% Trips	% Trip Makers	% Trips	% Trip Makers	% Trips	% Trip Makers	% Trips	% Trip Makers	% Trips	% Trip Makers	% Trips	Trip Makers	Trips
Ring														
0	25.6	27.5	23.3	24.0	42.1	34.8	1.8	3.6	1.7	3.7	5.5	6.3	12,784	30,048
1	32.1	39.4	16.7	15.6	42.9	34.5	0.9	2.2	1.2	2.1	6.2	6.2	46,282	118,032
2	38.2	43.6	17.2	15.3	32.7	25.1	3.1	5.5	1.6	2.6	7.2	7.9	200,524	548,267
3	42.4	47.8	23.6	20.4	21.4	15.5	3.7	6.8	1.9	2.4	7.0	7.1	328,587	920,962
4	51.9	55.0	29.2	23.9	6.9	4.3	6.5	10.9	1.4	1.7	4.1	4.2	560,336	1,811,568
5	55.1	56.7	29.4	25.0	5.1	3.2	6.5	10.6	1.1	1.3	2.8	3.2	324,127	1,021,620
6	52.9	56.5	32.6	27.5	5.9	3.9	5.3	8.7	0.6	0.7	2.7	2.7	197,282	583,205
7	54.5	58.6	35.5	29.4	3.5	2.4	4.5	7.2	0.5	0.6	1.5	1.8	73,832	220,725
Total	48.7	52.7	27.1	23.1	13.1	8.9	5.2	8.9	1.3	1.7	4.6	4.7	1,735,754	5,254,427

* Does not include D+P+T or unknown modes

Income $000	% Trip Makers (D)	% Trips (D)	% Trip Makers (P)	% Trips (P)	% Trip Makers (T)	% Trips (T)	% Trip Makers (D + P)	% Trips (D + P)	% Trip Makers (D + T)	% Trips (D + T)	% Trip Makers (T + P)	% Trips (T + P)	Trip Makers (TOTAL*)	Trips (TOTAL*)
0-3	41.3	47.6	34.5	31.0	19.1	15.0	1.7	2.8	–	0.3	3.3	3.2	69,735	183,402
3-4	36.1	41.7	22.9	21.6	34.6	28.2	1.0	1.9	0.6	1.2	4.8	5.4	42,844	109,698
4-6	40.3	45.6	25.2	22.3	25.1	19.2	2.7	4.9	1.0	1.5	5.7	6.5	120,666	326.652
6-8	46.6	51.8	25.8	22.6	17.9	12.9	3.2	5.7	1.1	1.3	5.4	5.7	218,181	628,589
8-10	49.6	54.0	27.3	23.6	13.4	9.3	4.3	7.3	1.2	1.6	4.2	4.2	263,070	778,240
10-12	50.0	54.1	28.3	23.5	11.1	7.6	5.3	9.3	1.1	1.3	4.1	4.2	272,552	822,166
12-15	49.7	53.0	28.7	24.0	9.2	5.9	6.3	10.4	1.6	2.1	4.5	4.6	280,447	891,219
15-20	51.0	53.7	27.5	23.2	8.6	5.4	6.5	10.7	1.9	2.4	4.5	4.6	245,528	786.493
20-25	53.0	55.3	23.8	18.8	8.5	5.4	7.9	13.3	2.0	2.5	4.8	4.7	121,588	392,016
25-+	53.4	54.7	24.5	20.6	7.1	4.3	9.2	14.7	1.3	1.6	4.5	4.1	95,326	321,375
Total	48.7	52.7	27.1	23.1	13.1	8.9	5.2	8.9	1.3	1.7	4.6	4.7	1,729,937	5,239,850

