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TRAVELTIME BUDGETS AND MOBILITY IN URBAN AREAS

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FINAL REPORT

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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.

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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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TABLES AND FIGURES

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.

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 feedback 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.

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.

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.

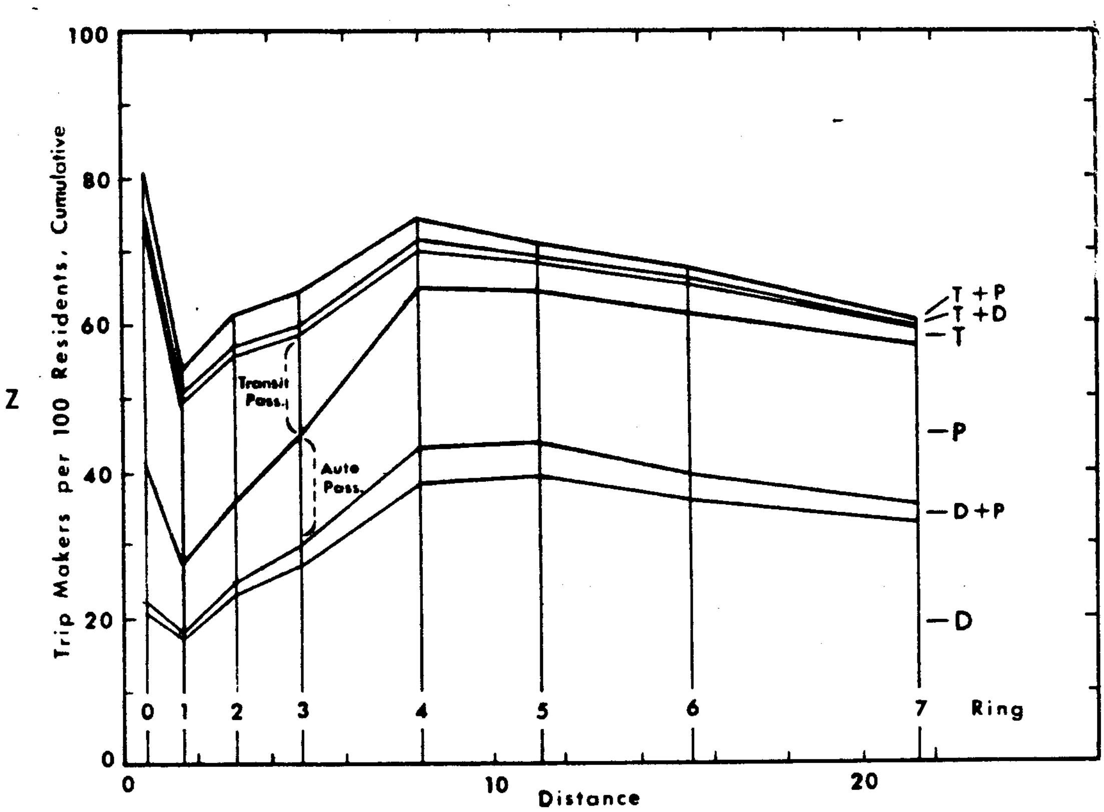
Another test was then conducted by deriving the Z rates for the labor force instead of the population, since the household structure in the center may differ from other parts in the area. Indeed, the Z rate decreased somewhat in this case, although it was still higher than in ring 1, and very near to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

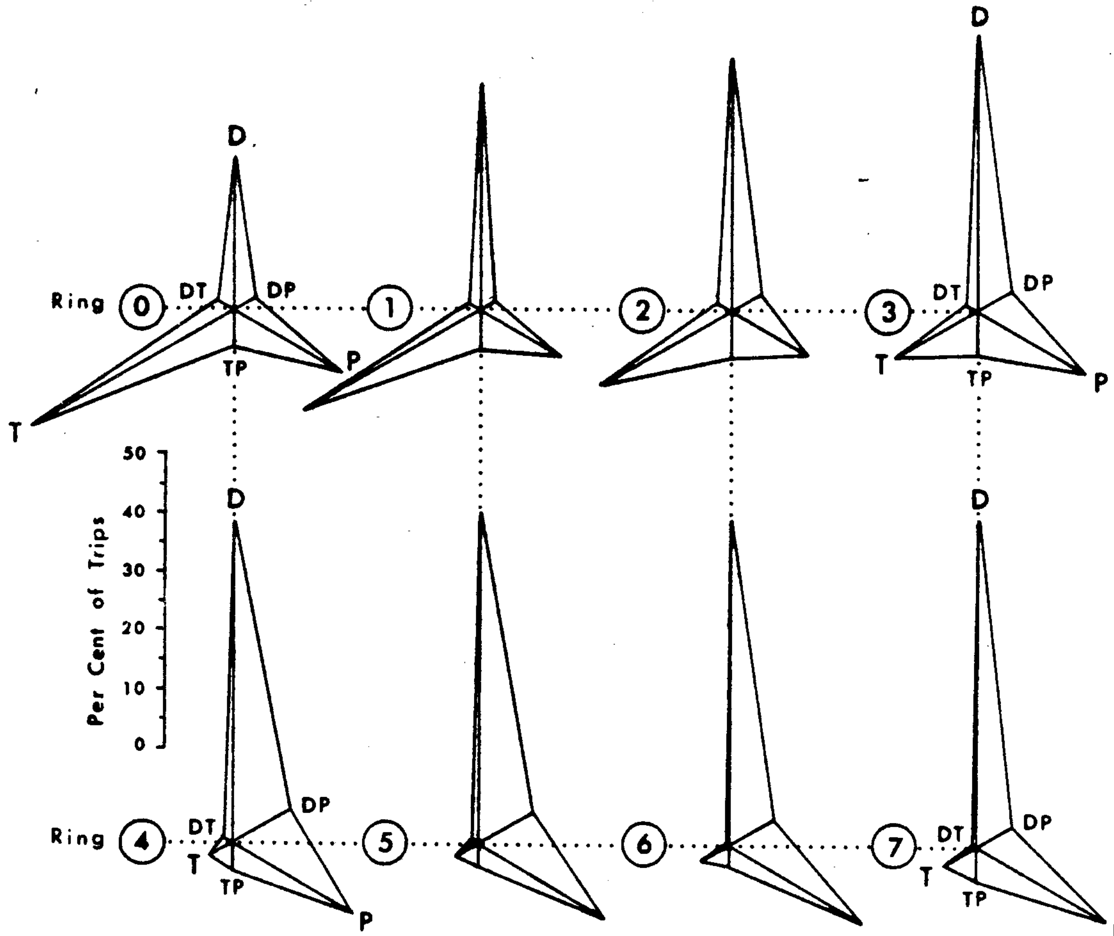
Discussion

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 travel-times 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 trip-makers 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.

