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THE "UMOT" PROJECT

YACOV ZAHAVI

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This report presents the results of two complementary research studies, conducted by the author for the U.S. Department of Transportation and for the Federal Republic of Germany Ministry of Transport.

16. Abstract

A new urban travel model is being developed to aid transportation policy analysis, based on a theory of consumer behavior. The model is based on the theory that travelers attempt to maximize their utility of spatial and economic opportunities, represented by the total daily travel distance, subject to constraints of time and money budgets.

The application of explicit constraints is a powerful tool, since the constraints do away with the need for much of the coefficient calibration of conventional models. Thus, once the constraints and unit costs of all alternative modes are known, the model produces estimates of such travel characteristics as daily travel distance, modal shares, and car ownership levels. These outputs are then compared with the observed values of the variables, and not calibrated to them, for the model's validation. This approach enables the model to be transferable both between cities within the same country, and over time.

The first part of the report develops the analytical framework of the model, which is found to be consistent with established economic principles. The second part examines the evidence of predictable regularities in time and money expenditures on travel by households and travelers, with favorable results. The third part develops the operational framework of the model, including travel generation, mode choice, and car ownership levels, all of which interact by a feedback process, to converge rapidly to the observed travel characteristics. The report concludes with recommendations for further developments of the model, especially with respect to the integration of urban structure within the feedback process.

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The author also wishes to thank Dipl. Ings. Dirk Zumkeller and Manfred Poeck, representatives of Kocks Consult GMBH, of Koblenz, for their assistance in carrying out parts of the research in Germany.

Last, but not least, the consultants to this study should be praised for their devoted efforts to assess and further develop the UMOT approach: Prof. Martin Beckmann, Dr. Thomas Golob and Prof. Antti Talvitie, who have accompanied the research to its conclusion; and Prof. Chong Liew and Prof. Richard Weissbrod, who were involved in the initial stages of the research.

FOREWORD

The results presented in this report are part of a long range research program at DOT which has as its objective the improvement of transportation planning methodologies. The emphasis is on providing analytical means to aid decision makers in exploring long term policy alternatives for major system changes. The initial focus of the program is on urban passenger transportation, with particular attention being given to estimating transportation energy consumption.

Great steps have been taken since the pre-1950 era of intuitive methods, and there are now available sophisticated, computerized planning tools that are widely used throughout the U.S. While these tools have been employed quite successfully for short-term, incremental changes in transportation systems, they have been found to be inadequate for assessing long-term socio-economic effects. In addition, they have been hampered by difficulties in transfer between cities. The underlying reason for this, I believe, is in the perception of the urban system as a cause and effect process, where the causes are calibrated to the observed effects under no explicit constraints.

The UMOT process, the subject of this report, is based upon a fundamentally different perception of the urban system. It is seen as a dynamic feedback process, linking people, transportation and urban form under explicit constraints. Given an urban form and transportation supply, the UMOT process generates all observed travel characteristics as direct outputs within the time and money constraints. This makes the UMOT a powerful tool for the evaluation of both short and long-term policy options under a wide range of scenarios.

Of course, much more needs to be done than is presented in this report to achieve these goals. The DOT program envisions further research in several important topics, including:

1. Further stratification of travel groups, geographically at least.
2. The determination of travel fields.
3. Improvements in the representation of important elements of urban form, such as housing, job locations, and facilities.
4. The introduction of dynamics to the equilibrium process.

In carrying out this program, steps have been taken to coordinate the effort in urban transportation with similar work done in the Federal Republic of Germany on intercity travel, and at the World Bank in transportation systems for developing countries.

Robert W. Crosby

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EXECUTIVE SUMMARY

- This report presents the results of two complementary research studies, conducted for the U.S. Department of Transportation and for the Federal Republic of Germany Ministry of Transport. The former study investigated and developed the theoretical framework of a proposed new transportation planning methodology, first conceptualized for the World Bank, and called the Unified Mechanism of Travel, or UMOT for short. The latter study involved testing several of the UMOT principles using observed data in Germany and supplemented by data from other countries.

1. Purpose

The purpose of the research reported herein is twofold. First, to analyze the consistency of previously observed phenomena that travelers within urban areas appear to have average daily time and money expenditures on travel which display predictable regularities both between cities and over time in the same country. Second, if such expenditures are indeed found to be predictable, the study intended to develop the conceptual framework of a new transportation planning tool which takes advantage of such regularities in relating travel demand and transportation system supply to urban form.

2. The UMOT Concept

The UMOT concept is based on the assumption that when the daily mean expenditures on travel, per traveler and per household(*), in time and money terms, display predictable regularities that can be attributed to such factors as the socioeconomic characteristics of the household, transport system supply and urban structure, and when these regularities are found to be transferable both between cities and over time in the same country, then these expenditures can be regarded as "travel budgets". Furthermore, under certain conditions these travel budgets may be applied as constraints on travel behavior.

The application of explicit constraints in modeling travel behavior is a powerful tool, since the constraints do away with the need for much of the coefficient calibration of conventional models.

(*) Within this context, "traveler" and "household" refer to a representative traveler or household within a socioeconomic group, and not to a specific, identifiable traveler or household who may, over time, move from one socioeconomic group to another.

Current travel demand models(*) are calibrated to the travelers observed choices. Since such choices are many and varied, separate models have to be calibrated to their components, such as trip rate by purpose, trip distance and time, mode choice, and trip distribution.

The UMOT process, on the other hand, is based on the money and time budgets under which travel choices are made. Thus, all travel components are unified by trade-offs within one system.

The implications of this concept can be stated in the following way:

(1) The Travel Money Budget

- The household's expenditure on travel is strongly related to its socioeconomic characteristics, and is stable over time.

- Hence, the total generated travel distance per household will depend on the allocated travel money budget and the unit costs, by mode.

(2) The Travel Time Budget

- The daily travel time per traveler is a function of such factors as travel speed and urban structure, and the function is stable over time.

- Hence, the total daily travel distance per traveler will depend on his allocated travel time budget and the travel speed, by mode.

(3) The Interaction Process

- Assuming that a household allocates to travel a money budget of M dollars per day and a time budget of T minutes per day, and it has m available modes with different travel speeds and costs, it then must choose a certain combination of modes to maximize its total spatial and economic opportunities, as represented by the total travel distance.

Solving this problem results in the following outputs:

- Daily travel distance, by mode (i.e., from which modal shares are direct derivation).

- The car ownership levels required to satisfy the demand for travel distance by car.

(*) Through common usage, models which develop estimates of travel are called "travel demand models", although this is technically imprecise. Nonetheless, the terms travel model and travel demand model are used interchangeably in this report. See Section 1.2, on p.6 of the report, for a further exposition of this point.

- Expenditures of money and time allocated to each mode and, hence, the expected revenues for public transit operators.

- Many other travel components, such as trip rates vs. trip distances, within the total travel distance; trip rates vs. trip times, within the total travel time; and trip distribution vs. urban structure, within the total travel money and time budgets.

These outputs are then validated by comparing them with the observed choices, not calibrated to them.

The following sections present the theoretical foundation of the UMOT and the empirical evidence for its application.

3. Theoretical Foundation of the UMOT

The travel behavior concepts of the UMOT process were developed with respect to a particular theory of human decision making called utility theory. While this is not the only theory capable of providing a basis for the analytical structure of the proposed process, it is adequate to, and may in fact be, the best alternative currently available, particularly in light of its extensive and successful use in describing many types of consumer choices in microeconomics.

The particular forms of utility functions applicable to travel situations were formulated, and it was found that these forms predict the empirical regularities in travel decisions which form the bases of the UMOT process.

Forecasting individual travel demand can be accomplished by two alternative approaches. The current approach is to calibrate a "demand" model to individual travel behavior with an extensive number of independent variables in order to describe the variability of individual choices. This approach has the difficulty that each of the independent variables must be predicted separately for the future date. Therefore, operational planning models are typically restricted to a subset of the independent variables, at a sacrifice of explanatory power.

The UMOT approach, on the other hand, is based on the observation that the variabilities in the travel budgets among individuals within groups are similar for all population segments. Therefore, assuming that such variabilities remain stable over time as well, it is necessary to forecast only the mean values of the budgets for each group. These mean values, together with the variabilities around them, provide the probabilities of individual travelers behaving in predicted ways.

One advantage of this process is that it needs only a few independent variables in order to predict individual travel behavior under new conditions.

4. The Findings

The findings of this study were very encouraging and agreed with previous findings. Although they need further verification in more cases in order to become conclusive, their consistency in the available cases in Germany, the U.S., the U.K., and even in developing countries, appears to be above coincidence, as summarized below.

The Travel Time Budget (TT-budget)

(1) The mean daily TT-budget per motorized traveler (car, bus, train, taxi) of each of 55 different household types in Munich is stable over weekdays, and is similar to the TT-budget observed in other cities of developed countries.

(2) The variations around the mean value of daily TT-budgets by individual travelers within each population segment in Munich and Nurenberg are very similar for all population segments, and are consistent with those found in other cities, including cities of developing countries (Coefficient of variation about 0.6).

(3) The mean daily TT-budget per traveler is an inverse function of speed, decreasing as speed increases, to an asymptote of about 1.1 hours per day. Thus, when low speeds increase, such as by transfer from bus to car travel, part of the "saved" time is actually saved, while the other part is traded-off for more travel distance. However, at initially high speeds, practically all speed increases are traded-off for more travel distance.

(4) The minimum mean daily TT-budget per motorized traveler in an urban area, at high travel speed, is just over 1 hour per day. The maximum mean daily TT-budget per motorized traveler, at low travel speed, is about 1.5 hours per day in cities of developed countries.

However, in large and/or fast expanding cities in developing countries, the mean daily TT-budget per motorized traveler at low travel speeds can reach the two-hour level per day.

In conclusion, the mean TT-budget per traveler was found to be closely related to the speeds of the available transportation system supply, and to urban structure. High income travelers, having better opportunities for traveling at higher speeds than low income travelers, can both travel more daily distance (i.e., and have better spatial and economic opportunities) than low income travelers, and expend less travel time. Low income travelers, on the other hand, have to spend more time in order to travel less daily distance.

This difference in mainly due to the travel money budget, as detailed below.

The Travel Money Budget (TM-budget)

(1) The mean TM-budget per household, for all households over time, is found to be a relatively stable proportion of disposable income in Germany, the U.S., the U.K. and Canada. While the proportion may vary by definition and conditions between countries, the stability within one country remained unchanged even during the energy crisis and cost increases in 1973-75.

(2) The daily TM-budget in an urban area is strongly related to the household's disposable income level and car availability. It is about 11-12 percent of disposable income for car owning households, and about 3-5 percent for carless households, for all income levels. Such results in the Nurenberg region are similar to those in Washington, D.C. and Twin Cities in the U.S.

(3) The significant gap, or "quantum-jump", in the TM-budget of car and carless households suggests that purchasing a car is a major household decision, closely related to other major decisions, such as residence location. However, the probability of a household to make such a decision increases rapidly with income.

(4) The daily variations around the mean TM-budgets per household within each segment of the 55 household types in the Nurenberg region (as reflected by the daily travel distance) are higher by about 50 percent than the variations around the mean TT-budgets. One explanation for this is that it is easier to transfer money between days than to transfer travel time; daily travel times are constrained by 24-hours per day, while the travel money is constrained by the monthly or the yearly income. The point to note, however, is that the coefficient of variation of the TM-budget, similar to the case of the TT-budget, is very similar for all population segments.

In conclusion, the TM-budgets of car and carless households appear to be strongly related to income and car ownership, and stable over time. Hence, the TM-budget, together with the TT-budget, can be applied as two simultaneous budgets under which all travel choices take place, as summarized in the following section.

It may thus be inferred that travelers have preferred levels of expenditures for travel in both time and money. In other words, travelers prefer to expend certain amounts of time and money for travel in order to derive the benefits that it brings. However, actual expenditures may or may not accord with preferred expenditures, depending on income, urban form and transportation supply. When such a difference occurs, a social disequilibrium may be said to exist, despite the fact that a local equilibrium in travel demand and supply has been achieved. The social disequilibrium can be regarded as a force for change in urban structure or transportation supply.

5. Implications of the TT and TM budgets

Given the households' socioeconomic characteristics and the transportation system characteristics, the UMOT process proceeds along the following, simplified, steps:

(1) Household income affects the upper limit of the TM-budget, allocated to travel. Household size and income level affect the number of travelers per household and, hence, the initial TT-budget per household.

(2) Applying the travel-distance maximization process under the TM and TT budgets, and the unit costs of available or planned modes, in money and time terms, results in the demand for travel distance by each mode.

(3) Car ownership is generated by the demand for car travel distance.

(4) The interaction between the estimated number of cars and a given road network results in new unit costs of travel. These new unit costs are fed back into the travel demand phase, affecting both the TT-budgets (which are sensitive to speed) and the demand for travel distance by mode, and the process is repeated by iterations until convergence of the demand for travel and system supply is reached.

Tests have shown that convergence of the process is rapid, and results in the observed travel characteristics.

It should be noted at this stage that:

(a) The process converges to the observed travel characteristics even when starting the process with extreme assumptions, such as every household owns, say, five cars; the constraining budgets and unit costs ensure that the process will converge rapidly to the observed characteristics, thus suggesting that the process is robust.

(b) The variability between individual households is expressed by the variabilities in the TT and TM budgets, thus resulting in the probability of a household with certain socioeconomic characteristics to own 0-1-2-3+ cars and make certain travel choices.

(c) Since the process is not dependent on calibration to observed travel characteristics, it is responsive to policy options beyond observed conditions, such as to new modes or to new travel costs. Furthermore, since the constraints are more stable than the choices (i.e., choices change when conditions change because of the relatively stable constraints), there is more assurance in the transferability of the process between cities and over time than with models which are calibrated to the observed choices.

(d) The process gives equal attention to all modes, generating estimates of travel by all defined modes, such as walking, car, bus, urban and interurban train, and even air modes, all of which are expressed by their operational characteristics.

Further developments, as suggested below in Section 7, include the addition of other characteristics, such as comfort and safety, in order to make the process more sensitive to small differences between similar modes.

6. Urban Structure

Operational urban form models and travel demand models currently are developed and operated separately, where each one requires the assistance of the other in order to deal with the complexities of the urban system.

The UMOT process has the potentiality of combining both aspects in one process. Preliminary tests suggest that given system supply, the process can generate the probabilities of different household types to reside in certain areas of a city. In this case, however, the process will have to include the housing supply as an explicit component, and the travel utility functions will have to include money expenditures on housing.

One important advantage of the UMOT process in dealing with urban structure is the question of equilibrium. Practically all urban form models that deal with dynamic changes in urban structure are based on the principle of equilibrium between demand and supply, so that all tested alternative urban structures always reach, or at least approach, equilibrium conditions, such as between population and job spatial distributions. In the UMOT process, on the other hand, urban structure may impose on the population long trip distances or trip times/costs which may become the binding constraints, overriding the preferred TT and TM budgets. Put another way, travelers in such cities may have to spend 4 hours per day and 25 percent of their income in order to travel to and from work, as is the case for some population segments in several cities of developing countries. While conventional models regard such a case as being in equilibrium, based on the definition that observed demand is always in equilibrium with supply, the UMOT process measures the amount of disequilibrium between the preferred TT and TM budgets under stable urban conditions and the TT and TM budgets that travelers will be forced to spend in order to satisfy their minimum demand for travel, such as nondiscretionary travel.

This subject is one of the areas suggested for further development, as proposed below.

7. Conclusions and Recommendations

The conclusions may be summarized as follows:

(1) The analyses conducted in Germany corroborate previous observations, in that households and their travelers tend to exhibit consistent and predictable travel time and money expenditures, closely related to the socioeconomic characteristics, levels of system supply and urban structure. The data also display very stable variations around mean TT and TM budgets for all population segments, which reflect individual departures from the groups' mean values, such as daily variations and personal preferences in travel behavior.

(2) The UMOT process appears to be theoretically consistent and passes empirical tests by being able to produce observed travel characteristics independently, even without being calibrated to them. Furthermore, all travel components are closely interlinked by trade-offs within the process.

(3) The UMOT process appears to be able to address many important policy issues, such as increasing fuel prices, land use control, population migration, and changing transportation infrastructure, when based on the travel budgets under which decisions are made.

The resultant changes in travel behavior can be predicted for each policy alternative without having to assume that each new choice is based on the interpolation or extrapolation of previous relationships. Indeed, extreme policy changes can bring about extensive, but interrelated, changes in the various travel choices.

The Recommendations may be summarized as follows:

(1) Further developments of the UMOT process should include:

(a) Further verification of the regularities of travel budgets over time.

(b) Determination of whether additional attributes besides travel time and cost are needed to derive mode choice from the budgets. These attributes are allowed for in the utility functions of UMOT. A further part of this investigation would determine what modal characteristics, such as comfort and safety, would be required.

(c) To further relate trip rate with trip distance for different purposes and modes.

(d) Further elaboration of the car ownership model, as a link to travel demand, system supply and urban structure.

(2) The relationship of travel and urban structure should be more fully developed. This would include the determination of aspects such as the probability distribution of residence and job locations.

(3) A further goal of this work is to include the dynamic processes of urban development and travel as integral parts of the model.

(4) Even at this stage of development of the UMOT process, the multiple interactions among the travel components require its development into a computerized model. Such development would enable it to both be examined and checked under more complex situations and to be tested on more data that vary over time.

(5) A regional and interurban UMOT model, not being dependent on urban structure, can be developed directly as a computerized model, including car travel and all major public transport modes, ground and air.

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CONTENTS

(Cont.)

Page

B. The Travel Money Budget

APPENDICES

THE UMOT PROJECT

FOREWORD

1. This report presents the results of two research studies, conducted during 1978-1979 in two different countries:

   (a) "Further Development of the UMOT Process"(*), carried out for the U.S. Department of Transportation, Research and Special Programs Administration, Office of Systems Engineering, Washington, D.C.;

   (b) "Verification of the VUSI Components"(**), carried out in collaboration with Kocks Consult GMBH, Koblenz, for the Ministry of Transport of the Federal Republic of Germany.

   The former study investigated the conceptual framework of a proposed transportation planning methodology called the UMOT process, concentrating on its theoretical bases. The latter study involved testing several of the UMOT principal assumptions using observed travel data.

   While the two studies were initiated as separate projects, their complementarity was soon recognized and - to the full credit and foresight of the two authorities - an interchange of progress reports ensued, culminating in this integrated final report.

2. The presentation in this report proceeds from the general to the specific, and from the theoretical structure of the UMOT to its testing and application. The report is divided into six parts:

   Chapter 1. Introduction, outlines the UMOT process and discusses the basic principles of the approach.

(*) UMOT - Unified Mechanism Of Travel

(**) VUSI - Verkehr Und Stadt als Interaktionsmechanismus (UMOT)

Chapter 2. The Theoretical Basis, presents underlying principles and mathematical formulations of models used within the UMOT process. Various model components are defined and analyzed for internal consistency and potential applicability.

Chapter 3. The Travel Budgets, summarizes available German travel data, supplemented by data from other parts of the world. The data are analyzed and compared, both cross-sectionally and over time, in light of compatability with UMOT assumptions and model results.

Chapter 4. Implications of the Travel Budgets, explores the effects the relatively stable time and money budgets have on relationships among travel distances and speeds by modes.

Chapter 5. The UMOT Model, details the structure of the UMOT process, with several example applications and sensitivity tests.

Chapter 6. Conclusions, summarizes the conclusions from the research study and recommends directions for further developments.

Readers not interested in detailed theoretical model developments might find it appropriate to skip some of the material presented in Chapter 2.

3. The approximate shares of the two projects in the six chapters, in percent, are:

Chapter	U.S. DOT	F.R.G. MOT
1	50	50
2	90	10
3	10	90
4	20	80
5	80	20
6	50	50

4. This report is the outcome of concerted efforts of a devoted team of consultants, who have put much thought and time into this research study.

While it is not possible to isolate the personal contributions of each consultant in this report, the general fields of expertise are:

Prof. Martin Beckmann - mathematical economics and microeconomic theory;

Dr. Thomas Golob - consumer theory and transportation analyses;

Prof. Antti Talvitie - systems performance and numerical analyses.

Two additional consultants participated in the early stages of the study:

Prof. Chong Liew - econometrics;

Prof. Richard Weissbrod - urban geography.

The author is deeply indebted to all consultants for their helpful assistance. However, the final responsibility for the opinions, analyses and conclusions presented in this report rest with the author only.

CHAPTER 1: INTRODUCTION

1.1 The Approach

The UMOT was conceptualized for the World Bank, Urban Projects Department, as a tool for the rapid estimation of urban travel and the evaluation of alternative transportation plans (Zahavi, 1977). It was further developed for the U.S. Department of Transportation and tested with actual travel data for the Ministry of Transport of the Fed. Rep. of Germany, as presented in this report.

The UMOT process differs from the majority of transportation planning procedures, whether aggregate or disaggregate, recursive or simultaneous, in several aspects. These differences are elaborated upon in the following chapters but can be summarized here as follows.

(1) Calibration: Most conventional models are calibrated to the observed choices. Such models are then validated by their ability to reproduce the same observed choices, such as car ownership, trip rates and modal choice. The UMOT process, on the other hand, is based on parameter estimation of the constraints under which the choices are made. The process is then validated by its ability to produce the observed choices as independet outputs.

(2) Travel Demand: In most conventional models travel demand is expressed by trip rates. Such models start with trip rates and conclude with passenger and vehicle travel distance. The UMOT process starts with the "demand for travel" as expressed by desired passenger and vehicle travel distance that can be generated within the travel constraints and, after a feedback process, concludes with trip rates.

(3) Car Ownership: In most conventional models car ownership is treated as a long-term decision that affects short-term trip generation and mode choices. In the UMOT process long-term and short-term decisions interact. For instance, it is proposed that demand for high-speed personal travel generates demand for cars. The number of cars, estimated to satisfy the demand then interacts with system supply, resulting in revised unit costs of travel. These costs then feed back

into the first phase, resulting in a revised demand for car travel and for each alternative mode. The process is iterated until convergence is reached. Tests have shown that this convergence is rapid.

In summary, a major difference between conventional planning processes and the UMOT process is that conventional models are generally calibrated to observed choices, such as car ownership, trip rates and modal split, choices which may change beyond the range of observations if conditions change. A basic assumption, therefore, is that such models can predict future choices, even beyond the range of base-year observations. The UMOT process, on the other hand, can be initiated even with extreme assumptions, such as every household in an urban area owning 5 cars, and the model outputs will nonetheless converge to the observed choices. This is achieved by shifting the emphasis from the observed choices to the constraints under which the choices are made.

The UMOT process presupposes that most travel choices are made because travelers are under constraints, such as those of time and money. Current transportation supply conditions dictate how travelers can allocate their constrained resources so as to best achieve travel benefits. If these conditions change, the choices are likely to change, while the constraints remain relatively stable. A purpose of this study is to identify such travel constraints, test their stabilities over space and time, and - if they are verified - explore their implications to travel modeling.

1.2 The Measurement of Travel Demand

"Travel demand", in the conventional meaning, is the part of travel that is realized and observed after interaction of the "demand for travel" with system supply. Travel demand is currently measured mostly by trip rates, based on the reasoning that the direct "utility", or benefit, of making a trip to a certain destination for a certain purpose by a certain mode at a certain time, should surpass its "disutility", such as its cost in time and money terms.

The performance and productivity of system supply, on the other hand, are measured by the passenger-km., ton-km., or vehicle-km. "produced" at certain speeds. Therefore, the only possible way to establish a common denominator between demand and supply is to base it, in both cases, on either trips or travel distance. There is an increasing number of independent indications to suggest that the daily travel distance per traveler/household is a better measure of travel demand than trips, especially when aggregating travel over time and travelers. While more on this subject is detailed in Section 2.6, the following example illustrates the problem and its possible solution.

Consider, for example, a traveler who is observed to make 6 trips per day in his small home-town, but after moving to a large city is found to make only 3 trips per day: Did his travel demand decrease ?; Is his utility of travel, and mobility, less in a large city than in a small town ?; Or did the utility of each trip change ?

Let us now add another travel component to the above example, namely trip distance, and it is found that the trip distance is 5 km. in the former case, and 10 km. in the latter case. It now becomes evident that the traveler covers 30 km. per day in both cities, within which he trades off trips vs. trip distances. Put another way, city size, which affects trip distances, can also affect trip rates, while the total travel demand, if measured by the daily travel distance, may remain unchanged by city size. The question, of course, is whether travelers do behave in this way ?

Table 1.3-1 presents one such example, from England, for the relatively small town of Kingston-upon-Hull and the large metropolitan area of London. Although the size of the study area of Kingston-upon-Hull is only 4.4 percent that of London, the daily travel distance per average car is similar in both cities, while the trip rate and trip distance are inversely related within the total travel distance. The same patterns were also observed in a wide selection of cities in the U.S., Europe and developing countries (Zahavi, 1979-a).

Table 1.3-1: Travel Characteristics in Two U.K. Cities

Characteristic	Kingston-upon-Hull	London
Year	1967	1962
Population	344,890	8,857,000
Area, Sq.Km.	107	2,450
Cars	43,185	1,249,450
Cars/100 Persons	12.5	14.1
Car Trips	238,000	4,119,000
Car Trip Rate	6.25	3.27
Trip Distance, Km.	4.15	7.18
Trip Time, Min.	6.9	13.7
Car Daily Distance, Km.	25.9	23.5
Car Daily Time, Hrs.	0.72	0.75

An additional interesting result in the above example is that the same inverse relationship also applies to the trip rate vs. trip time within the total daily travel time per average car which, once again, is very similar in both cities, namely 0.72 vs. 0.75 hours.

One possible interpretation of the above example is that the daily travel per average car driver in the two cities, if measured by the total daily travel distance, and for which the traveler has to pay in both time and money terms, is practically the same. It may, therefore, be inferred that if we wish to have a measure of travel demand, that can be generated within certain amounts of allocated travel time and money, and which is transferable between cities of different sizes, it appears that the total daily travel distance per representative traveler/household is a better measure than the daily trip rate. It is shown later in this report that this measure of travel allows us to unify travel demand, system supply, car ownership, modal choice and urban structure within one operational system, with full feedback between all components.

That travel distance, at least for car travel, is transferable between cities, as well as even between countries, is shown also in Table 1.3-2, which summarizes the daily travel per average car (internal-internal trips of cars registered in the study area) in the metropolitan area of Washington, D.C., U.S. 1968, the Nurenberg Region in the Fed. Rep. of Germany 1975, and the city of Kuala Lumpur, Malaysia 1973.

Table 1.3-2: Travel Characteristics of Washington, D.C., Nurenberg and Kuala Lumpur

Characteristic	Washington	Nurenberg	Kuala Lumpur
Year	1968	1975	1973
Population	2,558,100	1,160,000	912,490
Area, Sq.Km.	3,410	3,000	337
Cars	1,018,900	328,000	65,440
Cars/100 Persons	39.8	28.3	7.2
Car Trips	3,342,000	1,007,000	443,950
Car Trip Rate	3.28	3.07	6.78
Car Trip Distance, km.	10.59	11.20	5.36
Car Daily Distance, km.	34.7	34.4	36.3

It may be inferred from the above table that travel distance is indeed a relatively stable measure of travel, transferable between cities, while the trip rate and the trip distance interact within it by trade-offs.(*)

Much attention is given to such relationships already at this introductory stage of the report in order to emphasize two points; first, that most travel components interact with each other and, therefore, they should be treated simultaneously within one analytical system; and second, that if a model is to be transferable <u>over time</u>, for prediction purposes in one city, it should first demonstrate transferability <u>over space</u>, between different cities, with no need for recalibration of the model to the isolated travel components, such as trip rates. This, then, is also a prerequisite for the UMOT process.

(*) Variations about mean values, on a disaggregate levels, are discussed in Section 4.8.

An additional important conclusion from the above examples is that when travel components are summed up over a day (and preferably over a more prolonged period, such as a week), several travel factors and patterns emerge as stable. While the observed stability of the daily travel distance per average car regardless of city size has many implications for both planners and policy makers, as discussed in Section 4.11 , it is quite obvious that it is still only one part of a more complex system, since different households may have three cars, or no car at all, and still generate travel by other modes. Hence, when extending the search for travel behavioral factors which are stable, all results lead to the travel budgets of time and money that travelers/households are willing to allocate to travel, and within which all observed travel is generated.

At this stage, however, several questions need to be addressed before proceeding with development of the UMOT process. Foremost are the questions:

- Do such travel "budgets" exist in the real world ?
- If such travel budgets exist, can they be derived from available travel observations, and can they be related to the socioeconomic characteristics of population segments ?
- How stable are such budgets spatially and temporaly, and what are the distributions around the means of the budgets for different population segments ?
- How sensitive are the travel budgets to exogenous changes, such as changes in the cost of travel ?
- How can the "willingness" of population segments to allocate travel budgets be inferred and estimated if they are not actually observed ?
- Finally, how can they be integrated within a unified theory of travel ?

A first step in answering the above questions is to determine whether or not the requirements of the UMOT process are condusive to the development of travel demand models which are consistent with established theories of human behavior. This is the subject of the next chapter.

CHAPTER 2: UMOT MODELS OF TRAVEL BEHAVIOR

2.1 Introduction

The UMOT process is based upon the strong evidence that travelers have two explicit and separate travel budgets, of money and time, as detailed in Chapter 3. The effects of such money and time budgets on travel behavior can be summarized as follows:

(1) The Travel Money Budget

- o The household's expenditure on travel is strongly related to its income, and is relatively stable over time.
- Hence, the total generated travel distance will depend on the unit costs, by mode.

(2) The Travel Time Budget

- o The daily travel time per traveler is relatively stable over time.
- Hence, the total travel distance will depend on the travel speed, by mode.

(3) The Interaction Process

- Assuming that a household allocates to travel a money budget of M dollars per day and a time budget of T minutes per day, and it has m available modes with different travel speeds and costs, the question is by what combinations of modes can the household maximize its spatial economic opportunities, as represented by the total travel distance ?

The first purpose of the research reported in this chapter is to test whether principles underlying the UMOT process are consistent with established theories of behavior in economics. The second purpose is to explore implications of such economic theories to further formulation and verification of the UMOT process. The particular economic theory chosen to accomplish these purposes is consumer utility theory, as elaborated in the following sections.

Those models within the UMOT process which deal directly with traveler decision-making behavior must satisfy three sets of requirements:

(1) The models must correspond to UMOT objectives in terms of transferability, data requirements and policy sensitivity. Since the UMOT is ultimately intended for use as a planning tool for cities and regions of various sizes, with parallel extension to interurban travel, in countries of various levels of economic development, the behavioral models must be transferable among diverse population groups without recalibration.

Data availability restrictions dictate that the models use only three types of socioeconomic data: total households within a study area, household size distributions, and household income distributions. Further stratification is possible - and recommended - if more basic data are available.

Policy sensitivity needs dictate that meaningful inputs also include transportation system supply, in terms of travel times and costs by all modes, and data on the urban/regional structure. Finally, the behavioral models must generate outputs in terms of travel demand by mode and demand for car ownership.

(2) The models must yield results which are consistent with empirical observations when based on the UMOT hypotheses. Travelers are postulated to face a minimum required amount of travel, called nondiscretionary travel. Decisions involving travel over and above the minimum travel, called discretionary travel, are subject to constraints on the amount of time and money individuals and households are willing to spend for <u>all travel</u> during an average day. These constraints, called budgets, are observed to be relatively stable, but are in turn functions of the total resources available to the individual or household (that is, to total available time and income).

(3) The models must be consistent with established research in the social and behavioral sciences. In particular, microeconomics and psychology offer potentially useful theoretical concepts.

The purpose of the research reported in this chapter is to establish whether or not there is a theoretical basis for travel behavior models which allows the incorporation of travel budgets in a manner consistent with behavioral science principles. It is proposed herein that such a theoretical basis does exist, although further testing is needed before final conclusions can be drawn.

2.2 Summary of Chapter 2

This section presents a summary of the steps of model developments detailed in the rest of this chapter. The summary is presented also for the convenience of readers not interested in the theoretical aspects of the model, who might find it appropriate to skip the material detailed in the following sections, and proceed to Chapter 3.

The proposed theoretical basis of the UMOT model involves utility theory from microeconomics. Utility theory principles have been previously applied in travel demand forecasting models. For example, applications have been reported in the context of mode choice (Quandt and Baumol, 1966; Shunk and Bouchard, 1970), trip generation and distribution (Niedercorn and Bechdolt, 1969; Beckmann and Golob, 1972; Golob et al., 1973), car ownership (Beckmann, et al., 1973) and combinations of travel decisions (Golob and Beckmann, 1970); Charles River Associates, 1972). The present application is consistent with previous work, but it differs by drawing upon many economic principles heretofore not utilized in travel models.

The theoretical developments of the UMOT model begin in Section 2.3 with an introduction to the concept of utility as a quantification of preferences. All choice models based upon traditional utility theory are shown therein to be consistent with the premise of "rational choice". Rational choice in turn is useful in relating utility theory models to models of decision-making behavior developed in psychology, and is useful in defining which choice scenarios meet the criteria for representation by utility theory models. Section 2.3 concludes with a definition of the concept of "diminishing marginal utility", which is a salient characteristic of mathematical functions used in representing utility.

In Section 2.4 the general form of a travel utility model is presented and analyzed. This model form can be used as the basis for a wide variety of travel forecasting models. Indeed, it serves as the basis for both the travel generation - modal choice model proposed in Sections 2.7 - 2.10 and the car ownership model proposed in Section 2.11. In the present section, those qualitative properties of the model which characterize the model in any application are derived. These properties, listed on page 20 and 21 are shown to be consistent with general economic principles.

In Section 2.5 the general form of the utility model is made operational in a travel forecasting sense by defining specific mathematical forms for the utility functions. Logarithmic forms are chosen because these forms are shown to be the only forms which are consistent with the observed relationship that travel money expenditures are approximately a fixed proportion of income over certain income ranges. The implications of using the logarithmic form are further investigated in the following Sections 2.7 through 2.9.

The theoretical development of an operational travel demand forecasting model continues in Section 2.6 with the comparison between the use of individual trips in accounting for utility gained from travel and the use of total daily travel distance. While it is noted that specifying utility in terms of individual trips has certain advantages in modeling behavioral components such as destination choice, the use of travel distance is found to be equivalent to the use of trips if certain plausible relationships involving urban structure were true in approximation. Most importantly, however, the use of travel distance is cited to be more appropriate in light of policy relevance of the final form of the model; issues of energy conservation and environmental impacts, for example, are more directly related to total travel distance than to individual trips.

In Section 2.7 the implications of applying the logarithmic form of the utility model within the UMOT process are initially investigated by simplifying the model to the case of one travel budget, either time or money. Equations are derived for travel distances on available modes, for the sum of travel distance on all modes, and for total expenditure on travel, in terms of either money or time, depending on the budget applied. Independent variables in these equations are the speeds or costs of travel on the various available modes, the total time available to the household for travel or household income, the relative attractions of the modes, and the money value of time, quantities to be estimated. All of the derived equations depict relationships among the aforementioned variables which are logical in light of the empirical evidence on travel budgets.

The more complicated two-budget utility model is specified in Section 2.8. The simultaneous presence of travel budgets on both time and money is predicted by the model to introduce nonlinearities in relationships between households' available incomes and monies expended on travel and between available time and total time spent traveling. However, the nonlinearities are consistent with economic principles involving diminishing returns to scale and are realistic in terms of common scenarios of travel choice. Furthermore, attention is focussed in this section on the derived equation for the "value of time". Realistically, this equation specifies a household's marginal value of travel time to be a function of income, total time available for travel, the costs of travel on available modes, the speeds of those modes, and ceratin "taste" coefficients.

In Section 2.9 the situation is investigated where travel decisions are assumed not to impact markedly on household resources. For such "short-run" travel behavior relevant to small changes in modal costs or speeds, a simplified utility model is derived. From this simplified model equations are developed which show how time and money expenditures on travel would be related if the utility model is a valid representation of reality. Empirical data from Nurenberg and from Munich are both found to depict the predicted relationships, and interpretations are made of the specific parameter values estimated for these data.

In Section 2.10 the utility model is extended in two directions: Firstly, the model is modified to account for nondiscretionary travel, such as work trips. Secondly, the model is modified to accept functional relationships between price indices of general consumption and travel in order to predict consequences of future trends in such relationships. In both cases more complicated, but nevertheless tractable, equations are derived for travel distance, expenditures and the value of travel time.

Section 2.11 involves development of a car ownership model. It is shown that the general form of the utility model predicts that a household will consider a car to be advantageous whenever car travel distance desired by the household is above a certain threshold value. This threshold travel distance is a function of the household's income, available time, fixed costs of car ownership, car operating costs, fares on public transit, and average speeds of travel by car and by public transit. The relationships between the threshold distance and each explanatory variable are found to be consistent with economic principles, and specification of the logarithmic form for the utility model leads to an equation which is consistent with certain empirical evidence, as shown in Section 5.2.

Finally, Section 2.12 discusses the major estimation problems involved in applying the utility model in a transportation planning procedure.

In the case of only two available modes of travel, say car and bus, no such problems exist and the model can be based on observations of travel time and money budgets alone. However, in the general case of more than two modes, either additional parameter estimations are necessary along the lines of conventional mode split models, or certain approximations must be applied. It is shown how such approximations can be tested for compliance with real-world data.

The above points are elaborated in great detail in the following sections.

2.3 The Concept of Utility

Rational choice behavior is the basic premise underlying economic utility theory. Rational choice behavior asserts that a decision-maker is able to rank possible alternatives in order of personal preference and will choose that alternative that is ranked highest, subject to relevant constraints placed on the choice decision.

In addition to its fundamental role in utility theory, rational choice underlies most theories of judgement in psychology. These psychological theories are important complements to economic utility theory in explaining travel decision-making behavior because they serve to introduce distributions of choices. For instance, theories concerning perception and learning can be applied in explaining why travelers faced with identical alternatives might choose differently. Economists are generally unconcerned with the causes of such differences and attribute them universally to "differences in tastes".

Axioms have been developed which define under what conditions the preferences of rational choice behavior can be represented by a continuous numerical function known as a utility function. These axioms primarily concern the properties of transitivity and continuity (Debreu, 1954). Most rational choice scenarios involving consumer choices of goods and services, including those involving travel choices, easily pass the tests for utility representation. However, a small minority of scenarios are outside the scope of utility theory. One example involves lexicographic ordering: a traveler prefers the faster mode of transportation under all circumstances unless two modes are equally fast, in which case he or she prefers the cheaper of the two. However, economists have shown that in most situations such preference discontinuities as those characterizing lexicographic ordering can be approximated adequately by continuous preferences which do not violate utility theory axioms. Such approximation is usually accomplished by introducing probability statements and limits.

Assuming then that travel preferences are transitive and continuous, rational choice can be translated into utility terms in the following manner: a traveler chooses that alternative which maximizes his or her utility, subject to relevant constraints. The utility function expresses the net benefits of the various alternatives. The arguments of this utility function can be either actual amounts of the goods and services which comprise the choice alternatives, or levels of characteristics or attributes which are produced by the goods and services in varying proportions. The former approach is that of traditional microeconomics, while the latter approach is associated with relatively recent attempts at generalizing constructs of consumer behavior (Lancaster, 1966). Both approaches have been applied to travel behavior.

An example of the traditional approach is the specification by Golob, et al. (1973) of the utility of a trip to a particular destination in terms of the economic opportunities (say, jobs or total floor space of retail shops) located at that destination. A familiar example of the attribute approach is the abstract mode model of Quandt and Baumal (1966), in which travel mode utilities are specified exclusively in terms of travel times and costs (Utility functions were not explicitly defined in original documentations of the abstract mode model, but were subsequently introduced; cf. Quandt, 1970).

Selection of a particular mathematical form for utility functions aimed at modeling particular behavior is a problem involving a priori assumptions followed by checks against observed manifestations of that behavior, with the sequence repeated as necessary. However, economic theory limits the selection of functional forms to those which exhibit the well-known property of "diminishing marginal utility". That is, there must exist a monotone transformation of the utility function which is monotonically increasing and concave in the domain of the goods and services or attributes. For mathematical forms which are continuously differentiable (such as most simple functions), this property implies

$$\frac{du}{dx} \geqslant 0 \quad \text{and} \quad \frac{d^2u}{dx^2} \leqslant 0 \quad , \tag{2.3-1}$$

where $u = u(x)$ denotes the utility function, and x is the level of any included good and service or attribute(*).

2.4 A General Utility Model

A household's utility is properly a function of each and every good and service which the household is capable of consuming. An initial step in developing a tractable travel utility model is to divide such an ideal comprehensive utility function into the separate contributions of groups of commodities. Such commodity group utilities are usually considered to be additive in contributing to total household utility. Examples of commodity groups include food items, housing, leisure time, and transportation.

Stroz (1957, 1959) proposed a theory of household decision making based on additive separable utilities (cf. Houthakker, 1960). The theory states that consumers allocate expenditures on the various commodity groups, given price indices of each group, so as to maximize utility subject to budget constraints. Next, after having decided how much

(*) It is often realistic to further assume that there is no saturation of utility. This implies that the first derivative of the utility function is strictly greater than zero.

to spend on each group, the consumer allocates expenditures on each good and service, subject to the constraints on the total amounts allocated to the commodity groups. Small changes in prices of individual goods and services are assumed not to appreciably affect the first stage group decisions. However, changes in prices which influence relative price indices of the groups can feedback to the first-stage decisions, potentially leading to reallocations among the commodity groups.

One definition of commodity groups which is useful in modeling travel decisions is

$$u = u(x,c,t) \tag{2.4-1}$$

where u is household utility, x is the amount or quantity of travel, c is consumption of non-travel goods and services (call this general consumption), and t is leisure time. Specifying price indices for travel and residual consumption as p_x and p_c, respectively, the household faces the following money budget constraint when allocating expenditures:

$$p_x x + p_c c \leqslant Y \tag{2.4-2}$$

where Y is household disposable income. Similarly, the time budget constraint is

$$t_x x + t \leqslant T \tag{2.4-3}$$

where t_x is given time per unit distance traveled, and T is the total time available to all household members. Presumedly, T is total clock time for the analysis period, minus time required for nondiscretionary activities such as sleep and income generation.