* Does not include D+P+T mode or unknown income

TABLE C-2

TRAVEL DATA BY MODE, LOCATION AND INCOME

Washington Metropolitan Area

Mode	Driver					Passenger					Transit					D + P					D + T					T + P					Total Average				
Ring	h	F	t	d	v	h	F	t	d	v	h	F	t	d	v	h	F	t	d	v	h	F	t	d	v	h	F	t	d	v	h	F	t	d	v
0	0.58	2.7	13.0	4.7	21.6	0.36	2.4	8.9	3.0	20.3	0.58	1.9	17.8	3.4	11.4	0.74	4.7	9.3	3.3	21.5	1.07	5.3	12.1	2.4	11.7	0.85	2.7	18.8	4.7	14.9	0.55	2.4	13.9	3.7	16.1
1	0.64	3.1	12.3	4.3	21.1	0.47	2.4	11.8	4.2	21.1	0.56	2.1	16.4	3.0	10.9	1.40	6.5	12.9	4.8	22.3	1.02	4.4	13.8	4.1	17.6	0.83	2.5	19.5	4.3	13.2	0.60	2.6	14.1	3.8	16.3
2	0.64	3.1	12.3	4.3	21.2	0.46	2.4	11.4	4.2	22.1	0.73	2.1	20.8	3.5	10.1	1.01	4.9	12.3	4.9	22.8	1.02	4.4	13.8	3.6	15.6	0.83	3.0	16.7	3.9	13.8	0.67	2.7	14.7	4.1	16.7
3	0.77	3.2	14.3	5.4	22.6	0.53	2.5	12.7	4.8	22.7	0.94	2.1	27.2	4.9	10.9	1.04	5.2	11.9	4.6	23.3	1.36	3.9	20.9	4.6	13.2	0.97	2.9	19.9	4.6	13.7	0.79	2.9	16.4	5.1	18.6
4	0.82	3.4	14.4	6.1	25.2	0.55	2.7	12.4	5.4	26.0	0.77	2.0	22.9	4.8	12.6	1.54	5.4	12.5	5.4	25.9	1.74	3.9	26.4	6.1	13.7	1.12	3.3	20.2	5.2	15.6	0.79	3.2	14.6	5.7	23.6
5	0.91	3.2	16.8	7.4	26.6	0.63	2.7	14.1	6.5	27.6	0.69	2.0	20.7	4.5	13.0	1.29	5.2	14.9	6.7	27.1	2.30	3.7	37.2	7.5	12.1	1.13	3.6	19.0	5.6	17.8	0.87	3.2	16.4	7.0	25.5
6	0.98	3.2	18.6	8.6	27.7	0.70	2.5	16.9	8.1	28.8	0.99	2.0	30.2	7.2	14.2	1.37	4.8	17.0	8.0	28.3	2.64	3.5	45.1	9.7	12.9	1.38	2.9	28.6	8.0	16.8	0.93	3.0	18.9	8.4	26.4
7	1.24	3.2	23.1	10.8	28.1	0.78	2.5	18.9	9.1	28.8	0.89	2.0	26.5	9.4	21.2	1.64	4.8	20.5	9.8	28.6	3.0	3.8	47.6	11.8	14.9	1.58	3.5	27.3	9.1	20.0	1.09	3.0	22.0	10.2	27.8
Average	0.85	3.3	15.6	6.6	25.4	0.59	2.6	13.7	6.0	26.2	0.79	2.0	23.1	4.4	11.4	1.19	5.2	13.7	6.0	26.2	1.67	4.0	25.2	5.7	13.5	1.04	3.1	20.0	5.1	15.2	0.81	3.0	16.0	6.1	22.8

Mode	Driver					Passenger					Transit					D + P					D + T					T + P					Total Average				
Income	h	F	t	d	v	h	F	t	d	v	h	F	t	d	v	h	F	t	d	v	h	F	t	d	v	h	F	t	d	v	h	F	t	d	v
0-3	0.70	3.03	13.9	6.2	26.7	0.60	2.4	15.2	6.9	27.4	1.07	2.1	31.2	6.2	11.9	0.91	4.5	12.2	5.3	26.0	1.82	8.1	13.5	4.3	19.1	1.28	2.6	29.8	8.1	16.3	0.76	2.6	17.4	6.5	23.3
3-4	0.69	2.95	14.1	5.9	25.1	0.54	2.4	13.3	5.8	25.9	0.82	2.1	23.5	4.2	10.8	1.43	5.3	16.1	7.7	28.5	2.29	5.1	26.8	5.6	12.4	1.02	2.9	21.5	4.8	13.4	0.73	2.6	17.2	5.4	18.8
4-6	0.71	3.06	13.8	5.7	24.8	0.52	2.4	13.0	5.4	25.1	0.78	2.1	22.7	4.0	10.7	1.10	4.9	13.6	6.2	27.5	1.24	4.3	17.4	3.8	13.0	0.87	3.1	17.0	4.2	14.7	0.71	2.7	15.6	5.2	20.1
6-8	0.79	3.20	14.8	6.1	24.9	0.59	2.5	14.0	6.1	26.4	0.81	2.1	23.2	4.2	11.0	1.11	5.1	13.2	5.8	26.1	1.52	3.5	26.3	5.5	12.5	1.02	3.0	20.3	5.0	14.7	0.77	2.9	16.1	5.8	21.6
8-10	0.82	3.21	15.3	6.4	25.1	0.56	2.6	13.1	5.6	25.8	0.74	2.1	21.6	4.2	11.6	1.11	5.0	13.3	5.8	26.1	1.58	3.9	24.3	5.9	14.6	1.08	3.0	21.7	4.9	13.6	0.78	3.0	15.7	5.9	22.6
10-12	0.87	3.26	16.0	6.8	25.5	0.56	2.5	13.4	5.8	26.1	0.77	2.0	22.7	4.3	11.5	1.21	5.2	13.6	6.1	26.3	1.81	3.7	29.1	6.6	13.6	1.05	3.1	20.6	5.4	15.8	0.81	3.0	16.1	6.3	23.4
12-15	0.90	3.39	15.9	6.8	25.6	0.63	2.7	14.1	6.3	26.7	0.79	2.0	23.2	4.4	11.4	1.22	5.2	13.9	6.1	26.4	1.70	4.0	24.3	5.6	13.2	1.08	3.3	19.7	5.1	15.4	0.86	3.2	16.1	6.4	23.6
15-20	0.91	3.37	16.2	6.9	25.5	0.63	2.7	14.0	6.1	26.4	0.77	2.0	22.7	4.6	12.2	1.27	5.3	14.5	6.3	26.2	1.82	4.1	26.7	5.9	13.2	1.03	3.3	18.7	5.1	16.3	0.87	3.2	16.3	6.4	23.7
20-25	0.91	3.36	16.3	6.9	25.5	0.58	2.6	13.6	5.9	26.0	0.72	2.0	21.1	4.7	13.4	1.22	5.4	13.6	5.9	25.9	1.64	4.0	24.4	5.7	14.0	0.96	3.2	18.1	5.0	16.6	0.86	3.2	16.0	6.4	23.8
25-+	0.90	3.45	15.6	6.6	25.4	0.60	2.8	12.6	5.4	25.6	0.78	2.0	22.9	4.6	12.0	1.16	5.4	12.9	5.4	25.1	1.46	4.0	21.8	4.9	13.5	1.02	3.1	19.8	5.1	15.4	0.85	3.4	15.2	6.0	23.6
Average	0.85	3.28	15.6	6.6	25.4	0.59	2.6	13.7	6.0	26.2	0.79	2.1	23.1	4.4	11.4	1.19	5.2	13.7	6.0	26.2	1.67	4.0	25.2	5.7	13.5	1.04	3.1	29.9	5.1	15.2	0.81	3.0	16.0	6.1	22.8