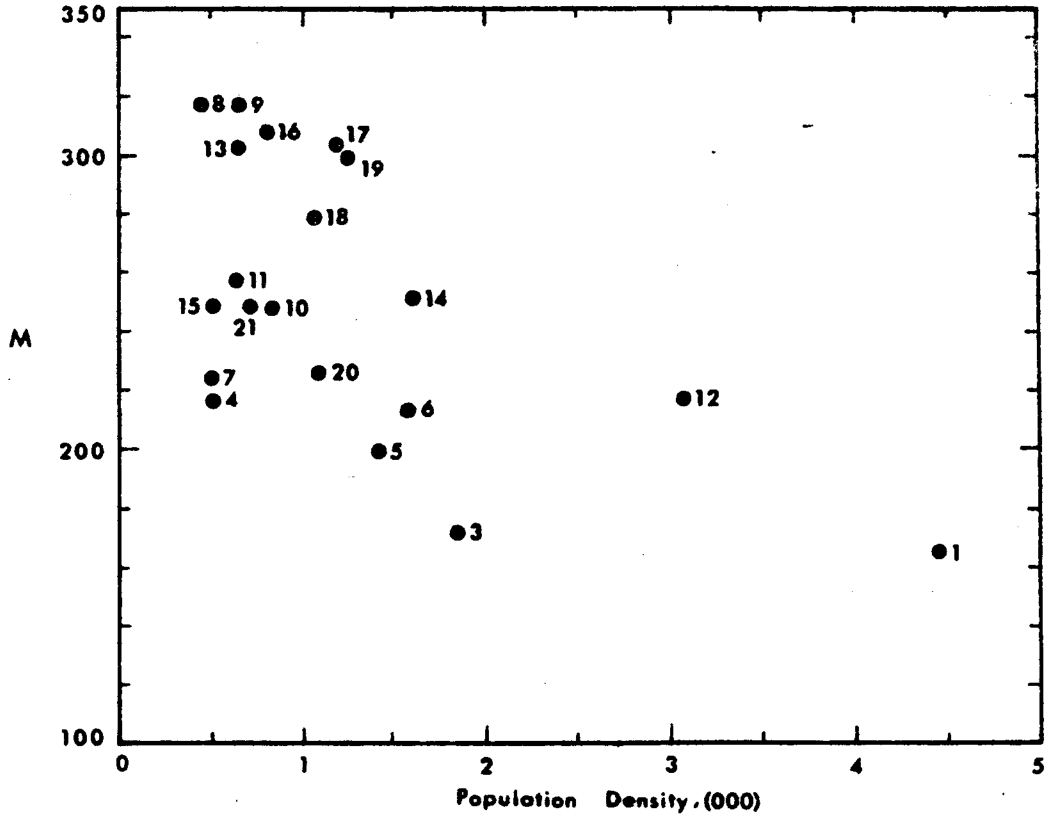
Analysis

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

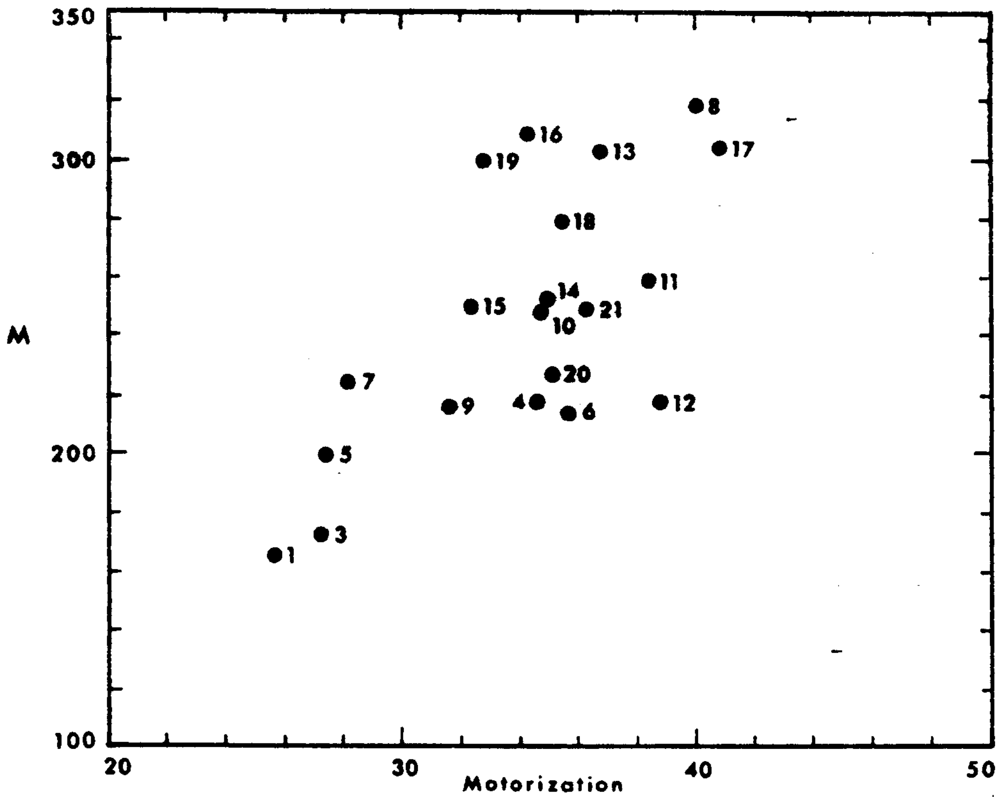
It has always been recognized that mobility is closely related to motorization, namely the higher the motorization, the higher is the mobility. However, Figure 3.2 shows a peculiar result. Although there is a general tendency for mobility to increase with motorization, the dispersion is too wide for 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

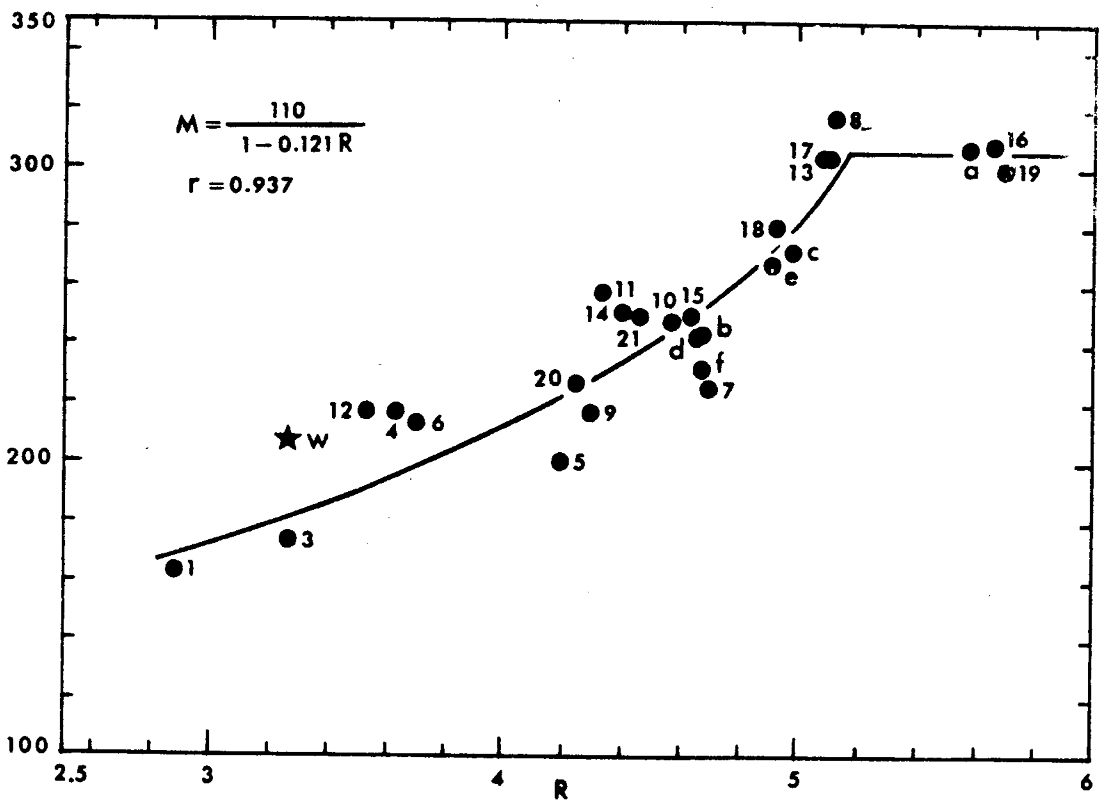
The relationship in Figure 3.3 is of particular interest in spite of the argument that M is inherently dependent on R; it is the nonlinear shape of the relationship which is of importance for the understanding and formulation of mobility.