The first-stage decision is then to maximize Eq. 2.4-1 subject to Eqs. 2.4-2 and 2.4-3. Assuming additivity in the spirit of the economic theories, this decision becomes:

$$\max_{x,c,t} U = \phi(x) + \psi(c) + \xi(t) \tag{2.4-4}$$

subject to $x \geqslant 0$, $c \geqslant 0$, $t \geqslant 0$ and

$$p_x x + p_c c \leqslant Y ,$$

$$t_x x + t \leqslant T$$

where ϕ , ψ and ξ represent utilities due to travel, general consumption and leisure, respectively. The additivity assumption is equivalent to declaring that the marginal rates of substitution among various goods and services within one commodity group, say transportation, are independent of the marginal rates of substitution among goods and services within any other commodity group, say general consumption. Nevertheless, the actual levels of consumption of any good or service within one commodity group are dependent upon the overall price index of another commodity group because all commodity groups compete for the same budgeted resources.

Since income not consumed has no intrinsic value (where saving or investment can be considered as commodities consumed within general consumption), and the same is true of available time, the budgets of problem (2.4-4) can be considered binding and the inequality signs vanish. Consequently, since a decision oriented toward transportation is desired, the general consumption and leisure time quantities can be solved for,

$$c = \frac{Y}{P_c} - \left(\frac{P_x}{pc}\right)x \qquad (2.4\text{-}5)$$

$$t = T - t_x x$$

and these quantities can be substituted into the utility function. This is termed internalizing the constraints. Maximization problem 2.4-4 then becomes

$$\operatorname*{Max}_{x}\ u = \phi(x) + \psi\left[\frac{Y}{P_c} - \left(\frac{P_x}{P_c}\right)x\right] + \xi(T - t_x x) \qquad (2.4\text{-}6)$$

where the remaining decisions variables are the transportation commodities.

Problem (2.4-6) represents the general form of the travel utility model applied in the UMOT process. The necessary and sufficient conditions for the solution of (2.4-6) are:

$$\frac{du}{dx} = 0 \text{ for } x > 0 \quad ; \qquad (2.4\text{-}7)$$

and

$$\frac{du}{dx} \leqslant 0 \text{ for } x = 0 \quad ; \qquad (2.4\text{-}8)$$

Assuming that some travel is optimum, condition (2.4-8) vanishes, and the single necessary and sufficient condition (2.4-7) for utility maximization can be written

$$\phi'(x) - (\frac{p_x}{p_c})\,\psi'[\,\frac{Y}{p_c} - (\frac{p_x}{p_c})x] - t_x\,\xi'(T-t_x x) = 0 \qquad (2.4\text{-}9)$$

where the "prime" symbols denote first partial derivatives of the functions.

In light of the requirements (2.3-1) that the utility components ϕ, ψ and ξ each be monotonically increasing and concave, the following qualitative properties can be derived from the solution condition (2.4-9). These properties are fundamental to the general utility model, as they will characterize the model solution in any application:

(1) Travel (x) can never decrease as income (Y) increases. (In economic terms, travel is a "superior good"). To show this, (2.4-9) implies that

$$\frac{dx}{dY} = - \frac{\partial^2 u}{\partial y^2} \quad \frac{\partial^2 u}{\partial x^2} \qquad (2.4\text{-}10)$$

Since u is maximized in x,

$$\frac{\partial^2 u}{\partial x^2} < 0 \qquad (2.4\text{-}11)$$

so that

$$\text{Sign}(\frac{dx}{dy}) = \text{Sign}(\frac{\partial^2 u}{\partial y^2}) \qquad (2.4\text{-}12)$$

Thus,

$$\text{Sign}(\frac{dx}{dy}) = \text{Sign}(-\frac{p_x}{p_c}\,\psi'') \qquad (2.4\text{-}13)$$

and so

$$\frac{dx}{dy} \geqslant 0 \quad ; \qquad (2.4\text{-}14)$$

since prices are positive quantities and ψ is non-convex. In the range of diminishing marginal utility, ψ is strictly concave, and the equality sign is dropped from (2.4-13): travel must increase by some amount, however small, as income increases.

(2) Travel can never decrease as available time (T) increases. To show this,

$$\frac{dx}{dT} = - \frac{\partial^2 u}{\partial T^2} \Big/ \frac{\partial^2 u}{\partial x^2} \qquad (2.4\text{-}15)$$

which leads to

$$\text{Sign}(\frac{dx}{dT}) = \text{Sign}(\frac{\partial^2 u}{\partial T^2}) \qquad (2.4\text{-}16)$$

Thus,

$$\text{Sign}(\frac{dx}{dT}) = \text{Sign}(-t_x \xi') \qquad (2.4\text{-}17)$$

and so

$$\frac{dx}{dT} \geq 0 \qquad (2.4\text{-}18)$$

since travel time is positive and ξ is non-convex. Again, in the range of diminishing marginal utility, the equality sign is dropped, and travel must increase as available time increases.

(3) Travel decreases with increasing costs. (In economic terms, the demand curve for travel is downward sloping). To show this,

$$\frac{dx}{dp_x} = - \frac{\partial^2 u}{\partial p_x^2} \Big/ \frac{\partial^2 u}{\partial x^2} \qquad (2.4\text{-}19)$$

which leads to

$$\text{Sign}(\frac{dx}{dp_x}) = \text{Sign}(\frac{\partial^2 u}{\partial p_x^2}) \qquad (2.4\text{-}20)$$

Thus,

$$\text{Sign}(\frac{dx}{dp_x}) = \text{Sign}(-\psi' + (\frac{p_x}{p_c}) x \psi'') \qquad (2.4\text{-}21)$$

or,

$$\frac{dx}{dp_x} < 0 \qquad (2.4\text{-}22)$$

since ψ is monotone increasing and non-convex(*).

(4) Finally, travel increases with increasing speed. To show this,

$$\frac{dx}{dt_x} = - \frac{\partial^2 u}{\partial t_x} \Big/ \frac{\partial^2 u}{\partial x^2} \qquad (2.4\text{-}23)$$

which leads to

$$\text{Sign}(\frac{dx}{dt_x}) = \text{Sign}(\frac{\partial^2 u}{\partial t_x}) . \qquad (2.4\text{-}24$$

(*) Only in the extreme case of utility saturation, $\frac{du}{dx} = 0$, would the demand curve for travel be totally inelastic, $\frac{dx}{dp_x} = 0$; this is dismissed as being unrealistic, and thus a strict inequality is specified in (2.4-22).

Thus,

$$\text{Sign}\left(\frac{dx}{dt_x}\right) = \text{Sign}(-\xi' + x\,\xi'') \qquad (2.4\text{-}25)$$

or,

$$\frac{dx}{dt_x} < 0 \qquad (2.4\text{-}26)$$

since ξ is monotone, increasing, and non-convex.

Having established the general form (2.4-6) for a travel utility model, and having stated the general properties of this model, operational travel demand forecasting models can be developed by specifying mathematical functions and defining how the travel quantity is to be measured. In addition, certain simplifications of (2.4-6) might be pursued when a short-run time frame is to be modeled.

It is possible to avoid such direct specifications of utility functions only by defining utility to be generated exclusively through a sequence of travel choices among sets of discrete alternatives, each choice being conditional upon the choice or choices that preceed it in the sequence. Choices could include: what broadlly-defined section of an urban area to reside in, whether or not to own cars, how many cars to own, whether or not to make a trip to a particular destination, which mode to use, and whether to travel at peak or non-peak times. Potentially, each choice, or a combination of choices, can then be modeled separately by specifying only the <u>differences</u> in utility achievable by the various discrete alternatives. Parameters can be estimated by introducing probability statements concerning the utility differences subject to random disturbances. This approach has been applied successfully to only a few of the large number of choices in a comprehensive travel decision sequence, with focus usually on choice of mode (e.g., Quandt, 1968; CRA, 1972).

Unfortunately, this approach of avoiding utility specification is counterproductive in light of the UMOT objectives. When modeling the <u>overall</u> travel decision-making behavior of households, the series of conditional choices approach necessarily implies that the travel utility decision variables are the choices themselves, interrelated in the manner described by the choice series. Thus, while this approach has led to improved insights into travel behavior manifested in particular decisions such as mode choice, it cannot easily be extended to a comprehensive consideration of overall travel behavior without complicated and tenuous hypotheses involving sequencing of decisions and combinations of alternatives.

The approach described herein is to determin which definitions of travel veriables and which mathematical forms for utility functions are consistent with requirements of the UMOT process. Such an approach does not preclude a mixed strategy, in which a utility-comparison choice of discrete alternatives is introduced to account for the car ownership decision (cf., Beckmann, et al., 1973). However, specification of the discrete choice part of the model logically depends upon specification of the continuous utility part and, as such, is the subject of a latter section of this presentation.

2.5 The Logarithmic Utility Model

There are many simple functional forms for utility which satisfy the requirements of monotonicity and concavity. The field is narrowed, however, by introducing an additional requirement that the functions be homogeneous. Homogeneity leads to very useful simplifications when the decisions of individual households are aggregated to total demand. Another benefit related to homogeneity is that certain standardizations can be made to the arguments of the utility components without loss of generality. For example, in the optimization problem (2.4-6), the price index for residual consumption p_c can be set equal to one if ψ is homogeneous, and since maximization of u is equivalent to maximizing any monotone transformation of u. For these and other reasons beyond the scope of the present discussion, homogeneous utility functions are common in economic analyses.

Two simple homogeneous forms are possible. One is the power function

$$u(x) = bx^a \qquad (2.5\text{-}1)$$

and the other is the natural logarithm function

$$u(x) = a \log x + b \qquad (2.5\text{-}2)$$

It is difficult to choose between the forms empirically, since no distinction is generally possible between fits of the two curves to data. However, the logarithmic form is more popular among economists studying other resource-allocation problems. For example, this form appears transformed as the Cobb-Douglas production function

$$v(x_1, x_2) = bx_1^{a} x_2^{b}, \tag{2.5-3}$$

where the transformation is

$$\exp[u(x_1) + u(x_2)] = \exp(a_1 \log x_1 + a_2 \log x_2 + b_1 + b_2). \tag{2.5-4}$$

A more important reason for the selection of the logarithmic form is that it alone yields results which are consistent at first approximation with certain empirical evidence underlying the UMOT process. This consistency is demonstrated in the following theorem:

<u>Theorem 2.5-1</u>: In the absence of a constraint on available time, an income constraint on total household expenditure implies a budget proportional to income on expenditure for travel if, and only if,

$$u = a \log x + b \log\left(\frac{Y}{p_c} - \frac{p_x}{p_c} x\right). \tag{2.5-5}$$

<u>Proof</u>: Let total household utility be given by the general form (2.4-6) with leisure utility ξ ignored:

$$u = \phi(x) + \psi\left(\frac{Y}{p_c} - \frac{p_x}{p_c} x\right). \tag{2.5-6}$$

Utility maximization with respect to the composite travel commodity implies

$$\phi'(x) = \frac{p_x}{p_c} \psi'\left(\frac{Y}{p_c} - \frac{p_x}{p_c} x\right). \tag{2.5-7}$$

Thus, total expenditure on all non-travel consumption is

$$Y - p_x x = p_c (\psi')^{-1} \frac{p_c}{p_x} \phi'(x), \tag{2.5-8}$$

where $(\psi')^{-1}$ denotes the inverse function of the marginal utility ψ'. Now the right-hand side of (2.5-8) is dependent on the amount of travel quantity x only in the combination $p_x x$ representing total expenditure on travel, if and only if,

$$\phi'(x) = \frac{a}{x} \quad . \tag{2.5-9}$$

This implies by integration

$$\phi(x) = a \log x \quad . \tag{2.5-10}$$

Substituting (2.5-9) into (2.5-8),

$$Y - p_x x = p_c (\psi')^{-1} \left(\frac{a p_c}{p_x x} \right) . \tag{2.5-11}$$

Now the right-hand side of (2.5-11) is independent of p_c, and $p_x x$ is proportional to Y if, and only if,

$$(\psi')^{-1} \left(\frac{p_c}{p_x x} \right) = - \frac{p_x x}{b p_c} \quad , \tag{2.5-12}$$

which implies

$$\psi(z) = b_1 \log(z) \quad . \tag{2.5-13}$$

Thus,

$$u = a_1 \log x + b_1 \log\left(\frac{Y}{p_c} - \frac{p_x}{p_c} x \right) . \tag{2.5-5}$$

Q.E.D.(*)

A similar situation holds for utility of travel and leisure in the absence of utility of residual consumption:

<u>Corollary 2.5-1.1</u>: In the absence of an income budget, a constraint on available time for all activities implies a budget proportional to available time on total time spent for travel if, and only if,

$$u = a_1 \log x + b_2 \log(T - t_x x) \tag{2.5-14}$$

<u>Proof</u>: The proof is analogous to that of Theorem 2.5-1.

(*) Strictly speaking, the utility function of (2.5-5) is unique only up to a linear transformation of the arguments of the logarithms and a monotone transformation of the entire function. Also, while the theorem was expounded for additive separable utility functions, it has been claimed for general separable functions as well (cf., Beckmann and Kunzi, 1979).

Complications arise in the simultaneous presence of time and money constraints. The constraints interact, and stable money and time travel budgets are no longer observable as travel times and/or costs vary. In order to further analyze such interactions, and to interpret the results of the first theorem and corollary in terms of competing travel times and costs for various trips, it is advantageous to detail the travel decision variables (x) before proceeding further.

2.6 Decision Variables for Travel

Numerous types of decision variables are involved in individuals' choices of where, when, and how to travel. One possible single representation of this complex of variables involves the concept of travel as an intermediate good: a trip has no intrinsic value; utility is gained at the destination of the trip. An appropriate travel utility representation is thus

$$\phi(x) = \sum_{i=1}^{D} f(a_i, n_i) \quad , \tag{2.6-1}$$

where $f(a_i, n_i)$ represents the utility of destination i ($i = 1,\ldots,D$), which is a monotone increasing and concave function of the attraction of the destination, a_i, and the number of trips to the destination, n_i (for $i = 1,\ldots,$ D possible destinations). Assuming that $f(a_i, n_i)$ is homogeneous in a_i (e.g., $f(a_i, n_i)$ is a power function),

$$\phi(x) = \sum_{i=1}^{n} a_i f(\frac{n_i}{a_i}) \ . \tag{2.6-2}$$

The general utility model (2.4-6) can be written

$$u = \sum_{i=1}^{n} a_i f(\frac{n_i}{a_i}) + \psi(Y - \sum_{i=1}^{n} n_i c_i) + \xi(T - \sum_{i=1}^{n} n_i (d_i/v_i)) \ , \tag{2.6-3}$$

where c_i is the cost of a trip to destination i, d_i is the distance and v_i is the speed for such a trip. (Without loss of generality, the price index for all non-travel goods and services is standardized to one).

Optimality implies (2.4-9)

$$f'(\frac{n_i}{a_i}) = c_i \psi' + (d_i/v_i)\xi' \quad , \quad i = 1,\ldots, D \tag{2.6-4}$$

Solving conditions (2.6-4) for the n_i:

$$n_i/a_i = (f')^{-1}(c_i \psi' + (d_i/v_i)\xi') \ , \ i = 1,\dots, D \quad (2.6\text{-}5)$$

where $(f')^{-1}$ denotes the inverse function of the marginal utility of travel. Achieved travel utility is then calculated by substituting the utility-maximizing trip rates (2.6-5) into the equation (2.6-2). Denoting achieved utility by a star-superscript,

$$\phi(x)^* = \sum_{i=1}^{n} a_i[(f')^{-1}(c_i \psi' + (d_i/v_i)\xi')] \ . \quad (2.6\text{-}6)$$

Application of such a utility definition consequently implies measuring the destination attractions and trip rates to all visited destinations.

In the above conventional approach, the trip distance is regarded as a disutility, in the sense that the distance has to be overcome - in time and money terms - in order to reach a destination. There are, however, several indications, both empirical and theoretical, to suggest that the total daily travel distance to all visited destinations, is an efficient measure of the total daily utility derived from travel within the constraints of time and money. For instance, (i) it was already noted that when travel speeds increase, travelers prefer to trade-off their saved time for longer trips, rather than for more trips; i.e., either for further destinations, or for residence dispersion, than for more destinations (cf., Smith, 1978; Zahavi, 1979-a). (ii) When incomes increase, travelers tend to purchase higher speeds (such as by transferring from bus to car travel) and travel longer distances within their relatively stable TT-budgets, instead of generating more trips (the higher trip-rate per household as incomes increase is caused mainly by more travelers per household, not by more trips per traveler). (iii) Total daily travel utility should not be affected by the way in which single trips are linked. Hence, the only invariant components of the daily travel, which are not affected by different definitions of trip linking, are the total expenditures in time and money, and the total travel distance purchased by these two budgets. (iv) Daily travel distance is one possible measure of the spatial or economic opportunities that can be reached within the daily money and time constraints. The traveler can then maximize his daily spatial or economic opportunities by maximizing his total daily travel distance within his travel constraints. On a second level, the traveler can then have the choice of making more trips at shorter distances (such as in small or compact cities), or of making less trips at longer distances (such as in large or dispersed cities). (v) Finally, as already mentioned in Section 1.3, the most consistent common denominator between travel demand and system supply is travel distance, not trips.

In light of the above considerations, daily travel distance was selected as the travel decision variable employed in the UMOT approach. Its maximization within the travel constraints and the available travel modes and their operational characteristics reflects the maximization of travel utility under given conditions or planning alternatives.

The question central to resolving differences between the conventional and UMOT approaches is: under what circumstances is total travel distance (and associated average speeds and costs) an acceptable proxy variable for destination-specific trip rates, speeds and costs ? The answer is: whenever the achieved utility (2.6-6) is independent of the structure of the a_i, v_i, d_i and c_i terms for the $i = 1, \dots, D$ destinations.

Rewriting (2.6-6) in terms of the contributions of the individual destinations,

$$a_i f[(f')^{-1}(c_i \psi' + (d_i/v_i)\xi')] = \mu_i \quad , \; i = 1, \dots, D \; , \tag{2.6-7}$$

then

$$(f')^{-1}(c_i \psi' + (d_i/v_i)\xi') = f^{-1}(\mu_i/a_i) \quad . \tag{2.6-8}$$

Thus, achieved utility is independent of the structure of the destination terms if, and only if, the following function exists:

$$a_i = g(c_i \psi' + (d_i/v_i)\xi') \quad , \; i = 1, \dots, D \tag{2.6-9}$$

This is possible if the following hold to an acceptable approximation: (1) costs (c_i) are proportional to travel times (d_i/v_i), across various destinations visited by a single household; (2) velocities (v_i) are independent of destinations; and (3) attractions (a_i) are some monotone increasing function of distances (d_i).

The key to the use of total travel distance as a measure of achieved utility is to what extent perceived attractions of various destinations are related to distances traveled to reach the destinations. This is testable through statistical analysis of attitudinal and travel diary data; discovery of a monotone increasing function between a_i and d_i with satisfactory goodness-of-fit to survey data would be supportive to the use of $\sum_{i=1}^{D} d_i$ as a utility measure.

There is a second possibility for condition (3) above. If a reasonable spatial definition of destinations i exists such that n_i takes on only the binary values of 0 and 1 (that is, destinations are either visited once during the time duration of analysis, or not at all), then achieved utility is independent of structure. Once again, this is testable

Resolution of the conventional and UMOT approaches introduces the issue of micro vs. macro approaches. Daily travel budgets are macro factors since they are averaged over an extended period, while single trips are micro factors, subject to daily fluctuations. For example, discretionary trips, such as shopping trips, are so infrequent on a daily basis that they need to be aggregated in any case, either for the same traveler over an extended period of, say, a week, or for groups of travelers during one day. Even non-discretionary trips, such as trips to work, can change daily, either by chaining with trips to other purposes, or by changing modes. Hence, the UMOT approach is based on an hierarchical structure: First, the daily travel distance is maximized within the travel constraints, resulting in the demand for average daily travel distance by mode. Second, trip rates and trip distances interact by trade-offs within the total daily travel distance, depending on city size and structure (e.g., the spatial or economic opportunities), resulting in probabilities of trips for different purposes terminating in various zones.

Applying the logarithmic form and specifying travel in terms of total distance traveled

$$\underset{x_i}{\text{Max}}\ u = \sum_{i=1}^{m} a_i \log x_i + b_1 \log(Y - \sum_{i=1}^{m} c_i x_i) + b_2 \log(T - \sum_{i=1}^{m} \frac{x_i}{v_i}) . \quad (2.6\text{-}10)$$

Here x_i is distance traveled on mode i ($i=1,\ldots,m$), c_i is cost per unit distance for mode i, v_i is speed on mode i, Y is disposable household income, T is available time aggregated for all household travelers, a_i is the attraction of mode i, and b_1 and b_2 are the utility weights for general consumption and leisure time, respectively.

Strictly speaking, the arguments of the logarithmic travel utility function are $(x_i + 1)$, travel distance on mode i plus one unit distance. This establishes the proper boundary conditions

$$\phi_i(x_i = 0) = a_i \log(1) = 0; \quad i=1,\ldots,m . \quad (2.6\text{-}11)$$

For simplicity, the added unit distance has been dropped in the equations which follow. Similar boundary condition considerations apply to the general consumption and leisure terms. These conditions are expressed in the additional constraints

$$Y - \sum_{i=1}^{m} c_i x_i \geq 1 \quad ,$$
$$T - \sum_{i=1}^{m} x_i / v_i \geq 1 \quad , \quad (2.6\text{-}12)$$

which are assumed <u>a priori</u> for simplicity.

2.7 A Model of Travel with One Budget

The implications of applying utility model (2.6-10) within the UMOT process can initially be investigated by simplifying the model to the case of one travel budget, either money or time. The second step, pursued in the following section , is to analyze the more complicated two-budget form.

Model (2.6-10) in terms of a money budget only is written

$$\underset{x_i}{\text{Max}}\ u = \sum_{i=1}^{m} a_i \log x_i + b_1 \log(Y - \sum_{i=1}^{m} c_i x_i) \quad (2.7\text{-}1)$$

and in terms of a time budget is written

$$\underset{x_i}{\text{Max}}\ u = \sum_{i=1}^{m} a_i \log x_i + b_2 \log(T - \sum_{i=1}^{m} x_i/v_i) \ . \qquad (2.7\text{-}2)$$

Focussing first on interpretations in money budget terms, the necessary and sufficient conditions for the maximization (2.7-1) are

$$a_i/x_i - \frac{b_1 c_i}{(Y - \sum_{i=1}^{m} c_i x_i)} = 0 \quad , \quad i = 1,\ldots,m. \qquad (2.7\text{-}3)$$

Thus,

$$c_i x_i = (a_i/b\ )(Y - \sum_{i=1}^{m} c_i x_i) \quad , \quad i = 1,\ldots,m \qquad (2.7\text{-}4)$$

which states that the total money expenditure on any mode is a constant proportion of income net of total travel expenses. The proportionality constant is the ratio of the attractiveness of the particular mode to the attractiveness of residual consumption, parameters which are to be estimated. Summing both sides of (2.7-4) over all modes,

$$\sum_{i=1}^{m} c_i x_i = (1/b)(Y - \sum_{i=1}^{m} c_i x_i) \sum_{i=1}^{m} a_i \ . \qquad (2.7\text{-}5)$$

Since, without loss of generality, the a_i coefficients can be standardized such that $\sum_{i=1}^{m} a_i = 1$, total travel expenditure is thus given by

$$\sum_{i=1}^{m} c_i x_i = \left(\frac{1}{b_1 + 1}\right) Y \quad , \qquad (2.7\text{-}6)$$

and, substituting (2.7-6) into (2.7-4), distance traveled on mode i is:

$$x_i = \frac{1}{c_i}\left(\frac{a_i}{b_1 + 1}\right) Y \quad , \quad i = 1,\ldots,m \qquad (2.7\text{-}7)$$

Equations (2.7-6) and (2.7-7) are restatements of Theorem 2.5-1 with mode travel distances as arguments of the travel utility function: total expenditure for travel is a fixed proportion of income, regardless of the costs of travel. Moreover, the total distance traveled on a given mode is inversely proportional to the cost per unit distance of travel on that mode.

Analogeously, in terms of a travel time budget, the following two relationships are derived:

$$\Sigma\, x_i/v_i = \left(\frac{1}{b_2 + 1}\right) T \quad , \qquad (2.7\text{-}8)$$

and

$$x_i = v_i\left(\frac{a_i}{b_2 + 1}\right) T \quad , \qquad i = 1,\ldots,m \qquad (2.7\text{-}9)$$

Thus, total time spent traveling is a fixed proportion of total available time, regardless of travel speeds; and total time spent traveling on any given mode is directly proportional to the speed of that mode.

Application of the simplified single-budget version of the logarithmic travel distance utility model implies that a household's total expenditures on travel (in terms of either money or time) remains constant as the relative costs of travel among modes change. What does change is the allocation of travel distances on the various modes, the changes in distances being in proportion to the changes in costs. These results are modified, however, by the simultaneous inclusion of both budgets, as explored in Section 2.8.

Substituting the utility-maximizing travel distances, (2.7- 7) and (2.7-9), into the original utility functions described in (2.7-1) and (2.7-2), respectively, yields the <u>achieved</u> utility levels. In the case of the time-budget model, this yields

$$u^* = \sum_{i=1}^{m} a_i \log\left[v_i\left(\frac{a_i}{b_2 + 1}\right)T\right] + b_2 \log\left[T - \left(\frac{1}{b_2 + 1}\right)T\right] \quad : \quad (2.7\text{-}10)$$

Simplifying,

$$u^* = \sum_{i=1}^{m} a_i \log a_i + \sum_{i=1}^{m} a_i \log v_i + (b_2 + 1)\log T -$$

$$- (b_2 + 1)\log(b_2 + 1) + b_2 \log b_2 \; ; \qquad (2.7\text{-}11)$$

Equation (2.7-11) shows that a household's achieved utility, or total benefit from travel and leisure after travel is adjusted to yield maximum possible benefit, is an increasing concave function of travel speeds and of total available time. Also, achieved utility is a decreasing linear function of $(-\Sigma a_i \log a_i)$, which is of an entropy form. In light of the well known properties of such forms developed in information theory, achieved utility is greatest when modal attractions are highly unequally distributed, and is smallest when modal attractions are equal.

Equation (2.7-11) can be interpreted from a point of view of potential policy implications: achieved utility increases with time available and with any modal speed in a diminishing marginal manner. Moreover, increases in speeds faced by households with low levels of available time (say, more workers per total travelers) have greater proportional effects on achieved utility than do increases in speeds faced by households with high levels of available time (tastes being equal). Finally, the incremental increase in a household's achieved utility resulting from an increase in the speed on any mode is proportional to the attraction of the mode and inversely proportional to the present average speed of the mode. Assuming that faster modes are also more attractive for reasons other than travel times alone (say, for reasons related to comfort or personal security), the two effects of high speed and high attraction counteract, and it is possible that achieved utility can be improved to the same proportion by improvements in speeds of the either faster or slower mode. Results depend upon the actual estimated values of the a_i and v_i terms.

Analogous relationships are obtainable for the money-budget model:

$$u^* = \sum_{i=1}^{m} a_i \log a_i - \sum_{i=1}^{m} a_i \log c_i + (b_1 + 1) \log Y + \text{Constant.} \quad (2.7\text{-}12)$$

A household's achieved utility is a decreasing convex function of costs, an increasing concave function of income and a decreasing linear function of the entropy of modal attractions.

2.8 A Model of Travel with Two Budgets

The necessary and sufficient conditions for the maximization of the complete two-budget model (2.6-10) are

$$a_i/x_i - \frac{b_1 c_i}{Y - \sum_{i=1}^{m} c_i x_i} - \frac{b_2}{v_i(T - \sum_{i=1}^{m} x_i/v_i)} = 0 \; ; \; i=1,\ldots,m. \quad (2.8\text{-}1)$$

In general, conditions (2.8-1) represent an intractable set of non-linear equations. Gradient-search and similar algorithms (Bard, 1974) can be used to find approximate solutions in practical applications.

However, certain approximations can be introduced in order to develop closed-form relationships. These relationships help to reveal the implications of employing the model of (2.6-10) and (2.8-1) in travel demand forecasting procedures.

One approximation involves assuming that total travel expenditure is a relatively small proportion of income, and that total time spent traveling is a relatively small proportion of time available. A conventional definition of "small" in such cases is typically "ten percent or less", but 11 or even 15 percent might be acceptable. Thus, defining

$$\sum_{i=1}^{m} c_i x_i \ll Y \quad , \qquad (2.8\text{-}2)$$

and

$$\sum_{i=1}^{m} x_i/v_i \ll T \quad , \qquad (2.8\text{-}3)$$

conditions (2.8-1) become:

$$a_i/x_i = b_1 c_i/Y + b_2/v_i T \quad , \quad i = 1,\ldots,m. \qquad (2.8\text{-}4)$$

or

$$x_i = \frac{a_i}{(b_1 c_i/Y) + (b_2/v_i T)} \quad , \; i = 1,\ldots,m. \qquad (2.8\text{-}5)$$

Thus, assuming that travel time and money budgets are relatively small proportions of total money and time constraints, travel on any mode is proportional to the harmonic mean of two distance limits: (1) Y/c_i, the maximum distance that can be reached with the available money, and (2) $v_i T$, the maximum distance that can be reached with the available time.

Comparing equations (2.8-5) with the optimum travel distance equations for the two alternative single-budget models (2.7-7) and (2.7-8), it is apparent that the simultaneous presence of two budgets introduces nonlinearities between travel distances and income or the inverse of costs, and between travel distances and available time or speeds. These relationships become concave functions. Income, the inverse of costs, available time, and speeds all exhibit diminishing marginal influences on travel distance. Thus, for example, a change ΔY in income will have a greater effect on travel for a household at income level Y_1 than it will for a household at income level $Y_2 > Y_1$, ceteris paribus.

Such nonlinearities might be approximated in practice by stratifying households by income level and available time (number of travelers, number of workers and possibly type of work) and specifying different linear relationships for each stratum. Similarly, different cost-distance or speed-distance relationships could be specified for various ranges of costs or speeds.

One further implication of the two-budget model (7.1) is the resulting expression for the ratio of the marginal utility of time to the marginal utility of money. This ratio is commonly known as the "money value of time" or simply the "value of time". It is derived from (7.1) by calculating

$$\frac{du}{dT} = \frac{b_2}{(T - \sum_{i=1}^{m} x_i/v_i)} \; ; \qquad (2.8\text{-}6)$$

and

$$\frac{du}{dY} = \frac{b_1}{(Y - \sum_{i=1}^{m} c_i x_i)} \; ; \qquad (2.8\text{-}7)$$

so that

$$\frac{du}{dT} \Big/ \frac{du}{dY} = \frac{b_2}{b_1} \frac{(Y - \Sigma c_i x_i)}{(T - \Sigma x_i/v_i)} \; ; \qquad (2.8\text{-}8)$$

Thus, the value of time implied by the two-budget logarithmic utility model is directly proportional to money available for non-travel consumption and inversely proportional to time available for non-travel discretionary purposes. The proportionality constant reflects the taste of the household.

2.9 Simplifications for Short-Run Behavior

In developing the general form of the travel utility model (2.4-6) and the more specific logarithmic travel distance model (2.6-10), constraints on travel were postulated to be the total money and time available to the household. In other words, the constraints were household disposable income and total traveler-days minus time devoted to obligatory activities, such as sleep and work. This approach allows total travel expenditures in terms of money and time (that is, travel money and time "budgets") to be functions of the income and time constraints.

In situations where the results of a travel decision do not impact markedly on household resources, it is possible to model behavior more simply. For such "short-run" behavior the travel time and/or money budgets can be considered fixed, thus becoming constraints on the short-run travel decisions. The utility model is then:

$$\underset{x_i}{\text{Max}}\ u = \sum_{i=1}^{m} \phi_i(x_i) \quad ; \qquad (2.9\text{-}1)$$

subject to

$$\sum_{i=1}^{m} x_i c_i \leqslant M^* \quad ,$$

$$\sum_{i=1}^{m} x_i/v_i \leqslant T^* \quad ,$$

where $\phi_i(x_i)$ are the travel utilities associated with the $i = 1,\ldots m.$ modes, M^* is the fixed travel money budget, and T^* is the fixed travel time budget. Forming a Lagrangean function, the necessary and sufficient conditions for optimality are:

$$\phi_i'(x_i) - \lambda/v_i - \mu c_i = 0 \quad ; \quad i = 1,\ldots,m \ , \qquad (2.9\text{-}2)$$

where λ and μ are the Lagrangean multipliers associated with the money and time constraints, respectively. Operationalizing the short-run model (2.9-1) thus requires specifying appropriate utility functions $\phi_i(x_i)$. The implications of applying such a model can be determined once such a function is specified.

In fact, the motivations in selecting a functional form for short-run travel utility are precisely those in selecting the functional forms for the utility components of the general model (2.4-6). This is demonstrated by the following theorem which links the general and short-run utility models. The theorem is shown for the single (money) budget case.

Theorem 2.9-1: Maximization of the (additive separable) utility of consumption and travel is equivalent to maximizing the utility of travel under appropriate money budget constraints.

Proof: Let expenditures on all non-travel goods be a given function of income:

$$g = g(Y) \quad . \tag{2.9-3}$$

The problem is to find a utility function $\psi(g)$ such that the solution of

$$\max_{x_i} u = \sum_{i=1}^{m} \phi_i(x_i) + \psi(Y - \sum_{i=1}^{m} c_i x_i) \tag{2.9-4}$$

is equivalent to

$$\operatorname{Max} u = \sum_{i=1}^{m} \phi_i(x_i) \tag{2.9-5}$$

subject to

$$\sum_{i=1}^{m} c_i x_i \leqslant Y - g(Y)$$

for all Y and c_i, $i = 1,\ldots m$. Writing the latter problem (2.9-5) in Lagrangean form:

$$\operatorname{Max} L = \sum_{i=1}^{m} \phi_i(x_i) + \lambda(Y - g(Y) - \sum_{i=1}^{m} c_i x_i) \; , \tag{2.9-6}$$

the solution is determined by

$$\phi_i(\hat{x}_i) = \lambda c_i \quad , \tag{2.9-7}$$

The solution to the former problem (2.9-4) is determined by

$$\phi_i(\hat{x}_i) = c_i \psi'(Y - \sum_{i=1}^{m} c_i x_i) \quad , \tag{2.9-8}$$

or, assuming that the constraint of (2.9-5) is binding,

$$\phi_i'(\hat{x}_i) = c_i \psi'(g(Y)) \quad . \tag{2.9-9}$$

The problem thus reduces to determining the conditions under which expressions (2.9-7) and (2.9-9) are equivalent, or under which

$$\lambda = \psi'(g(Y)) = \lambda(Y) \quad . \qquad (2.9\text{-}10)$$

Differentiating,

$$\int_0^Y \lambda(z)g'(z)dz = \int_0^Y \psi'(g(Y))g'(z)dz \quad ; \qquad (2.9\text{-}11)$$

or

$$\int_0^Y \lambda(z)g'(z)dz = \psi(g(Y)) \quad , \qquad (2.9\text{-}12)$$

which specifies $\psi(g(Y)) = \psi(Y - \sum_{i=1}^{m} c_i x_i)$.

Q.E.D.

The proof of Theorem (2.9-1) is constructive in that it specifies the utility function for residual consumption as a function of income. The theorem holds for any monotonically increasing concave utility functions, not just for the logarithmic form.

In light of Theorem (2.5-1), if the short-run model (2.9-1) is to yield results which are consistent with those of the chosen form of the general model, logarithmic utility is dictated:

$$\text{Max } u = \sum_{i=1}^{m} a_i \log x_i \quad , \qquad (2.9\text{-}13)$$

subject to

$$\sum_{i=1}^{m} x_i c_i \leq M^* \quad ,$$

$$\sum_{i=1}^{m} x_i / v_i \leq T^* \quad .$$

Optimality thus implies

$$x_i = \frac{a_i}{\mu c_i + \lambda / v_i} \quad , \quad i = 1,\ldots,m \ . \qquad (2.9\text{-}14)$$

The short-run travel equations (2.9-14) are simplifications of the general equations (2.8-5). The effect of assuming fixed income and fixed available time is to fix the money value of time in equations (2.9-14) as λ/μ. This is compared to the income-and time-dependent money value of time in the general equations.

Two hybrid models are also possible. If it is postulated that available time is fixed, but income may vary, the appropriate model is

$$\underset{x_i}{\text{Max}}\ u = \sum_{i=1}^{m} a_i \log x_i + b_1 \log(Y - \sum_{i=1}^{m} c_i x_i) \quad , \qquad (2.9\text{-}15)$$

subject to

$$\sum_{i=1}^{m} x_i/v_i \leqslant T^* \quad ,$$

which implies

$$x_i = \frac{a_i}{(b_1 c_i/Y) + \lambda/v_i} \quad , \qquad i = 1,\ldots,m \ . \qquad (2.9\text{-}16)$$

Similarly, the appropriate model for fixed income and variable available time is

$$\underset{x_i}{\text{Max}}\ u = \sum_{i=1}^{m} a_i \log x_i + b_2 \log(T - \sum_{i=1}^{m} x_i/v_i) \quad , \qquad (2.9\text{-}17)$$

subject to

$$\sum_{i=1}^{m} x_i c_i \leqslant M^* \quad ,$$

which implies

$$x_i = \frac{a_i}{\mu c_i \ (b_2/v_i \cdot T)} \quad , \qquad i = 1,\ldots,m \ . \qquad (2.9\text{-}18)$$

The former model is potentially relevant for analyses of relative price changes among travel and non-travel goods; the latter model is potentially relevant for analyses of shorter work hours with equal pay.

The question in each of these cases is: how are the short-run, fixed travel time and travel money budgets M^* and T^* determined by a household ? This precursor problem can be specified in utility terms as:

$$\underset{T^*,\ M^*}{\text{Max}}\ u = a\log(\Sigma\, x_i) + b_1 \log(Y - M^*) + b_2 \log(T - T^*) \quad , \qquad (2.9\text{-}19)$$

where the fixed travel money budget is given by

$$M^* = \sum_{i=1}^{m} c_i x_i \quad , \qquad (2.9\text{-}20)$$

and the fixed travel time budget is given by

$$T^* = \sum_{i=1}^{m} x_i/v_i \quad . \qquad (2.9\text{-}21)$$

Here the household is purported to be interested in trading off the utility from <u>total</u> travel, $\phi(\sum_{i=1}^{m} x_i)$, against consumption and leisure utilities in determining travel budgets at the first stage of the travel decision process. The second stage of the decision process is represented by model (2.9-1). The necessary and sufficient conditions for an optimum in (2.9-19) are then

$$\frac{a}{\Sigma x_i} - \frac{b_1 c_i}{(Y - M^*)} - \frac{b_2}{v_i(T - T^*)} = 0 \quad , \quad i = 1,\ldots,m. \qquad (2.9\text{-}22)$$

The implications of (2.9-22) are revealed most readily in the case of two modes. Writing conditions (2.9-22) for $i = 1,2$ and equating:

$$\frac{b_1 c_1}{(Y - M^*)} + \frac{b_2}{v_1(T - T^*)} = \frac{b_1 c_2}{(Y - M^*)} + \frac{b_2}{v_2(T - T^*)} \quad . \qquad (2.9\text{-}23)$$

Thus,

$$(b_1(c_1 - c_2)/(Y - M^*) = (b_2(\frac{1}{v_1} - \frac{1}{v_2}))/(T - T^*) \ , \qquad (2.9\text{-}24)$$

or,

$$T - T^* = (Y - M^*)(b_2(\frac{1}{v_1} - \frac{1}{v_2})/(b_1(c_1 - c_2)) \ . \qquad (2.9\text{-}25$$

The coefficient

$$\gamma = (b_2(\frac{1}{v_1} - \frac{1}{v_2}))/(b_1(c_1 - c_2)) \ , \qquad (2.9\text{-}26)$$

relating time for leisure to money for residual consumption, is a function of the sum of modal costs and the sum of the inverse of modal speeds. It is positive, assuming one mode does not dominate the other (that is, if $c_1 > c_2$ for $v_1 > v_2$, or $c_1 < c_2$ for $v_1 < v_2$). Substituting definition (2.9-26) in Equation (2.9-25) and solving for the travel time budget,

$$T^* = (T - \gamma Y) + \gamma M^* \quad ; \qquad (2.9\text{-}27)$$

That is, travel time and money budgets are linearly related with slopes which are independent of income and available time, and dependent on travel costs and speeds.

The above result is easily testable on actual data, and Figure 2.9-1 shows two examples of the relationships between the households' travel time and money budgets in the case of three car ownership segments in the Nurenberg region and the metropolitan area of Munich, both in Germany. The parameters of the linear regressions plotted in Figure 2.9-1 are listed in Table 2.9-1. Statistics for testing hypotheses that the regressions for each car ownership segment are equivalent for Nurenberg and Munich are given in Table 2.9-2. These statistics are generated through a test procedure proposed by Chow (1960).