APPENDIX D

LIST OF SOURCES

No.	Study Area		I	II	III
1	Tri-State	New York	*	*	
2	Los Angeles	California	*		
3	Baltimore	Maryland	*	*	
4	Cincinnati	Ohio--Ky.-Indiana	*	*	
5	Kansas City	Missouri - Kansas	*	*	
6	Indianapolis	Indiana	*	*	
7	S. E. Virginia	Virginia	*		
8	Oklahoma City	Oklahoma	*	*	
9	Springfield	Massachusetts	*	*	
10	Salt Lake City	Utah	*	*	
11	Orlando	Florida	*		
12	St. Petersburg	Florida	*		
13	Peoria	Illinois	*		
14	Baton Rouge	Louisiana	*	*	
15	Knoxville	Tennessee	*	*	
16	Pulaski	Arkansas	*		
17	South Bend	Indiana	*		
18	Columbia	South Carolina	*	*	
19	Monroe	Louisiana	*	*	
20	Fort Smith	Arkansas	*		
21	Rapid City	South Dakota	*		
a	Binghamton	New York	*		*
b	Utica(regional)	New York	*		*
c	Syracuse	New York	*		*
d	Albany(regional)	New York	*		*
e	Rochester	New York	*		*
f	Buffalo(regional)	New York	*		*
w	Washington, D.C. Metropolitan Area				*
	Nationwide1/				*

I. Published Invidivual Transportation Study Reports
II. "Urban Transportation Planning Data," Federal Highway Administration, 1969
III. Data Derived from Original Computer Output Listings

1/ "Nationwide Personal Transportation Study," Federal Highway Administration, 9 Separate Reports, 1972 - 1973.

APPENDIX E

COMPUTER PROGRAMS

Trip Purpose by Travel Mode Program

The Computer Services Division, FHWA, duplicated a comprehensive trip file of the Washington metropolitan area from the Urban Institute. The tapes, COG 100 and COG 200, include the data described in "Development and Calibration of the Washington Mode Choice Models," by R. H. Pratt Associates, Inc., Technical Report No. 8, June 1973.

A series of programs--E3227K01, E3227K04, and E3227K02--were used to prepare and output the tables for the analysis of trip purposes by travel modes. The tables were grouped by districts within rings and by income. Within each trip purpose by mode were: tripmakers, person trips, trip rate, total distance traveled, average distance traveled per tripmaker, net and gross traveltime, net and gross average traveltime per tripmaker, and net and gross average vehicle speed.

Alpha Relationship Program

Data for six urban areas in New York State were received from the Planning and Research Bureau, New York State Department of Transportation. The data derived from the model assignments were read into the computer and stored in a matrix. The data for each urban area included by zone, land area, VMT, VHT, and vehicle speed for arterial, expressway, and total mileage.

Programs E3227K06 and E3227K07 were prepared to calculate the alpha relationship:

$$\alpha = I \left(\frac{V}{D}\right)^{b}$$

where (1) alpha and the exponent b were calculated and (2) only alpha was calculated while the exponent b was set equal to one.

Nationwide Program

The Nationwide Personal Transportation Survey was designed to obtain up-to-date information on national patterns of travel. The data were collected in 1969-70 by the Bureau of Census of the Department of Commerce for the Federal Highway Administration.

The Computer Services Division prepared the program E3213S01 from tapes 3021 and 3101 for the analysis of modes of travel by population size groups. Within each mode by population size the following tables were prepared: person trips, trip rate, VMT, VHT, average trip distance, average trip time, and average vehicle speed.

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