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:

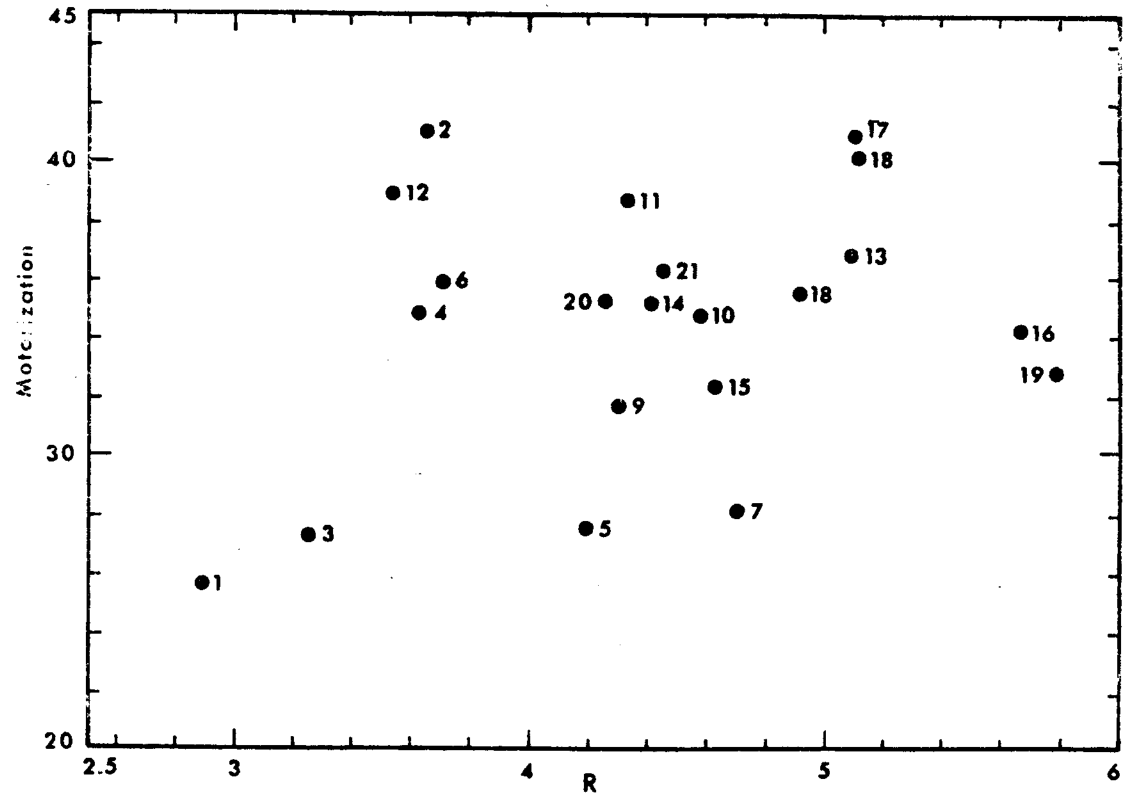
(a) Figure 36 in the publication "Future Highways and Urban Growth"[1/] presents the driver trip rates for the first, second, and third auto in multi-car households in Chicago, 1956, versus their location distance from the center. Indeed, the trip rate decreases successively for the second and third 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

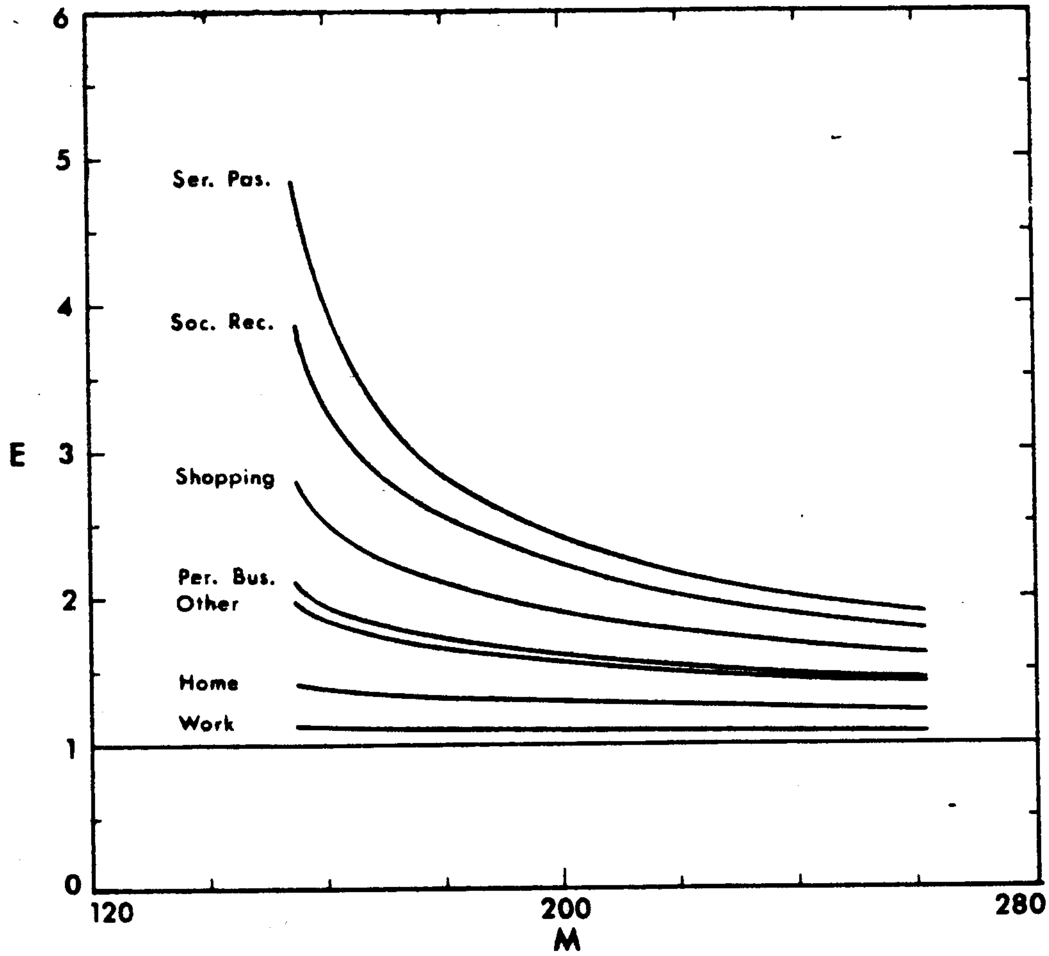
Table 3.4

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.