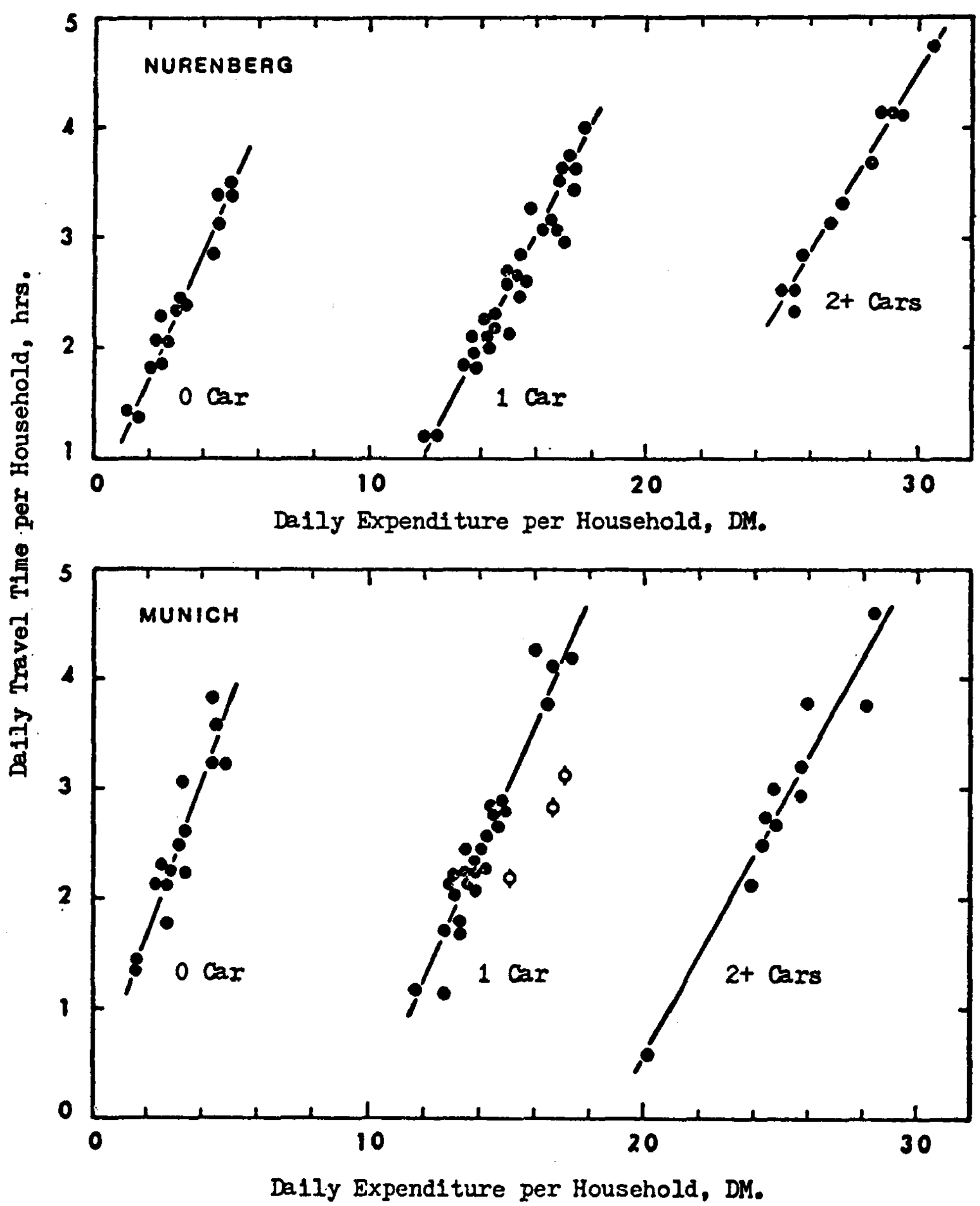

Figure 2.9-1: Daily Travel Time and Money Expenditures per Household, Nurenberg and Munich

Table 2.9-1: The Relationships Between Travel Time and Money Budgets per Household, Nurenberg and Munich

Regression Result	NURENBERG			MUNICH		
	0 Car	1 Car	2+ Cars	0 Car	1 Car	2+ Cars
Slope	0.559	0.469	0.433	0.700	0.587	0.453
Intercept	0.598	-4.544	-8.428	0.225	-5.831	-8.511
R^2	0.958	0.935	0.981	0.844	0.925	0.929

(Source: Appendices 1 and 2) Summarized in Appendix 4.

Table 2.9-2: Comparison of Regressions, Nurenberg versus Munich (* - Hypothesis rejected at 0.01 confidence level)

Hypothesis Tested	F - Statistics		
	0 Car	1 Car	2+ Cars
Equality of Regressions	1.68 (2,26)	31.73* (2,51)	9.12* (2,18)

(-) Degrees of freedom

The results indicate the following:

(1) Car ownership is an effective criterion by which to segment households into homogeneous segments with respect to relationships between allocated time and money travel budgets. For both areas, differences among car ownership segments far surpass differences among observations within each segment.

(2) For each car ownership segment in each area, there is a linear relationship between time and money budgets, as predicted by equation (2.9-27). For both of the areas, there are significant differences among the car ownership segments in terms of both the intercepts and slopes of the linear relationships. This indicates differences in the γ terms of equation (2.9-27), and possible differences in mean T and/or Y values, if this equation correctly specifies the underlying mechanism of the relationships.

(3) The time-money budget relationships for zero-car households <u>are not</u> significantly different, Nurenberg versus Munich. But the relationships <u>are</u> different between the two areas for both 1-car and 2+ car

households. This indicates that one or both of the following might be true if equations (2.9-26) and (2.9-27) hold: average speeds are lower for Munich; or average costs are higher for Munich. However, differences in tastes between the populations of these two areas (i.e., differences in average b_2/b_1 values) could also account for differences in the time-money budget relationships and such an effect is inseparable from the system supply (v_1, v_2 and c_1, c_2) effects.

In summary, the linearity of the observed relationships in Nurenberg and Munich tend to support the basic formulations of the UMOT process and their ability to predict actual travel behavior. The results also suggest that an effective criterion by which to segment households into homogeneous segments with respect to travel behavior is car ownership. Finally, the results also indicate that travel costs by car-owning households in the metropolitan area of Munich are higher than in the Nurenberg region. One plausible reason for this result is that travel speeds are slower in the former area than in the latter region.

Additional tests of other hypotheses central to principles of the UMOT process are analyzed in detail in Chapters 3 and 4.

2.10 Extensions for Nondiscretionary Travel and Price Indices

(1) The utility models developed thus far are based on the hypothesis that all travel is discretionary. This might not be true in the real world; certain travel, such as work trips and shopping trips for food needs, could be considered non-discretionary by a household and not subject to travel budgets if costs or times of such travel are high. The utility model is readily extended to account for nondiscretionary travel by redefining travel utility as

$$\phi_i(x_i) = a_i \log(x_i + r_i) , \qquad i = 1,\ldots,m \qquad (2.10\text{-}1)$$

where

$$\sum_{i=1}^{m} r_i = R \quad , \qquad (2.10\text{-}2)$$

and R is the household's nondiscretionary travel distance, while r_i is discretionary travel allocated to mode i. The implications of including nondiscretionary travel in various utility models are revealed by formulating the utility-maximizing conditions for the models, with expressions (2.10-1) and (2.10-2) replacing the previous travel utility specification.

Since the concept of nondiscretionary travel could be important in situations of low incomes relative to required travel expenditures, such as might be the case for certain population segments in developing countries, focus is initially placed on the single (money) budget model. Previously, in the absence of nondiscretionary travel, total travel in the money budget case was related to cost, modal attractions and income (cf. Equation 2.7-7):

$$\sum_{i=1}^{m} x_i = \frac{Y}{(b_1 + 1)} \sum_{i=1}^{m} a_i/c_i \quad . \qquad (2.10\text{-}3)$$

In the presence of nondiscretionary travel requirements this relationship is given by

$$\sum_{i=1}^{m} x_i = \frac{Y}{(b_1 + 1)} \sum_{i=1}^{m} a_i/c_i - R \qquad (2.10\text{-}4)$$

for

$$Y > ((b_1 + 1)R) / \sum_{i=1}^{m} a_i/c_i \quad ; \qquad (2.10\text{-}5)$$

and

$$\sum_{i=1}^{m} x_i = 0 \qquad (2.10\text{-}6)$$

for

$$Y < ((b_i + 1)R)/\sum_{i=1}^{m} a_i/c_i \qquad (2.10\text{-}7)$$

Thus, expenditure on discretionary travel is a linear function of income for incomes meeting condition (2.10-5):

$$\sum_{i=1}^{m} c_i x_i = \left(\frac{1}{b_1 + 1}\right)Y - \sum_{i=1}^{m} c_i v_i \quad , \qquad (2.10\text{-}8)$$

but lie above this budget line for incomes failing condition (2.10-5). In this latter case (2.10-7) it is reasonable to speculate that the forced travel budget is given by

$$\sum_{i=1}^{m} c_i r_i = Rc_k \quad , \qquad (2.10\text{-}9)$$

where k is the minimum-unit-cost mode:

$$c_k < c_i \quad ; \quad i = 1,\ldots m;\ i \neq k \qquad (2.10\text{-}10)$$

In the two-budget case, the utility-optimizing conditions become, in the presence of nondiscretionary travel requirements,

$$\frac{a_i}{(x_i + r_i)} = \frac{b_1 c_i}{(Y - \sum_{i=1}^{m} c_i x_i - \sum^{m} c_i v_i)} + \frac{b_2}{v_i(T - \Sigma x_i/v_i - \Sigma r_i/v_i)} ,$$

$$i = 1,\ldots,m. \qquad (2.10\text{-}11)$$

where

$$\sum_{i=1}^{m} r_i = R \quad . \qquad (2.10\text{-}2)$$

In cases of high incomes and high available times relative to total travel expenditure, the approximations (2.8-2) and (2.8-3) can be employed, and discretionary travel on any mode is

$$x_i = \frac{a_i}{(b_1 c_i/Y) - (b_2/v_i T)} - r_i \quad , \qquad i = 1,\ldots,m. \quad (2.10\text{-}12)$$

However, in cases where nondiscretionary travel expenditures strain incomes or available times, approximations (2.8-2) and (2.8-3) are no longer legitimate. These cases are characterized by discretionary travel approaching zero in (2.10-11), or

$$x_i \ll r_i \quad , \qquad i < 1,\ldots m, \qquad (2.10\text{-}13)$$

which leads to a simplification of (2.10-11):

$$\frac{a_i}{r_i} = \frac{b_1 c_i}{(Y - \Sigma c_i r_i)} + \frac{b_2}{v_i(T - \Sigma r_i/v_i)} , \quad i = 1,\ldots,m. \qquad (2.10\text{-}14)$$

Conditions (2.10-14) are restatements of the general two-budget model conditions (2.8-1) where nondiscretionary travel replaces discretionary travel. These conditions lead to complicated solutions describing how travel is allocated among modes given the modal costs, speeds and attractions, and the marginal money costs of time function.

(2) A second extension of the utility model concerns the price index for residual consumption. In the general logarithmic model, the price index for residual consumption, denoted as p_c, falls out of the model since

$$b_1 \log[Y/p_c - (1/p_c)\sum_{i=1}^{m} c_i x_i] = b_1 \log(Y - \sum_{i=1}^{m} c_i x_i) - b_1 \log p_c \, , \qquad (2.10\text{-}15)$$

and constant terms not containing x_i have no affect on utility maximization. In order for p_c to be internalized within the model structure, postulates relating Y and c_i to p_c are required.

One such postulate is that some modal costs respond directly to changes in consumer prices, or

$$\frac{dc_i}{dp_c} = \zeta_i \quad , \qquad i = 1,\ldots,m, \qquad (2.10\text{-}16)$$

which implies,

$$c_i = \zeta_i p_c + \delta_i \quad , \qquad i = 1,\ldots,m, \qquad (2.10\text{-}17)$$

where ζ_i is the component of mode i costs which responds within the time period of analysis to consumer prices, and δ_i is the cost component which is independent of consumer prices. If it is further assumed that incomes do <u>not</u> respond to consumer prices within the time period of analysis,

$$\frac{dY}{dp_c} = 0 \quad , \qquad (2.10\text{-}18)$$

then the single-budget logarithmic utility (2.7-4) becomes

$$\underset{x_i}{\text{Max}}\ u = \sum_{i=1}^{m} a_i \log x_i + b_1 \log(Y - p_c \sum_{i=1}^{m} \zeta_i x_i - \sum_{i=1}^{m} \delta_i x_i) \ ; \qquad (2.10\text{-}19)$$

Total travel expenditure implied by the extended model (2.10-19) is, as before,

$$\sum_{i=1}^{m} c_i x_i = (\frac{1}{b_1 + 1})Y \quad , \qquad (2.7\text{-}9)$$

This is insured by Theorem 2.5-1 and is readily verified by developing the optimizing conditions for (2.10-18) along the lines of expressions (2.7-3) through (2.7-5). However, postulate (2.10-17)-(2.10-18) is reflected in the equations for travel distances:

$$x_i = \frac{a_i}{(\zeta_i p_c + \delta_i)}(\frac{1}{b_1 + 1})Y \quad , \quad i = 1,\ldots,m \quad (2.10\text{-}19)$$

Thus, in the limiting case where cost for a mode is proportional to consumer prices ($\delta_i = 0$), distance travelled on that mode is inversely proportional to consumer prices. As modal costs become less sensitive to consumer prices (δ_i/ζ_i increases), this effect diminishes.

Similarly, postulate (2.10-17)-(2.10-18) can be adapted to the two-budget model (2.7-1). For incomes and available times meeting conditions (2.8-2) and (2.8-3), expression (2.8-5) for approximate travel distance is modified to:

$$x_i \cong \frac{a_i}{[(b_1\zeta_i p_c + b_1\delta_i)/Y] + (b_2/v_i T)} \ , \quad i = 1,\ldots,m \qquad (2.10\text{-}20)$$

An example application of (2.10-19) or (2.10-20) involves forecasting the short-term effects of changes in car operating costs resulting from increases in fuel costs which are proportional to a general consumer price index increase.

2.11 Car Ownership Decisions

The models developed in the preceeding sections postulate that a household reaches decisions concerning total travel on various available modes based upon the time and money costs of travel on each of those modes and the time and money resources which the household has available. Consequently, a household might desire a certain level of car travel. Such car travel could be realized by purchasing and maintaining various numbers of cars, light-duty trucks, and so on, ranging logically from a single vehicle to one vehicle for every driver-aged household member. Alternatively, a household could choose to rely upon ridesharing with neighbors, fellow workers, and so on, in an attempt to forego capital outlays, or could reevaluate its decision concerning desired car travel and reallocate such travel to competing modes.

Such a concept of short-term travel decisions feeding decisions involving longer-term commitments, which then feed back upon the short-term decisions, implies development of a car ownership model to be linked to the travel desire model in the UMOT process. A relevant question is then whether or not a car ownership model can be developed based upon the same utility theory formulation which underlies the UMOT travel desire model . Development of such a complementary series of travel behavior models is necessary, but not sufficient for theoretical consistency.

Beginning with a two-mode case exploring the relevance of the general form of the utility model (2.4-6) to car ownership decisions, assume that a household relies on car travel exclusively if it owns at least one car. Defining travel by car as x_1 and travel by the alternative mode(s) (which could be either public transit or ridesharing) as x_2, comparisons can be made between achieved utilities to derive conditions under which the household prefers to own, or not own, a car. The best the household can do with a car is given by

$$u_1^* = \phi(x_1^*) + \psi(Y - c_1 x_1^*) + \xi(T - x_1^*/v_1) \quad , \qquad (2.11\text{-}1)$$

where x_1^* is the utility-maximizing travel distance by car.

Since costs of car travel can be separated into fixed costs (p), allocated on a per-unit distance basis, and variable costs $\bar{c}_1$,

$$c_1 = p/x_1 + \bar{c}_1 \quad ,$$

achieved utility (2.11-1) can also be written

$$u_1^* = \phi(x_1^*) + \psi(Y - p - \bar{c}_1 x_1^*) + \xi(T - x_1^*/v_1) \ , \qquad (2.11\text{-}2)$$

Similarly, the best the household can do without a car is given by:

$$u_2^* = \phi(x_2^*) + \psi(Y - c_2 x_2^*) + \xi(T - x_2^*/v_2) \quad , \qquad (2.11\text{-}3)$$

where x_2^* is the utulity-maximizing travel by the alternative mode(s).

Considering first the simplest case in which there is no inherent attractiveness of car over the alternative mode(s) ($a_1 = a_2$ in the logarithmic utility model (2.7-1)), and cost and time differences trade-off such that distances x_1^* and x_2^* are approximately the same, then

$$\phi(x_1^*) = \phi(x_2^*) \quad . \qquad (2.11\text{-}4)$$

In this case a household decides to own a car whenever achieved utility (2.11-2) is greater than achieved utility (2.11-3), or

$$\psi(Y - p - \bar{c}_1 x) + \xi(T - x/v_1) > \psi(Y - c_2 x) + \xi(T - x/v_2), \qquad (2.11\text{-}5)$$

where x is the distance traveled independent of mode.

At a critical combination of travel distance (x), income (Y), fixed costs (p), variable costs ($\bar{c}_1$ and c_2) and speeds (v_1 and v_2), the household will be indifferent between owning and not owning a car, or

$$\psi(Y - p - \bar{c}_1 x) + \xi(T - x/v_1) - \psi(Y - c_2 x) - \xi(T - x/v_2) = 0 \quad , \qquad (2.11\text{-}6)$$

which can be denoted as the criterion function

$$H(x, Y, p, \bar{c}, v_1, v_2) = 0 \quad . \qquad (2.11\text{-}7)$$

From Equations (2.11-6)-(2.11-7) it is possible to determine how demand for car ownership depends qualitatively on other parameters:

(1) As income increases, the level of travel necessary to justify car ownership decreases.

To show this, note that

$$\frac{dx}{dY} = - \frac{\partial H}{\partial Y} \Big/ \frac{\partial H}{\partial x} \quad . \tag{2.11-8}$$

Thus, since

$$\frac{\partial H}{\partial x} > 0 \quad , \tag{2.11-9}$$

the sign of the derivative of distance with respect to income becomes

$$\text{Sign}\left(\frac{dx}{dY}\right) = - \text{Sign}\left(\frac{\partial H}{\partial Y}\right) \tag{2.11-10}$$

or

$$\text{Sign}\left(\frac{dx}{dY}\right) = - \text{Sign}\left[\psi'(Y - p - \bar{c}_1 x) - \psi'(Y - c_2 x)\right] . \tag{2.11-11}$$

Assuming that car travel is more expensive,

$$p/x + \bar{c}_1 > c_2 \tag{2.11-12}$$

but faster;

$$v_1 > v_2 \tag{2.11-13}$$

than travel by the alternative mode(s),

$$\psi'(Y - p - \bar{c}_1 x) < \psi'(Y - c_2 x) \quad , \tag{2.11-14}$$

since ψ' is concave (reflecting the principle of diminishing marginal utility). Thus,

$$\frac{dx}{dY} < 0 \quad . \tag{2.11-15}$$

(2) Similarly, as available time increases, the level of travel necessary to justify car ownership increases, or the necessity of a time saving by car decreases:

$$\text{Sign}\left(\frac{dx}{dT}\right) = - \text{Sign}\left(\frac{\partial H}{\partial T}\right) \tag{2.11-16}$$

or,

$$\text{Sign}(\frac{dx}{dT}) = - \text{Sign}[\ \xi'(T - x/v_1) - \xi'(T - x/v_2)] \ , \quad (2.11\text{-}17)$$

which leads to

$$\frac{dx}{dT} > 0 \quad (2.11\text{-}18)$$

due to (2.11-13) and the principle of diminishing marginal utility.

(3) As the fixed cost of car ownership increases, the level of travel justifying car ownership increases:

$$\text{Sign}(\frac{dx}{dp}) = - \text{Sign}(\frac{\partial H}{\partial p}) \quad (2.11\text{-}19)$$

or

$$\frac{dx}{dp} > 0 \ ; \quad (2.11\text{-}20)$$

since ψ is a monotonically increasing function.

(4) As the variable costs of car ownership increases, the level of travel justifying car ownership increases:

$$\text{Sign}(\frac{dx}{d\bar{c}_1}) = - \text{Sign}(\frac{\partial H}{\partial \bar{c}_1}) \quad (2.11\text{-}21)$$

or

$$\text{Sign}(\frac{dx}{d\bar{c}_1}) = - \text{Sign}(-x\,\psi') \ , \quad (2.11\text{-}22)$$

which leads to

$$\frac{dx}{d\bar{c}_1} > 0 \ . \quad (2.11\text{-}23)$$

(5) Similarly, as the cost of travel by the alternative mode(s) increases, the level of travel justifying car ownership decreases:

$$\text{Sign}(\frac{dx}{dc_2}) = - \text{Sign}(\frac{\partial H}{\partial c_2}) \quad (2.11\text{-}24)$$

or,

$$\text{Sign}(\frac{dx}{dc_2}) = - \text{Sign}(x\,\psi') \ , \quad (2.11\text{-}25)$$

which leads to

$$\frac{dx}{dc_2} < 0 \ . \quad (2.11\text{-}26)$$

(6) As average speed of car travel increases, the level of travel justifying car ownership decreases:

$$\mathrm{Sign}\left(\frac{dx}{dv_1}\right) = - \mathrm{Sign}\left(\frac{\partial H}{\partial v_1}\right) \tag{2.11-27}$$

or,

$$\mathrm{Sign}\left(\frac{dx}{dv_1}\right) = - \mathrm{Sign}\left(\frac{x}{v_1^2}\,\xi'\right) \quad , \tag{2.11-28}$$

which leads to

$$\frac{dx}{dv_1} < 0 \tag{2.11-29}$$

(7) Finally, as average speed of travel by the alternative mode(s) increases, the level of travel justifying car ownership increases:

$$\mathrm{Sign}\left(\frac{dx}{dv_2}\right) = - \mathrm{Sign}\left(\frac{\partial H}{\partial v_2}\right) \tag{2.11-30}$$

or,

$$\mathrm{Sign}\left(\frac{dx}{dv_2}\right) = - \mathrm{Sign}\left(- \frac{x}{v_2^2}\,\xi' \right) \quad , \tag{2.11-31}$$

which leads to

$$\frac{dx}{dv_2} > 0 \quad . \tag{2.11-32}$$

Another implication of applying the general two-budget utility model to the simplified fixed-travel car ownership decision is revealed by the qualitative relationship between income and car ownership cost:

(8) As the fixed cost of car ownership increases, the level of income necessary to justify car ownership increases. To show this, implicit differentiation of (2.11-6) yields

$$\psi'(Y - p - \bar{c}_1 x)\frac{dY}{dp} - \psi'(Y - p - \bar{c}_1 x) = \psi'(Y - c_2 x)\frac{dY}{dp} \tag{2.11-33}$$

or,

$$\frac{dY}{dp} = \frac{\psi'(Y - p - \bar{c}_1 x)}{\psi'(Y - p - \bar{c}_1 x) - \psi'(Y - c_2 x)} \tag{2.11-34}$$

Thus,

$$\frac{dY}{dp} > 0$$

from assumption (2.11-12) and the principle of diminishing utility.

Further implications are revealed by applying two Taylor Series expansions to criterion function (2.11-6)-(2.11-7). Small differences in utilities of residual consumption can be approximated by

$$\psi(Y - p - \bar{c}_1 x) - \psi(Y - c_2 x) \cong \psi'(Y)[(c_2 - \bar{c}_1)x - p] , \quad (2.11\text{-}35)$$

and small differences in utilities of leisure time can be approximated by:

$$\xi(T - \frac{x}{v_1}) - \xi(T - \frac{x}{v_2}) \cong \xi'(T)x(\frac{1}{v_2} - \frac{1}{v_1}) \quad . \quad (2.11\text{-}36)$$

Substituting (2.11-35) and (2.11-36) in (2.11-5),

$$p < x(c_2 - \bar{c}_1) + \frac{\xi'(T)}{\psi'(Y)} x \, (\frac{1}{v_2} - \frac{1}{v_1}) \quad , \quad (2.11\text{-}37)$$

which states that car ownership is advantageous whenever the fixed costs of ownership are less than the sum of the differences in variable costs and the time savings converted to money terms by the money value of time $\xi'(T)/\ \psi'(Y)$.

Solving (2.11-37) for the critical value of travel necessary to justify car ownership:

$$x > \frac{p}{\frac{\xi'(T)}{\psi'(Y)}(\frac{1}{v_2} - \frac{1}{v_1}) + (c_2 - \bar{c}_1)} \quad (2.11\text{-}38)$$

Thus, the travel threshold is (approximately) directly proportional to fixed costs of car ownership and inversely proportional to a composite term expressing the net of the money value of the time savings of using car over and above the differences in variable money costs.

Specifying the logarithmic utility model (2.7-1) results in expression (2.8-8) being inserted for the money value of time [$\xi'(T)/\ \psi'(Y)$] in threshold conditions (2.11-37) and (2.11-38). Focussing on (2.11-38), for incomes and available times "large" compared to travel money and time expenditures, respectively (conditions (2.8-2) and (2.8-3)), car ownership is advantageous whenever:

$$x > \frac{p}{(b_2 Y)/(b_1 T)\cdot(1/v_2 - 1/v_1) + (c_2 - \bar{c}_1)} \quad . \qquad (2.11\text{-}39)$$

Expressions of the critical level of income justifying car ownership for a given desired travel distance are simplified by defining the benefit of time savings by car travel as

$$\theta = \xi(T - x/v_1) - \xi(T - x/v_2) \qquad (2.11\text{-}40)$$

or, for logarithmic utilities,

$$\theta = b_2 \log[\frac{(T - x/v_1)}{(T - x/v_2)}] \quad . \qquad (2.11\text{-}41)$$

Thus, continuing the logarithmic case, car ownership is advantageous whenever

$$b_1 \log(Y - p - \bar{c}_1 x) + \theta > b_1 \log(Y - c_2 x) \quad . \qquad (2.11\text{-}42)$$

Condition (2.11-42) can be rewritten as

$$\frac{Y - p - \bar{c}_1 x}{Y - c_2 x} > e^{-(\theta/b_1)} \qquad (2.11\text{-}43)$$

which, for incomes "large" relative to travel expenditures , yields the approximate critical income

$$Y \cong \frac{p}{1 - e^{-(\theta/b_1)}} \quad . \qquad (2.11\text{-}44)$$

Thus, as car time savings benefits become large relative to the attraction of residual consumption, the income level justifying car ownership approaches the fixed costs of car ownership; as time savings benefits approach zero, the critical income level grows without bound.

Relaxing the assumption of equal travel utilities for car and the alternative mode(s) (2.11-4), the condition for car ownership is derived by comparing the achieved utilities (2.11-2) and (2.11-3):

$$\phi(x_1^*) + \psi(Y - p - \bar{c}_1 x_1^*) + \xi(T - x_1^*/v) >$$

$$\phi(x_2^*) + \psi(Y - c_2 x_2^*) + \xi(T - x_2^*/v) \quad . \qquad (2.11\text{-}45)$$

For relatively small differences in utilities, condition (2.11-45) can be approximated by employing a Taylor Series expansion at $x = x_1^*$, Y , and T. Thus, car ownership is advantageous whenever

$$\phi'(x_2^*)(x_1^* - x_2^*) + \psi'(Y)(c_2 x_2^* - \bar{c}_1 x_1^* - p) + \\ + \xi'(T)(x_2^*/v_2 - x_1^*/v_1) > 0 \quad . \quad (2.11\text{-}46)$$

Defining the difference in travel distance by car over travel distance by the alternative mode(s) as

$$\Delta x = x_1^* - x_2^* \quad , \qquad (2.11\text{-}47)$$

condition (2.11-46) can be rewritten

$$\frac{\phi'(x_2^*)}{\psi'(Y)} \Delta x + \frac{\xi'(T)}{\psi'(Y)} \left[x_2^*\left(\frac{1}{v_2} - \frac{1}{v_1}\right) - \frac{\Delta x}{v_1} \right] - \Delta x c_1 + \\ + x_2^*(c_2 - \bar{c}_1) > p \quad . \quad (2.11\text{-}48)$$

The first term on the left-hand side of inequality (2.11-48) represents the utility of the difference in travel distance, car versus alternative mode(s), converted to money terms. The second term, encompassing the bracketed differences, represents the value of the time saved by car net of the additional time required for travel of the difference in distance, again converted to money terms. Finally, the remaining terms on the left-hand side of the inequality represent the extra money cost of car travel. Condition (2.11-48) states that car ownership is advantageous whenever the value of the travel difference plus the value of the time savings minus the extra variable costs is greater than the fixed costs of car ownership.

It is feasible to extend these arguments to decisions involving ownership of more than one car by chaining the binary choices. That is, for households with more than one driver, choice of a second car can be considered conditional upon a favorable decision to own a first car. If incomes, available times and desired travel distances warrant car ownership, then the car ownership decision process can be repeated redefining car travel as travel using two cars and the alternative mode as travel using only one car. This modeling concept does require more detailed development of travel times and costs faced by household members with and without exclusive uses of household cars, which is in the realm of further research. Nonetheless, a simplified car ownership model can be applied even at this stage, as detailed in Section 5.5.

2.12 Estimation Considerations

The major estimation problems in applying various versions of the utility travel demand model involve the coefficients of the utility functions. These coefficients were identified in models (2.7-1), (2.7-4) and (2.7-5) as a_i, modal attractions for modes $i = 1,\ldots,m$, b_1, the attractiveness of residual consumption, and b_2, the attractiveness of leisure time. The ratio b_2/b_1 is also interpretable as the utility coefficient of the value of time (2.8-8). All of these coefficients express "tastes", which account for differences in behavior among households faced with similar travel alternatives and constraints. But as "tastes" they are not directly observable.

The a_i modal attractions potentially are functions of all modal attributes which are not encompassed in the utility function, which in the two-budget case, includes all attributes except door-to-door time and cost. Thus, if a traveler considers seriously such attributes as comfort, personal security or weather protection in choosing modes, the a_i values of the alternative modes are determined in some manner by the traveler's perceptions of how well the modes rate on these attributes. The effect of the a_i values is then similar to the effect of constant terms in conventional mode choice models in accounting for bias in choice not explained by the model independent variables.

Focussing on the short-run case in which incomes and available times are presumed fixed, _a priori_ knowledge of the a_i values for a particular population segment leads to determination of the x_i and μ and

λ values, barring degeneracy. This determination is made through solution of m + 2 equations (m = number of modes) in m + 2 unkowns. The m + 2 equations are the m optimality conditions (2.9-14), and the additional two equations are the travel money and time budgets specified as the constraints of problem (2.9-13). In the special case when m = 2, the two budget equations alone determine the two travel distances x_1 and x_2, and no information is derivable regarding travelers' money value of time (λ/μ); travelers' choices are determined by the budget equations, precluding trade-offs between time and money according to preferences.

In the general case when the number of modes exceeds the number of travel budgets, a priori knowledge of modal attractiveness (a_i) is required. In absence of any information, whatever, regarding the a_i values, equal attractiveness can be assumed ($a_1 = a_2 = \dots = a_m$) and tested against empirical observations. One possible test of such an hypothesis involves data on travel distances and speeds by mode for various populations of travelers:

The utility-maximizing travel distances in the short-run case for a single (time) budget are given by

$$x_i = \frac{1}{\lambda} a_i v_i \quad , \qquad (2.12\text{-}1)$$

assuming the logarithmic utility model (2.9-13) with a vanishing money budget. Thus, total utility-maximizing travel is

$$\sum_{i=1}^{m} x_i = \frac{1}{\lambda} \sum_{i=1}^{m} a_i v_i \quad , \qquad (2.12\text{-}2)$$

which can be written

$$\sum_{i=1}^{m} x_i = \frac{-1}{\lambda} \Sigma\, \eta_i v_i + \frac{1}{\lambda} \Sigma\, v_i \quad , \qquad (2.12\text{-}3)$$

where

$$\eta_i = 1 - a_i \quad , \qquad i = 1,\dots,m \qquad (2.12\text{-}4)$$

is a measure of the deviation of modal attractiveness from equality.

Regressions of the type

$$\sum_{i=1}^{m} x_i = \alpha + \beta \sum_{i=1}^{m} \left(\frac{x_i}{t_i}\right) \qquad (2.12\text{-}5)$$

where t_i is the time spent traveling on mode i, can then be employed in testing the hypothesis that $\alpha = 0$, or that

$$\eta_i = 0 \quad , \qquad i = 1, \ldots, m \qquad (2.12\text{-}6)$$

However, the role of the utility coefficients a_i, μ and λ (or a_i, b_1 and b_2 in the long-run case) is not limited to model calibration. Since these parameters represent "tastes", they are properly random variables distributed over a population of travelers. They account for variances in travel distances among households with similar incomes, available times, and transportation supply measures.

While the introduction of postulated distributions for tastes within the UMOT process travel behavior models awaits further research, one particularly transparent application of such distributions is to car ownership decisions. The critical distance conditions such as (2.11-38) can be specified in terms of random tastes as

$$x > \epsilon(T, Y) \qquad (2.12\text{-}7)$$

where ϵ is a random deviate. For example, if the time value of money in (2.11-38) is normally distributed, and variable costs by car and the alternative mode are similar, then the probability that a household with income Y and available time T chooses to own a car is also normally distributed. Such considerations are applied in the UMOT car ownership model, of which a simplified version is presented in Section 5.2.

CHAPTER 3: THE TRAVEL BUDGETS

3.1 Introduction

The constraints on travel choices can be many and varied. The most obvious ones are the limited resources of time and money that are available to a traveler. Additional factors, such as personal preferences and handicaps, or an imposed long trip distance to work, might also become binding constraints.

The purpose of the research reported in this chapter is to explore whether the allocation of time and money to the various daily activities suggests specific travel time and money budgets. The search for evidence of travel budgets should appropriately begin with aggregated data. Preferably individual trip data can be aggregated over a week for each surveyed household or, if such data are unavailable, data can be generated from the aggregation of one-day travel of households with similar socioeconomic characteristics.

One reason for beginning with aggregated data is the problem involved in day-to-day variations in travel behavior. Such variations are usually assumed to be accounted for by spreading the surveyed households over a fairly long period, although each sampled household is surveyed for one day only. Observed travel variations among households are then attributed to their socioeconomic characteristics, such as income, size and car ownership. If, on the other hand, households or individuals tended towards some stable travel time and money budgets over a long period, it would be wrong to attribute all the observed variations to the households' socioeconomic characteristics; not only would it mask the existence of such budgets, but part of the daily variations are actually variations between days for the same households rather than between different households (Goodwin, 1978). Even adding a probability distribution function in order to describe the observed variations does not solve the problem if the effects of such budgets are not recognized.

Many difficulties are encountered when comparing data on travel time and money budgets from different sources. Following are some examples referring to the travel time budget.

(1) <u>The daily travel time per household</u>

This definition is not fully satisfactory if the number of persons and travelers per household are not reported; it is the travelers who spend their own time on travel, not the 'household'.

(2) <u>The daily travel time per person</u>

The proponents of this definition point out that as a daily travel time budget has to be measured over an extended period (in order to remove the effects of daily variations), practically every person in a city is expected to be a traveler during this period, especially when walking trips are included. Hence, a daily travel time budget which is based on those who actually traveled during a <u>one-day</u> survey, should be applied per average person.

There are, however, two problems with this approach. First, if there is a daily travel time budget that acts as a constraint on travel, then it must apply to the traveler; a daily travel time budget (or TT-budget, for short) is a personal budget, not an average of travelers and non-travelers. And second, it makes comparisons difficult across cities or countries since the definition of a 'person' may vary. For example, persons over the age of 6 years are identified in some surveys, while those over the age of 10 or 12 years are identified in other surveys.

(3) <u>The daily travel time per traveler</u>

This appears to be a better measure than the above two, but there are complications here as well. Defining a traveler as a person who made at least one trip during the day, including walking trips, might result in the averaging of, say, a 4-minute walking round-trip of the wife to a crocery shop around the corner with the 60-minute car round trip of the husband to work. This would result in an average value of 32 minutes per average traveler, with much of the information on the behavior of motorized and non-motorized travelers being lost through the averaging process. A plausible way to solve this problem is to stratify the travelers by the mode used, such as walking only, public transport only, car only, and their combinations. Moreover, the daily variations in travel for one traveler can be considerably greater than the variations between travelers. It would, therefore, be preferable to derive average daily travel times from a weekly travel-diary per traveler, rather than from one-day cross-sectional data of different travelers.

(4) Network vs. reported travel times

The travel times that are typically regarded as affecting travelers' choices are the in-vehicle network times (either based on observed speeds or derived from the distribution/assignment of trips to the transportation networks) and the out-of-vehicle times (either assumed, or estimated from the calibration of mode-choice models). However, if possible, it is preferable to derive the daily travel time per traveler from the reported trip times, as the perceived times should reflect better the effects of travel times on the choices than the synthesized times.

(5) Rounding of reported times

One reason why analysts are reluctant to use reported trip times for calibration purposes is that travelers tend to round them off, either by the times of start-and-finish of a trip, or by the duration of the trip, thus introducing possible distortions into the analyses. However, aggregating reported travel times during a day tends to minimize these distortions.

The above examples reflect some of the difficulties that may be encountered when comparing daily travel times coming from different sources. Even so, it appears that some strong trends do emerge, surfacing above all difficulties and uncertainties.

The results suggest that although the average daily travel times may differ between cities and countries, they display a remarkable consistency within each data set when stratified by household characteristics, such as income. Furthermore, although the cross-sectional average daily travel times differ between individual travelers belonging to the same population segment, the average values display a stability for a group of above approximately ten travelers. Moreover, the variations around the mean values are very similar for all population segments. In summary, the available data suggest that the daily TT-budget is not coincidental.

The following examples begin with the TT-budget and conclude with the TM-budget. The examples proceed from the aggregate averages, per country or per city, to the disaggregate values per representative travelers of various population segments.

A. THE TRAVEL TIME BUDGET

3.2 The Use of Time: An International Comparison

The European Centre for Coordination of Research and Documentation in the Social Sciences, set up in 1963 in Vienna by the International Social Science Council, embarked on an international survey of the use of time for the daily activities of urban and suburban populations in twelve countries. The surveys were carried out during 1965/66, providing data on about 30,000 man-days of everyday life, and the results were published in Szalai et al. (1972). Table 3.2-1 summarizes relevant results of this study, including the daily travel times per person in the twelve countries.

The results show that average times allocated to different activities can vary significantly across populations. For instance, the range of sleep time, which probably is the most stable portion of 24-hours, is between a minimum of 6.97 to a maximum of 8.50 hours, a difference of about 22 percent. After considering such variations, the researchers

Table 3.2-1: The Use of Time in Twelve Countries

Country/City	TIME PER PERSON SPENT ON ACTIVITY, Hrs. (1)								
	Work	House-Work	Household Child & Personal Care	Sleep	Total Leisure	TRAVEL Work	TRAVEL Non-Work	TRAVEL Total	Grand Total
Belgium	4.38	2.42	3.23	8.35	4.73	0.40	0.50	0.93	24.04
Bulgaria, Kazanlik	6.05	1.67	4.37	6.97	3.55	0.68	0.70	1.48	24.09
Czechoslovakia, Olomouc	5.07	2.87	3.47	7.80	3.77	0.55	0.45	1.03	24.01
France, 6 cities	4.25	2.70	4.03	8.30	3.85	0.37	0.52	0.97	24.10
Fed.Rep. Germany (2)	3.88	2.95	3.92	8.50	4.18	0.30	0.28	0.65	24.08
Fed.Rep. Germany, Osnabruck	3.63	2.78	3.82	8.34	4.68	0.27	0.42	0.97	24.26
German Dem.Rep., Hoyerswerda	4.63	3.43	3.38	7.90	3.70	0.53	0.43	1.00	24.04
Hungary, Györ	5.55	2.73	3.57	7.88	3.10	0.68	0.50	1.23	24.06
Peru, Lima-Callao	3.57	2.87	3.10	8.28	4.68	0.62	0.87	1.50	24.00
Poland, Torun	4.97	2.67	3.25	7.78	4.10	0.62	0.63	1.30	24.07
U.S.A., 44 cities	4.03	2.37	3.78	7.83	4.75	0.42	0.83	1.30	24.06
U.S.S.R., Pskow	5.65	2.18	3.25	7.70	3.77	0.55	0.92	1.47	24.02
Yugoslavia, Kragujevac	4.00	2.80	3.28	7.87	4.78	0.45	0.80	1.28	24.01

(1) Because of rounding in the original table, subtotals do not sum to totals.

(2) 100 electoral districts.

Source: Szalai, 1972, p. 114.

came to the conclusion that the allocations of time to the daily activities show a consistent stabilities. With respect to travel, the researchers note that:

> "If there were no particularly active strain toward constancy in time allocations, we would expect average amounts of time spent going to work would be much shorter in survey sites where more efficient modalities of transport are available. However, this does not turn out to be the case. While there is some interesting variation in aggregate times spent to and from work across our sites, it is very much less than the differential efficiency of driving and walking taken alone would lead us to expect. The parameter that our populations do permit to vary much more freely than per capita time costs commuting are, of course, per capita distances to be travelled. Where the more efficient forms of transport are common, average distances to work increase dramatically while the amounts of time given over to achieving this general end seem to be kept within a remarkably narrow range. The resulting similarities in commuting times that emerge across sites certainly cannot be attributed to parallel effects of industrialization, for it is exactly these conditions that show marked variance!" (cf. Szalai, pp. 117. Emphasis added).

And later,

> "There seems to be a distinct preference toward using increased efficiency of transport to spread out in space, and modal distances to the workplace across our sites vary by a factor of fifteen or more, while time allocations remain in the average within an impressively narrow range. Much the same pattern of similarity holds for total travel as well as the trip to work. Non-owners of automobiles only spent about 6 % more time on travel than owners, although clearly the owners travel much greater distances". (cf. Szalai, pp. 123).

The researchers concluded that the allocation of time for travel on an aggregate basis tends to be both stable and transferable between countries. Moreover, it was observed that the travel time budget tends to be stable, while the travel distance is related directly to speed. In other words, when speeds increase, the saved travel time is traded-off for more travel distance.

The relative stability of the daily travel time per person on a nationwide basis was also noted recently in the U.S. (Robinson, 1977).

3.3 Activity Time Allocation in the Fed. Rep. of Germany

The KONTIV(*) nationwide travel survey, conducted in Germany during 1976, provided a wealth of information on the daily activity time allocation of over 41 thousand usable person-days. All persons over 10 years of age in each sampled household were surveyed for their activities during 2 weekdays, and during 3 days if the sample period included the weekend. Since the survey extended over a complete year, it allowed the stratification of the data over a period of 366 days, resulting in an average sample of 262 person-days per day.

The daily activity time allocation over 366 days is summarized in Table 3.3-1, and shown graphically in Figure 3.3-1 (Herz, 1978).

Noteworthy are two results: First, the most stable time budget over 366 days is "at home", followed by "travel". Second, the daily travel

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(*) "Kontinuierlichen Befragung zum Verkehrsverhalten"; Continuing Survey of Travel Behavior.

time budget per person, including walking, is just over 1 hour. Also, the daily travel time budget does not vary significantly between weekdays and weekends.