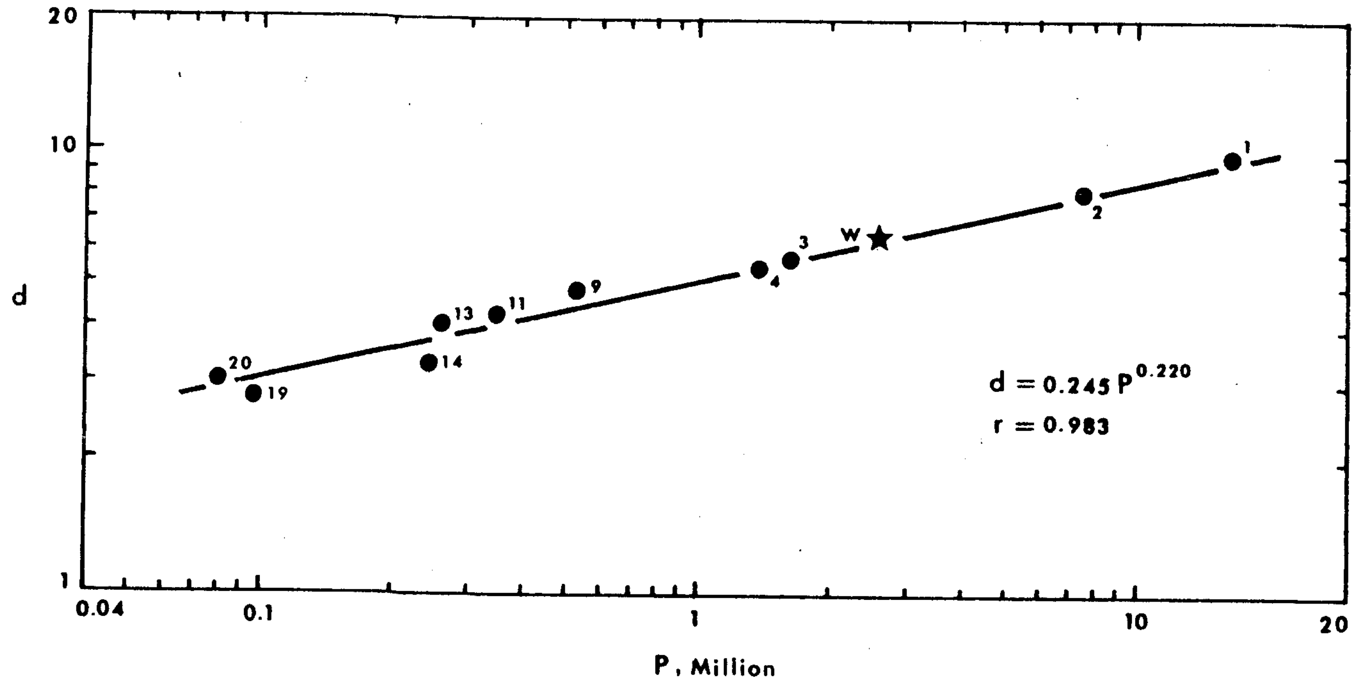


AUTO DRIVER AND PASSENGER'S INDEX OF ELASTICITY
BY TRIP PURPOSE vs. MOBILITY

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



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.

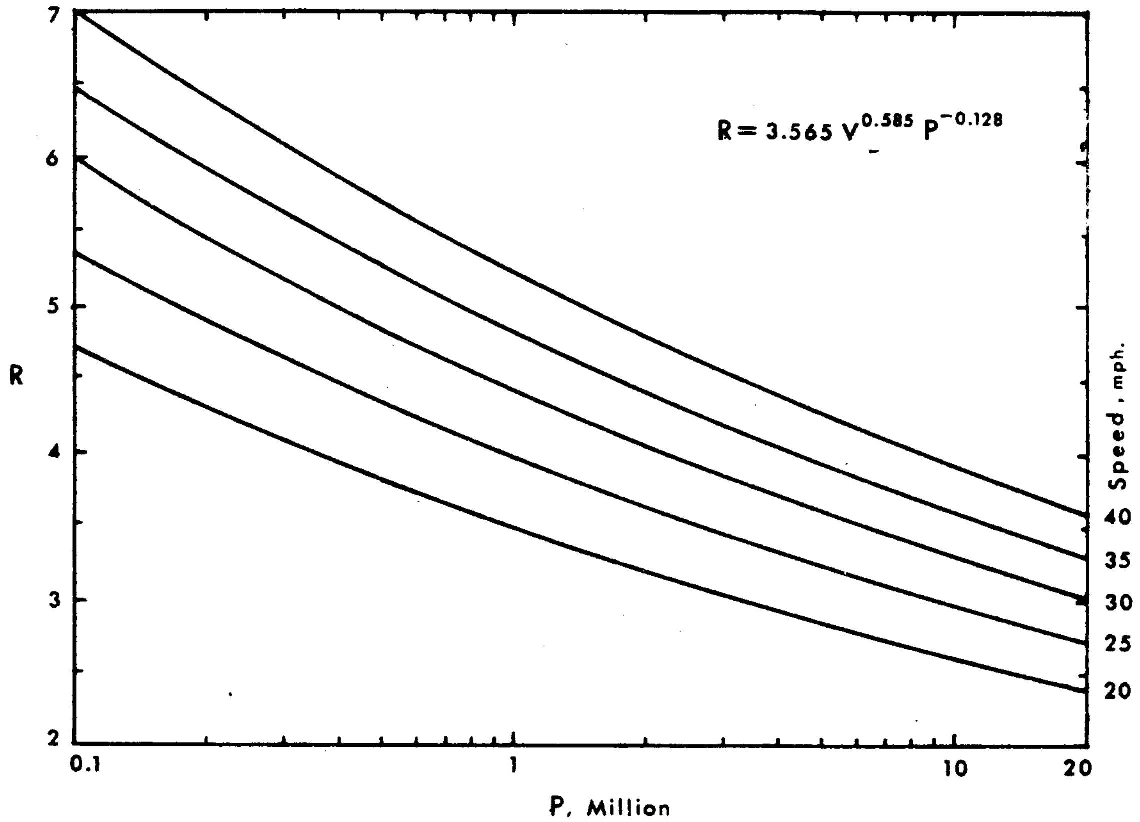
The formulation of R versus v and P was tested for the few studies which had detailed the necessary information, including Washington, D.C. The variability is quite noticeable in Table 3.7, where differences between estimated and given values of R reach and surpass 20 percent. Nevertheless, even such 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: $M = \frac{110}{1 - 0.121\ R}$ (Equation 3.1)

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

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

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

(b) The TT budget should be equal to:

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

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

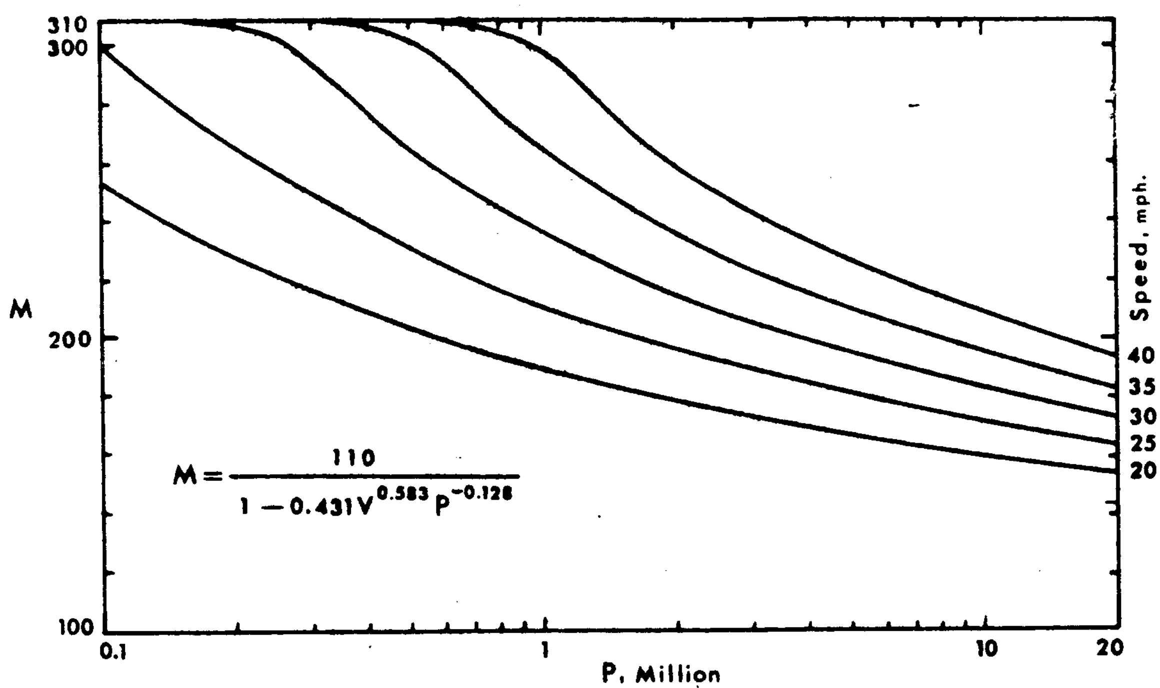
$$R = \frac{h}{t_{hr}} = 4.08\ h\ v\ P^{-0.220}$$ (Equation 3.8)

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

$$M = \frac{110}{1 - 0.494\ h\ v\ P^{-0.220}}$$ (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 micro-scale 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:

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

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:

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

Thus, α can be expressed as:

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

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:

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

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:

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

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

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

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.

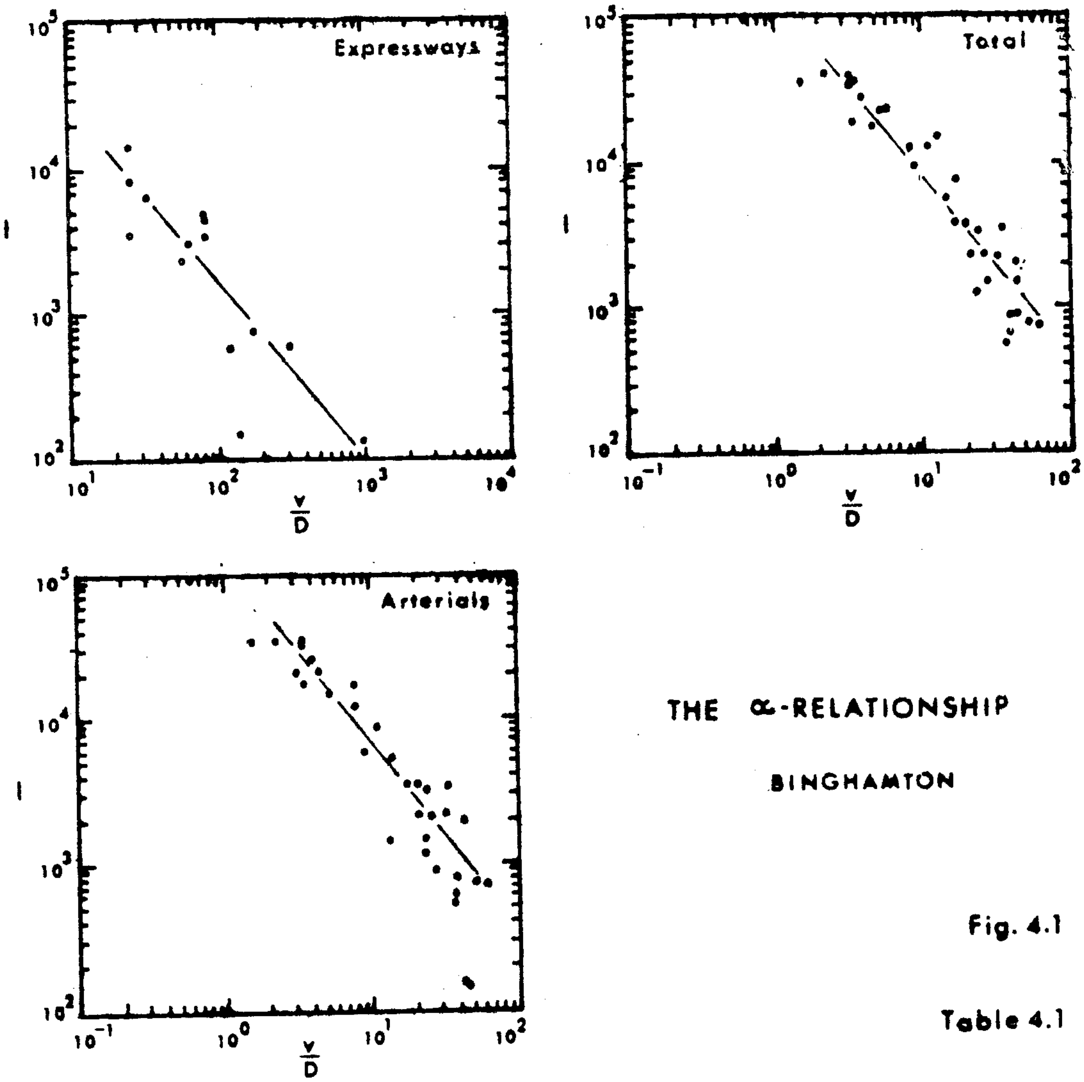
The results in Figures 4.1 to 4.6 indicate the validity of the alpha relationship under U.S. traffic conditions; in most cases, a clear linear relationship (on double logarithmic scales) emerges for both the arterial and the expressway networks as discussed in the next section. When comparing the above 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.