Table 3.3-1: Daily Time per Person (above 10 years), by Activity, KONTIV Survey, 1976, Fed. Rep. of Germany

	Daily Time per Person, by Activity, Hrs.									
	1	2	3	4	5	6	6a	6b	6c	7
Activity	Home	Work	Business	Education	Shopping	TRAVEL - TOTAL	Walk, Cycle	Car	Transit	Rest
Average for:										
251 Workdays	17.43	3.03	0.23	0.82	0.52	1.08	0.32	0.50	0.27	0.88
50 Saturdays	19.35	0.77	0.07	0.33	0.60	1.02	0.33	0.52	0.17	1.87
65 Sundays & Holidays	20.18	0.35	0.02	0.03	0.07	0.98	0.40	0.50	0.08	2.37
All 366 days	18.17	2.25	0.17	0.62	0.45	1.07	0.35	0.50	0.22	1.28
Maximum Value	21.90	3.87	0.48	1.48	1.10	1.50	0.75	0.83	0.52	3.52
Minimum Value	16.25	0.01	0	0	0	0.60	0.15	0.27	0	0.40
Standard Deviation	1.25	1.22	0.12	0.42	0.22	0.15	0.08	0.10	0.10	0.70

Source: Herz, 1978

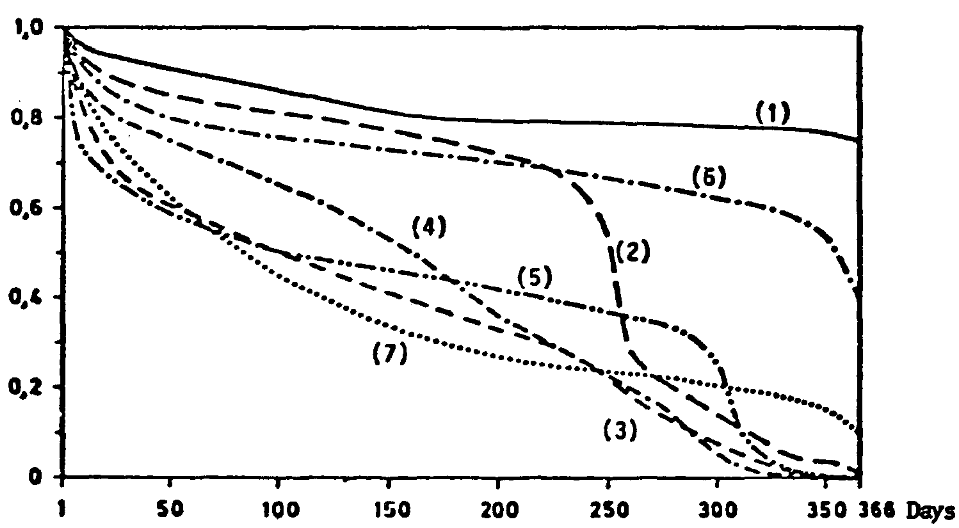

Figure 3.3-1: Relative Daily Time Allocation per Average Person for 7 Activity Categories (Herz, 1978)

3.4 Daily Travel Time per Person in the U.K.

The analysis in this case stratified the reported daily travel times per person in the United Kingdom 1972/73, by mode, including walking trips, versus population density of settlements from rural areas to dense cities (Goodwin, 1975). The data are summarized in Table 3.4-1 and presented in Figure 3.4-1, showing that the daily travel time per person is relatively stable along the complete range of densities, with a mean value of 46.3 minutes.

The same results were also noted while analyzing the national survey data of 1975/76 (Landbrock, 1979), with the conclusion that:

> "Mean travel-time per person per day, based on the data for whole journeys, is about 63 minutes in London, and between 50 and 55 minutes elswhere. Analysis of travel by all modes with respect to ward population density give results similar to those obtained by Goodwin using 1972/73 National Travel Surveys data (TE & C, 1979).

The somewhat higher daily travel time in London in 1975/76 than in 1972/73 is of particular interest, especially as it appears to increase over time. This specific subject, where the average travel time budget is above a minimum value noted elsewhere, is discussed in Section 4.11 .

Table 3.4-1: Daily Travel Time per Person, by Mode, vs. Population Density, U.K. Settlements, 1972/73

Population Density Persons/Sq.Km.	TRAVEL TIME, Min.			
	Walking	Bus	Private	Total
0 - 124	10.9	4.2	27.8	45.0
124 - 247	12.6	3.8	29.5	49.1
247 - 618	16.1	6.4	25.4	49.7
618 - 1,235	18.1	5.4	22.2	48.2
1,235 - 1,853	18.1	4.6	19.4	45.2
1,853 - 2,471	17.6	6.7	20.1	46.1
2,471 - 3,707	18.9	6.8	18.7	47.0
3,707 - 4,942	16.6	7.4	16.8	43.3
4,942 - 7,413	19.6	9.6	12.2	44.4
7,413 & Over	19.9	9.8	12.3	47.2
Average	17.0	6.5	20.4	46.3

Source: Goodwin, 1978

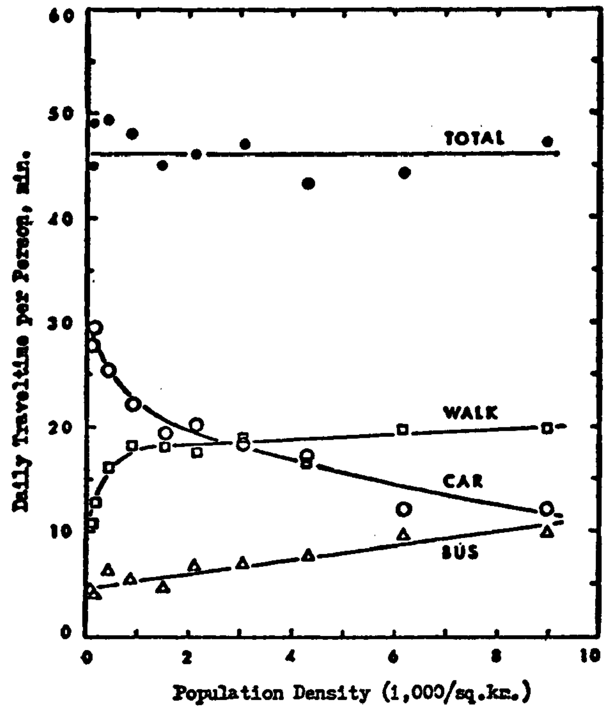

Figure 3.4-1: The Daily Traveltime per Person, by Mode, vs. Population Density, all Settlements in the UK 1972

3.5 Daily Travel Time per Person in French Cities

A comprehensive analysis of reported daily travel times per person (above the age of 5) in seven French cities, at two periods, was carried out recently at the Institute de Recherche des Transport (Godard, 1978).

Although strong reservations were expressed by the researchers about the reliability and comparability of the data sets, they came to the conclusion that the daily travel time per average person, including walking trips, tends to show some stability, although noticeable variations are also evident when the population is stratified by such factors as age, profession and sex.

The total average daily travel times per person in the seven cities and two periods are shown in Table 3.5-1. While there are noticeable differences in the average values between cities, there are also two general trends of special interest: (i) The total daily travel time per person tends to increase with city size; and (ii) the total daily

Table 3.5-1: Daily Travel Time per Person (above 5 years) in 7 Cities in France

City	Year	Population (000)(1)	Time, Hrs. Motorized Modes	Time, Hrs. All Modes(2)
Orleans	1969	160	0.53	0.73
	1976	200	0.56	0.81
Nancy	1965	220	0.44	0.79
	1976	230	0.50	0.78
Grenoble	1966	275	0.53	0.88
	1973	350	0.53	0.78
Nice	1966	310	0.60	1.06
	1973	350	0.58	0.97
Rouen	1968	350	0.46	0.70
	1973	400	0.50	0.77
Lyon	1965	850	0.59	0.91
	1976	1,000	0.66	0.98
Marseille	1966	900	0.58	1.16
	1976	950	0.65	0.98

(1) Population in metropolitan area, based on a diagram in the original study report

(2) Including travelers who only walked.

Source: Godard, 1978

travel time per person by motorized modes tends to increase over time, probably because of the increase in car ownership levels. Further analyses also suggested that the daily travel time per person tends to increase with income.

An additional analysis, in the case of Marseille, based on travelers and including walking trips (Le Maire et al, 1977), suggested that (i) out of 6,771 persons over 5 years old 5,788, or 85.5 percent, made trips during the survey day, and (ii) the daily travel time per traveler was 1.16 hours. More studies on the basis of travelers, stratified by their socioeconomic characteristics and modes used, are in progress. Preliminary results show that car travelers spend 1.19 hours per day on travel.

3.6 Daily Travel Times in the U.S.

(1) Washington, D.C. and Twin Cities

In-depth analyses of travel characteristics at two points in time were carried out in Washington, D.C. and Twin Cities (Minneapolis - St Paul) in the U.S. (Zahavi, 1979-a). This study differed from the studies mentioned above in two principal respects: first, all travel data were related to the travelers by their households' socioeconomic characteristics, and stratified into three groups by the mode used by all travelers per household, namely car only, bus only, and combinations of the two modes; and second, all the travel characteristics were analyzed and compared both spatially and over time.

Table 3.6-1 and Figure 3.6-1 summarize the daily travel time per traveler by major mode, while other travel characteristics in these two cities will be presented and discussed in other relevant sections in this report. Table 3.6-1 also includes the daily travel time per travelers in the whole U.S.

The results in Table 3.6-1 suggest that the daily travel time per car traveler is stable both over time and between cities, even when door-to-door speeds in Washington, D.C. and Twin Cities increased during a period of 13-12 years by 24 and 33 percent respectively. Hence, it may be inferred that the saved travel times were traded-off for more travel distance. Since the daily travel time appeared to be very stable under favorable travel conditions, it was regarded as a door-to-door travel time budget, or TT-budget for short.

The first test of the stability of the TT-budget was by residence distance from the city center, by district averages, in the two cities and two periods. The results suggested that no significant relationship between the TT-budget and residence distance could be established. Additional tests, where the dependent variable was the daily travel time per household, and the independent variables were the residence distance and the number of travelers per household, for both car travelers and total travelers, suggested once again that the effect of

Table 3.6-1: Daily Door-to-Door Travel Time and Speed per Traveler, by Mode, U.S. Cities (Source: Zahavi, 1979)

City		CAR (1)		TRANSIT	
		T, hr.	Speed, kph.	T, hr.	Speed, kph.
Washington, D.C.	1955	1.09	18.8	1.27	10.7
	1968	1.11	23.3	1.42	10.0
Twin Cities	1958	1.14	21.5	1.05	12.0
	1970	1.13	28.5	1.15	12.1
All U.S. (2)	1970	1.06	47.4	0.99	23.6

(1) Car Driver + Car Passenger;

(2) Including Inter-urban travel.

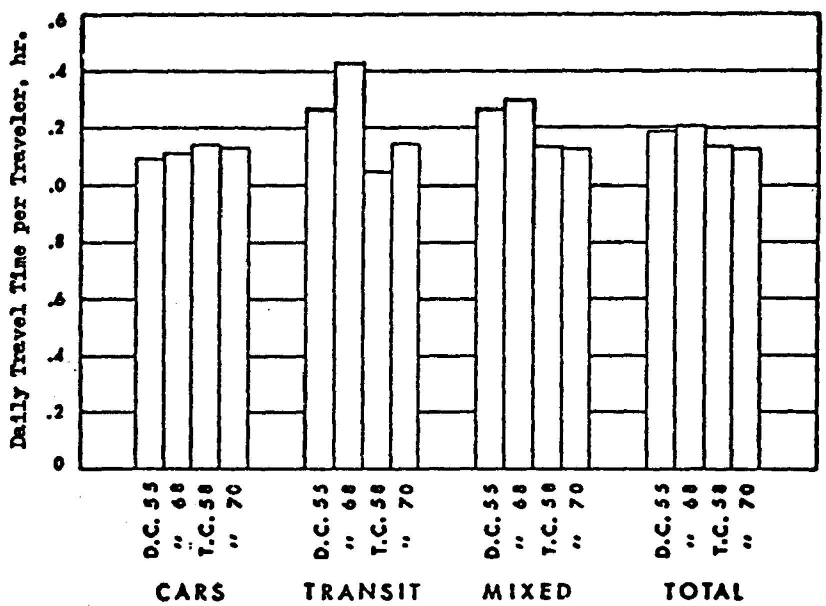

Figure 3.6-1: The Daily Travel Time per Traveler, by Mode, Washington 1955 + 1968 and Twin Cities 1958 + 1970

residence distance on the TT-budget was negligible, and that the same relationships hold for both cities and both periods. Thus, the TT-budget per traveler, on a district level, was found to be stable both between the two cities and over time.

Additional tests were performed stratifying households by size and car availability within each district. Statistical F-tests were carried out for each pair of household segments within each city and time period and for all cases of car and transit travelers in the Twin Cities and car travelers in Washington. The null hypothesis, that there are no significant differences between and within the travel time distributions, was accepted in 19 cases at a significance level of 0.05, and in 3 cases at a significance level of 0.01.

However, the stability of the TT-budget appeared to break down when the door-to-door speeds decreased below a minimum threshold of about 10 kph. For example, as shown in Table 3.6-1, the daily travel times per bus traveler in Washington were relatively high, and even increased over time when the bus door-to-door speeds decreased. No such changes were noted in the other cases. The effect of the door-to-door speed on the TT-budget per traveler is discussed in detail in Section 4.7.

(2) St. Louis

The daily travel times per car and bus traveler in St. Louis were derived from a telephone survey in 1976, as summarized in Table 3.6-2 (Bochner, 1978). Remarkably enough, the TT-budgets were found to be practically identical with those of car travelers in Washington, D.C. and with those of all travelers in Twin Cities. After further analyses "it was found that there is very little difference in total time spent traveling each day, regardless of income, automobile availability, or household size".

Table 3.6-2: Daily Travel Time per Traveler by Car Availability, St. Louis, 1976. (source: Bochner, 1978)

Car Availability	Daily Travel time per Traveler, hr.
0	1.06
1	0.99
2	1.05
3+	1.06
Average	1.04

(3) The TT-budget per Person in Seven U.S. Cities

Table 3.6-3 summarizes the data for 7 selected cities of different sizes (Peat, Marwick, Mitchell & Co., 1972). The travel times in this case were synthesized by a traffic model, and they express inter-zonal in-vehicle times per person. Figures 3.6-2 and 3.6-3 show how this daily travel time per person changes with urban size in a consistent way; the larger the city, the greater the proportion of weekday travel is within the study area.

Table 3.6-3: Daily Travel Time per Person vs. City Size in Selected Cities in the US.

No.	City	Year	Population (000)	Area sq.m.	Total Person Trip Hours	hrs./Person
1	River Fall	1963	138	110	62,599.2	0.45
2	Stockton	1967	170	190	82,620.0	0.49
3	Colorado Springs	1964	174	290	106,036.7	0.61
4	Louisville	1964	752	910	475,482.8	0.63
5	Seattle	1965	1,373	1,000	918,556.0	0.67
6	St. Louis	1965	2,175	1,640	1,567,299.2	0.72
7	Boston	1963	3,541	2,500	2,781,629.6	0.79

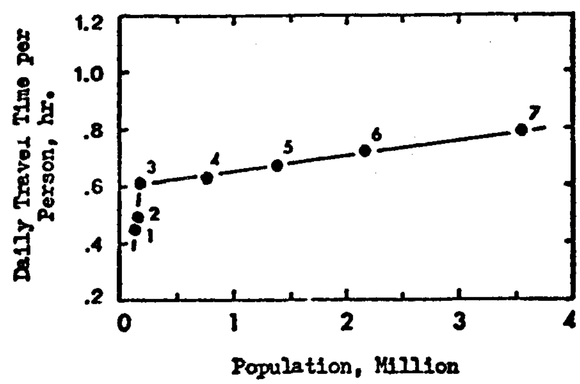

Figure 3.6-2: The Daily Travel Time per Person vs. Population Size in a selection of US Cities

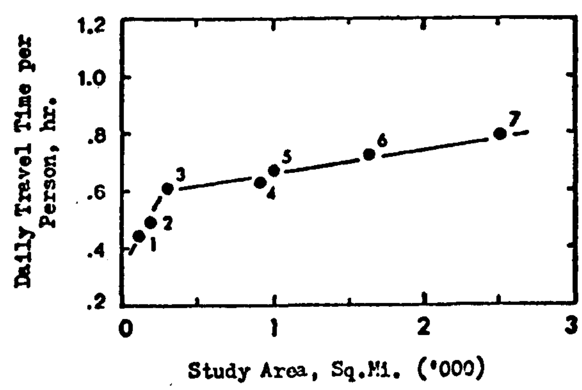

Figure 3.6-3 The daily Travel Time per Person vs. Size of the Study Area in a selection of US Cities

The above trend can also be seen in Table 3.6-4 and Figure 3.6-4, where the daily travel time per person is compared with the proportion of external to internal trips by the residents. When the proportion of external travel increases (as the size of the area decreases), the proportion of travel time per person within the study area decreases. Adjusting the travel time per person by the proportions of external travel, tends to stabilize the daily travel time per person in all cities.

Table 3.6-4: Daily Travel Time per Person vs. the Proportion of External to Internal Car Trips in Selected Cities in the US (*)

No.	City	Year	Driver Trips Internal	Driver Trips External	Ext./Int.%	hrs./Person
1	River Fall	1963	180,401	50,308	27.9	0.45
2	Stockton	1967	253,560	63.229	24.9	0.49
3	Colorado Sprongs	1964	310,698	35,777	11.5	0.61
4	Louisville	1964	779,000	56,448	7.3	0.63
5	Seattle	1965	1,756,320	94,559	5.4	0.67
6	St. Louis	1965	2,341,587	111,075	4.7	0.72
7	Boston	1963	4,013,884	349,658	8.7	0.79

(*) 'Internal' trips have both their ends within the study area. 'External' trips have one end within the study area and the other end outside the study area.

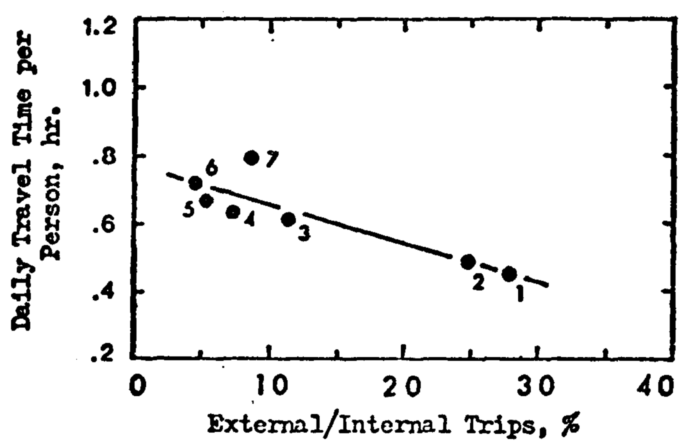

Figure 3.6-4: The Daily Travel Time per Person vs. Proportion of External to Internal Car Trips

(4) The Effect of an Expressway on the TT-budget

A study was conducted recently in the U.S. in order to determine whether or not an increase in highway supply induces more travel. (Smith, 1978). For this purpose, data from two origin-destination surveys conducted in Providence, Rhode island in the years 1961 and 1971, were compared. Between 1961 and 1971 a major expressway (I-95) was built in the area.

For each year the origin-destination survey data were split into two groups: samples representing households inside the I-95 corridor and samples representing households outside the corridor. For the resulting four groups of households, cross-classification matrices were developed using household size and car ownership as independent variables; the dependent variables were vehicle-miles of travel, vehicle-hours of travel per household, and car driver trips per household. It should be noted at this stage that the travel times in this case were synthesized in-vehicle times, as derived from a calibrated traffic model for car driver trips only. Furthermore, the daily travel times were allocated to households, not to travelers, while the households were cross-classified by size and car availability.

The comparison of the resulting matrices revealed that the highway did not increase trips or vehicle-hours of travel, but it did increase the vehicle-miles of travel. Based on these results, the authors came to the preliminary conclusion that travelers increase their vehicle-miles of travel by the same proportion that average travel speed increases. Namely, the TT-budget of car travel remained stable even after the introduction of a major expressway.

3.7 Some Comments on Disaggregate Data

The daily travel times in the above examples were mean values of groups of persons/travelers, and it is obvious that there must be variation of travel behavior about the mean values. The variations of travel behavior of travelers or households may be caused by many factors, including the following:

(a) Differences between households by socioeconomic characteristics;

(b) Differences between households within the same household type, by such factors as different tastes and preferences;

(c) Differences between travelers within the same household;

(d) Differences between days for the same travelers;

(e) Excessive tail on the distributions due to few travelers who travel much;

(f) Sampling errors;

(g) Coding errors.

It appears from analyses of various data sets described in the following sections that the variations about the mean travel times for certain population segments show consistent trends, where the coefficient of variation (standard deviation over the mean) approaches asymptotically a value of about 0.5. While this value is still relatively high (and probably can be further reduced by additional stratification and segmentation of the data), its stability between different population groups is important. Such distributions serve as a link between micro and macro analyses, where a "representative" average traveler/household is identified in deterministic models, and individual traveler/household can depart from average group behavior. One possible application of such a link is described in Section 5.2, dealing with the UMOT car ownership model.

3.8 Daily Variations in the Use of Cars

A study was conducted recently in Oxford, England, in order to analyze the variations in the intensity of car use (Goodwin, 1978). Although the sample of cars was small - 43 cars, of which 33 were in 1-car households and 10 in 2+ car households - the data included a seven-day travel diary for each car, thus presenting an opportunity for testing the variations in car use between days.

Of special interest to this report are the following tentative results:

(1) On a survey day, between one fifth and one quarter of all cars are likely not to be used. Hence, the daily travel time per average car is likely to be underestimated by the same proportion;

(2) The minutes that cars are in actual use on a day were found to be 55.4 minutes per car in use in 1-car households and 55.6 minutes per used car in 2+ car household, practically identical results. However, if all cars are considered, including the unused ones on a particular day, then an average car is used 42.7 minutes per day;

(3) The variations in the daily travel times per car in use are less when the time period of analysis is longer. The coefficient of variation decreases from 1.1 for one day to 0.7 for 5 weekdays, and to 0.6 for the full seven days. The results suggest that a survey over a long period would still find substantial variations in the intensity of car use, but considerably less than that suggested by a one day survey.

Consequently, part of the variations between car usage might be attributed to differences in usage among days of the week, and the stability of the TT-budget per car in use emerges, even for a small sample. The daily travel time per car in-use for this sample was determined to be 0.93 hours (55.5 minutes). If, however, it is adjusted to represent an average car, the daily travel time per average car is about 0.71 hours (42.7 minutes), which is in agreement with other cases in U.K. cities, as shown in Table 1.5-1, namely: London 1962, with a population of 8.8 million - 0.75 hours; and Kingston-upon-Hull 1967, with a population of 345,000 - 0.72 hours.

3.9 Daily Travel Time per Traveler in Bogota, Colombia

As an exercise in computer programming, the Urban Projects Department of the World Bank recently tabulated travel characteristics in Bogota 1972. The data, which were known to contain many errors, were from a conventional one-day survey of sampled households, and the daily travel times are for travelers who made at least one motorized trip during the day (by private vehicles or by public transport), although the data also include their walking trips. The travel times are door-to-door times, as reported by the respondents.

In order to find out the effect on the tables of travelers with abnormally long travel times, it was decided to re-tabulate the data with the exclusion of all travelers who were recorded as having traveled more than four hours per day. It was found that some of these travelers were drivers or salesmen by profession, and part only appeared to travel more than 4 hours per day due to errors, such as the miscoding of trips starting just before midnight and concluding just after midnight. Table 3.9-1 summarizes these two sets, where "Initial" refers to initial tabulations, including all travelers, while "Second" refers to the second tabulations, after the above cases were deleted from the data. The table details the daily door-to-door travel time per traveler (including walking trips) stratified by household income, and the coefficient of variation.

Table 3.9-1: Daily Travel Time per Traveler and Coefficient of Variation, by Income, Bogota, Colombia

HH Monthly Income, Pes.	INITIAL			SECOND		
	No. of TR.	TT per TR. hrs.	Coeff. of Variation	No. of TR.	TT per TR hrs.	Coeff. of Variation
Up to 500	78	2.12	.93	73	1.78	.60
500- 1,000	628	1.94	.78	594	1.69	.57
1,000- 1,500	707	1.89	.92	662	1.56	.58
1,500- 2,000	723	1.86	.86	685	1.60	.59
2,000- 3,000	702	1.79	.85	676	1.58	.55
3,000- 5,000	847	1.77	.84	812	1.56	.55
5,000-15,000	931	1.68	.89	896	1.48	.56
15,000-30,000	129	1.62	.95	123	1.36	.47
30,000 & Over	12	1.38	.91	11	1.05	.51
Total/Avg.	4,757	1.81	.87	4,532	1.57	.57

Three principal conclusions may be inferred from this table:

(1) The deletion of only 4.7 percent of travelers reduced the daily travel time per traveler by 13.3 percent, and the coefficient of variation by 34.5 percent: Thus, a relatively small number of travelers can account for a substantial part of the variations, suggesting that the original data should be screened carefuly for outlier cases.

(2) The coefficient of variation in the "second" table is very similar at all income levels, about 0.57. This value appears to be very stable, recurring in analyses of data from many different countries, as reported in the following sections.

(3) The mean travel times display a consistent trend, where the daily travel time per traveler decreases with increasing income, as shown in Figure 3.9-1 (based on the "Initial" data). Moreover, the TT-budget at very high incomes in Bogota is practically the same as for car travelers in U.S. cities, just over 1 hour. Low income travelers, on the other hand, spend more time on travel. The implications of these trends for travel modeling are discussed in Section 4.7.

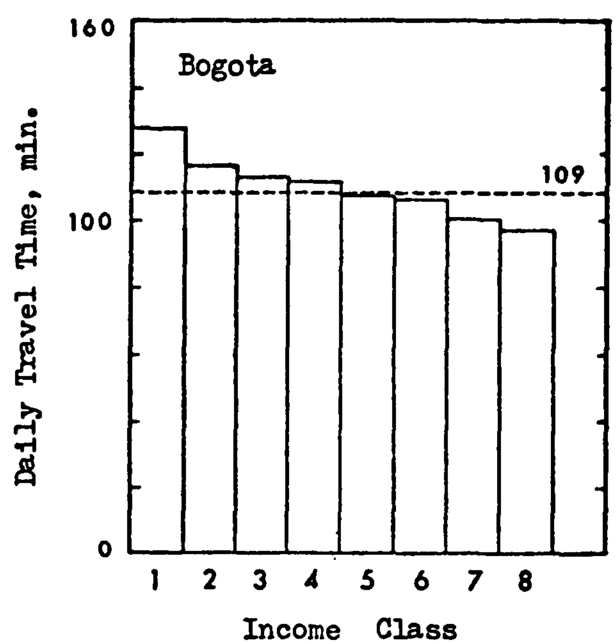

Figure 3.9-1: Daily Door-to-Door Travel Time per Average Traveler, by Household Income, Bogota

Table 3.9-2 details a further stratification of Table 3.9-1 by car ownership. The above trends remain stable for population segments comprising at least 25 travelers.

Table 3.9-2 : Daily Travel Time per Traveler and Coefficient of Variation, by Income and Car Ownership, Bogota, Colombia (Final Tabulation)

HH Monthly Income, Pes.	0 CAR			1 CAR			2+ CARS			TOTAL		
	No.	TT	C	No.	TT	C	No.	TT	C	No.	TT	C
Up to 500	73	1.78	0.60	-	-	-	-	-	-	73	1.78	0.60
501 - 1,000	576	1.71	0.57	(18)	(1.06)	(0.64)	-	-	-	594	1.69	0.57
1,001 - 1,500	647	1.56	0.58	(11)	(1.12)	(0.53)	(4)	(1.92)	(0.45)	662	1.56	0.58
1,501 - 2,000	655	1.60	0.59	29	1.62	0.69	(1)	(1.67)	(0)	685	1.60	0.59
2,001 - 3,000	577	1.60	0.54	83	1.51	0.56	(16)	(1.03)	(0.40)	676	1.58	0.55
3,001 - 5,000	629	1.59	0.54	166	1.44	0.58	(17)	(1.55)	(0.58)	812	1.56	0.55
5,001 -15,000	338	1.59	0.57	459	1.43	0.54	99	1.38	0.59	896	1.48	0.56
15,001 -30,000	(23)	(1.28)	(0.47)	56	1.43	0.48	44	1.31	0.47	123	1.36	0.47
30,001 & Over	(2)	(0.50)	(0)	-	-	-	(9)	(1.17)	(0.44)	11	1.05	0.51
Total/Average	3,520	1.61	0.57	822	1.43	0.56	190	1.35	0.55	4,532	1.57	0.57

No. - Number of travelers
TT - Daily travel time per traveler
C - Coefficient of Variation
(—) - Less than 25 travelers

Source: The World Bank

These data were also stratified by household size and car ownership, as shown in Table 3.9-3. Since household income tends to increase with household size, it is expected that the TT-budget should be inversely related to household size and car ownership, as verified in both stratifications, by both household size and car ownership, for segments of 25 or more travelers. Furthermore, the coefficient of variation is similar in all cells, both by household size and car ownership.

An additional comparison of the TT-budget is by the traveler's occupation, as detailed in Table 3.9-4. This table is based on thr "Initial" data and, therefore, the travel times are higher by an average 13 percent than in the previous two tables. Furthermore, no statistical analyses were available for this table. Even so, several important indications may be inferred:

Table 3.9-3: Daily Travel Time per Traveler and Coefficient of Variation, by Household Size and Car Availability, Bogota, Colombia (Final Tabulations)

Household Size		Cars per Household 0	1	2+	Total
1	No.	30	2	-	32
	TT	1.72	1.92		1.73
	C	0.54	0.55	-	0.54
2	No.	145	7	-	153
	TT	1.74	1.55	-	1.72
	C	0.47	0.43	-	0.47
3 - 4	No.	666	81	15	762
	TT	1.70	1.47	1.20	1.66
	C	0.54	0.50	0.58	0.54
5 - 6	No.	1,001	302	22	1,325
	TT	1.58	1.44	1.61	1.55
	C	0.59	0.57	0.49	0.58
7 +	No.	1,678	430	152	2,260
	TT	1.58	1.42	1.34	1.53
	C	0.57	0.57	0.55	0.57
Total	No.	3,520	822	190	4,532
	TT	1.61	1.43	1.35	1.57
	C	0.57	0.56	0.55	0.57

No. - Number of travelers;
TT - Daily travel time per traveler;
C - Coefficient of variation.

Source: The World Bank

Table 3.9-4: Daily Travel Time per Traveler, by Profession and Sex, Bogota, Colombia (Initial Tabulations)

	Male No.	Male TT	Female No.	Female TT	Total No.	Total TT
Technical, Professional Managerial	404	2.02	107	2.13	511	2.04
White Collar	471	2.09	280	1.89	751	2.02
Sales	219	2.12	76	2.34	295	2.18
Other	747	2.30	191	1.91	938	2.23
Retired	32	1.90	7	1.24	39	1.78
Housewife	-	-	363	1.68	363	1.68
Student	899	1.45	850	1.33	1,749	1.40

Source: The World Bank

(a) Employed travelers tend to spend more time on travel than unemployed travelers, although the differences are small. Although the proportions of retired people who travel may be small, those who do travel spend about the same travel time as those who are employed.

(b) The TT-budget of both male and female employed travelers is about the same. Furthermore, travelers of white-collar occupation tend to travel somewhat less time than travelers of blue-collar occupations, following the trend observed above for incomes.

The last comparison is by the travel time allocated by mode, and stratified by income, as detailed in Table 3.9-5 (based on the "Initial" data) and shown in Figure 3.9-2. The time allocated to car travel increases consistently with income, while the time allocated to walking is similar at all income levels.

Table 3.9-5: Daily Door-to-Door Travel Time per Average Traveler, by Mode, vs. Household Income, Bogota (Initial)

No.	Income per Month	TT-budget, by Mode, minutes				
		Private	Public	M/c-B/c	Walk	Total
1	Less than 500	0.1	117.8	0.3	9.0	127.1
2	500 - 1,000	4.8	101.5	0.6	9.9	116.7
3	1,000 - 1,500	4.9	93.2	0.5	13.4	112.0
4	1,500 - 2,000	3.5	98.6	0.9	9.8	112.8
5	2,000 - 3,000	6.3	87.0	0.6	11.6	105.4
6	3,000 - 5,000	10.9	88.8	0.1	7.8	107.7
7	5,000 - 15,000	20.9	74.3	-	6.9	102.1
8	15,000 - 30,000	34.4	54.8	-	8.5	97.7
9	30,000 & Over	39.2	25.0	4.2	14.2	82.5

Source: the World Bank

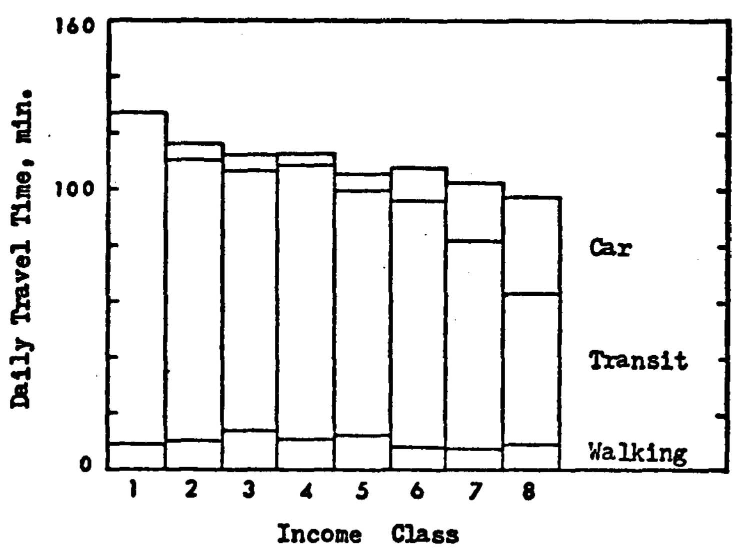

Figure 3.9-2: The Daily Door-to-Door Travel time per Average Traveler, by Mode, vs. Household Income, Bogota

In conclusion, the detailed analyses of travel times in Bogota suggest that: (i) the mean TT-budget of travelers belonging to specific population segments varies in a consistent way, by income, household size and occupation, (ii) the minimum daily travel time per traveler, at the highest income level, tends towards 1.1 hours, and (iii) the variations of the TT-budget about the mean values are very stable for all population segments.

3.10 Daily Travel Time per Traveler in Santiago, Chile

Table 3.10-1 summarizes the daily travel time per traveler in Santiago, Chile, based on the same definitions and procedures as in the case of Bogota (Source: The World Bank). Although this is "Initial" data, before identification and elimination of outlier cases, results are consistent with those for Bogota, namely:

(1) The daily travel time per motorized traveler decreases with increasing income and car ownership. The TT-budget at the highest income level is, once again, similar to that for U.S. cities for car travelers, just over one hour.

(2) The coefficients of variation are very stable at all income levels (for segments of over 25 travelers), and similar to those in Bogota, about 0.6.

Table 3.10-1 : Daily Travel Time per Traveler and Coefficient of Variation, by Income and Car Ownership, Santiago, Chile ("Initial" data)

HH Monthly Income, Pes.	0 CAR			1 CAR			2+ CAR		
	No.	TT	C	No.	TT	C	No.	TT	C
Up to 1,000	1,969	1.52	0.56	109	1.53	0.58	14	1.49	0.85
1,001 - 2,500	11,846	1.48	0.55	1,232	1.29	0.61	154	1.15	0.63
2,501 - 5,000	12,544	1.42	0.56	2,510	1.32	0.59	284	1.33	0.59
5,001 - 10,000	4,791	1.38	0.56	2,620	1.24	0.59	505	1.24	0.63
10,001 - 15,000	945	1.37	0.56	1,565	1.19	0.60	554	1.16	0.64
15,001 - 20,000	261	1.19	0.57	918	1.12	0.59	559	1.11	0.63
20,001 & Over	132	1.08	0.64	578	1.15	0.61	838	1.09	0.58
Total/Average	32,488	1.44	0.55	9,532	1.25	0.60	2,908	1.16	0.62

No. - Number of travelers
TT - Daily travel time per traveler
C - Coefficient of Variation

Source: The World Bank

Table 3.10-2 details the daily travel time by mode. Again, the trend is similar to that observed in Bogota: the time allocated to walking is relatively short, and stable at all income levels.

Table 3.10-2: Allocation of the Daily Travel Time per Traveler by Mode, Santiago, Chile ("Initial" data)

HH Monthly Income, Pes.	Allocation of Travel Time, in Percent								
	0 CAR			1 CAR			2+ CAR		
	Car	Bus	Walk	Car	Bus	Walk	Car	Bus	Walk
Up to 1,000	1.6	92.7	5.5	23.0	74.1	2.8	21.4	68.9	9.6
1,001 - 2,500	1.7	93.6	4.6	20.3	75.0	4.5	21.5	73.1	4.0
2,501 - 5,000	2.2	93.4	4.3	20.4	74.7	3.7	24.9	71.8	3.2
5,001 - 10,000	3.6	92.6	3.7	29.6	66.8	3.4	40.1	57.1	2.6
10,001 - 15,000	5.4	91.4	3.1	36.4	60.2	3.2	53.1	44.6	1.9
15,001 - 20,000	11.7	85.5	2.8	40.5	57.5	2.0	62.2	35.9	1.8
20,001 & Over	17.7	77.2	5.0	44.4	52.7	2.9	60.3	37.2	2.3
Average	2.4	93.1	4.4	29.0	67.5	3.4	50.1	47.3	2.4

Car - Travel by all private modes;
Bus - Travel by all public transport modes;
Walk - Walking by travelers who made at least one motorized trip during the survey day.

Source: The World Bank

The available data also allowed the derivation of daily travel time for travelers who only walked during the survey day (all previous tables for Bogota and Santiago referred to travelers who made at least one motorized trip during the day, while their travel times included also their walking trips). Table 3.10-3 presents data for travelers of the same households who made all their daily trips by walking only. Table 3.10-4 shows the proportions of travelers who made at least one motorized trip during the day.

These last two tables suggest the following trends:

(a) The proportions of travelers who made at least one motorized trip during the survey day increases with increasing income and with car ownership, ranging from about 70 to over 95 percent of all travelers.

(b) The daily travel time per traveler who only walked is about one half the daily travel time per traveler who also used motorized modes.

The coefficient of variation of the TT-budget of travelers who only walked is within the same range as observed for motorized travelers.

Table 3.10-3: Daily Travel Time per Walking Traveler and Coefficient of Variation, by Income and Car Ownership, Santiago, Chile

HH Monthly Income, Pes.	0 CAR			1 CAR			2+ CARS		
	No.	TT	C	No.	TT	C	No.	TT	C
Up to 1,000	543	0.83	0.71	40	0.84	0.70	5	1.27	1.04
1,001 - 2,500	2,258	0.73	0.65	284	0.75	0.64	27	0.73	0.54
2,501 - 5,000	1,833	0.69	0.61	451	0.72	0.63	50	0.65	0.95
5,001 - 10,000	596	0.67	0.72	264	0.66	0.65	49	0.76	0.87
10,001 - 15,000	86	0.59	0.62	127	0.64	0.60	36	0.66	0.70
15,001 - 20,000	26	0.63	0.46	62	0.46	0.59	27	0.59	0.46
20,001 & Over	5	0.42	0.28	45	0.53	0.49	48	0.53	0.46
Total/Average	5,347	0.71	0.66	1,273	0.68	0.64	242	0.67	0.79

No. - Number of travelers
TT - Daily travel time per traveler
C - Coefficient of Variation

Source: The World Bank

Table 3.10-4: Proportions of Motorized Travelers, Santiago, Chile

HH Monthly Income, Pes.	0 CAR		1 CAR		2+ CARS	
	Total TR	% Mot. TR	Total TR	% Mot. TR	Total TR	% Mot. TR
Up to 1,000	2,512	78.4	149	73.2	19	73.7
1,001 - 2,500	14,104	84.0	1,516	81.3	181	85.1
2,501 - 5,000	14,377	87.3	2,961	84.8	334	85.0
5,001 - 10,000	5,387	88.9	2,884	90.9	554	91.2
10,001 - 15,000	1,031	91.7	1,692	92.5	590	93.9
15,001 - 20,000	287	90.9	980	93.7	586	95.4
20,001 & Over	137	96.4	623	92.8	886	94.6
Total/Average	37,835	85.9	10,805	88.2	3,150	92.3

Total TR - Total number of travelers;
% Mot. TR - Percent of travelers who made at least one trip by motorized modes.

Source: The World Bank

3.11 Daily Travel Time per Traveler in Singapore

The following is a summary of analyses of travel data collected before and after the introduction of the Area License Scheme (ALS) in Singapore's central business district in June 1975. This scheme imposed a fee on each car and taxi with less than 4 persons entering the restricted central zone during the morning peak period. The following tables refer to the daily travel times per traveler, based on the tabulations prepared in the World Bank.

The data were derived from conventional before-and-after home-interview surveys, where the household sample was augmented by a sample of car-owning households. The same households were interviewed twice, before and after the introduction of the ALS.

Table 3.11-1 summarizes the daily travel time per traveler (including walking trips) by income and private vehicle ownership (car and/or motorcycle), before and after the introduction of the ALS.