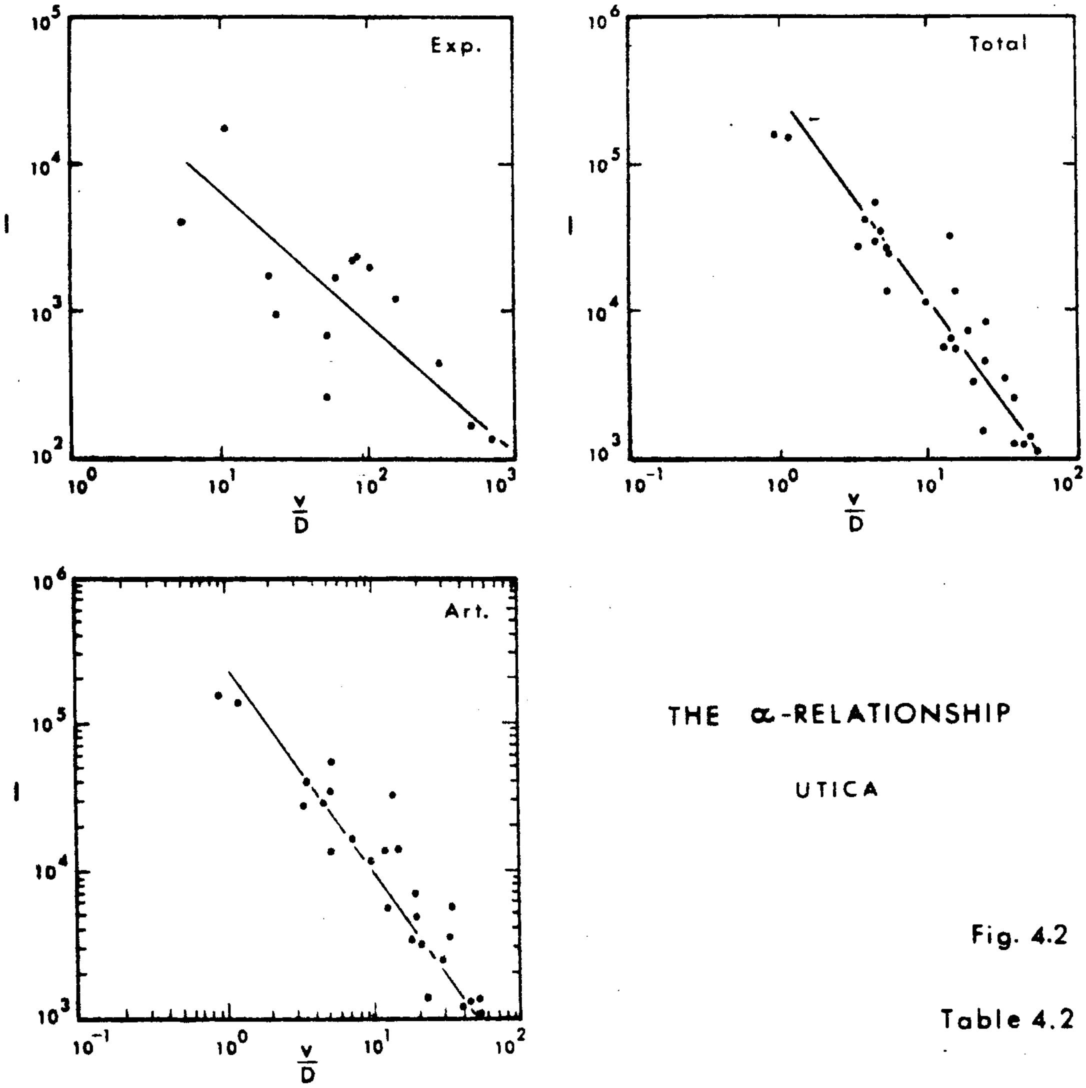
THE α-RELATIONSHIP

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



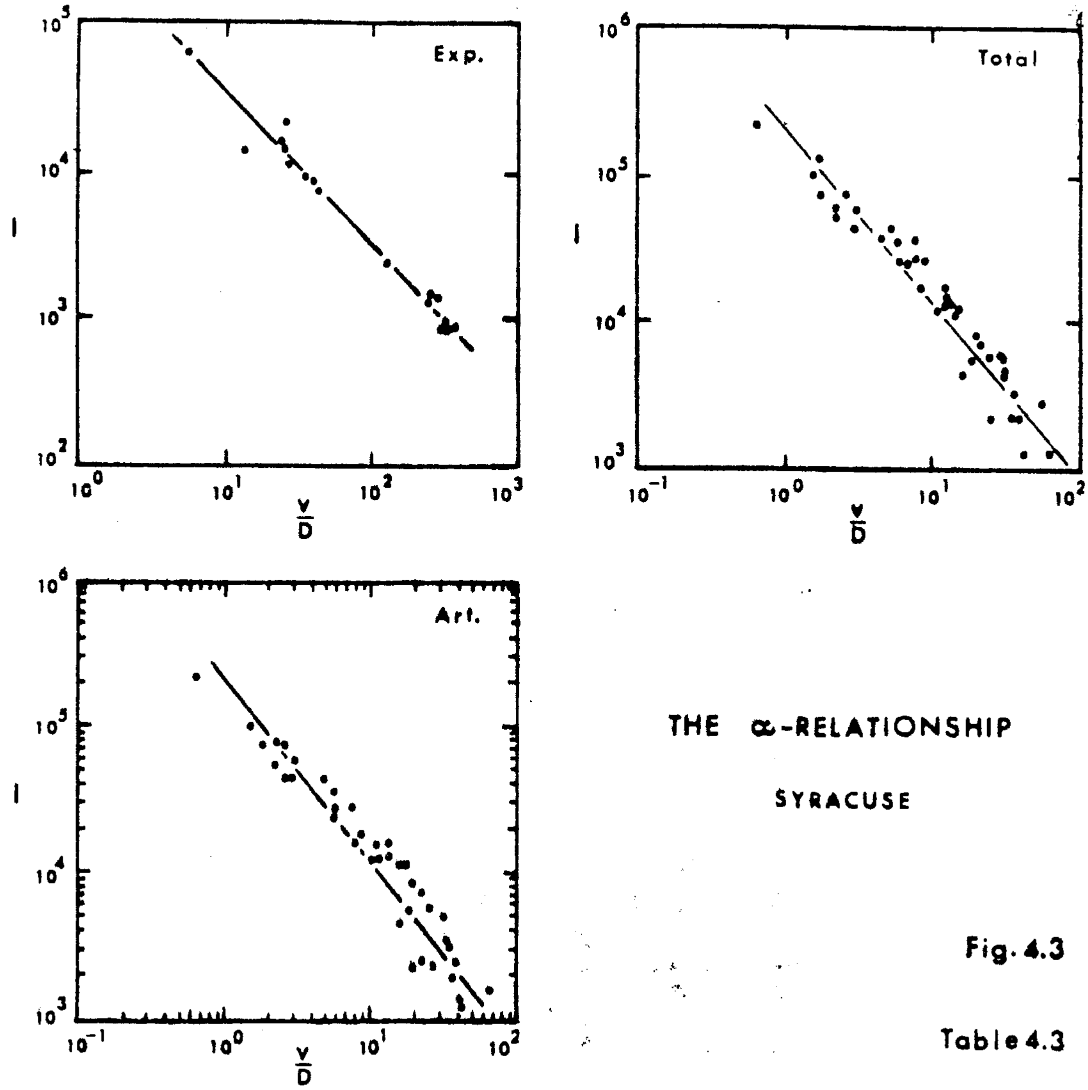
THE α-RELATIONSHIP

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



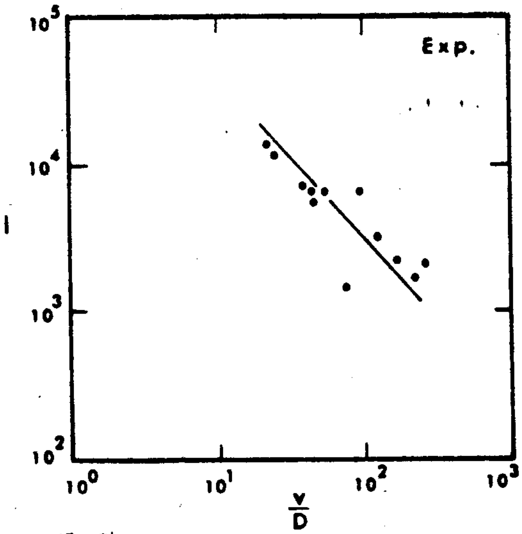
THE α-RELATIONSHIP

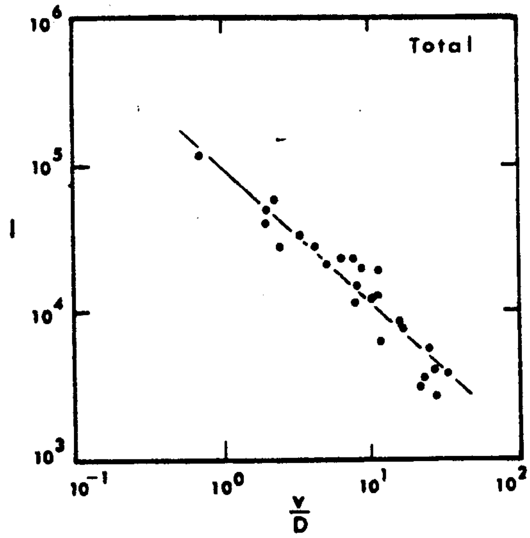
SYRACUSE

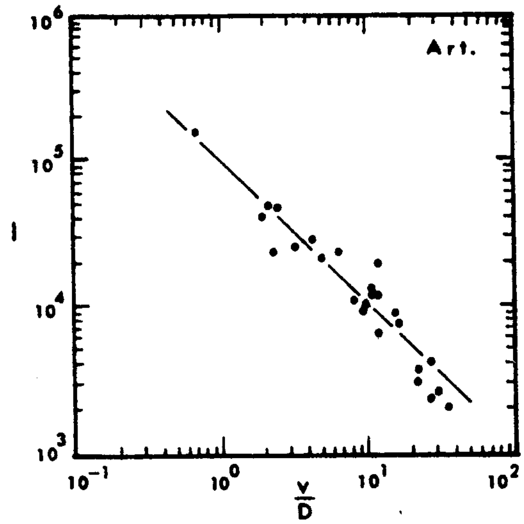
Fig. 4.3