Table 3.11-1: Daily Travel Time per Traveler and Coefficient of Variation, by Income and Private Vehicle Ownership, Singapore "Before-and-After" Study

HH Monthly Income, S$	BEFORE						AFTER					
	Owning			Not-Owning			Owning			Not-Owning		
	No.	TT	C	No.	TT	C	No.	TT	C	No.	TT	C
Up to 200	9	1.06	0.39	36	1.29	0.40	4	0.54	0.46	38	1.12	0.40
201 - 400	136	1.17	0.52	257	1.40	0.78	129	1.17	0.50	184	1.21	0.49
401 - 700	612	1.25	0.58	581	1.30	0.51	403	1.25	0.62	521	1.25	0.52
701 - 1,000	630	1.31	0.74	342	1.51	0.88	669	1.34	0.56	463	1.36	0.54
1,001 - 1,500	1,036	1.28	0.54	232	1.49	0.73	971	1.29	0.59	312	1.35	0.48
1,501 - 2,000	618	1.25	0.54	97	1.42	0.51	812	1.25	0.51	64	1.47	0.48
2,001 - 2,500	473	1.23	0.55	20	1.65	0.43	392	1.20	0.51	49	1.56	0.41
2,501 & Over	838	1.27	0.64	8	1.26	0.40	678	1.14	0.48	4	2.50	-
Total/Average	4,352	1.27	0.60	1,573	1.40	0.70	4,058	1.25	0.56	1,635	1.31	0.51

Source: The World Bank

The results in Table 3.11-1 suggest:

(1) The daily travel time per traveler from private vehicle-owning households is relatively stable at a wide range of income levels in both periods. The daily travel time per traveler from house-

holds not owning a private vehicle is appreciably higher than that of travelers from vehicle owning households, although the stability by income and period still holds.

(2) The coefficients of variation are relatively stable in most cases (again for segments with over 25 travelers), and similar to those observed in other cities. Even when some instabilities are noted in the "before" survey, they disappear in the "after" survey, and conversely. Since the same households were interviewed in both the "before" and "after" surveys, this suggests that some differences may be attributable to survey procedures. (For example, even though the coefficient of variation in the case of vehicle-owning households at the income range S$ 701 - 1,000 is 0.74 in the "before" survey, it reverts back to a more stable level of 0.56 in the "after" survey). Table 3.11-2 shows that the same general and stable patterns also hold when the data are stratified by household size.

Table 3.11-2: Daily Travel Time per Traveler and Coefficient of Variation, by Household Size and Private Vehicle Ownership, Singapore "Before-and-After" Study

Household Size	AFTER					
	OWNING			NOT-Owning		
	No.	TT	C	No.	TT	C
1	11	1.15	0.61	3	0.72	0.29
2	34	1.13	0.44	25	1.19	0.44
3 - 4	476	1.24	0.59	167	1.36	0.45
5 - 6	983	1.21	0.52	430	1.28	0.51
7+	2,554	1.26	0.56	1,010	1.32	0.53
Total/Average	4,058	1.25	0.56	1,635	1.31	0.51

Source: The World Bank

The basic tabulations also included stratifications by occupation, sex and age of the travelers, and one example is shown in Table 3.11-3 for the occupation "skilled craft". While no statistical comparisons are available for the basic data, a visual inspection of Table 3.11-3 suggests that: (i) age does not seem to have an appreciable effect on the TT-budget, (ii) women tend to spend less time on travel than men

Table 3.11-3: Daily Travel Time per Traveler, by Occupation, Age, Sex and Car Ownership, Singapore Before-and-After Study (Occupation - Skilled Craft)

Age	MALE							
	Owning				Not-Owning			
	Before		After		Before		After	
	No.	TT	No.	TT	No.	TT	No.	TT
5 - 10	-	-	-	-	-	-	-	-
11 - 15	-	-	1	2.58	2	1.75	11	1.21
16 - 20	45	1.67	59	1.58	32	1.59	57	1.58
21 - 30	205	1.50	201	1.45	51	1.88	72	1.70
31 - 40	90	1.42	79	1.41	19	1.48	15	1.31
41 - 50	47	1.26	48	1.34	35	1.56	37	1.36
51 - 64	27	1.40	34	1.40	12	1.30	17	1.29
65 +	7	1.74	6	1.38	1	0.50	-	-
Total/Avg.	421	1.47	428	1.45	152	1.64	209	1.52
	FEMALE							
5 - 10	-	-	-	-	-	-	-	-
11 - 15	1	0.33	-	-	5	1.10	-	-
16 - 20	37	1.26	46	1.10	66	1.28	87	1.15
21 - 30	92	1.17	87	1.22	62	1.00	59	1.16
31 - 40	6	1.36	6	1.46	12	1.32	9	1.18
41 - 50	4	1.56	5	1.35	3	1.19	3	1.58
51 - 64	-	-	1	1.00	-	-	-	-
65 +	-	-	-	-	-	-	1	1.00
Total/Avg.	140	1.21	145	1.19	148	1.16	159	1.16

Source: The World Bank

at all population segments, and (iii) the TT-budgets remained relatively stable between the "before" and "after" surveys.

More relationships from the Singapore data are presented in Sections 4.3 and 4.7.

3.12 Daily Travel Time per Traveler in Salvador, Brazil

The last city of a developing country for which detailed data on travel times were available from the World Bank is Salvador, Brazil. The basic tabulations were prepared for the World Bank by Colin Buchanan and Partners, and Table 3.12-1 summarizes the TT-budget per motorized traveler stratified by income. Although no statistical measures are available in this case, the TT-budget shows a stable regularity versus income, as seen in Figure 3.12-1, and compared with the data from Bogota.

Table 3.12-1: Daily Travel Time per Traveler, by Income, Salvador, Brazil

Household Monthly Income, Cr.	Daily TT-budget per Traveler, hr.
Up to 417	1.72
417 - 834	1.80
834 - 1,251	1.80
1,251 - 2,085	1.85
2,085 - 3,336	1.95
3,336 - 4,587	1.91
4,587 - 5,838	1.95
5,838 - 8,340	2.08
8,340 - 12,510	2.07
12,510 & Over	2.02
Average	1.89

Source: The World Bank

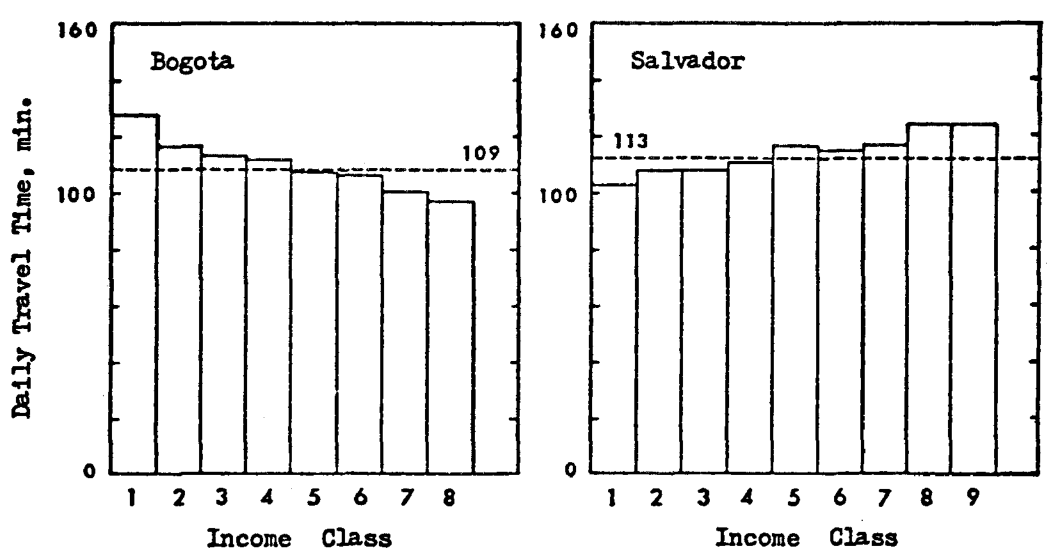

Figure 3.12-1: Daily Door-to-Door Travel Time per Average Traveler, by Household Income, Salvador and Bogota

In this case, however, and in contrast to trends in Bogota, the TT-budget tends to increase with income. While no immediate explanation for this trend is available at this stage, it appears that the unusual structure of Salvador is the reason; the city center and low income residences are situated in a valley, while the high income residences are spread along high ridges, connected by a tortuous road network. It may, therefore, be inferred that urban structure may affect the TT-budgets, a subject which is discussed in Section 4.11.

* * *

Table 3.12-2 summarizes the general characteristics of the four cities, described in Sections 3.9 to 3.12.

Table 3.12-2: City General Characteristics

	Bogota	Santiago	Singapore	Salvador
Country	Colombia	Chile	Singapore	Brazil
Study year	1972	1977	1975	1975/76
Population, Million	2.8	3.2 (1)	2.3	1.4
Currency	Peso	Peso	S$	Cruzeiro
U.S. $ 1 =	22.0	25.7	2.5	15.0

(1) Over 5 years.

Source: The World Bank

The general trends that may be inferred from the above examples are:

(1) The daily travel time per average motorized traveler exhibits consistent trends for different population segments in a given city; while it is not constant, its change is systematic, such as by income.

(2) The variations in the daily travel time per traveler about the mean values for each population segment is remarkably stable, with the coefficient of variation being within the range of 0.5-0.6.

(3) There are significant changes in the daily travel time per traveler in different cities, especially in cities of developing countries.

(4) The lowest daily travel time per average traveler appears to be about 1 hour, even when travel speeds are high.

The implications of the above indications for travel demand modeling are discussed in Chapter 4.

With the above examples concludes the introductory part to travel time budgets. In the following sections attention is focussed on the TT-budgets in Germany, with increasing levels of detail.

3.13 Daily Variations in TT-budgets in Munich, Germany

(1) Introduction

This section presents the results of an analysis of a three-weekday trip diary in Munich, based on detailed home interviews in 1976. Some four hundred households, approximately six hundred travelers, responded to the questionairs detailing, among other things, the total daily travel times, as detailed in Appendix 1.

Two basic issues are investigated in this section. First, are there substantial differences in the average daily travel time per motorized traveler by type of household ?, and second, do travelers' daily travel times vary between days ?.

For purposes of statistical analysis the household interview data are aggregated by 55 household types, as detailed in Table 3.13-1. The stratification dimensions are household size and car ownership. It should be noted at this stage, and emphasized, that no data on household incomes are available in travel surveys in Germany and, hence, households are differentiated by their other socioeconomic characteristics.

In order to make the household types manageable in number and responsive to real world situations, and since about fifteen types have no observations, they were collapsed into twelve in number, according to car ownership (0, 1, 2+) and household size (1, 2, 3, 4+).

The total average values per day, for all travelers, are as follows:

Day	TT-budget, hrs.	Coefficient of Variation
1	1.15	0.57
2	1.16	0.56
3	1.16	0.56

Hence, it becomes evident that the daily TT-budget on an aggregate level is very stable both between days and within each day. Of particular interest is the result that the coefficient of variation is practically identical with those noted in other cities. The following analysis tests whether these stabilities remain also at disaggregate levels.

Table 3.13-1: Household Types (E - Employed Person; H - Housewife, Retired; S - Student)

Type	Size	Car Availability 0	Car Availability 1	Car Availability 1+	Car Availability 2+	Household Structure	Employed No	Employed Yes	Primary Worker Blue	Primary Worker White 1	Primary Worker White 2
1	1	●				1 E		●			
2				●				●			
3		●				1 H or (1 S)	●				
4	1			●			●				
5	2	●				1 E + 1 S or		●			
6				●		1 E + 1 H		●			
7		●					●				
8			●			1 H + 1 S	●				
9					●		●				
10		●						●			
11			●					●	●		
12			●			2 E		●		●	●
13					●			●			
14		●				2 H or 2 S	●				
15	2			●			●				
16	3	●				1 E + 1 H + 1 S		●			
17			●			or: 1 E + 2 S		●	●		
18			●			or: 1 H + 2 S		●		●	
19			●			or: 2 H + 1 S		●			●
20					●			●			
21		●						●			
22			●			2 E + 1 S		●	●		
23			●					●		●	●
24					●			●			
25		●						●			
26			●			2 E + 1 H		●	●		
27			●					●		●	●
28					●				●		
29		●						●			
30			●			1 E + 2 H		●	●		
31			●					●		●	
32			●					●			●
33	3				●			●			
34	4+	●						●			
35			●			1 E + 2^+H + 1 S		●	●		
36			●			or: (2 H + 2 S)		●		●	
37			●					●			●
38					●			●			
39		●						●			
40			●			2^+E + 1 H + 1 S		●	●		
41			●					●		●	●
42					●			●			
43		●						●			
44			●					●	●		
45			●			1 E + 1 H + 2^+S		●		●	
46			●					●			●
47					●			●			
48		●						●			
49			●			2^+E + 2^+S		●	●		
50			●					●		●	●
51					●			●			
52		●						●			
53			●			2^+E + 2^+H		●	●		
54			●					●		●	●
55	4+				●			●			

(2) The Analysis

The effects of the above factors, car ownership and household size, on TT-budgets can be conveniently analyzed as a multifactor experiment. In general, there are two factors (say, A and B) and three (R) sets of data. It is desired to separate the effects of the factors A and B and of the data set R on a dependent variable Y. The model for the analysis of this type of problem can be written as:

$$y_{ijk} = \mu + \alpha_i + \beta_j(\alpha\beta)_{ij} + \gamma_k + e_{ijk} \quad ; \qquad (3.13\text{-}1)$$

$i = 1, 2, \ldots, a$; (factor A)

$j = 1, 2, \ldots, b$; (factor B)

$k = 1, 2, \ldots, r$; (data set R)

In Equation (3.13-1) y_{ijk} is the observation (travel time budget) in the k-th data set, at the i-th level of factor A and j-th level of factor B, μ is the grand mean (of the TT-budget), α_i is the effect of the i-th level of factor A (say, car ownership), β_j is the effect of the j-th level of factor B (household size), $(\alpha\beta)_{ij}$ is the interaction or joint effect of the i-th and j-th levels of factors A and B, and γ_k is the effect of the k-th data set.

It is assumed that e_{ijk} are independent normally distributed random variables with zero means and common variance of δ^2. With the following restrictions unique estimates can be estimated for parameters μ, α, β, and γ :

$$\sum_{i=1}^{a} \alpha_i = \sum_{i=1}^{b} \beta_j = \sum_{i=1}^{a} (\alpha\beta)_{ij} = \sum_{j=1}^{b} (\alpha\beta)_{ij} \sum_{k=1}^{r} \gamma_k = 0 \quad ; \qquad (3.13\text{-}2)$$

The analysis of a x b factorial experiment with r replicates is based on the breakdown of the total sum of squares into components. First the total sum of squares (SST) is divided into components attributed to factors, replicates and error by means of the identity [(1)],

(1) In the following equation period (•) denotes the subscript(s) over which the average is taken, e.g.,

$$\bar{y}_{ij.} = \frac{1}{r} \sum_{k} y_{ijk} \quad ;$$

$$\sum_i \sum_j \sum_k (y_{ijk} - \bar{y}_{...})^2 = r \sum_i \sum_j (\bar{y}_{ij.} - \bar{y}_{...})^2 + ab \sum_k (\bar{y}_{..k} - \bar{y}_{...})^2 + \sum_i \sum_j \sum_k (y_{ijk} - \bar{y}_{ij.} - \bar{y}_{..k} - \bar{y}_{...})^2 ; \quad (3.13\text{-}3)$$

The total sum of squares on the left-hand side has (abr - 1) degrees of freedom. The terms on the right-hand side are, first, the sum of squares due to factors, SSF, having (ab - 1) degrees of freedom; second, the replicate sum of squares, SSR, with (r - 1) degrees of freedom; and third, the error sum of squares, SSE, with (ab - 1)(r - 1) degrees of freedom.

The sum of squares due to factors A and B can be subdivided into components corresponding to the factorial effects. In a two factor experiment we have the following subdivision:

$$r \sum_i \sum_j (\bar{y}_{ij} - \bar{y}_{...})^2 = rb \sum_i (\bar{y}_{i..} - \bar{y}_{...})^2 + ra \sum_j (\bar{y}_{.j.} - \bar{y}_{...})^2 + r \sum_i \sum_j (\bar{y}_{ij.} - \bar{y}_{...})^2 ; \quad (3.13\text{-}4)$$

The first term on the right measures the variability of the means due to factor A; this is called factor A sum of squares, SSA. The second term is the factor B sum of squares, SSB. And the third term is the interaction sum of squares SSAB which measures the variability in y_{ijk} which is not attributable to separable effects of factors A and B. The (ab - 1) degrees of freedom for factors A and B are divided into (a - 1) degrees of freedom for A, (b - 1) degrees of freedom for B, and (a - 1)(b - 1) for interaction. The results below illustrate the analysis method best.

Because there were no observations for households size 1 at 2+ car ownership level, the analysis proceeded in steps. First, the car owning households were compared to carless households, and then one and two-plus car households were compared to each other.

Table 3.13-2 gives the mean TT-budgets for each factor level. First, compute the term $C = \frac{(28.42)^2}{24} = 33.654$; Then compute the sums of squares:

$$SST = (1.12^2 + 1.23^2 + \ldots + 1.19^2) - 33.654 = 0.368 \;;$$

$$SSF = \frac{1}{3}(3.6^2 + \ldots + 3.56^2) - 33.654 = 0.250 \;;$$

$$SSR = \frac{1}{8}(9.25^2 + \ldots + 9.52^2) - 33.654 = 0.010 \;;$$

$$SSF = 0.368 - 0.250 - 0.010 = 0.108 \;;$$

The sums of squares of the factors are:

B \ A	0	1+	Total
1	3.60	3.29	6.89
2	3.67	3.34	7.01
3	3.19	3.52	6.71
4+	4.25	3.56	7.81
Total	14.71	13.71	28.42

$$SSA = \frac{1}{12}(14.71^2 + 13.71^2) - 33.654 = 0.118 \;;$$

$$SSB = \frac{1}{6}(6.89^2 + \ldots + 7.81^2) - 33.654 = 0.042 \;;$$

$$SSAB = 0.250 - 0.118 - 0.042 = 0.090 \;;$$

and the analysis of variance table is detailed in Table 3.13-3.

Table 3.13-2: Travel Time Budgets by Day and Factor

Factor A Car Ownership	Factor B HH-Size	Day 1	Day 2	Day 3	Total
0	1	1.12	1.32	1.16	3.60
0	2	1.23	1.12	1.32	3.67
0	3	1.01	1.06	1.12	3.19
0	4+	1.35	1.60	1.30	4.25
1+	1	1.06	1.13	1.10	3.29
1+	2	1.14	1.10	1.10	3.34
1+	3	1.10	1.19	1.23	3.52
1+	4+	1.24	1.13	1.19	3.56
Total		9.25	9.65	9.52	28.42

Table 3.13-3: **Analysis of Variance for Travel Time Budget**

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F-value	F crit. 0.05
Days	2	0.010	0.005	0.65	3.74
HH-Size	3	0.118	0.039	5.06	3.34
Car Ownership	1	0.042	0.042	5.44	4.60
Interaction	3	0.090	0.030	3.89	3.34
Error	14	0.108	0.0077		
Total	23	0.368			

It is seen that car ownership, household size and household size - car ownership interaction all have statistically significant effects on the TT-budgets, but that the TT-budgets do not vary between days.

A reflection on Table 3.13-2 indicates that the household size and interaction effects are most likely due to the 0-car, three member households. These households maybe husband, wife, child types where the wife is "trapped" at home with a child and with little desire to travel using often "child-repellant" public transport modes.

This issue can be examined by making an analysis of variance by car ownership levels; at the same time such analysis of variance shows whether there are differences in travel time budgets for car owning households. The results are shown in Tables 3.13-4 and 3.13-5.

Table 3.13-4: **Analysis of Variance of TT-budgets for Carless Households**

	Degrees of Freedom	Sum of Squares	Mean Square	F-value	F Crit .05
Days	2	.019	.010	.70	5.14
HH-size	3	.191	.064	4.79	4.76
Error	6	.080	.0133	–	
Total	11	.290			

Examinations of possible differences between 1 and 2+ car households yields the following analysis of variance table:

Table 3.13-5: Analysis of Variance of TT-budgets for 1 and 2+ Car Households

	Degrees of Freedom	Sum of Squares	Mean Squares	F-value	$F_{Crit .05}$
Days	2	.003	.0015	.16	4.10
HH-size	2	.006	.003	.65	4.10
Car Ownership	1	.002	.002	.22	4.96
Interaction	2	.015	.0075	.82	4.10
Error	10	.092	.0092		
Total	17				

It is seen that the travel time budgets of carless households are dependent on household size but the travel time budgets of car owning households are not dependent on household size or level of car ownership (1). Again, there are no difference in travel time budgets between days for either household type.

The major conclusion of this section can be summarized thus: travel time budgets per traveler do not appear to vary by day. This should not be interpreted to mean that individual travelers would spend equal amounts of time for travel every day but rather that, on the average, within a given homogeneous group of travelers, travel time budgets do not vary over the weekdays. Furthermore, travel time budgets seem to vary with car ownership levels and household size. Specifically, there is a difference in travel time budgets between car owning and carless households. There also appears to be a household size effect, but it is minor and confined to carless households with three household members.

(1) An analysis of variance was also done at given levels of household size. These tables showed, somewhat tenuously due to losses in degrees of freedom, that household size effects are confined to the 3-member households. A richer data base is needed for more definite conclusions.

It is shown later that the difference in the TT-budgets between travelers of car and carless households is not an intrinsic characteristic of the travelers, but rather stems from different travel speeds. One such indication was already noted when comparing the TT-budgets of car and bus travelers in Washington, D.C. (Section 3.6-1), and it is further analyzed in Section 4.7.

It becomes evident at this stage that although the daily TT-budget per traveler tends to be stable between days, it is not constant across travelers, as it tends to vary by such factors as car ownership levels. After further consideration, it can also be inferred that the analysis of the TT-budgets across travelers is not going to be very fruitful if done in isolation; the daily TT-budget is used in order to travel a certain distance at a certain speed and, therefore, it should be related to these travel characteristics. For instance, and referring back to Table 3.6-1, it can be seen that bus travelers in Washington, D.C. spent more time in order to travel less distance than car travelers.

The analyses of isolated TT-budgets will conclude with the case of the Nurenberg Region in Germany, presented below, while more thorough examinations of the relationships between TT-budgets/travel distance/speed are detailed in Section 4.7.

3.14 Daily Travel Time per Traveler in the Nurenberg Region

The Nurenberg region includes a population of about 1,162,000 persons above the age of 10 years, distributed between settlements of varying sizes in a study area of about 3,000 sq.km. A comprehensive one-day home-interview survey, of about 10 percent of all households, was conducted in the region in 1975 and the relevant results, stratified by the same household types as shown in Table 3.13-1, are summarized in Appendix 2. (Kocks, 1977).

Following the analysis of variance of the TT-budgets detailed in the preceding section, the results for the motorized travelers above 10 years in the Nurenberg region are presented in Table 3.14-1 for travelers of car vs. carless households, and in Table 3.14-2 for travelers of 1 car vs. 2+ car households.

Table 3.14-1: The Analysis of Variance of TT-budgets per Traveler, Car vs. Carless Households, The Nurenberg Region

HH Size	Daily TT-budget per Traveler, hr.		
	0 Car	1+ Car	Total
1	1.41	1.22	2.63
2	1.42	1.25	2.67
3	1.36	1.28	2.64
4+	1.35	1.27	2.62
Total	5.54	5.02	10.56

Interaction	Sum of Squares	Degrees of Freedom	Mean Square	F-value	F crit. 0.05
Between Cars	0.034	1	0.034	20.00	10.13
Between HH Size	0.001	3	0.0003	0.176	9.28
Error	0.005	3	0.0017		
Total	0.040	7			

Table 3.14-2: The Analysis of Variance of TT-budgets per Traveler, 1 car vs. 2+ car Households, The Nurenberg Region

HH Size	Daily TT-budget per Traveler, hr.		
	1 Car	2+ Car	Total
2	1.24	1.38	2.62
3	1.27	1.30	2.57
4+	1.26	1.30	2.56
Total	3.77	3.98	7.75

Interaction	Sum of Squares	Degrees of Freedom	Mean Square	F-value	F crit. 0.05
Between Cars	0.008	1	0.008	5.33	18.51
Between HH Size	0.002	2	0.001	0.667	19.00
Error	0.003	2	0.0015		
Total	0.013	5			

The results in the first table show similar trends to those observed in Munich, namely: (i) there are no significant differences between the TT-budgets by household size; and (ii) there are significant differences by car ownership. The results in the second table suggest that there are no significant differences between the TT-budgets of travelers from car and carless households, regardless of household size or the number of cars owned.

It is also of interest to note that the coefficients of variation of the TT-budgets in the Nurenberg region are somewhat higher than those observed in Munich, namely 0.74, although they are relatively stable by household type. For instance, the standard deviation of the coefficient of variation by household type (of equal weight) is only $\pm$ 0.07 ($\pm$ 9.5 percent).

Furthermore, the average TT-budget in the Nurenberg region is somewhat higher than the one observed in Munich, namely 1.30 vs. 1.16 hours respectively, probably because it also includes regional travel, <u>between</u> the settlements. Another possible reason is the deletion of travelers who traveled more than 4 hours per day in Munich, which reduced the average TT-budget from 1.21 to 1.16 hours. Even so, the TT-budgets are similar, suggesting once again that such similarities are not coincidental.

A last test at this stage is to relate the TT-budget <u>per household</u> versus household size and car ownership (household types of equal weight), and the best-fit multiple regression can be expressed by

$$TT/HH = 0.589 + \underset{(13.03)}{0.578(\text{HH Size})} + \underset{(3.24)}{0.295(\text{Cars/HH})} \; ; \qquad (3\text{-}14\text{-}1)$$

where the numbers in parentheses are the t-statistic, and the coefficient of multiple correlation is 0.914.

It may, therefore, be inferred that while the relationship is significant, the TT-budget per household is predominantly affected by household size. We shall see later that this is so because the TT-budget per household is the sum of the TT-budgets of the household's travelers, and that the number of travelers per household is predominantly affected by household size. Thus, while the above relationship may be regarded as relatively satisfactory on statistical grounds, it is unsatisfactory from behavioral considerations since the allocation of the TT-budget to travel is done more by the individual travelers, as the decision unit, than by the "household" as a whole.

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With the example of the Nurenberg Region concludes the part dealing with isolated TT-budgets, and all further analyses will focus on the relationships between the travelers' TT-budgets/travel distance/speed, as detailed in Chapter 4. Therefore, the final conclusions about the TT-budgets are deferred until we see how they interact with other factors within the urban/regional systems.

B. THE TRAVEL MONEY BUDGET

3.15 The Travel Money Budget

The travel money budget, or TM-budget for short, is the second principal constraint on travel applied in the UMOT process. The TM-budget, similar to the TT-budget, becomes apparent only after a certain level of aggregation is reached, a level higher than in the case of the TT-budget; time cannot be transfered between days, but money can. Hence, a money constraint on travel can be identified only after a certain threshold of aggregation over several days or weeks.

The following examples of TM-budgets start from macro conditions, total averages for countries, and go down to the level traffic districts within cities.

3.16 The TM-budget between Countries

All available data suggest that there is a TM-budget that, on a macro level at least, tends to be stable both between western countries and over time. The following examples express the total expenditures on travel as percent of the total consumer expenditures in a selection of countries and, depending on the local definitions, they tend to be similar.

U.S., 1963 - 1975	: 13.18 ± 0.38	percent
Canada, 1963 - 1974	: 13.14 ± 0.43	"
Fed. Rep. of Germany, 1971 - 1974	: 11.28 ± 0.54	"
U.K., 1972	: 11.7	"

The stability of the TM-budget over time is shown in Figure 3.16-1 for the U.S. and Canada. Although the TM-budget displays minor cyclical variations over the years, the general stability is quite noticeable.

The stability of the TM-budget, at least on a nationwide scale, was corroborated recently by the extensive changes in the cost of travel that took place in 1974/75, as shown in Figure 3.16-2. The expenditures on car travel are broken down into standing costs

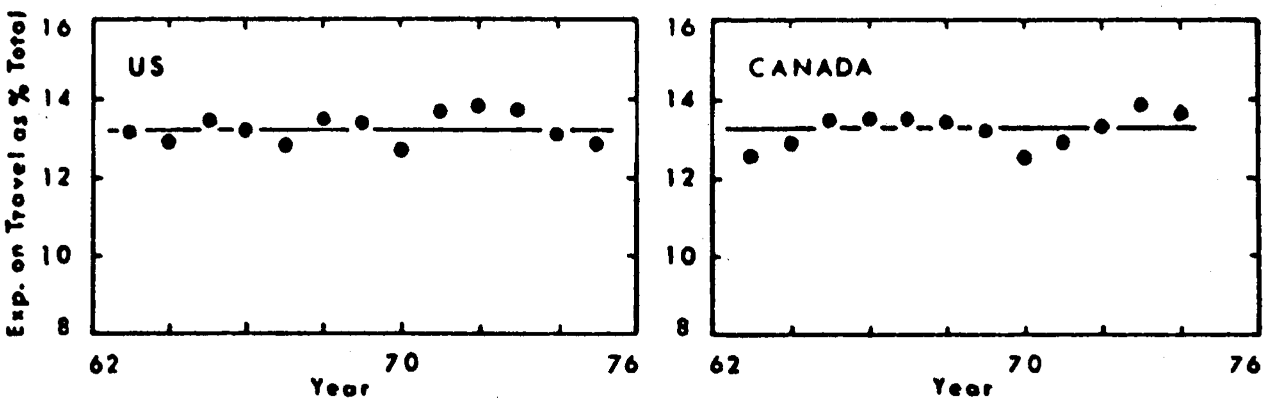


Figure 3.16-1 : Expenditure on Travel vs. Total Consumer Expenditure, US 1963-1975 and Canada 1963-1974

(such as depreciation, license fees and insurance) and <u>operating costs</u> (such as gasoline, oil, tires, maintenance, tolls and parking). The remarkable result is that the TM-budget remained relatively stable, at about 12.6 percent, although major changes took place within it. Namely, when the car operating costs increased during 1974, the car standing costs decreased in proportion, thus making the total travel money budget relatively stable. The same results were also observed in the U.K. (Mogridge, 1977).

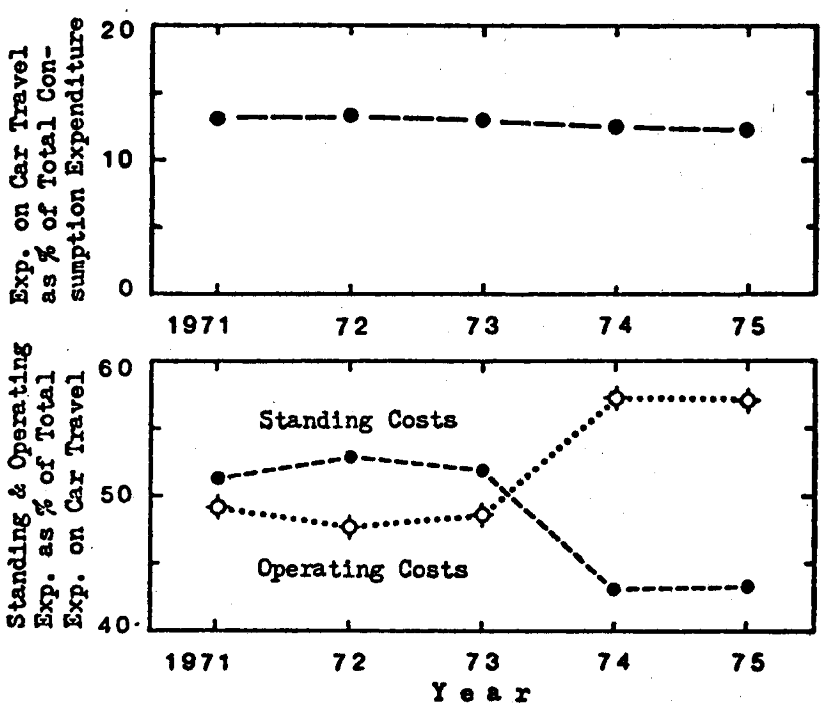


Figure 3.16-2 : Expenditures on Car Travel as Percent of Total Consumption Expenditure and Proportions of Standing and Operating Costs of Car Travel, Total US 1971 - 1975

It appears, therefore, that the TM-budget tends to remain relatively stable, with trade-offs within it, as long as the exogenous changes are below a critical threshold. This indication is of special interest, as the identification of such a critical threshold is of prime importance for policy makers. For example, although the standing costs decreased by only a few percent during 1974/75, by such measures as a slowing down in the rate of car replacement, it had a significan effect on the economy, such as when millions of new cars remained unsold, with spreading effects to other segments of the economy. The real concern, however, is when the TM-budget itself will start to change in relation to other money budgets, thus accelerating the effects on other segments of the economy.

The relation between the TM-budget and other money budgets are discussed in the following section.

3.17 The Money Budgets of Households

The personal consumption expenditures by type of product in the U.S. during 1963-1973 are detailed in Table 3.17-1 and shown in Figure 3.17-1.

Table 3.17-1 : Personal Consumption Expenditure by Major Activity/Product, as a Percent of Total Consumption Expenditure, US 1963-1973

Activity/Product	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
Housing	29.2	29.3	29.0	28.8	28.9	28.6	28.7	28.9	28.9	29.2	29.0
Food	25.6	25.1	24.8	24.6	23.9	23.3	22.6	22.9	22.1	21.5	22.2
Clothing	9.9	10.1	10.1	10.4	10.4	10.4	10.3	10.2	10.1	10.1	10.1
Transport	13.1	12.9	13.4	13.0	12.7	13.4	13.4	12.6	13.6	13.7	13.6
Medical	6.2	6.4	6.5	6.7	7.0	7.0	7.4	7.7	7.8	7.8	7.8
Soc. Rec.	9.3	9.5	9.4	9.7	10.0	10.0	10.1	10.4	10.2	10.4	10.2
Other	6.7	6.7	6.8	6.8	7.1	7.3	7.5	7.3	7.3	7.3	7.1

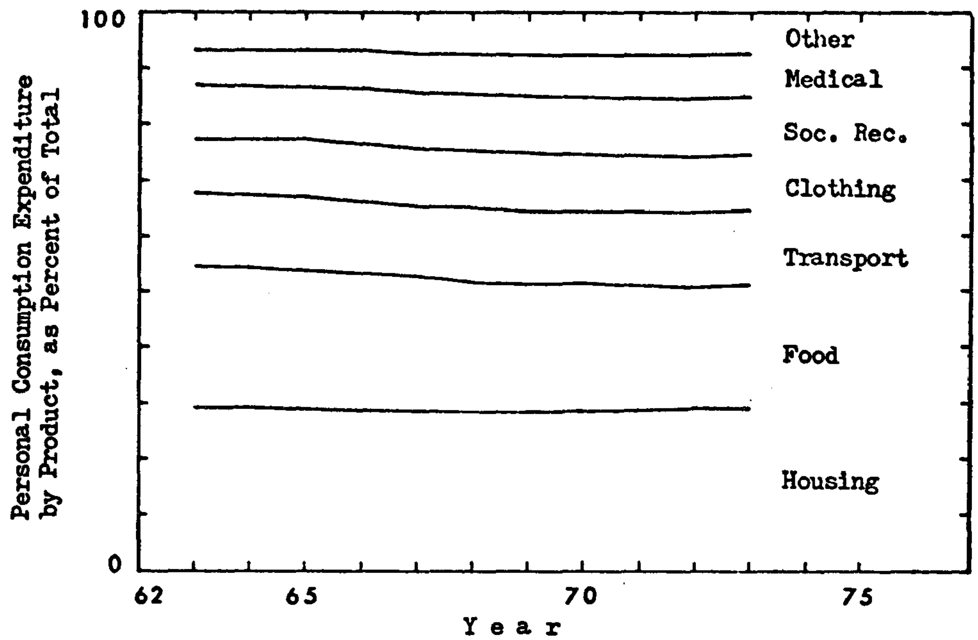


Figure 3.17-1 : Personal Consumption Expenditures by Type of Product as a percent of the Total Personal Consumption Expenditures, US 1963-1973

It becomes evident that the expenditures allocated to the various major activities/goods are very stable, although not necessarily constant, over time. Thus, while the proportion allocated to food tended to slightly decrease in a consistent way, the proportion allocated to nedical care tended to slightly increase in a consistent way. The expenditures on travel and housing, on the other way, tended to remain both stable and constant over the 11-year period, as well as during the period 1973-75.

While the TM-budget may be stable over time as a controlling total for a country, the question is how stable is it within the country for different population segments, especially for car and non-car owning households ?. The only example available at this stage is from the U.K., where the household expenditure on travel versus the household total weekly expenditure (and income) are separately detailed for car owning and non car owning households, in 1971, as summarized in Table 3.17-2 and shown in Figure 3.17-2 for the two household groups.

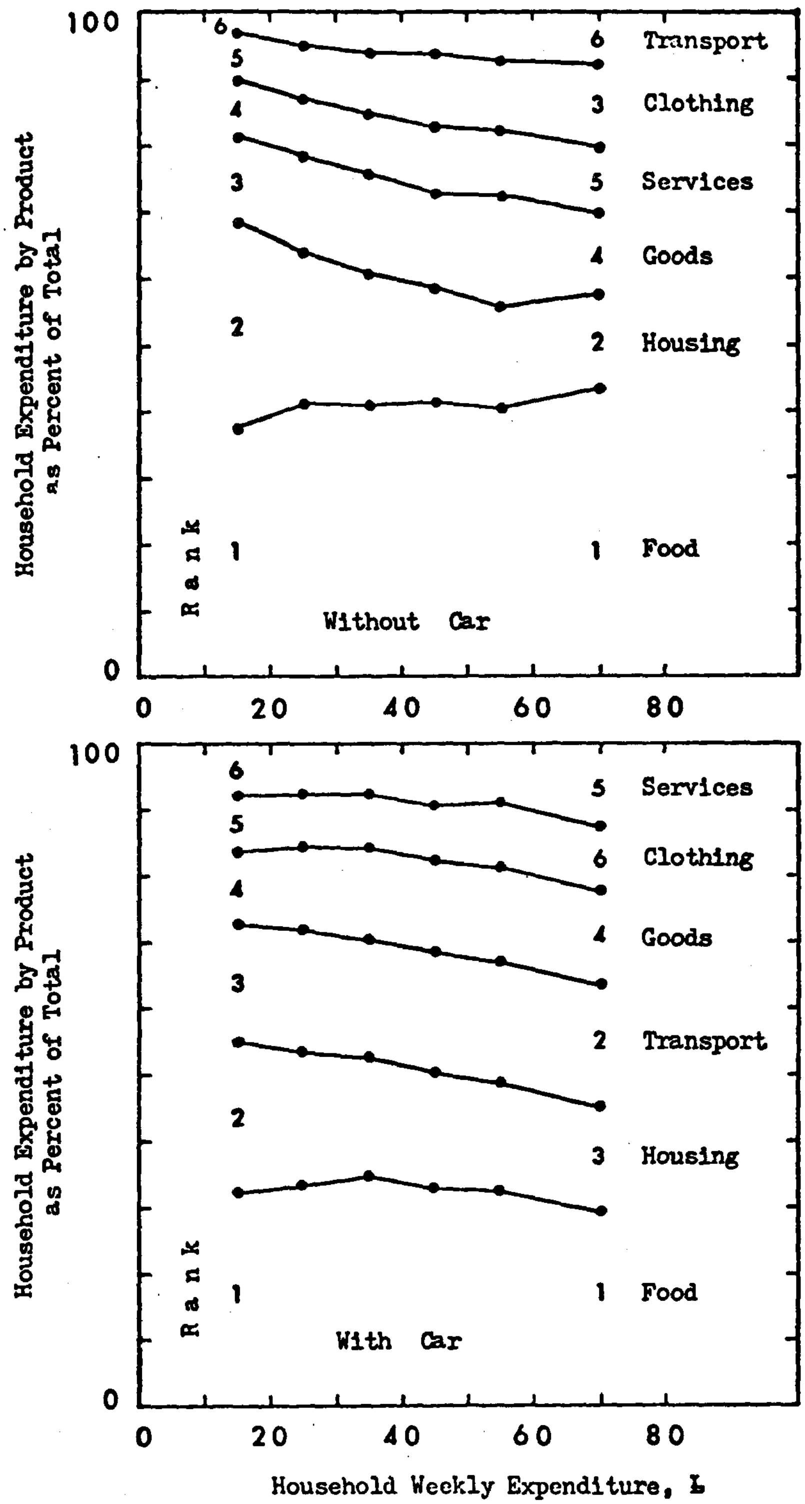


Figure 3.17-2 : Household Weekly Expenditure by Type of Product as a Percent of the Total Expenditure, Households With and Without Car, UK 1971

Table 3.17-2 : Expenditures by Major Activity/Product by Households With and Without Cars, as a Percent of Total Expenditure, UK 1971.

Activity/Product	Weekly Income of Household, £					
	Under 20	20-30	30-40	40-50	50-60	Over 60
Without Cars						
Housing	31.0	22.5	20.2	17.2	15.5	14.7
Food	37.5	41.1	40.7	41.2	40.3	43.1
Clothing	7.0	7.8	9.1	11.1	10.5	12.5
Goods	12.7	14.8	14.6	14.2	17.0	11.8
Transport	3.0	5.2	6.0	6.1	7.4	8.0
Services + Other	8.8	8.6	9.4	10.2	9.3	9.9
Total Expenditure, £	12.8	21.5	27.8	33.5	41.4	49.9
With Cars						
Housing	23.3	19.8	18.2	17.2	16.0	15.8
Food	32.2	33.5	34.5	32.9	32.8	29.3
Clothing	8.5	7.4	8.6	8.5	9.9	9.6
Goods	10.8	13.1	13.9	13.8	14.3	14.3
Transport	17.3	18.5	17.5	18.4	18.3	18.3
Services	7.9	7.7	7.3	9.2	8.7	12.7
Total Expenditure, £	21.6	27.7	31.4	36.7	42.4	57.8

When comparing this figure with Figure 3.17-1, it becomes evident that the ranking of money expenditures by activity/goods may differ between countries; the highest expenditure in the U.S. is for housing, while the highest in the U.K. is for food. Such differences depend on the economic structure of a country, a subject which is beyond the framework of this report. But what is of special interest to our subject is the significant difference in the ranking of travel expenditures by households owning and not owning a car, although belonging to the same income group; it is the last for households not owning a car, while it is second/third for households owning a car, similar to the total average in the U.S.

Figure 3.17-3 stratifies the travel expenditures of the two household types versus the total expenditures. The remarkable result is that the expenditure on travel by households owning cars is a relatively stable proportion of the total household expenditure, about 17-18 percent, at all income levels.