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







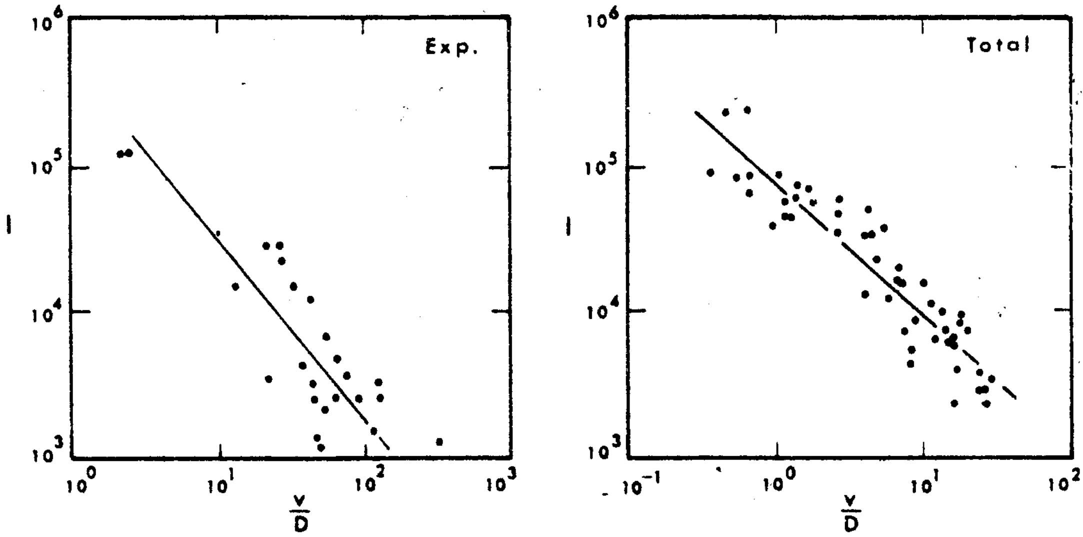
THE α-RELATIONSHIP

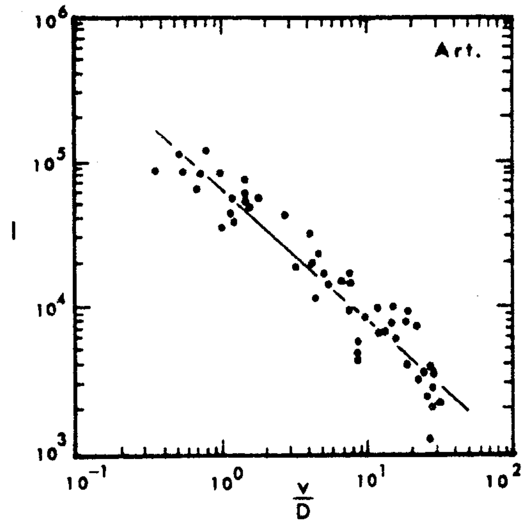
ALBANY

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





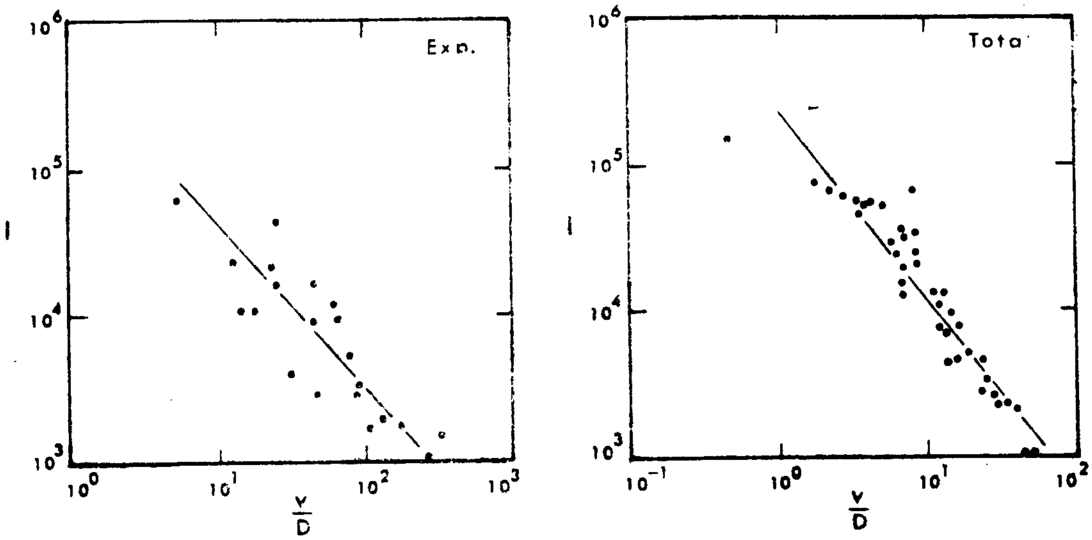
THE α-RELATIONSHIP

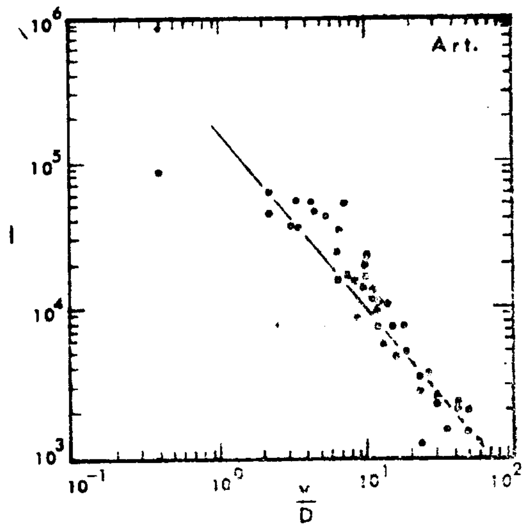
ROCHESTER

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.

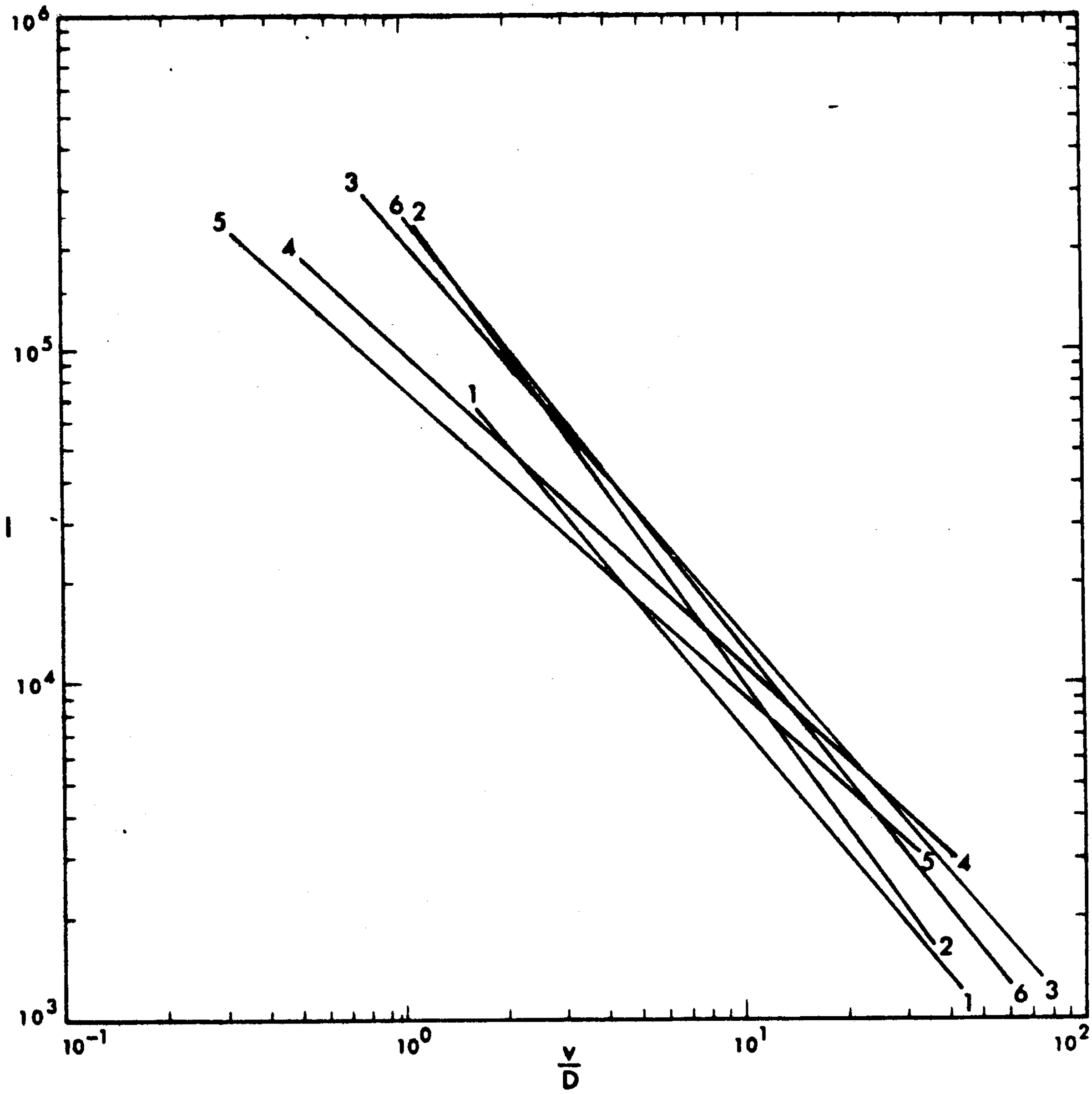
Of special interest is the tendency of the six relationships in Figure 4.7 to merge within a relatively narrow band along their middle parts. This tendency indicates that traffic districts with average traffic loads behave in a similar way (although their level of traffic performance may be quite different). 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