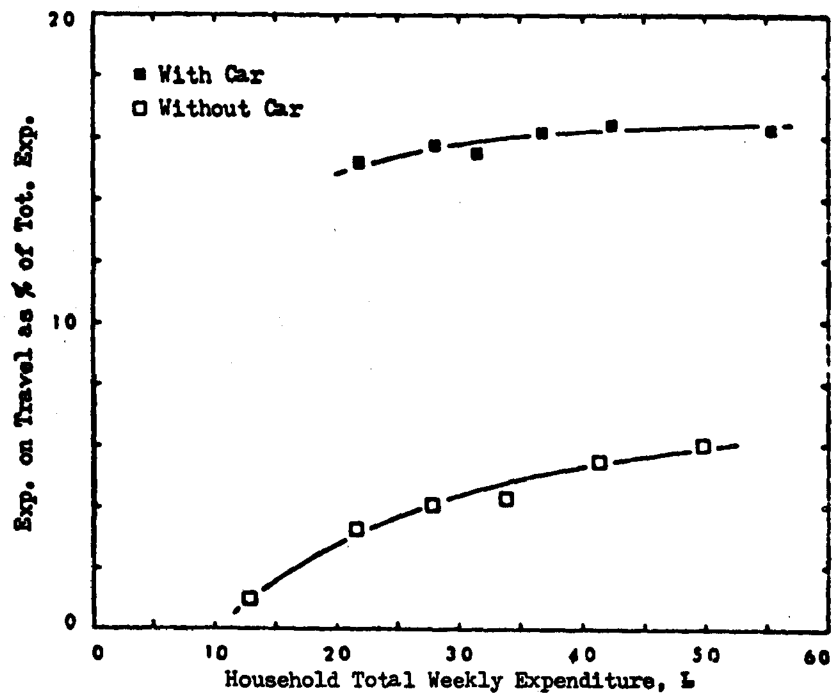


Figure 3.17-3: Household Weekly Expenditure on Travel as Percentage of Total Weekly Expenditure, by Car Availability, All U.K. 1971

Households not owning a car, on the other hand, expend on travel less than half the above proportion, but again at a relatively stable proportion at all income levels. It will be shown below that the same trends were found in Washington, D.C. and Twin Cities in the U.S., and in the Nurenberg Region in Germany.

It is of interest to note at this stage that both groups of households expend on housing about the same proportions, as can be seen in Figure 3.17-4. Namely, the wide gap between the two expenditures on travel seen in Figure 3.17-3 appears to be unique for travel, and not affected much by the expenditures on housing.

Three indications may be inferred at this stage:

(1) There is a significant gap between the expenditures on travel by households owning and not owning cars. The possible reasons for such a wide gap are discussed below;

(2) The expenditures on car travel appear to be a stable proportion of income at all income levels;

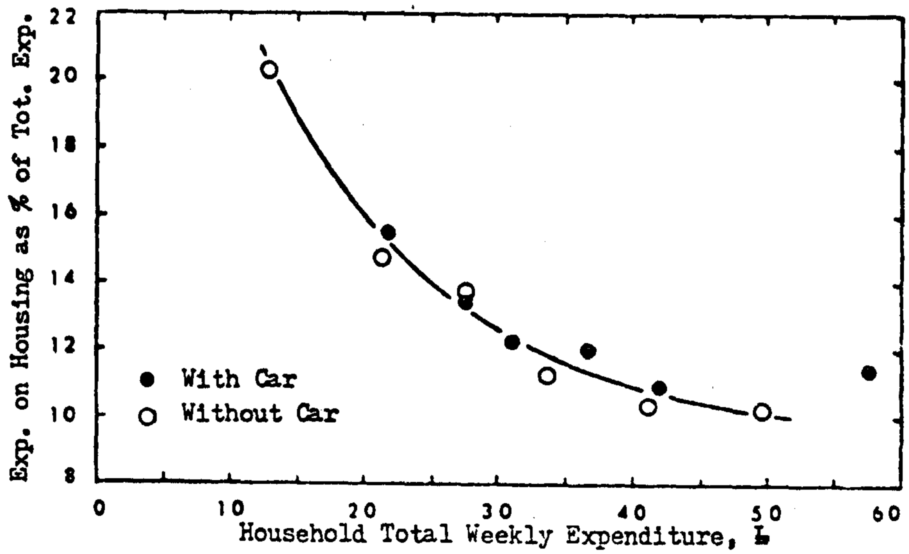


Figure 3.17-4: Household Weekly Expenditure on Housing as Percentage of Total Weekly Expenditure, by Car Availability, All UK 1971

(3) The total average proportion of a TM-budget for a given population will depend on the proportions of households owning and not owning cars at each income level.

The last point is of special interest for cases where the stratification of households by car ownership is not known. Such a case is shown in Figure 3.17-5 for household expenditures on travel in the U.K. in 1972, where it appears as if the expenditures on travel as a proportion of the total household incomes increase with incomes(*). This apparent increase in the TM-budget, when based on all households, can now be explained by the two distinctly different TM-budgets of two distinctly different household types; those owning a car versus those that do not own a car. Thus, the apparent increase in the TM-budget by income is due to the increasing

(*) It should be noted that the relationship in this case is based on the households' weekly income, while in the previous cases it was based on the households' weekly total expenditures; hence, the proportion of the TM-budget will depend on whether it is based on income or expenditures.

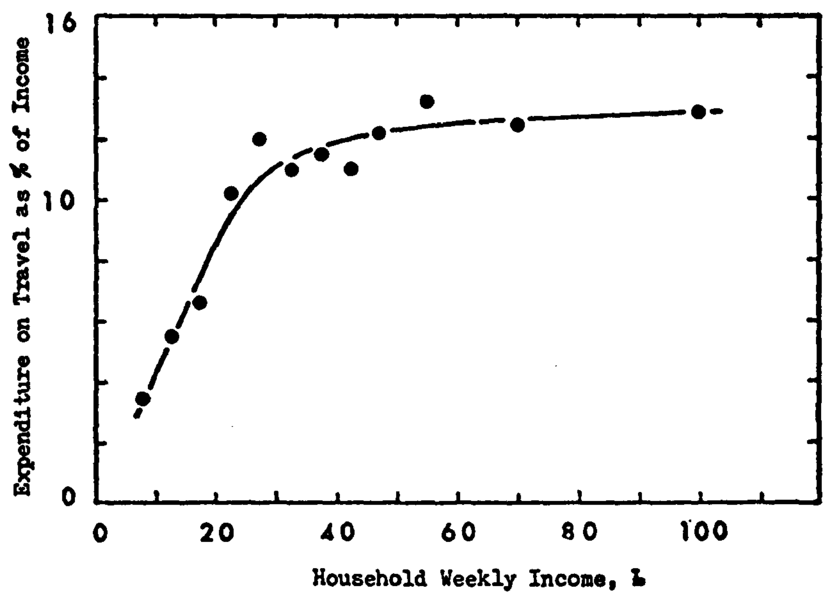


Figure 3.17-5 : Household Weekly Expenditure on Travel vs. Household Weekly Income, UK 1972

proportion of households owning a car with increasing income, although the TM-budget of each household type is a stable proportion of their income.

The next examples are of TM-budgets within cities, as detailed in the following sections.

3.18 The TM-budget in Two U.S. Cities

1. Extreme difficulties were encountered when trying to extend the analysis of the TM-budget down to the level of cities for households owning and not owning cars, as no direct data on such expenditures were available from travel surveys. The only possible way, therefore, was to derive such TM-budgets by indirect, though controlled, methods.

The following results are based on data from the transportation studies in Washington, D.C. 1968 and Twin Cities 1970 in the U.S. (Zahavi, 1979-a), where households were first stratified by the mode used during the survey day, namely car-only and transit-only, by district of residence. The expenditures on travel were then derived as the product of the daily distance traveled by each mode and the cost per unit distance. The results are shown in Figure 3.18-1 and summarized in Table 3.18-1.

Table 3.18-1 : Household Expenditure on Car and Transit Travel, by District, Washington, D.C. 1968 and Twin Cities 1970

WASHINGTON

District	Car Travel Only		Transit Travel Only	
	Income	Expend. %	Income	Expend. %
1	6,800	8.35	5,000	2.66
2	6,800	11.88	5,400	3.32
3	7,500	9.20	5,500	3.38
4	6,600	9.51	5,400	3.60
5	8,300	8.73	4,300	3.95
6	7,300	10.78	4,500	4.86
7	8,100	10.94	5,800	4.66
8	7,500	11.68	5,800	5.37
9	9,000	10.21	5,600	5.26
10	8,900	10.37	5,000	5.51
11	9,300	11.88	5,300	4.71
12	9,000	10.95	5,100	5.63
13	9,200	11.12	5,100	6.76
14	10,100	11.89	4,700	6.55
Average	8,600	10.95	5,300	4.16

(Cont.)

TWIN CITIES

2	8,967	8.85	4,443	4.59
3	10,386	9.68	6,946	2.69
4	(11,730)	(8.21)	5,801	3.68
5	8,859	10.71	3,826	4.53
6	8,974	10.74	4,906	3.45
8	9,858	10.04	6,634	2.09
9	10,654	8.92	5,995	3.01
10	9,813	10.50	5,239	4.05
11	9,005	10.21	(4,350)	(1.55)
12	11,547	12.04	7,336	2.56
13	(14,531)	(9.20)	6,834	3.01
14	11,811	11.87	5,993	3.62
15	12,643	10.31	6,500	2.20
16	12,170	10.52	9,000	4.70
17	13,501	11.02	(15,282)	(2.53)
18	11,792	10.23		
Average	11,669	10.08	5,567	3.42

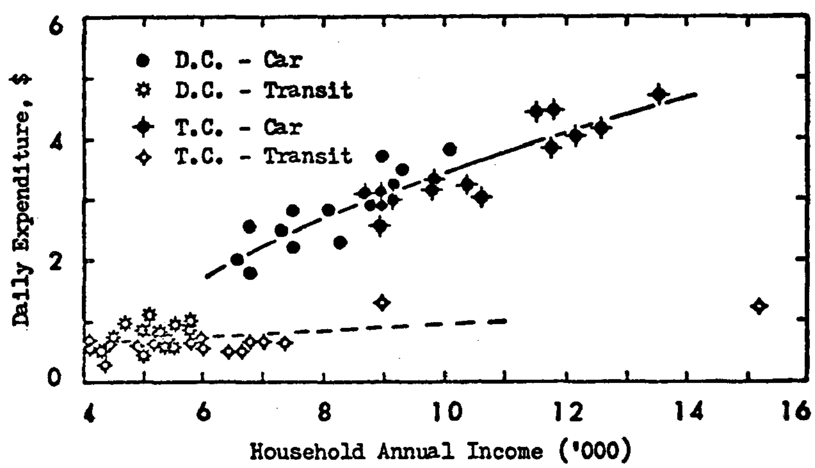


Figure 3.18-1 : Daily Expenditure on Travel by Households that made all their Trips by Car Only or Transit Only vs. Household Annual Income, Washington, D.C. 1968 and Twin Cities 1970

The indications that may be inferred from the above examples are:

(1) The TM-budget of car-owning households is found, once again, to be a relatively stable proportion of income, about 10.5 percent, at practically all income levels;

(2) The TM-budget of non-car owning households is found to be very low, about 3-5 percent of income, at a wide range of incomes;

(3) There is a wide gap between the two TM-budgets, similar to the gap in the U.K. data.

Thus, although the proportions may differ between countries, or even within the same country if based on different definitions, such as total income, disposable income, or actual expenditures, the proportions are still inherently stable within a given data set, showing the same trends as observed in other places.

3.19 The TM-budget in the Nurenberg Region, Germany

Application of the above procedure to cities in Germany was found to be practically impossible, as transportation surveys do not include data on the households' income. Hence, although the travel expenditures can be estimated by the actual travel distances by mode per household, there are no incomes to compare them with.

The problem was solved by estimating the probable income level of households by their available socioeconomic characteristics, such as household size and car ownership, and although the methodology is not fully satisfactory, the results suggest that the TM-budget is robust enough to emerge above all uncertainties.

The procedure applied to the case of the Nurenberg region is based on the information available during the conduction of this study, as follows:

(1) The proportions of households, by size, vs. disposable income in 1973 are detailed in Table 3.19-1. The average disposable incomes in 1975 are based on the 1973 disposable incomes multiplied by a nationwide average factor of 1.24;

(2) Table 3.19-2 shows the proportions of car and carless households vs. disposable incomes in 1973;

(3) Based on the above two tables, Table 3.19-3 details the estimated household disposable income by household size and car ownership.

Thus, we could derive estimates of disposable incomes of households by size and car ownership in 1975. The next step was to estimate the unit costs of travel in 1975 by different modes.

Table 3.19-1: Percentage of Households, by Size, versus Disposable Income, Germany 1973 and 1975

Income Group	Monthly Income Range,DM('000)	Average Income 1973	Average Income 1975	Households, % 1	2	3	4+	Avg. HH Size
1	Up to 0.6	510	631	93.3	6.5	0.2	-	1.07
2	0.6 - 0.8	751	929	80.3	18.7	0.8	0.2	1.21
3	0.8 - 1.0	967	1,196	61.8	34.6	2.6	1.0	1.43
4	1.0 - 1.2	1,177	1,456	46.1	44.1	6.0	3.8	1.69
5	1.2 - 1.5	1,452	1,796	28.2	42.2	16.5	13.1	2.20
6	1.5 - 1.8	1,791	2,215	14.2	35.2	23.1	27.5	2.78
7	1.8 - 2.5	2,298	2,843	5.4	29.9	27.6	37.1	3.19
8	2.5 - 5.0 ( ) 5.0 - 15.0	3,741	4,628	1.7	22.9	24.2	51.2	3.64
Average Income, DM				1,148	2,015	2,812	3,240	

Table 3.19-2: Proportions of Car and Carless Households by Income, Germany 1973

Income Group	Proportion of HH, % 0 Car	1+ Cars
1	93	7
2	87	13
3	71	29
4	51	49
5	37	63
6	27	73
7	19	81
8	12	88

Table 3.19-3: Average Disposable Income per Household, by Household Size and Car Ownership, Germany 1975

Income Group	Households %	Households Owning a Car, %		% of Households, by Size and Car Ownership							
				1		2		3		4+	
		0	1+	0	1+	0	1+	0	1+	0	1+
1	5.5	5.11	0.39	4.77	0.36	0.33	0.03	0.01	-	-	-
2	6.3	5.47	0.82	4.40	0.66	1.02	0.15	0.04	0.01	0.01	-
3	6.6	4.69	1.91	2.90	1.18	1.62	0.66	0.12	0.05	0.05	0.02
4	5.4	2.75	2.65	1.27	1.22	1.21	1.17	0.17	0.16	0.10	0.10
5	12.1	4.48	7.63	1.26	2.15	1.89	3.22	0.74	1.26	0.59	1.00
6	12.1	3.26	8.83	0.46	1.25	1.15	3.11	0.75	2.04	0.90	2.43
7	24.9	4.74	20.17	0.26	1.09	1.41	6.03	1.31	5.57	1.76	7.48
8	27.1	3.26	23.85	0.06	0.41	0.74	5.46	0.79	5.77	1.67	12.21
Total	100.0	33.75	66.25	15.38	8.32	9.37	19.83	3.93	14.86	5.08	23.23
Average Disposable Income				1,087	1,882	1,946	2,912	2,749	3,339	3,150	3,663

2. Travel costs of car travel were subdivided into operating and standing costs. Operating costs comprise expenditures on fuel, depending on the travel speed and the fuel price. The relationship between speed and fuel consumption used is related to an average private car of 1,600 ccm., and a price of 0.90 DM per liter, as shown in Figure 3.19-1. (Meewes, 1973).

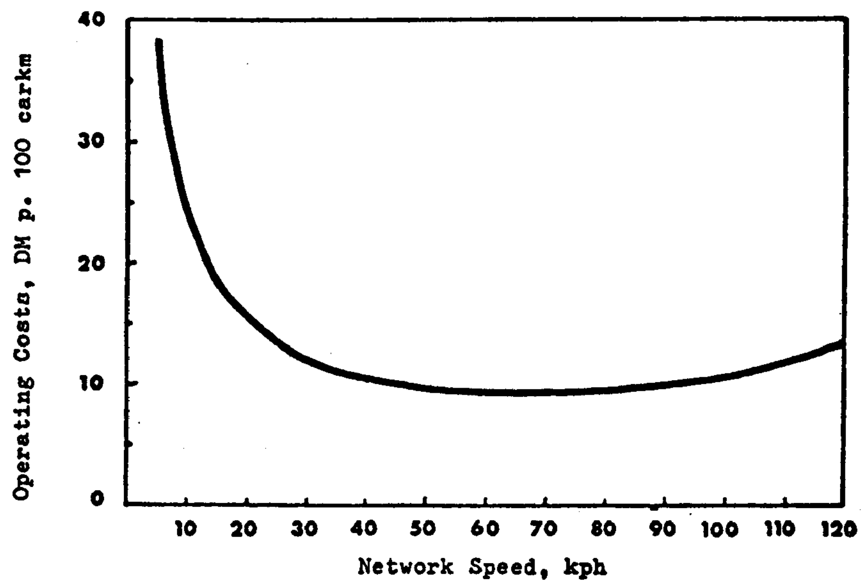


Figure 3.19-1 : Operating Costs, Car Travel

It should be noted that the original relationship is based on the assumption of constant travel speeds. If, however, the daily average speed is considered, operating costs will be slightly higer than shown in the above figure. Furthermore, the speeds in Appendix 2 are the door-to-door speeds, derived from the daily travel distance over the daily travel time and, therefore, they have to be translated into network speeds. Based on such ratios in U.S. cities (Zahavi, 1979-a), the door-to-door speeds were multiplied by a factor of 1.5 in order to derive the network speeds. Lastly, the total daily travel distance per household was divided by the average car occupancy of 1.25 in order to derive the daily car-kilometers per household.

The second components of travel costs of car travel is the standing costs which, for travel conditions in Germany in 1975, are detailed in Table 3.19-4. The depreciation part is based on a price of 11,770 DM and a life span of 10 years per standard car, and it was

Table 3.19-4: Standing Costs per Year, Standard Car, Germany 1975

Item	Cost, DM
Tax, insurance	828
Depreciation	1,177
Repair	800
Car-care	80
Other (e.g., parking)	120
Total per Year	3,005

assumed to be linear. By assuming 310 days per year, the standing cost per day was estimated to be about 9.70 DM. This should be regarded as a rough average value, which probably overestimates travel costs of low income households, and underestimates travel costs of high income households, due to different sizes and ages of the owened cars.

The travel costs in public transport in the Nurenberg region were available from the comprehensive transportation study conducted in the region, and the fare system for the three public transport enterprises are detailed in Table 3.19-5.

Table 3.19-5: Public Transport Fare System in the Study Area

a) VAG

Type of Ticket	DM per Ticket	Remark
Single trips	1.3o	within the urban area of Nuremberg, Fuerth and Stein
	2.5o	between the a.m. area and the City of Erlangen
	2.oo	between the a.m.area and the City of Schwabach
"Ticket for more trips"	o,8o per trip	
Weekly tickets	11.oo	within the a.m. area
Monthly tickets	4o.oo	within the a.m. area
	24.oo	for students, only

b) DB (Deutsche Bundesbahn) and OVG

Distance	DB Fare		OVG Fare	
	DM	DM/km	DM	DM/km
1 - 5	1.2o	o.48	1.oo	o.4o
6 - 1o	1.6o	o.2o	1.4o	o.2o
11 - 15	2.oo	o.15	2.1o	o.16
16 - 2o	2.4o	o.13	2.4o	o.13
21 - 3o	3.2o	o.13	3.oo	o.12
31 - 4o	4.4o	o.12	4.2o	o.12
41 - 5o	5.8o	o.12	5.4o	o.12

3. The travel costs in public transport per kilometer traveled is shown for trip-related fares in Figure 3.19-2. Time-related fares (monthly and weekly tickets) will be cheaper than single tickets from a distance of at least 275 km. per month, or 11 km. per day, as shown in Figure 3.19-3.

The average daily travel distance per traveler of carless households is between 15 to 20 km. (see Figure 3.19-2), thus suggesting that these travelers will predominantly use time tickets. (Indeed, about 65 percent of the tickets are time-tickets), resulting in 0.10 DM per kilometer.

Assuming that travelers of car owning households will predominantly use trip-related tickets, travel costs were estimated to be 0.14 DM per kilometer.

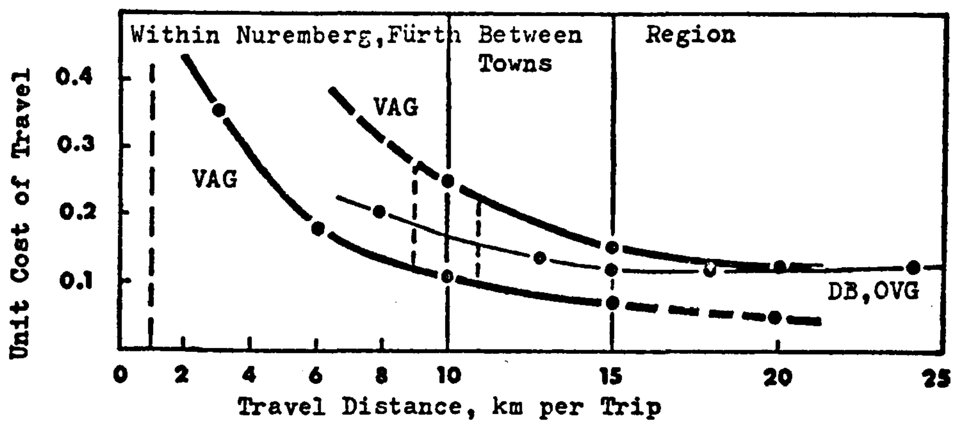


Figure 3.19-2 : Trip-Related Fares in Public Transport, Nuremberg Region 1975

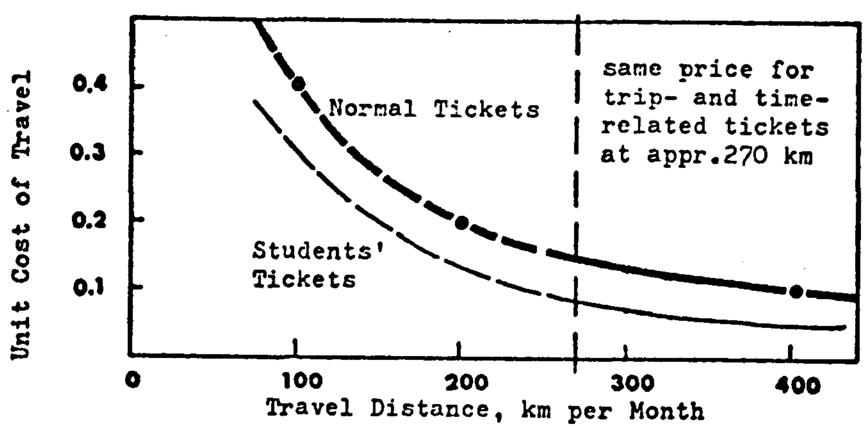


Figure 3.19-3 : Time-Related Fares in Public Transport, Nuremberg Region 1975

4. Based on the above unit costs, the daily travel costs were estimated for the 55 household types (detailed in Table 3.13-1), by their daily travel distance by mode, as presented in Appendix 4 and summarized in Figure 3.19-4.

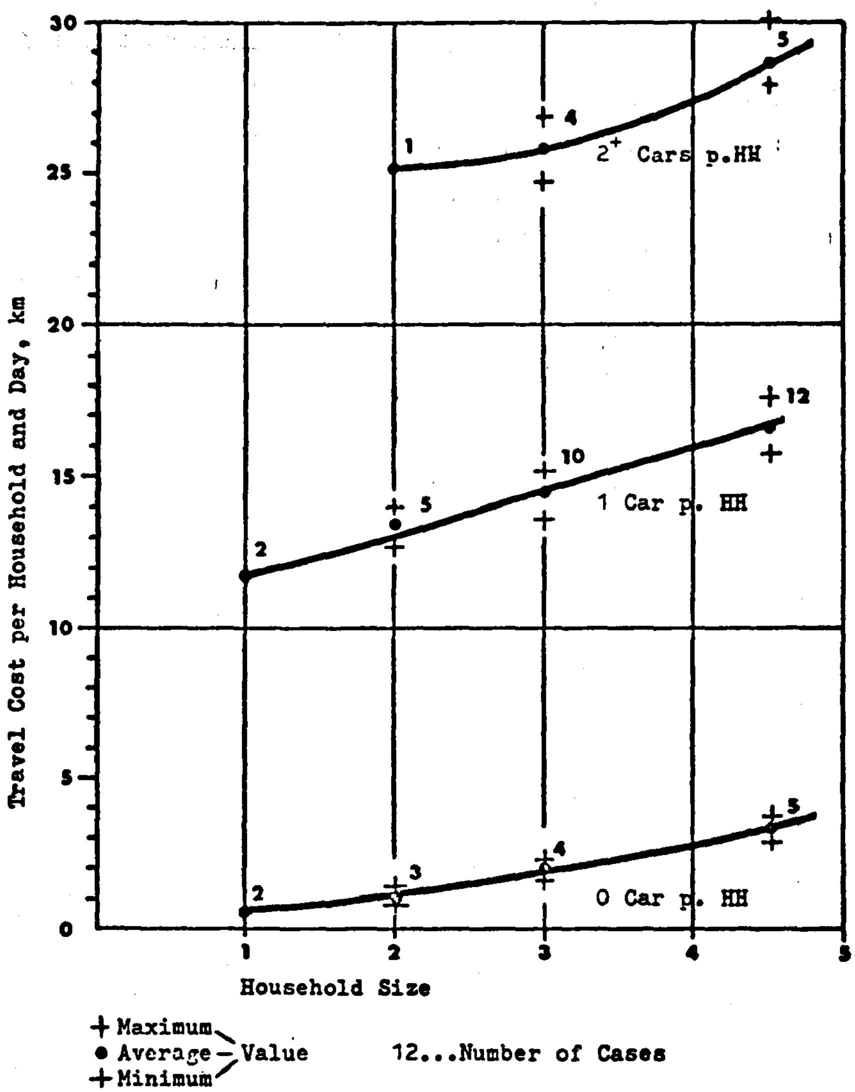


Figure 3.19-4 : Travel Money Budget of Households, Car Travel and Transit, Nuremberg Region 1975

It may be inferred from Figure 3.19-4 that:the daily travel costs per household: (i) increase with household size; and (ii) they differ significantly by car ownership. The most important result is that the existance of a travel money budget is suggested by the very narrow dispersion of the values, even though only two explanatory variables, household size and car ownership, were considered.

5. At this stage it is possible to match the estimated TM-budgets with the estimated disposable incomes, and the results are shown in Figure 3.19-5. It is to be noted that the data shown in this figure refer to 0 and 1-car households, as no income estimates could be derived for 2+ car households. Even so, the remarkable result is that the TM-budgets of carless households cluster at the 3-4 percent level, while the TM-budgets of 1-car households cluster at the 10-12 percent level, with an average value of 11.8 percent for the latter case. Thus, these results follow the trends noted before in the U.K. and the U.S., namely that TM-budgets of carless and car owning households are relatively stable for each group, and that there is a significant gap between these two TM-budgets.

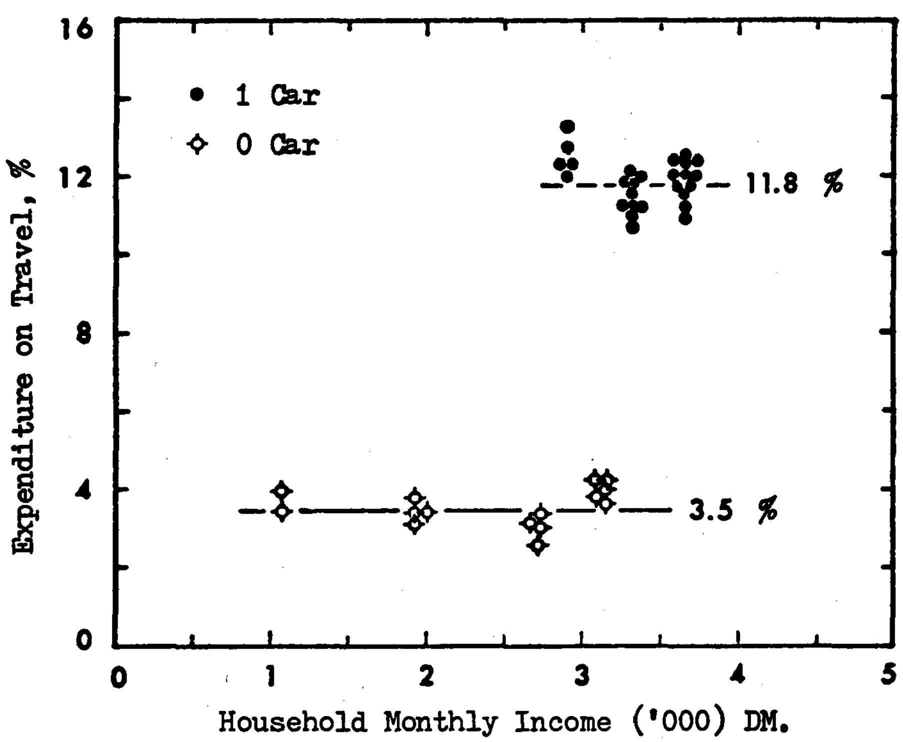


Figure 3.19-5 : Household Expenditure on Travel as Percent of Disposable Income, the Nurenberg Region

3.20 General Comments on the TM-budgets

In summary, the available data suggest that there is a travel money budget per average household, that tends to be a stable proportion of income by car availability, both between cities in the same country and over time. The proportions of the TM-budgets may differ between countries, depending on their economic structure and definitions of income, but its stability within each country, and within cities, is noteworthy. Furthermore, the TM-budget of car owning households appears to be the upper limit for expenditures on surface travel, about 11 percent of income in U.S. cities and about 11 percent of disposable income in Germany. The point is that when a household purchases a car, its TM-budget makes a quantum-jump from about 3-5 percent of income to about 11 percent of income, at practically all income levels.

Three closing comments are to be noted at this stage. First, as car ownership levels increase, from 1 to 2 and 3+ cars per household, an additional factor has to be considered, namely the factor of business expenses, where part of the travel costs are paid - directly or indirectly - by the employer. Thus, while the TM-budget per household owning 2 or 3 cars, estimated on the basis of the daily travel distance, may reach a higher proportion than 12 percent of income, it seems reasonable to assume that the actual out-of-pocket expenditure does not vary much from the upper level of about 12 percent.

Second, The TM-budget should not be divorced from other major money budgets in long range forecasts, especially if significant changes in travel costs by policy decisions are to be expected. In such cases the upper level could easily reach 20 percent - as is already the case in many developing countries, where heavy duties and costs are imposed on private cars - thus affecting other major money budgets.

And third, a wide dispersion of the TM-budgets about the mean values are to be expected, especially if the data are based on the observed travel distances during a one-day survey. This problem is similar to the one already discussed with respect to the TT-budget, but even more noticeable in the case of TM-budgets. Indeed, and as can be seen in Appendices 1 and 2, the coefficient of variation of daily travel distances is higher by about 50 percent than in the case of TT-budgets; about 0.8-0.9 vs. 0.6 respectively. Nonetheless, as long as the dispersion about the mean values are similar for all population segments, it is not a serious shortcoming. Perhaps this is the place to note that even conventional disaggregate choice models are based on the principle that the travel choices of a typical, representative household, or traveler, apply to all other households in the same population segment, with a probability distribution that expresses the deviations of choices made by individual households from the ones made by the representative household. Such distributions about the means represent the personal tastes and preferences of different households, that cannot be captured by the limited number of independent variables, as well as the variations in choices between days and the statistical variations associated with surveys that are based on samples. Thus, the same basic considerations that apply to other models also apply to the case of the TT and TM budgets.

The implications of the interactions between the TM and TT budgets to travel demand modeling, as well as related relationships, are presented and discussed in the following chapter.

CHAPTER 4: IMPLICATIONS OF THE TRAVEL BUDGETS

4.1 The Daily Travel Distance

It was noted in Chapter 3 that the range of the daily TT-budget per representative traveler of different population segments is relatively narrow, within about 1.0 to 1.5 hours in cities of developed countries, and about 1.0 to 2.0 hours in cities of developing countries. The range of the daily TM-budget, on the other hand, is much wider, depending on the range of households' disposable incomes. These trends can be seen clearly in Figure 2.9-1, where comparisons between the TT and TM budgets per household in Nurenberg and Munich are made.

When the daily travel purchased by the two budgets is measured in travel distance, it is evident that a higher TM-budget enables the traveler to purchase more travel distance, through the purchase of higher travel speeds. Hence, variations in the TT and TM budgets can also be analyzed through their end-product, namely travel speed and distance. Such basic relationships per traveler are summarized in Table 4.1-1 and shown in Figures 4.1-1 and 4.1-2 for the case of the Nurenberg region.

Table 4.1-1: Daily Travel Expenditures, Travel Distance and Speed per Traveler, by Household Size and Car Ownership, the Nurenberg Region 1975

HH Size	Cars/HH	TT/TR, hr.	TM/TR, DM.	Distance/TR. km.	Door-to-Door Speed, kph.
1	0	1.40	1.53	15.76	11.3
	1	1.22	12.36	29.41	24.1
2	0	1.43	1.77	18.22	12.7
	1	1.25	8.81	28.65	23.0
	2+	1.39	13.93	37.56	27.0
3	0	1.36	1.82	18.80	13.8
	1	1.27	7.43	25.59	20.2
	2+	1.30	11.31	31.80	24.5
4+	0	1.35	1.97	20.37	15.1
	1	1.26	6.20	24.82	19.7
	2+	1.30	9.21	31.24	24.0

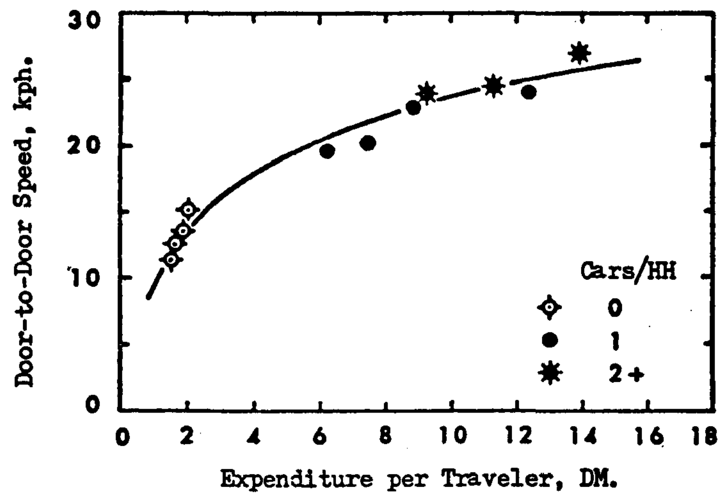


Figure 4.1-1: Door-to-Door Speed vs. Travel Expenditure per Traveler, by Car Ownership, the Nurenberg Region 1975

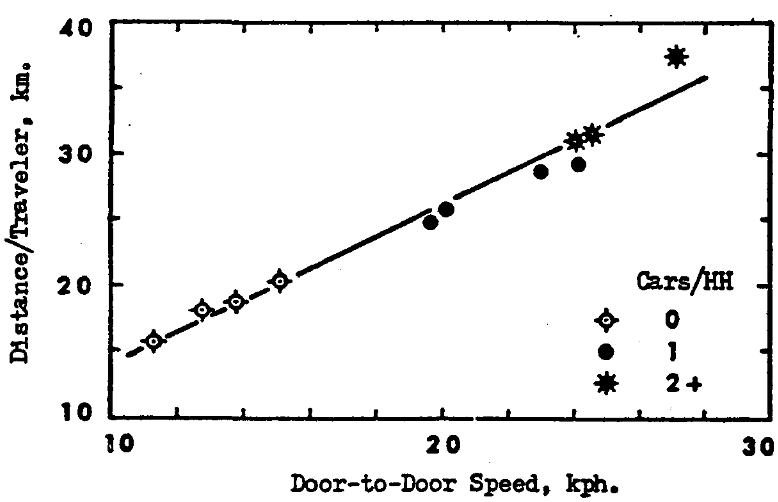


Figure 4.1-2: Daily Travel Distance per Traveler vs. Speed by Car Ownership, the Nurenberg Region 1975

Such analyses suggest that there is a strong relationship between the daily travel distance per traveler and his door-to-door speed. However, since the speeds were derived not independently, but as a quotient of travel distance over travel time per representative traveler, the relationship of distance vs. speed is a translation of the relationship of distance vs. travel time. Thus, if an absolutely constant TT-budget is observed for all distances, the distance vs. speed relationship will be a straight line, with a slope equal to the constant TT-budget and an intecept on the positive distance axis equal to the distance that can be reached by the slowest mode, walking, within the TT-budget. Variations from such straight lines and the transferabilities of these lines across time periods and cities are subjects of the following sections.

The following examples start with previous macro-examples of travel distance vs. speed relationships, and conclude with micro analyses of such relationships in Germany. Additional relationships where the TT and TM busgets play a central role, such as modal choice, close this chapter.

4.2 Travel Distance per Traveler vs. Speed in Two U.S. Cities

Table 4.2-1 summarizes the daily travel distance per representative motorized traveler vs. the daily door-to-door speed in Washington, D.C. and Twin Cities at two periods, and the relationship between the two factors is shown in Figure 4.2-1 (Zahavi, 1979-a). The travelers in this example are stratified by the travel mode used during the survey day, namely car only, transit only, and mixed modes. The original relationship, as summarized in Table 4.6-1, was based on 171 data points.

Table 4.2-1: Daily Travel Distance per Traveler, by Motorized Modes, vs. Door-to-Door Speed, Washington, D.C. 1955 + 1968 and Twin Cities 1958 + 1970

Mode Used	Washington, D. C.				Twin Cities			
	1955		1968		1958		1970	
	Distance	Speed	Distance	Speed	Distance	Speed	Distance	Speed
Car	20.48	18.83	25.91	23.33	24.48	21.45	32.26	28.51
Transit	13.60	10.70	14.35	10.04	12.59	11.99	13.86	12.08
Mixed	18.89	14.88	22.31	17.10	21.09	18.52	26.19	23.23

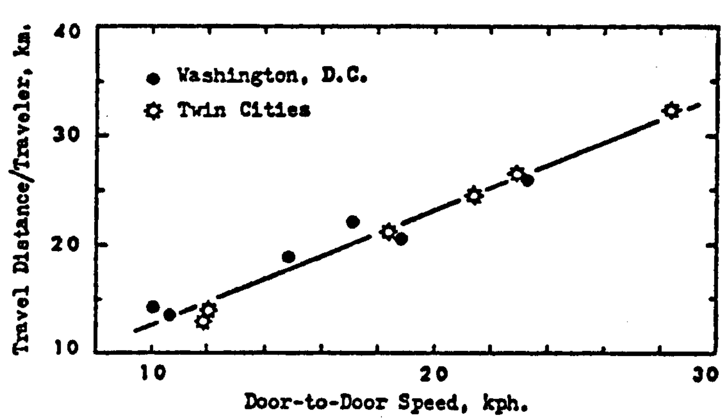


Figure 4.2-1 : Daily Motorized Travel Distance per Traveler, by Mode, vs. Door-to-Door Speed, Washington, D.C. 1955 + 1968 and Twin Cities 1958 + 1970

It becomes evident from Figure 4.2-1 that there is a clear linear relationship between the daily travel distance per traveler and the travel speed. The data for the two cities and two periods intermingle as depicted in Figure 4.2-1, and as shown dramatically in plots of the original 171 data points. Thus, the distance-speed relationship appears to be transferable both between cities in the same country and over time, although more detailed investigations are still called for.

4.3 Travel Distance per Traveler vs. Speed in Singapore

A similar relationship to the above one was also developed on the basis of the data from the Before-and-After AIS study in Singapore, referenced in Section 3.11. The data points in Figure 4.3-1 are stratified by income and car ownership during two periods.

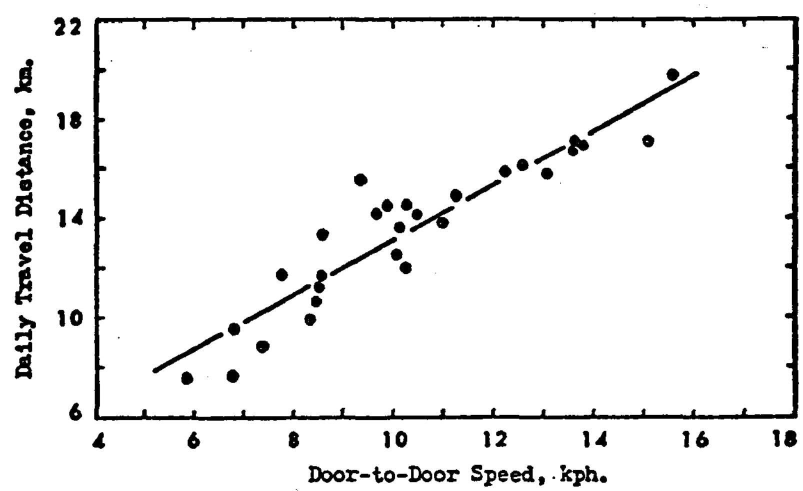


Figure 4.3-1 : **Daily Travel Distance per Traveler vs. Door-to-Door Speed, Singapore Before-and-After Study**

4.4 Travel Distance per Traveler vs. Speed in the Nurenberg Region

Figure 4.4-1 presents the distance vs. time relationship per traveler by the 55 household types in the Nurenberg region, stratified by car availability, based on the data in Appendix 2. As can be seen, all mean travel times are within a narrow band, while travel distances vary to a large extent. Figure 4.4-2 shows the distance vs. speed relationship, based on the same data. Once again, a clear linear relationship becomes evident, as summarized in Table 4.6-1. Table 4.4-1 and Figure 4.4-3 show that the same relationship also holds when the travelers are stratified by occupation and car availability. In this case, however, a gap between car and carless travelers developes, suggesting that the two groups might behave differently.

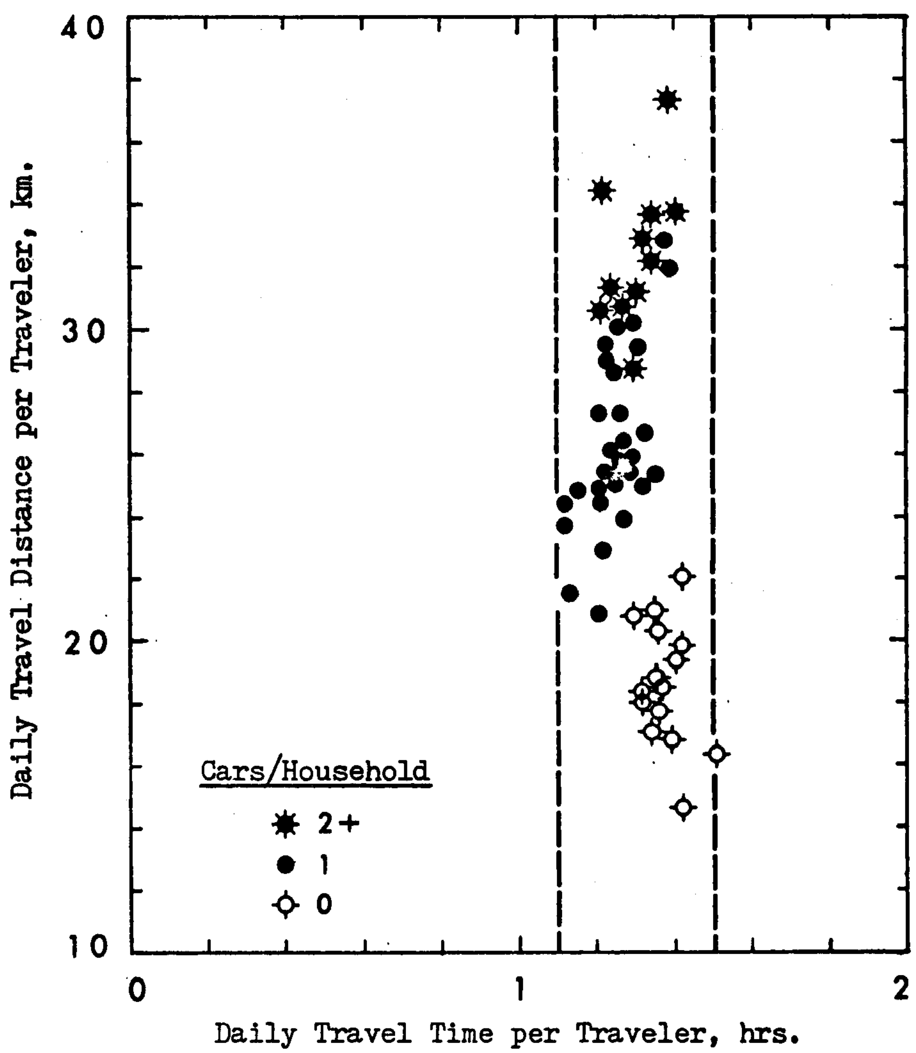


Figure 4.4-1 : Daily Travel Distance vs. Daily Travel Time per Traveler, by Household Car Availability, Nurenberg Region, 1975

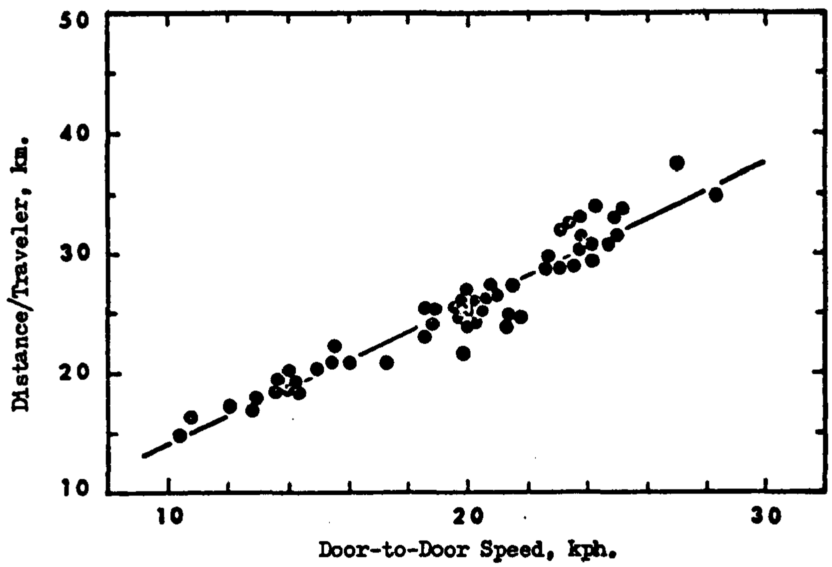


Figure 4.4-2 : Daily Travel Distance per Traveler vs. Speed Nurenberg Region

Table 4.4-1: Daily Travel Distance per Traveler, by Motorized Modes, vs. Door-to-Door Speed, Nurenberg Region 1975

Household Status	Car Availability					
	0 Cars		1 Car		2 + Cars	
	Distance	Speed	Distance	Speed	Distance	Speed
No Worker	15.47	10.67	26.87	21.11	33.93	23.82
Blue Collar Worker	17.98	13.22	24.83	20.98	28.01	23.22
White Collar Worker 1	19.49	14.02	27.14	21.25	32.74	24.62
White Collar Worker 2	20.79	15.39	28.12	22.68	33.93	25.68
Average	17.84	12.77	26.76	21.39	32.54	24.75

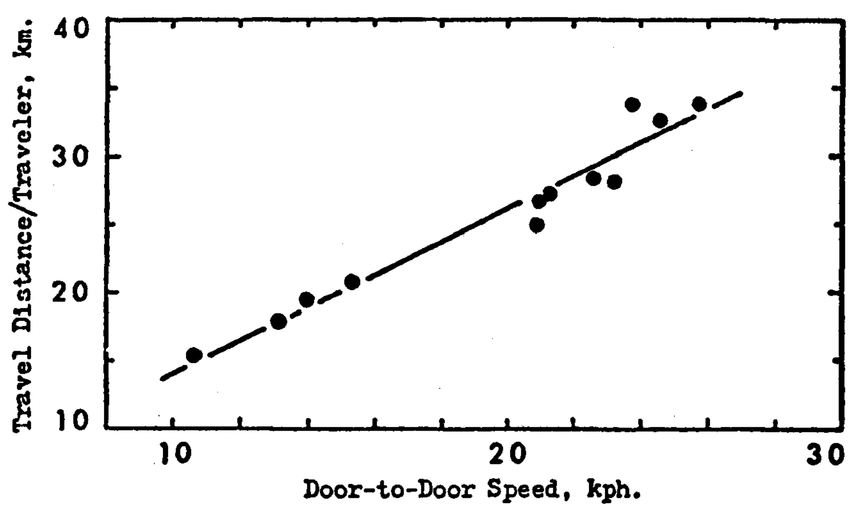


Figure 4.4-3 : Daily Motorized Travel Distance per Traveler, by Household's Car Availability and Worker's Status, the Nurenberg Region 1975

The objective is to examine the stability of regressions distance (y) vs. speed (x) by some market segments. For the present, three market segments have been assumed: 0 cars, 1 car, and 2+ cars. The mean distances traveled by these three household types differed substantially (23.4, 31.8, and 37.6) and justified the division.

Two mathematical forms were used in the regressions: a linear form $y = a + bx$, and a double logarithmic $\ln y = \ln a + b \ln x$ (or $y = ax^b$). The regressions were designed to show (1) whether the slopes (b), of the regression lines are different for each market segment, (2) whether the intercepts (a) are different for each market segment, and (3) whether the overall relationship is homogeneous over the three car ownership groups. The households having at least one employed household member were used in the analysis.

The simple regression of distance vs. speed is expressed, using matrix notation, and incorporating the constant term in (x) as follows:

$$y = Xb + u \qquad (4.4\text{-}1)$$

y is a (nx1) column vector of travel distance
X is a (nx2) matrix of observations (a column of ones and speeds)
b is a (2x1) vector of coefficients

It may be assumed that y is organized by the three subvectors pertaining to the three market segments.

According to Equation (4.4-1) all variation in distance is explained by travel speeds.

We also can postulate a more general model which provides for differential intercepts for all the three car ownership groups. This model is as follows:

$$y = Da + Xb + e$$

where D is a matrix of dummy variables so that the models for the three classes are:

$$y_1 = b_1 + b_2x + e_1 \qquad \text{0 cars}$$

$$y_2 = (b_1 + a_2) + b_2x + e_2 \qquad \text{1 car}$$

$$y_3 = (b_1 + a_3) + b_2x + e_3 \qquad \text{2+ cars}$$

In this model the intercepts vary by group but there is a common slope for each group.

Finally, regressions can be run separately for each class, or

$y = Zb + r$, where

$$Z = \begin{bmatrix} x_1 & 0 & 0 \\ 0 & x_2 & 0 \\ 0 & 0 & x_3 \end{bmatrix}$$

The complete analysis table can then be written as:

<u>Table 4.4-2</u>: Analysis of Covariance Table

Source	Sum of Squares	Degrees of Freedom[1]	Mean Square
Z	Residual $r'r=y'y - b'Z'y=S_4$	$n - pk$	$S_4/(n - pk)$
	Reduction in residual due to different slopes $=e'e - r'r=S_3$	$p \cdot k - p - k + 1$	$S_3/(p \cdot k - p - k + 1)$
X and D	Residual $e'e=y'y - a'b'y - b'X'y=S_2$	$n - p - k + 1$	$S_2/(n - p - k + 1)$
	Reduction in residual due to different intercepts $= u'u - e'e=S_1$	$p - 1$	$S_1/(p - 1)$
X	Residual $u'u=y'y - b'x'y$	$n - k$	

p is the number of groups

k is the number of parameters estimated

Then the test of differential slopes is:

$$F_s = \frac{S_3/(pk - p - k + 1)}{S_4/(n - pk)}$$

The test of differential intercepts is

$$F_i = \frac{S_1/(p - 1)}{S_2/(n - p - k + 1)}$$

And the test of overall homogeneity of the regression is

$$F_h = \frac{(S_1 + S_3)/(kp - k)}{S_4/(n - pk)}$$

Empirical results for the linear model follow.

Table 4.4-3: Analysis of Covariance: The Linear Model y = a + bx

Source	Sum of Squares	d.f.	Mean Square
Z	S_4 = 247.33	42	5.89
	S_3 = 27.00	2	13.50
X and D	$S_2 = S_3 + S_4$ = 274.33	44	6.23
	S_1 = 73.80	2	36.90
X	Residuals 348.13	46	7.57

The F - statistics are:

$F_s = \frac{13.50}{5.89} = 2.29 < F_{crit.}$ (3.22) accept at .05 level

$F_i = \frac{73.80}{6.23} = 5.91 > F_{crit.}$ (5.18) reject at .01 level

$F_h = \frac{25.2}{5.89} = 4.28 > F_{crit.}$ (3.83) reject at .01 level

Thus, the hypothesis of equal regression slopes for the three car ownership groups is accepted while the hypothesis of equal intercepts is rejected. This means that the hypothesis of overall homogeneity is also rejected.

The results for the power function are given in Table 4.4-4.

Table 4.4-4: Analysis of Covariance: The Power Function $y = ax^b$

Source	Sum of Squares	d.f.	Mean Square
Z	S_4 = .324	42	.0077
	S_3 = .038	2	.0190
X and D	S_2 = .362	44	.0082
	S_1 = .056	2	.0280
X	Total Residual .418	46	.0091

And the F - tests:

$$F_s = \frac{0.0190}{0.0077} = 2.46 < F_{crit.}$$ (3.22) accept at .05 level

$$F_i = \frac{0.0280}{0.0082} = 3.40 < F_{crit.}$$ (5.18) accept at .01 level (but not at .05 level)

$$F_h = \frac{0.0235}{0.0077} = 3.05 < F_{crit.}$$ (3.83) accept at .01 level

It can be seen that using the power function all three hypotheses can be accepted at .01 level of confidence (but not at .05 level of confidence).

The coefficients and R^2's are given below for information

Source	Group	Linear Function			Power Function			Standard Error
		a	b	R^2	a	b	R^2	
Z	0 - cars	- 2.799	1.644	.967	2.471	.810	.728	.098
	1 - car	- .138	1.327	.518	1.115	1.052	.527	.098
	2+ - cars	-29.587	2.516	.816	.083	1.862	.831	.045
X and D	0 - cars	- 1.286	1.549	.866	1.731	.939	.850	.075
	1 - car	- 5.472	1.549	.866	1.596	.939	.850	
	2+ - cars	- 3.768	1.549	.866	1.714	.939	.850	
X	all	1.808	1.293	.830	2.041	.872	.827	.095

It appears that for 0 and 2+ car households the regressions are quite powerful, while for 1-car households the relationship, even though satisfactory, is less powerful. However, the standard error of the estimate is not higher for the 1-car household group than for the other groups.

Finally, the choice between the linear and power functions has little practical significance. The equations for the different groups have different intercepts if the linear function is used. However, the near zero speed area is of minor importance and the simple linear model is attractive on grounds of simplicity of the underlying utility function.

In conclusion of the above tests, it appears that the null-hypothesis, of no significant differences between car and carless travelers, is accepted by one model and is rejected by another model. But this rejection concentrates on the intercepts of the relationships, at zero speed, which is beyond the range of observations. Hence, it may be concluded that the same distance vs. speed relationship holds for the three travelers' groups. Additional conclusions of these tests are discussed in Section 4.6.

4.5 Travel Distance per Traveler vs. Speed in Munich

Figure 4.5-1 shows the distance vs. speed relationship for the 55 household types in Munich, based on the 3-day data in Appendix 1. As can be seen, large variations are noted when the sample size is within the range of only 5-10 households.

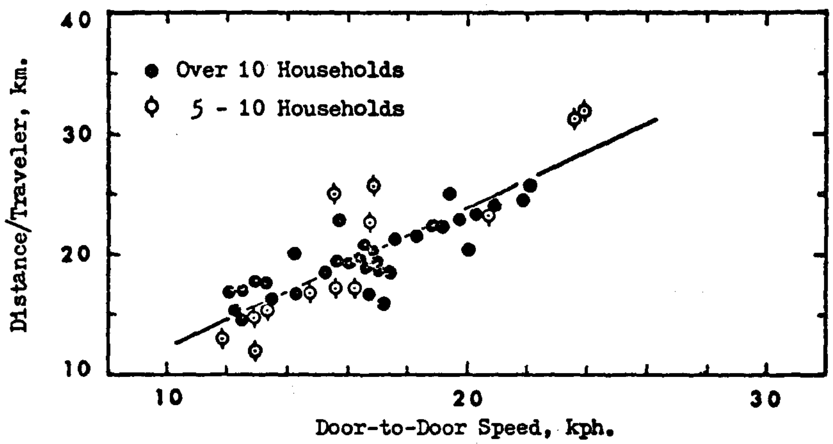


Figure 4.5-1 : Daily Travel Distance per Traveler vs. Speed Munich Metropolitan Area

Following an approach similar to that used in the Nurenberg case, several regressions analyses were performed for Munich data and the most salient results are reported herein. (Again, data point having two or less observations are deleted because of sampling variance considerations).

The regressions are of the following type:

$$\text{Dist/Traveler} = b_o + b_1 A + b_2 A \cdot \text{Speed} + b_3 (1-A)\text{Speed} \quad (4.5\text{-}1)$$

where: $A = 1$ if Cars/HH > 0

$A = 0$ otherwise

Model (4.5-1) permits for a straightforward testing of hypotheses of equal slopes ($b_2 = b_3$) and equal intercepts $b_1 = 0$ for car and carless households. The results are summarized in Table 4.5-1.

Table 4.5-1: Statistics of Three Regressions, Distance vs. Speed, Munich

	Model 1 $b_1=0,\ b_2=b_3$	Model 2 $b_1=0$	Model 3 —
b_0	0.455 (1.64)	-2.604 (2.07)	-7.184 (3.82)
b_1	—	—	6.445 (4.53)
b_2	1.133 (.088)	1.263 (.10)	1.173 (.12)
b_3	1.133 (.088)	1.421 (.15)	1.738 (.27)
R^2	.64	.66	.67
Std. Error	3.79	3.70	3.68
CV	.18	.18	.17
Percent Outliers	5.2	7.3	5.0
ESS	1348.09	1273.54	1246.24
ESS/(n-1-p)	14.34	13.69	13.55

(The standard error of the coefficient is given in the parentheses. ESS stands for error sum of squares not divided by degrees of freedom and ESS/(n-1-p) is the error sum of squares divided by degrees of freedom)

The first model estimates equal slopes and intercepts for both household types. This model may be compared to the second model where only the regression intercepts are equal but the slopes are different; the F-test yields a value of 5.45, with 1 and 93 degrees of freedom, which exceeds the critical value of 3.90 at the 0.95 confidence level. Thus, the coefficients for speed are statistically different for the car and carless households. Testing then for the equality of the intercepts on F-value of 2.01, which is statistically significant at 0.95 level of significance. If model 1 was tested against Model 3 directly we would accept inequality of both slopes and intercepts, the F-test yielding $F_{2,92} = 3.76$, which exceeds the critical value of 3.10 at the 0.95 level of significance.

In conclusion, the coefficients for speed are similar to those obtained using the Nurenberg data. The values for carless households are 1.74 and 1.41, and for car owning households 1.17 and 1.09. Also the statistical indicators R^2 and the coefficient of variation are almost identical.

Finally, it is of interest to record the regressions when the data points containing only 1 and 2 observations are included. The results are shown in Table 4.5-2.

Table 4.5-2: Statistics of Three Regressions, including "Outliers", Munich

	Model 1 $b_1 = 0,\ b_2 = b_3$	Model 2 $b_1 = 0$	Model 3
b_0	0.685 (1.72)	-.896 (1.94)	-6.359 (3.68)
b_1	—	—	7.511 (4.31)
b_2	1.123 (.093)	1.184	1.083 (.11)
b_3	1.123 (.093)	1.304 (.14)	1.667 (.25)
R^2	.56	.57	.58
Std. Error	4.85	4.81	4.76
CV	.23	.23	.23
Percent Outliers	4.2	4.2	4.2
ESS	2724.91	2656.99	2588.28
ESS/n-1-p	23.49	23.10	22.70

The F-test for the equality of models in this case are just on the border of being accepted and rejected at 0.95 level of confidence; all the F-values are approximately 3.00 with the critical value being 3.07.

Models were also run allowing different slopes and intercepts by household size for carless households since the analysis of variance reported earlier indicated a household size effects for travel time budgets in carless households. The F-tests for both differential intercepts or slopes by household size were soundly rejected with the F-values being well below the critical values for both tests. Thus, household size has no significant effect on distance vs. speed relationships.

In Conclusion, it may be repeated that the best relationships for distance per traveler vs. door-to-door speed are the following (standard error of coefficients in the parentheses):

$$\text{Dist/Traveler} = -\underset{(3.82)}{7.184} + \underset{(0.27)}{1.738}\ \text{Speed}\ , \text{ for carless households}$$

$$\text{Dist/Traveler} = -0.739 + \underset{(0.12)}{1.173}\ \text{Speed}\ , \text{ for car owning households}$$

4.6 Comparisons of the Distance vs. Speed Relationships

The two final models of the distance vs. speed relationships in Nurenberg and Munich can be expressed by a single equation for travelers of both car and carless households:

Nurenberg (all data)

$$D/TR = 0.268 + 4.305\ A + 1.094\ A\ (Speed) + 1.410\ (1-A)\ Speed$$

Munich (all data)

$$D/TR = -6.359 + 7.511\ A + 1.083\ A\ (Speed) + 1.667\ (1-A)\ Speed$$

where $A = 1$ if Cars/HH > 0, and $A = 0$ otherwise.

When comparing and assesing the many sets of distance vs. speed relationships in Nurenberg and Munich, the intercepts, at zero speed, are found to fluctuate widely, depending on whether all or part of the observations are used. Furthermore, in many cases the intercepts have a negative sign, which is contrary to expectation, possibly since the observed speeds are far above zero and, therefore, small deviations in the observations at high speeds tend to shift the intercept significantly.

It can be concluded that the results of the statistical analyses, with respect to either accepting or rejecting the null-hypothesis that the distance vs. speed relationships of car and carless households are equal, is far from being conclusive. Furthermore, the actual differences in travel distance resulting from applying either the two separate relationships (for car and carless households) or the combined relationship, are very small within the range of observations. For example, Figure 4.6-1 shows the same distance vs. speed relationship per traveler of the 55 household types in Nurenberg, as already shown in Figure 4.4-1, but this time stratified by car and carless travelers, as well as their combined relationship. The differences in travel distance between the separate and the combined relationships within each group of travelers are quite small, amounting to less than 1 km. per day.

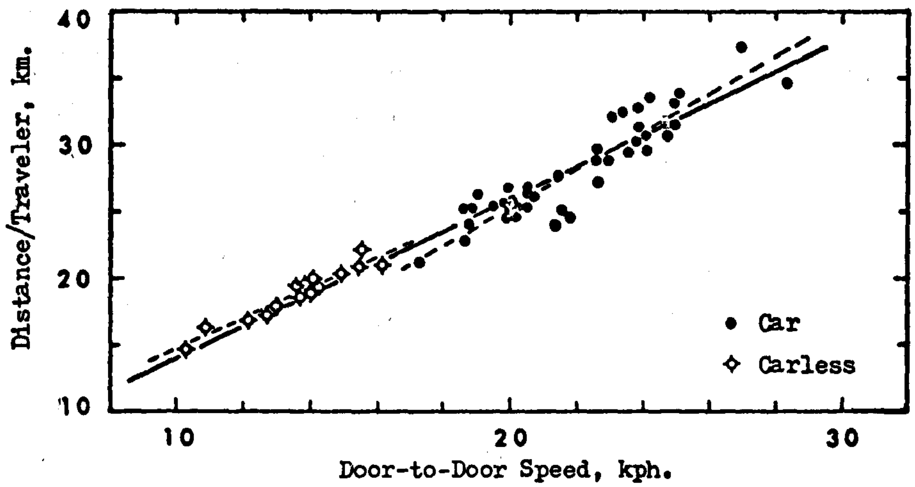


Figure 4.6-1 : Daily Travel Distance per Traveler vs. Speed Households owning and not owning Cars, Nurenberg Region

Thus, while more tests with better data are still required in order to resolve conclusively the issue of equality, there are several reasons to suggest that, from a practical point of view, the combined relationship should be used in the initial phase of travel analysis, namely:

(1) Although the travelers are stratified by their households' car availability, the daily travel distance and the daily average door-to-door speed per traveler are weighted averages of travel by both car and transit. As car households generate also transit travel, and carless households generate also car travel, there is no apparent reason for dividing the distance/speed relationship into two parts;

(2) When further stratifying the available data, it is found that the observations of travelers by high-speed transit-travel intermingle with the observations of travelers by low-speed car-travel, thus suggesting that although the two separate relationships may be significantly different, they overlap at the area of similar speeds; i.e., travel behavior of the two types of travelers is similar under similar travel speeds, indicating one and continuous relationship in this area.

(3) When applying the distance/speed relationship for travel analysis and prediction purposes in the UMOT process, it is not yet known how the travelers will be differentiated by car and carless households, as this division is an output from an iterative process. Hence, the one and continuous relationship should be applied in the initial phase , while the two separate relationships - if found to be significantly different - may enter the process after the first iteration.

Table 4.6-1 summarizes these relationships for the cities of Munich, Washington + Twin Cities, Singapore and the Nurenberg region, and Figure 4.6-2 shows them graphically. It appears that the relationships for the cities overlap within the range of observations, while the relationship for the Nurenberg region is somewhat higher. A possible reason for this is discussed in Section 4.7, where distinctions between regional and urban travel are noted.

Table 4.6-1 : The TT-budget vs. Speed Relationship

City	No. of Observ.	a	b = minimum time	R^2	Max. Time at Walking Speed	Distance at Walking Speed
D.C. + T.C.	171	2.18	1.03	0.87	1.50	7.0
Singapore	28	2.01	1.11	0.86	1.54	7.2
Nurenberg	55	2.10	1.18	0.93	1.63	7.7
Munich	46	0.77	1.16	0.71	1.32	6.2

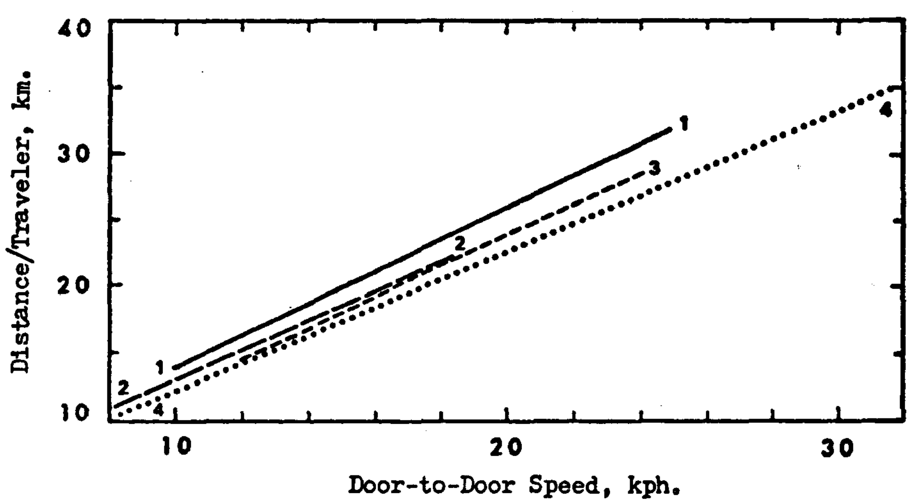


Figure 4.6-2 : Daily Travel Distance per Traveler vs. Speed in Selected Cities: 1. Nurenberg; 2. Singapore; 3. Munich; 4. Washington, D.C. + Twin Cities

The importance of Figure 4.6-2 is that it suggests the possibility that the distance vs. speed relationship is transferable between cities and, therefore, it strenghtens its transferability capabilities over time for one city. Travel distance per traveler is an output of conventional models, resulting generally from the phases of trip generation, trip distribution, modal split, and trip assignment. Figure 4.6-2, on the other hand, suggests that the travel distance per traveler is strongly related to the supply variables of modal speed. Development of travel demand models with travel distance as an input might potentially lead to improved insight in demand-supply relationships.

The way in which the distance vs. speed relationship is applied in the UMOT process is detailed in Chapter 5.

4.7 The TT-budget vs. Speed Relationship

In the linear relationship

$$D/TR = a + b \text{ Speed}$$

the 'a' intercept on the Y-axis at zero speed is meaningless, as the practical minimum speed is the walking speed, of about 4.7 kph. Furthermore, the 'b' coefficient is the minimum travel time that the travelers would be willing to allocate to travel at very high travel speeds; i.e., by dividing both sides of the above relationship by speed, the result is

$$\frac{D/TR}{\text{Speed}} = TT/TR = b + \frac{a}{\text{Speed}}$$

Thus, at high speeds the TT-budget per traveler approaches asymptotically the value of 'b'.

Table 4.6-1 in the previous section summarized the 'a' and 'b' values of the distance vs. speed relationships for the four cases mentioned there, as well as the travel distance at walking speed and the minimum and maximum TT-budgets.

The results in Table 4.6-1 indicate:

(1) The minimum daily door-to-door travel time allocated by average travelers within urban areas appears to be about 1.1 hours, both between cities and over time; in the Nurenberg region the minimum travel time, including intra-regional travel between different settlements, is slightly higher. The minimum TT-budget of 1.1 hours is observed at high income levels even in cities where the average TT-budget is high; see Tables 3.9-1 and 3.10-1.

(2) When extrapolating the speed down to the speed of walking, it results in a maximum walking distance of 7-8 kilometers. This corresponds to historical observations of agricultural villages in Germany, as noted by Walter Christaller and explained by a maximum walking time of about 1.5 hours. Thus, it appears that travel behavior, in its most basic aspect, is similar in many places and over time, whether in historical villages or in modern cities.

(3) The relationships in Table 4.6-1 suggest that travelers derive two distinctly different benefits from speed increases; while increases in speed result in time savings, it appears that part of the saved time is traded off for more travel distance.

These results aid in explaining the phenomenon noted in the case of Washington, D.C. (Section 3.6(1)), namely that transit travelers have to spend more time in order to travel less distance than car travelers. These trends can be seen in Figure 4.7-1, where the derived relationships of the TT-budgets vs. speed in Table 4.6-1 are shown together.

This figure displays three trends:

(a) The TT-budgets increase as speeds decrease and, together with Figure 4.6-2, result in more travel time for less travel distance.

(b) The range of the TT-budgets vs. speed in Washington, D.C. + Twin Cities, Singapore and Munich is relatively narrow at the observed speeds, emphasizing similarity of travel behavior in different cities.

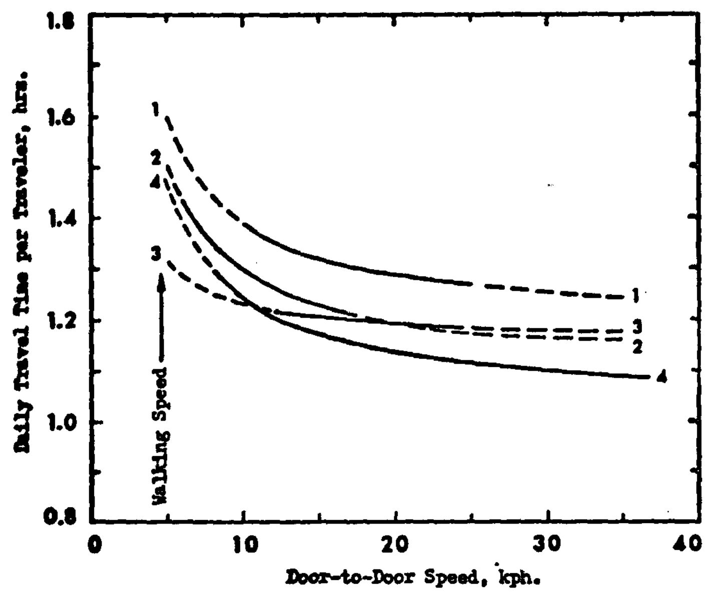


Figure 4.7-1 : Daily Travel Time per Traveler vs. Speed in Selected Cities: 1. Nurenberg; 2. Singapore; 3. Munich; 4. Washington, D.C. + Twin Cities

(c) The relative stability of the TT-budget of car travelers in different cities is explained by the flat part of the curves at relatively high speeds. Moreover, the door-to-door speed of about 10 kph. can be regarded as a critical speed, below which the TT-budget increases rapidly.

It may be further inferred from Figure 4.7-1 that speed is a key factor in travel behavior and, hence, in travel demand models. However, speeds must be purchased through the use of more expensive modes. Thus, high income travelers are more likely to travel at high speeds than low income travelers. For example, and based on the TM-budgets in Appendix 4 and the speeds in Appendix 2 , the relationship between the door-to-door speed and cost of purchasing it in the Nurenberg region 1975 can be expressed by (see also Figure 4.1-1)

$$\text{Speed}_{d-d}, \text{ kph.} = 8.432 + 4.693 \ln(\text{TM-budget, DM}), \quad (R^2 = 0.822)$$

Thus, the differential cost of increasing the door-to-door speed by increments of 5 kph., from 10 through 15 and 20 to 25 kph., are 2.66, 7.71 and 22.37 DM, respectively. Put another way, the cost of doubling the speed, from 10 to 20 kph., increases by a factor of more than 8 times. Such relationships, which may differ between cities, also allow to derive the values of the two components of the saved time, part of which is traded-off for more travel distance, and part which is actually saved.

4.8 Variations in Daily Travel Distance Between Days

The Munich data detailed in Appendix 1 allowed to test also the variations in the daily travel distance per traveler between days, similar to the analysis of the TT-budget described in Section 3.13. An analogous procedure was carried out, and the results are shown in Tables 4.8-1 to 4.8-3.

Table 4.8-1: Daily Travel Distance per Traveler by Day and Factor

Factor A Car Ownership	Factor B HH-size	Day 1	Day 2	Day 3	Total
0	1	15.61	15.75	15.12	46.48
0	2	21.95	13.64	20.45	56.04
0	3	16.53	12.85	12.78	42.16
0	4 +	18.87	27.00	22.16	68.03
1 +	1	22.65	22.18	20.64	65.47
1 +	2	23.25	22.66	24.72	70.63
1 +	3	24.34	23.49	22.60	70.43
1 +	4 +	22.60	21.86	27.71	72.17
Total		165.80	159.43	166.18	491.41

$$C = (491.41)^2 / 24 = 10061.825$$

$$SST = 10491.778 - C = 429.954$$

$$SSF = 10383.410 - C = 321.586$$

$$SSR = 10065.420 - C = 3.595$$

The sums of squares by factors are:

A \ B	1	2	3	4 +	
0	46.48	56.04	42.16	68.03	212.71
1 +	65.47	70.63	70.43	72.17	278.70
	111.95	126.67	112.59	140.20	491.41

$$SSA = 181.445$$

$$SSB = 89.949$$

$$SSAB = 50.192$$

The analysis of Variance is then given by:

Table 4.8-2: Analysis of Variance Table for Daily Travel Distance

	Degrees of Freedom	Sum of Squares	Mean Squares	F-value	F Crit .05
Days	2	3.595	1.798	.24	3.74
HH-size	3	89.949	29.983	4.00	3.34
Car Ownership	1	181.445	181.445	24.25	4.60
Interaction	3	50.192	16.731	2.24	3.34
Error	14	104.773	7.484	—	
Total	23				

It is seen that both car ownership and household size exert statistically significant effects on the daily travel distance, where the major impact is car ownership. The household size effect, on the other hand, is minor and may be due to the carless three person households, as already mentioned in Section 3.13.

Separation of the effects of multiple car ownership on daily travel distance yields the following analysis of variance table for car owning households.

Table 4.8-3: Analysis of Variance Table for Daily Travel Distance per Traveler of Car Owning Households

	Degrees of Freedom	Sum of Squares	Mean Squares	F-value	F Crit .05
Days	2	9.952	4.976	.68	4.10
Car Ownership	1	42.014	42.014	5.78	4.96
HH-size	2	6.745	3.373	.46	4.10
Interaction	2	12.617	6.309	.87	4.10
Error	10	72.754	7.275	—	
Total	17				

It is seen that the level of car ownership does have a statistically significant effect on travel distance per traveler for car owning households. A quick look at the data shows that this effect is small, a little over 2 kilometers per traveler per day (In Nurenberg data this effect was 1.7 km.). It is concluded that only car ownership has a practically significant effect on the daily travel distance. This, of course, is only a partial answer, as car ownership allows the travelers to travel at higher speeds than carless travelers. But the most important result is that there is no significant difference in the average daily travel distance per traveler between the three travel days.

4.9 Daily Travel Distance vs. Household Income

The daily travel distance per household tends to increase rapidly with increase in household income. This is so not only because a higher income allows the household's travelers to purchase higher travel speeds, but also because the number of travelers per household tends to increase with income. Figure 4.9-1 shows the relationship between the daily travel distance per household and income in Washington, D.C. and Twin Cities, where a doubling in annual income, say from \$ 6,000 to \$ 12,000, quadruples the daily distance, from about 20 to 80 passenger-kilometers per day.

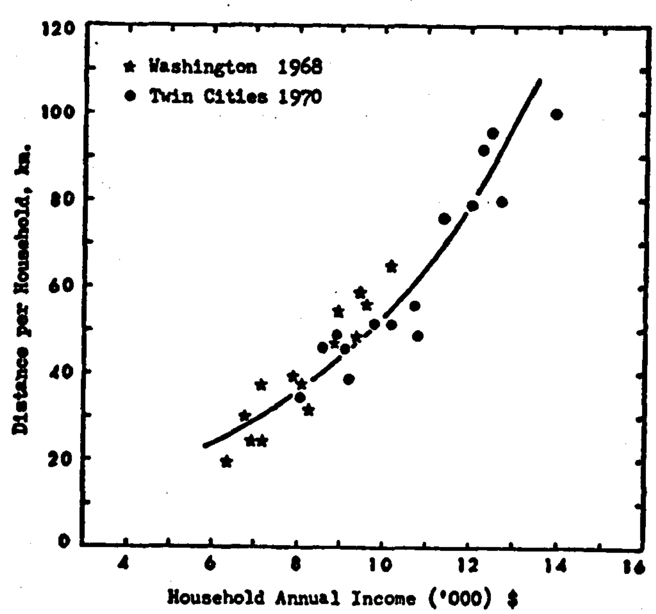


Figure 4.9-1: Daily Travel Distance per Household vs. Income, All Households, by District, Washington 1968 and Twin Cities 1970

Table 4.9-1 summarizes the observed daily travel distance per household, by household size and car ownership, in the Nurenber region 1975. The table also includes the household estimated incomes for 0 and 1-car households, as estimated in Section 3.19, and Figure 4.9-2 shows the relationship between distance and income, where the same trend as in Figure 4.9-1 can be seen.

Table 4.9-1: Daily Travel Distance per Household, by Household Size and Car Ownership, vs. Income, Nurenberg 1975

HH Size	Cars/HH	Distance, km.	HH Monthly Income, DM.
1	0	15.76	1,087
	1	29.41	1,882
2	0	26.42	1,946
	1	45.55	2,912
	2+	68.73	-
3	0	33.09	2,749
	1	51.43	3,339
	2+	73.77	-
4+	0	50.31	3,150
	1	68.00	3,663
	2+	98.42	-

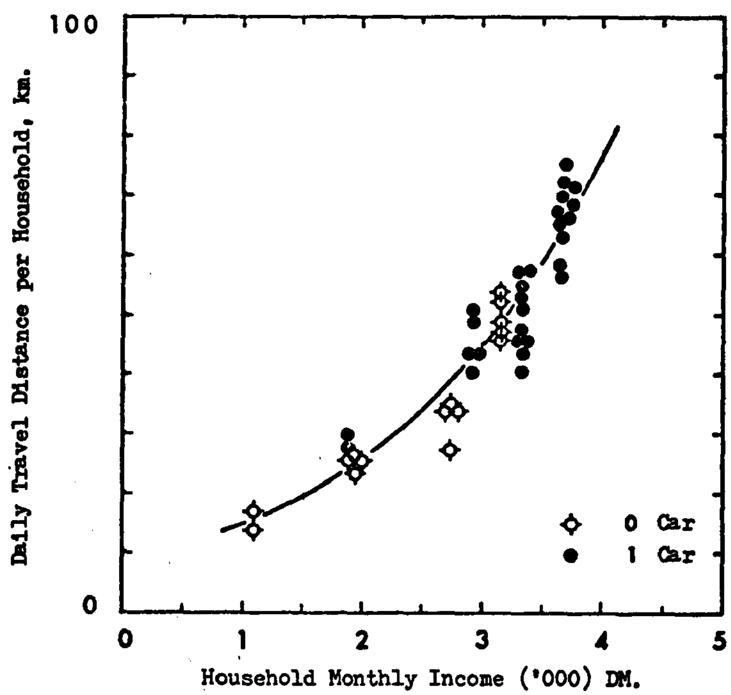


Figure 4.9-2 : Daily Travel Distance per Household vs. Household Monthly Income and Car Ownership, the Nurenberg Region 1975

No further analyses based on income were carried out in the case of Nurenberg since income levels had to be derived indirectly and, therefore, income cannot be regarded as an independent variable.

4.10 Modal Choice

Modal split is usually defined as the proportion of public transport trips to total motorized trips. In the UMOT process, however, modal split refers to travel distance, and is defined as the proportion of public transport passenger-kilometers to total motorized passenger-kilometers. Furthermore, both the total passenger-kms. and the modal split are generated simultaneously by the UMOT process when the TT-budget, TM-budget and the unit costs by mode are known (as described in Section 1.2).

Modal split can be expressed by either an absolute value, as done in deterministic models, or by a probability distribution, as done in disaggregate models. The latter approach reflects two important aspects of human travel behavior; the variety of tastes and preferences by individual travelers and households, that might not be captured by a limited number of independent variables, and the daily variations in travel by individual travelers, which can be wider than the variations between different travelers during one day. These two aspects are reflected in the UMOT process by the distributions around the mean values of the TT and TM budgets, as already discussed in Section 3.7. Furthermore, the explicit application of the TT and TM budgets in the UMOT process results in the indication that the range of modal choices is quite narrow. Put another way, in the conventional approach mode-choice is unknown until observed, and a mode-choice model has to be calibrated to the observed choices if possible changes in in mode choice, brought by changing travel conditions, are to be predicted. In the UMOT process, on the other hand, mode choice is an integral part of the travel system, requiring no separate calibration. Perhaps the best way of describing the process is by presenting two simple examples.

The first example refers to travel in Washington, D.C. 1968, and Table 4.10-1 summarizes the TT and TM budgets per household by income, as well as the unit costs of travel by car and bus, in terms of money and time. Applying the process described in Section 1.2 to the above values results in the estimated daily travel distance per household, by mode, as detailed in Table 4.10-1.

Table 4.10-1: Summary of Estimated Travel Demand per Household, by Income, Washington, D.C. 1968 (Times and speeds are door-to-door)

Annual Income, $	4,000	5,000	6,000	7,000	8,000	9,000	10,000	11,000
Cars/HH	-	(0.1)	0.35	0.71	1.02	1.29	1.54	1.76
TM-budget, $	0.51	0.75	1.24	2.01	2.82	3.17	3.53	3.88
TT-budget, hr.	2.02	2.02	2.09	2.20	2.29	2.41	2.53	2.63
CAR: v, kph.	13.5	15.0	16.0	19.0	21.0	24.0	26.0	28.0
c, $/km.	0.104	0.096	0.092	0.081	0.075	0.068	0.064	0.060
D, km.	0.02	2.39	8.40	19.74	34.14	42.38	50.81	60.59
TRANSIT: v, kph.	6.8	7.5	8.0	9.5	10.5	12.0	13.0	14.0
c, $/km.	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
D, km.	13.63	13.96	12.52	11.02	6.97	7.73	7.45	6.56
Total Distance	13.65	16.35	20.92	30.76	41.11	50.11	58.26	67.15

Figure 4.10-1 shows the estimated travel distance per household, by mode, as continuous curves, and the observed values as dots. The fit between the estimated and the observed values can be considered as satisfactory, especially when realizing that the estimated values were not calibrated to the observed values.

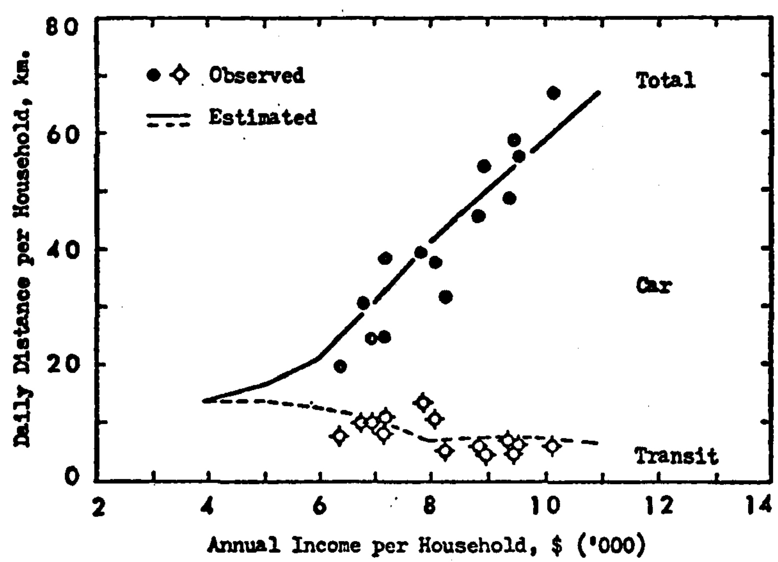


Figure 4.10-1 : Estimated vs. Observed Daily Travel Distance per Household, by Mode, vs. Income by District, Washington, D.C. 1968

The data in Table 4.10-1 can also be expressed in a different way, as shown in Figure 4.10-2. The diagram details the daily travel distance per household that can be generated by each mode within each travel budget separately (i.e., by dividing each budget by the unit costs of each mode). If one mode would be both faster and cheaper than the other mode, practically all travelers would be expected to choose the former mode. However, as the faster mode usually is also the more expensive mode, the travel distance that can be realized within the two constraining budgets simultaneously is expected to be within the area enclosed by the constraining relationships. This area is shaded in Figure 4.10-1, within which lies the maximum travel distance that can be generated by using combinations of the available modes, as detailed in Table 4.10-1.

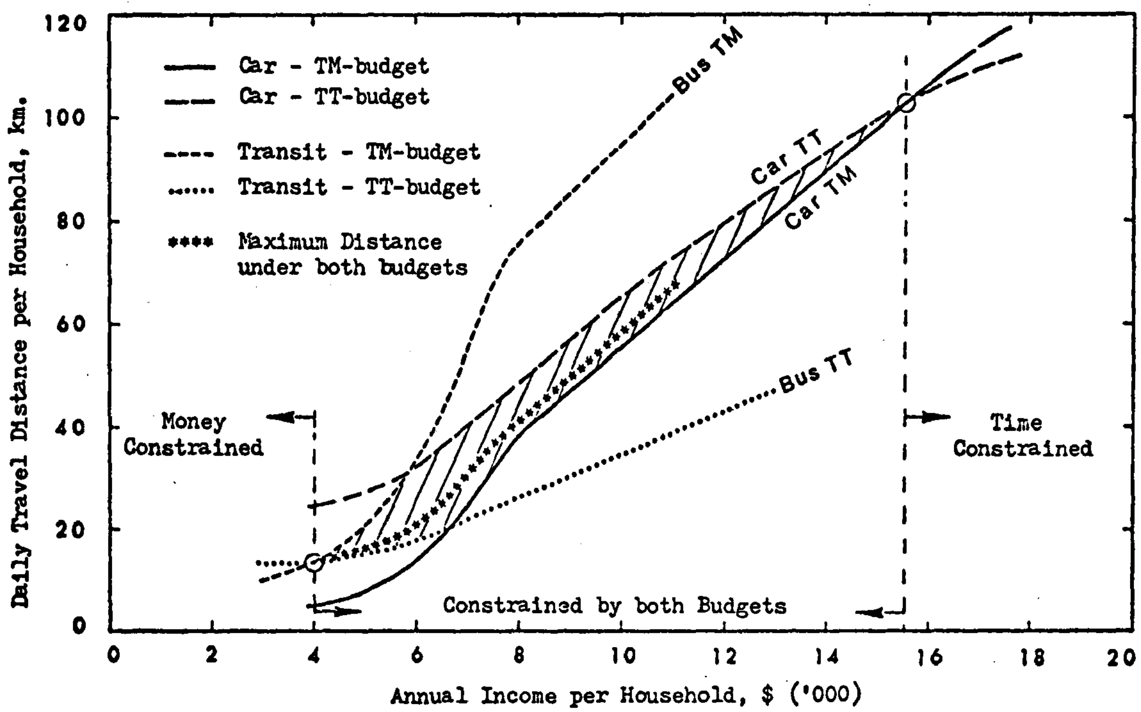


Figure 4.10-2 : Maximum Daily Travel Distance per Average Household under the Travel Time and Money Budgets vs. Household Annual Income, Washington, D.C. Travel Conditions in 1968

It may, therefore, be concluded that if travelers are considered to behave in a rational way, by trying to realize the maximum spatial and economic opportunities, as represented by their maximum daily travel distance, within their travel constraints, their mode-choice combinations lie within a narrow <u>choice-set</u>. Indeed, the observed mode choices are found to be contained within this narrow strip.

It is obvious that the observed choices on an individual basis may vary both among travelers and between days for the same traveler, but such variations are already expressed by the variations in the TT and TM budgets, which are found to be relatively stable for all population segments, as noted in Chapter 3.

The relationships in Figure 4.10-2 also suggest what possible shifts in modal choices are to be expected if travel conditions change. For example, increasing the unit cost of car travel will lower the Car-TM curve, thus resulting in (i) a wider choice-set, (ii) an increase in bus travel, and (iii) a decrease in total daily travel distance.

The last result is of considerable importance, as it suggests that modal transfers are not one-to-one transfers (as usually is the case when mode choice is based on trips) since travel may be gained or lost, depending on the direction of transfer. Furthermore, as the total daily travel distance may change, modal splits should not be expressed as proportions, but preferably by absolute values. For instance, if a transfer from car to bus results in loss of travel distance, the shift in modal split expressed in percent can lead to erroneous predictions; e.g., a 10 percent increase in bus modal split does not necessarily mean a 10 percent increase in ridership, as it can result in either a marginal increase in the actual bus passenger-kilometers, or even a loss, when measured in absolute terms.

Figure 10.4-2 illustrates an additional important aspect of travel. The figure suggests that representative households with an average annual income within the range of \$ 4,000-11,000 can utilize the two travel budgets to their full extent under the given two travel modes, thus maximizing their travel distance within the two constraints by using various combinations of the two modes. There are cases, however, where one constraint can become binding, overruling all other constraints. Such cases are of special importance as they indicate the need for either new modes or changes in the available modes. For instance, it can be inferred from this diagram that households below an annual income of about \$ 4,000 become constrained by the TM-budget alone, while households above an annual income of about \$ 15,500 become constrained by the TT-budget alone. Thus, travelers of a household at a very low income level may expend their TM-budget much before they spend their TT-budget; they cannot afford even a bus fare on a regular, daily, basis and therefore they are forced to walk instead (or spend an unusually high proportion of their income on travel, as discussed in Section 4.11). Conversely, travelers of a household at a very high income level may expend their TT-budgets much before they reach their TM-budget; they would then seek additional, fast, modes of travel. Put another way, households within the income range where the TT and TM budgets can be fully utilized, may be regarded as being under equilibrium travel conditions. Households below and above this income range, on the other hand, are restricted by only one binding constraint and, therefore, may be regarded as under disequilibrium travel conditions. Hence, the critical thresholds where one constraint becomes binding under given - or planned - travel modes and costs, serve as a warning sign to the transportation planner and policy maker that the transportation system may not adequately serve some population segments.

The second example of modal splits is based on the Nurenberg data. As no direct data on income levels were available, the example is based on the stratification of households by size and car availability, as summarized in Table 4.10-2 and shown in Figure 4.10-3.

Table 4.10-2: Daily Travel Distance per Household, by Mode, Size and Car Ownership, the Nurenberg Region 1975

HH Size	Cars/HH	Daily Distance, km.			Transit Modal Split, %
		Car	Transit	Total	
1	0	3.45	12.31	15.76	78.1
	1	27.97	1.44	29.41	4.9
2	0	6.87	19.55	26.42	74.0
	1	39.79	5.76	45.55	12.7
	2+	67.83	0.90	68.73	1.3
3	0	8.28	24.81	33.09	75.0
	1	37.78	13.65	51.43	26.5
	2+	67.07	6.70	73.77	9.1
4	0	14.03	36.28	50.31	72.1
	1	42.61	25.39	68.00	37.3
	2+	80.21	18.21	98.42	18.5
Average		32.81	12.84	45.64	28.1

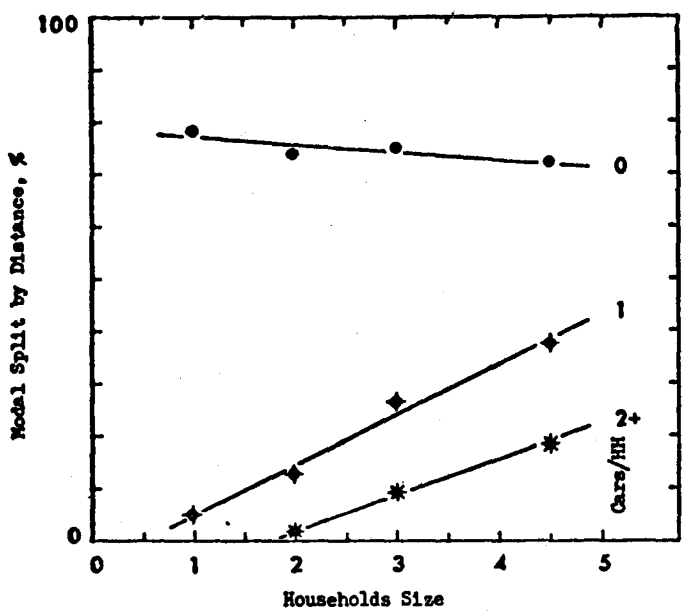


Figure 4.10-3: Modal Split by Distance, by Household Size and Car Ownership, the Nurenberg Region 1975 (Travel distance by transit vs. total travel distance)

An interesting result is that transit modal split by distance is still relatively high for households with three and more members, even when one car is available; evidently, one car cannot satisfy all travel demand and, hence, a substantial part of travel is still generated by transit.

Applying the same procedure as shown in Figure 4.10-2 to the Nurenberg data results in Table 4.10-3 and Figure 4.10-4. The daily travel distance that can be generated by each mode within each travel budget is stratified in this case by the average car ownership level per household, by household size (as no independent data on income levels were available).

Table 4.10-3: Maximum Daily Travel Distance per Household that can be Generated by Mode within each Travel Budget, Nurenberg

HH Size	Cars/HH	TM,DM	TT,hr.	Unit Cost DM		Unit Time,min.		Distance,TM		Distance,TT		Observed Distance
				Car	P.T.	Car	P.T.	Car	P.T.	Car	P.T.	
1	0.37	6.32	1.30	.435	.104	2.44	5.99	14.53	60.77	31.97	13.02	20.85
2	0.82	12.36	2.01	.335	.110	2.33	4.99	36.90	112.36	51.76	24.17	42.12
3	1.05	15.35	2.59	.352	.118	2.36	4.65	43.61	130.08	65.85	33.42	52.41
4+	1.21	17.38	3.64	.321	.122	2.25	4.48	54.14	142.46	97.07	48.75	74.40

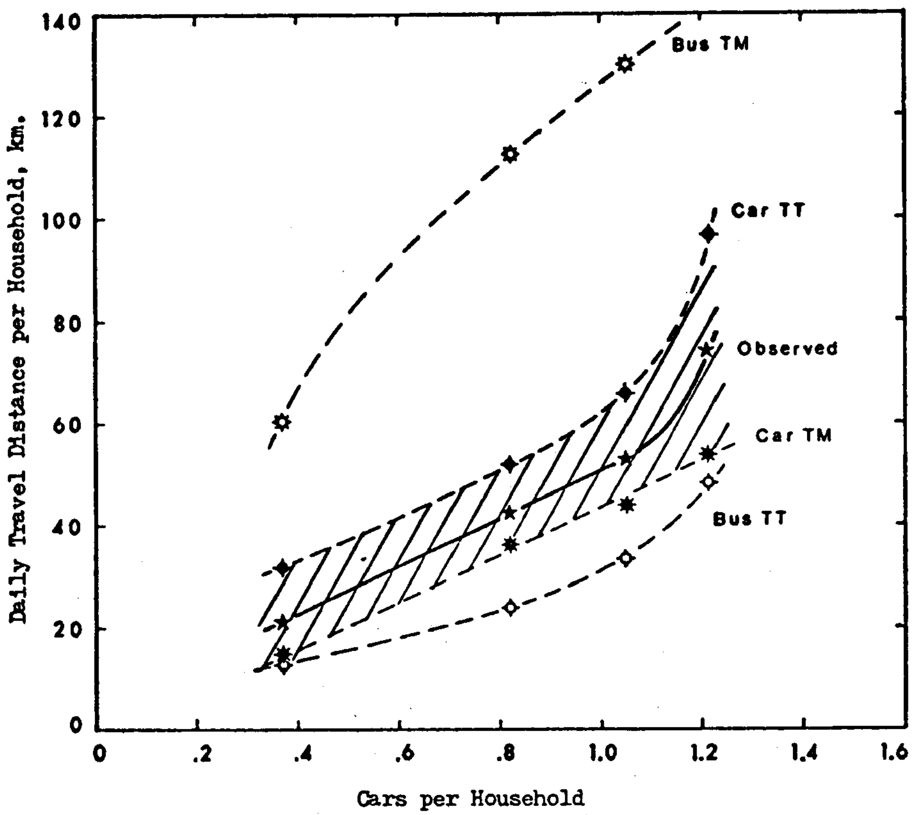


Figure 4.10-4: Maximum Daily Travel Distance per Average Household under the Travel Time and Money Budgets vs. Car Ownership, The Nurenberg Region 1975

It becomes evident once again that the mode-choice set is relatively narrow, as shown by the shaded area in Figure 4.10-4, and that the observed choices tend to be located at the center of this choice set.

It may be concluded from the above two examples that if the TT and TM budgets per representative households of various population segments are known, then the total daily travel distance per household, as well as modal choices, can be estimated for alternative system supply and travel costs. Furthermore, the probability distributions about the daily travel distances and mode choices can be derived from the observed variations in the daily TT and TM budgets alone. The final estimates generated by the UMOT process can then be compared with the observations for validating the ability of the process to generate real-life conditions.

4.11 Minimum Daily Travel Distance

There are cases where one travel constraint can become binding, overruling all other travel constraints. Such cases usually occur when conditions in a city change faster than the rate at which its population can adjust their locations and activities to the new conditions. For example, cities in developed countries usually change at moderate rates and hence their populations can adjust their urban strcture (e.g., residence-job locations) to changing conditions within reasonably short times. Some cities in developing countries, on the other hand, double their population every decade, the changes in their size and structure being largely due to migration from outside. Furthermore, the new-comers are mostly poor, their trip distances increase (such as from their residences at the fringe of the urban area to jobs in the city center), while travel speeds decrease. For example, it is reported that workers who travel from the Northern suburbs of Rio de Janeiro spend four hours for traveling to and from work, and expend 25 percent of their income on public transport fares (Webber, 1977). Thus, if conditions change at a faster rate than the "relaxation" time of urban structure, an ever-increasing trip distance (and trip time) to work can become the binding constraint, overruling the stable TT and TM budgets observed in stable cities in developed countries.

Cases where a minimum daily travel distance becomes an exogenously imposed constraint are of special importance, as they suggest a dis-equilibrium condition, as discussed in more detail in Section
At this stage, however, the attention is focussed on another type of minimum daily travel distance, namely the threshold of the daily travel distance that would justify the purchase of a car.

Table 4.11-1 details the relevant data on car travel in a wide selection of cities in the U.S., Europe and developing countries. The remarkable result is that the car daily travel distance is similar in all cities. This can be seen in Figure 4.11-1, where the cities of developing countries, Europe and the U.S. intermingle; all cities, small and large, poor and rich, compact and dispersed, display similar daily travel distance per average car.(Zahavi, 1978).

Table 4.11-1: Car Travel Characteristics in Selected Cities in the US, Europe and Developing Countries

UNITED STATES ★

CITY	MONROE	ORLANDO	CINCINNATI	TWIN CITIES	D.C.	PHILADELPHIA
	1	2	3	4	5	6
Year	1965	1965	1965	1970	1968	1960
Population	96,530	355,620	1,391,870	1,874,380	2,558,100	3,812,460
Area, sq.km.	200	1,400	3,495	7,680	3,410	3,040
Cars	31,650	137,260	484,770	717,000	1,018,900	1,087,900
Cars/100 Persons	32.8	38.6	34.8	38.3	39.8	28.5
Car Trips	183,196	594,230	1,759,080	2,953,870	3,342,000	4,308,750
Car Trip Rate	5.79	4.33	3.63	4.12	3.28	3.96
Trip Distance, km.	4.51	6.92	8.85	8.19	10.59	7.88
Trip Time, min.	7.3	9.7	13.7	12.5	15.6	n.a.
Speed, kph.	37.1	42.8	38.8	39.3	40.7	n.a.
Car Daily Distance, km.	26.1	30.0	32.1	33.7	34.7	31.2
Car Daily Time, hrs.	0.71	0.70	0.83	0.86	0.85	n.a.

EUROPE ●

CITY	KINGSTON-UPON-HULL	BELFAST	NUREMBERG	COPENHAGEN	LONDON
	7	8	9	10	11
Year	1967	1966	1975	1967	1962
Population	344,890	504,620	1,160,000	1,707,000	8,826,620
Area, sq.km.	107	127	3,000	2,760	2,450
Cars	43,180	64,250	328,000	432,950	1,249,450
Cars/100 Persons	12.5	12.8	28.3	20.1	14.1
Car Trips	226,000	361,430	1,007,000	1,445,300	3,648,740
Car Trip Rate	6.25	5.63	3.07	4.21	3.27
Trip Distance, km.	4.15	4.65	11.20	7.91	7.18
Trip Time, min.	6.9	8.6	17.2	10.5	13.7
Speed, kph.	36.0	32.4	39.2	45.0	31.3
Car Daily Distance, km.	25.9	26.2	34.4	33.3	23.5
Car Daily Time, hrs.	0.72	0.81	0.88	0.74	0.75

DEVELOPING COUNTRIES ☼

CITY	TEL AVIV	KUALA LUMPUR	SINGAPORE	BOGOTA	BANGKOK
	12	13	14	15	16
Year	1965	1973	1968	1969	1972
Population	817,000	912,490	1,536,000	2,339,600	4,067,000
Area, sq.km.	190	337	518	2,520	3,100
Cars	39,640	65,440	62,390	55,000	175,000
Cars/100 Persons	4.9	7.2	4.1	2.4	4.3
Car Trips	288,580	443,950	314,000	250,000	612,500
Car Trip Rate	7.28	6.78	5.03	4.55	3.50
Trip Distance, km.	4.09	5.36	7.03	6.76	7.40
Trip Time, min.	9.1	12.4	12.7	18.0	22.8
Speed, kph.	27.0	25.9	33.2	22.5	19.5
Car Daily Distance, km.	29.8	36.3	35.4	30.8	25.9
Car Daily Time, hrs.	1.10	1.40	1.06	1.37	1.33

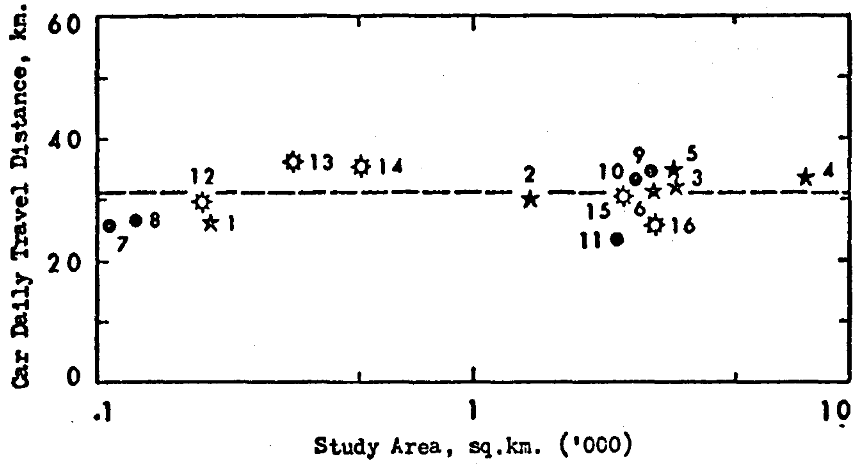


Figure 4.11-1 : Car Daily Travel Distance vs. Study Area

Figure 4.11-2 shows the relationship between the daily travel distance per average car and the daily average network speed. As expected from the previous relationship, the daily travel distance remains stable, unaffected by speed.

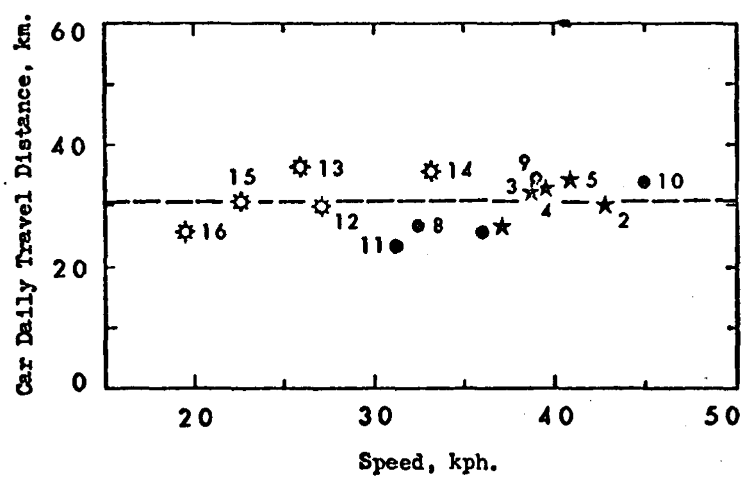


Figure 4.11-2 : Car Daily Travel Distance vs. Speed

At this stage, however, another travel component enters the picture, namely the daily travel time per average car, as the link between distance and speed. The addition of travel cost, as a function of speed (based on travel costs at different speeds, standard car under U.S. conditions in 1968, serving as a common denominator for all cases), and the relationship between all the above factors, are shown in Figure 4.11-3.

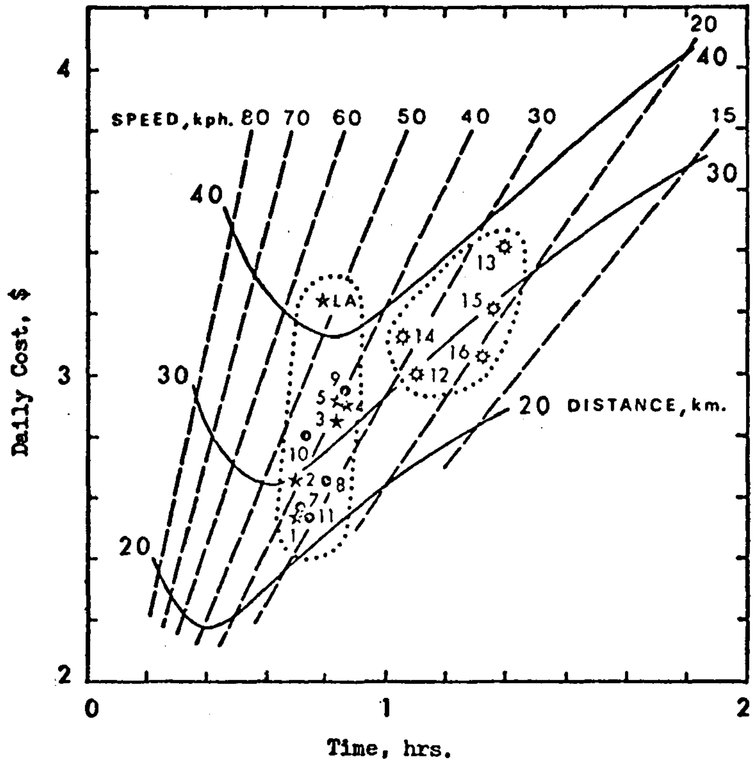


Figure 4.11-3: The Daily Cost and Time per Car Required to Travel a Certain Distance at Different Speeds, Standard Car, US Costs in 1968

The interpretation of this figure is as follows:

(1) When speeds are low, within the range of 20-30 kph., as often found in cities of developing countries, both the daily travel times and costs are high, in order to travel the daily distance, of about 30 kilometers per day.

(2) When speed are within the range of 30-40 kph., as usually found in European and U.S. cities, both travel times and costs go down. Hence, an increase in speed from 20 to 30 kph. will result in both real time and money savings.

(3) When speeds increase above 40-50 kph., the daily travel times reach a minimum level of about 0.7-0.8 hours per day (which can be compared with a door-to-door TT-budget of about 1.1 hours), after which the daily travel distance starts to increase above 30 kilometers per day. For instance, in the Los Angeles region in 1960, with over 7.5 million people residing in a large area of over 23,000 sq.km., the average car still traveled 0.8 hours per day, at a relatively high network speed of about 53 kph.,

thus traveling a daily distance of about 42 kilometers, as shown in Figure 4.11-3.

The point to note, therefore, is that car travelers in cities where speeds are low have to pay in more time and money in order to travel the same distance as car travelers in cities where speeds are optimal. At high speeds, on the other hand, car travelers appear to be willing to travel longer distances during the minimum 0.8 hours per day, thus generating "induced" travel. The analysis suggests that the elasticity of daily travel distance vs. cost is in the range of 3 to 4, thus serving as a strong incentive for increasing spatial and economic opportunities at only marginal increases in cost.

The Nurenberg region is situated in Figure 4.11-3 at the top of the group of European and U.S. cities, suggesting that car travelers take advantage of the relatively high speeds in order to travel longer distances, although the car TT-budget is within the same range as found in other cities.

A more detailed analysis of the Nurenberg data is presented in Table 4.11-2, which shows the daily travel distance per household, for the 55 household types, by household size and car ownership. The travel distance in this case is expressed by passenger-kilometers, divided into car and transit travel. Figure 4.11-4 shows these distances, where significant gaps in car travel distances by car ownership become evident. Thus, it may be inferred that households of different sizes are expected to travel a minimum daily travel distance if they own 1 and 2+ cars. For instance, the daily travel distances per household owning 1 and 2+ cars are 35 and 73 passenger car-km., respectively; the daily travel distance by 2+ cars is just over two times the daily travel distance by 1 car.

The above results can also be viewed from another angle: there appears to be a minimum daily travel distance that would justify the ownership of 1 and 2+ cars per household. Such distance-thresholds are discussed in more detail in Section 5.2.

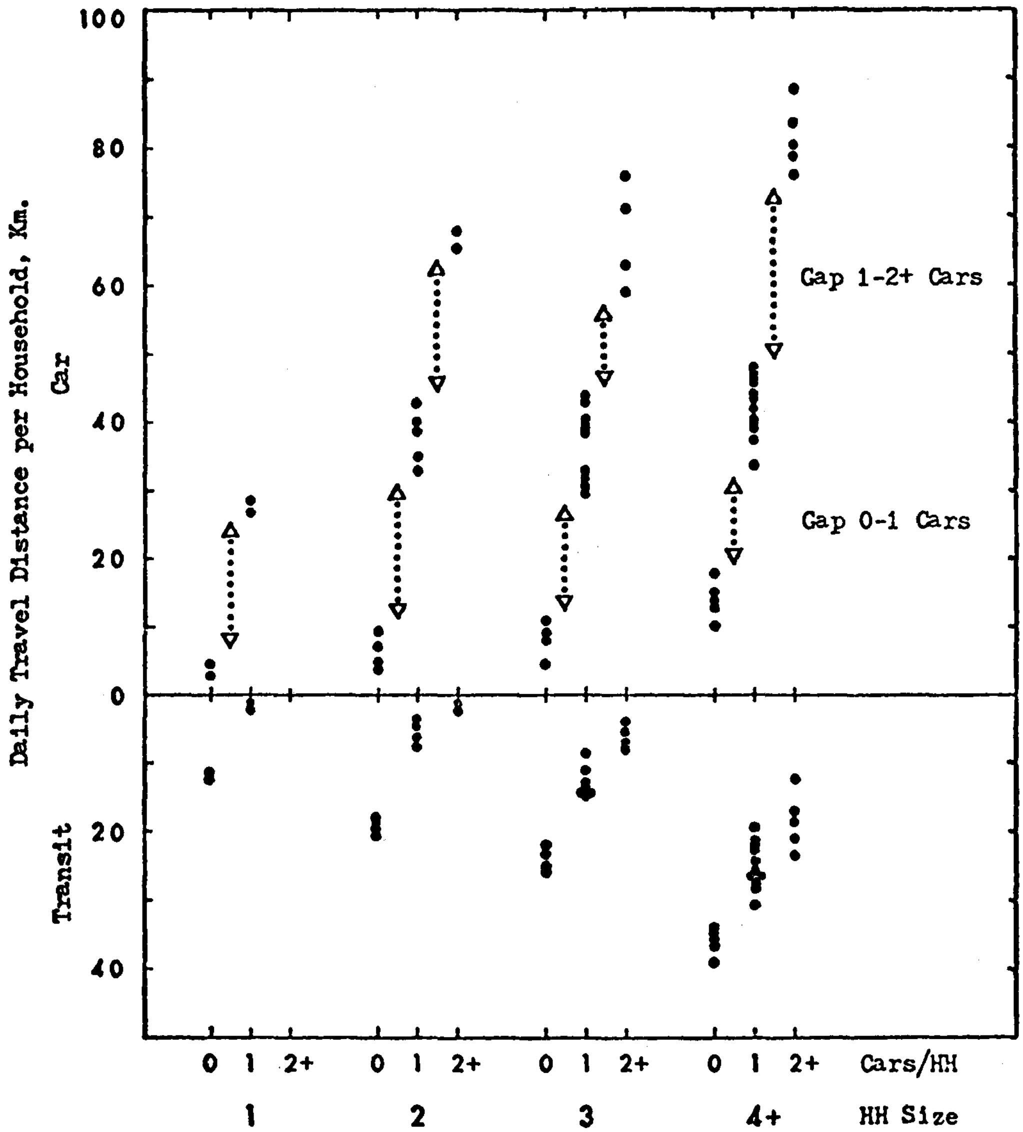


Figure 4.11-4 : Daily Travel Distance per Household, by Household Size and Car Ownership, the Nurenberg Region 1975

Table 4.11-2 : Travel Distance per HH, by Mode

CAR

0 Car			1 Car			2+ Cars		
Type	HH Size	D	Type	HH Size	D	Type	HH Size	D
1	1	4.37	2	1	28.22	-	-	-
3		2.60	4		26.89			
5	2	7.27	6	2	38.74	9	2	65.21
7		4.80	8		34.60	13		67.85
10		9.21	11		32.54			
14		4.14	12		42.74			
			15		39.57			
16	3	8.62	17	3	32.68	20	3	70.92
21		10.63	18		38.08	24		75.56
25		8.47	19		39.17	28		62.55
29		4.55	22		29.99	33		58.62
			23		43.05			
			26		31.26			
			27		39.57			
			30		29.44			
			31		38.43			
			32		43.19			
34	4	10.02	35	4	40.25	38	4	82.99
39		13.39	36		43.84	42		78.39
43		14.47	37		47.61	47		75.88
48		13.27	40		38.69	51		88.02
52		17.37	41		44.63	55		80.04
			44		39.81			
			45		41.67			
			46		43.17			
			49		33.28			
			50		44.87			
			53		37.56			
			54		45.98			

Summary - Car

HH Size	0 Car		1 Car		2+ Cars		Total	
	D	HH	D	HH	D	HH	HH	D
1	3.45	47,146	27.97	28,088	-	-	75,234	12.60
2	6.87	33,586	33.79	95,342	67.83	7,524	136,452	29.04
3	8.28	12,832	37.78	46,197	67.07	13,715	72,744	38.10
4+	14.03	9,704	42.61	35,552	80.21	19,216	64,477	49.51
Tot. Avg.	6.16	103,273	35.42	205,179	73.45	40,455	348,907	31.17

TRANSIT

0 Car			1 Car			2+ Cars		
Type	HH Size	D	Type	HH Size	D	Type	HH Size	D
1	1	12.52	2	1	1.27	-	-	-
3		12.12	4		2.15			
5	2	18.45	6	2	4.94	9	2	2.11
7		19.14	8		16.23	13		0.89
10		19.43	11		7.85			
14		20.94	12		6.39			
			15		4.04			
16	3	26.09	17	3	13.35	20	3	8.25
21		23.48	18		13.72	24		7.88
25		25.80	19		14.14	28		5.83
29		22.61	22		13.71	33		4.19
			23		14.12			
			26		14.15			
			27		14.61			
			30		11.03			
			31		8.86			
			32		14.23			
34	4	36.08	35	4	27.41	38	4	17.23
39		39.25	36		21.47	42		21.14
43		34.43	37		27.61	47		18.57
48		34.40	40		30.95	51		23.90
52		35.74	41		28.08	55		12.50
			44		23.21			
			45		24.54			
			46		25.46			
			49		23.43			
			50		26.54			
			53		19.46			
			54		21.29			

4.12 The Measure of Mobility

1. Introduction

While mobility is a central issue in transportation planning and policy decisions, it is often not clear what is meant by this term: is it the daily number of trips per household/person/traveler ? Is it the number of opportunities that can be reached within radii of varying travel times, such as 30, 45 and 60 minutes ? Is mobility beneficial, to be encouraged, or is it wasteful above a ceratin level, and should be discouraged ?

Whatever the definition of mobility is, it is apparent that it has to do with both travel demand and transportation system supply. For instance, the need for mobility tends to increase with such factors as household income while, on the other hand, mobility also increases by an improved system supply. Hence, mobility has to be expressed in terms of both travel demand and system supply.

As already presented in Sections 1.3 and 2.6, the demand for travel in the UMOT process is measured by the daily travel distance per traveler/household. It is further proposed in this section that mobility be defined as the product of the daily travel distance and the daily mean travel speed.

There are now two independent sources that corroborate this definition. The first part of this section presents the measure of mobility from the point of view of system supply, as derived from the empirical analysis of vehicular travel on road networks. The second part presents the measure of mobility from the point of view of travelers, with special emphasis on transit travel, as derived from theoretical considerations. The third part shows that the two mobility measures are actually the same, and an example of mobility in the Nurenberg region is presented.

2. Mobility Measure of Road Networks

The mobility measure of road networks was developed in 1972 for the Science Research Council in the U.K. and reported elswhere (Zahavi, 1972-a, 1972-b, 1974, 1976). Therefore, the following presentation is short, summarizing the salient points of the mobility measure, called the 'Alpha-relationship'.

There is a consistent regularity in the relationships between the arterial road density RD (road kilometers per sq.km.), the vehicle kilometrage density I (vehicle-kilometers per sq.km.), the resulting space-mean speed v, and the distance from the center of a city. One such relationship is shown in Figure 4.12-1 for London (cf.,1972-a).

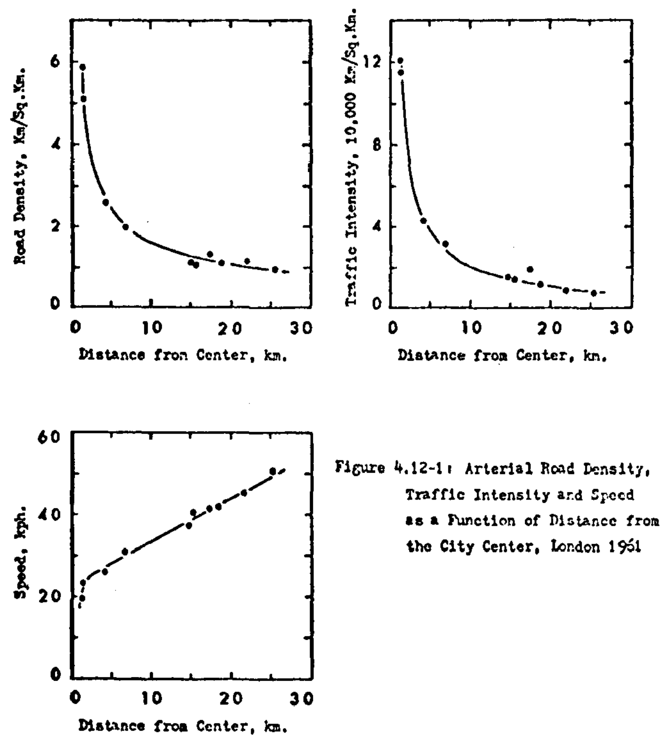


Figure 4.12-1: Arterial Road Density, Traffic Intensity and Speed as a Function of Distance from the City Center, London 1961

Based on the relevant data, it was found that the most representative relationship is in the form of:

$$I = f\left(\frac{RD}{v}\right) \qquad (4.12\text{-}1)$$

Such a relationship for London and Pittsburgh is shown in Figure 4.12-2, in the shape of an hyperbola. For practical reasons of presentation, however, all forthcoming relationships will be shown graphically on double-logarithmic scales, in the form of:

$$I = f\left(\frac{V}{RD}\right) \qquad (4.12\text{-}2)$$

so that data spread over several fields of magnitude can be shown with equal clarity. Therefore, Figure 4.12-2 was transformed into Figure 4.12-3.(It is to be noted that the dispersion of values in the last figure is distorted because of the logarithmic scales and does not signify the absolute scatter).

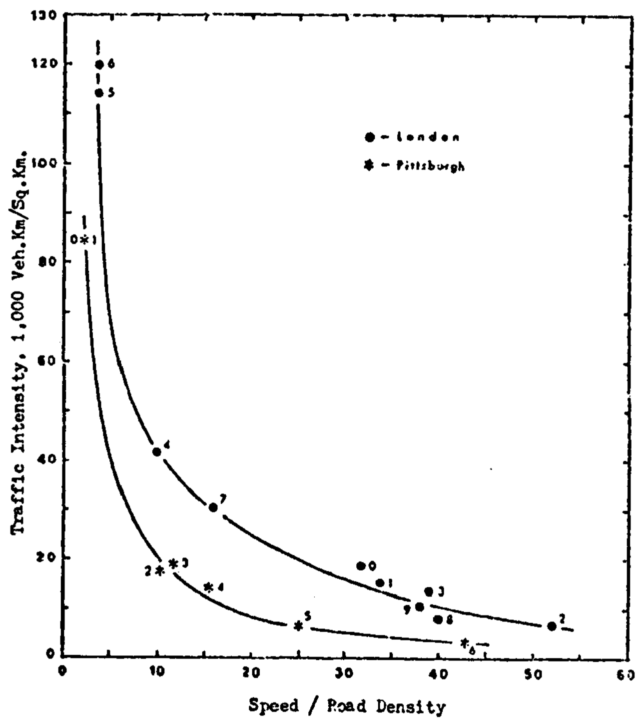


Figure 4.12-2: The Relationship between Traffic Intensity and the Ratio of Speed/Road Density in London and Pittsburgh

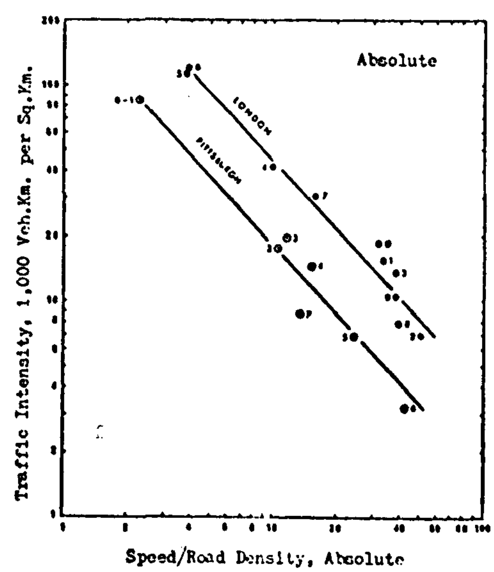


Figure 4.12-3: The Alpha-Relationship for the Arterial Networks of London and Pittsburgh, in Absolute Values

As can be seen in Figure 4.12-3, a clear linear relationship between the three parameters may be formulated along a wide range of their values. Now when the logarithms of two variables x and y are linearly related, it follows that the relationship between them is of the form

$$y = \alpha x^{m} \tag{4.12-3}$$

where α and m are constants. When, as in this case, the scales on the x and y directions are the same and the slope of the line relating them is negative and at 45 degrees to the axes, if follows that m = -1 and the relationship between them is of the form

$$y = \frac{\alpha}{x} \tag{4.12-4}$$

The slopes of the lines in Figure 4.12-3 are close to 45 degrees and it therefore appears that for London and Pittsburgh the relationship can be approximated by

$$I = \alpha \frac{RD}{v} \tag{4.12-5}$$

With the purpose of defining a common denominator for the two cities, the absolute values were transformed into relative ones by calculating the ratio between the observed values of I and v/RD for each sector and the average value for the whole area. The relationship between the relative values is shown in Figure 4.12-4, where the observations for the two cities lie along the same average line. It may be concluded, therefore, that the traffic characteristics of the arterial networks in these two cities are basically the same when compared on the basis of relative terms, and may be expressed by formula (4.12-5), namely that the traffic intensity is proportional to the ratio of the arterial road density to the speed.

The relationship between traffic intensity, road density and speed, as expressed by formula (4.12-5), was called the Alpha-relationship, and it was found to apply equally well to arterials and expressways in a wide range of cities, including in the U.K., U.S., Holland and Germany, as well as in developing countries. Figure 4.12-5 shows one such example in a U.S. city.

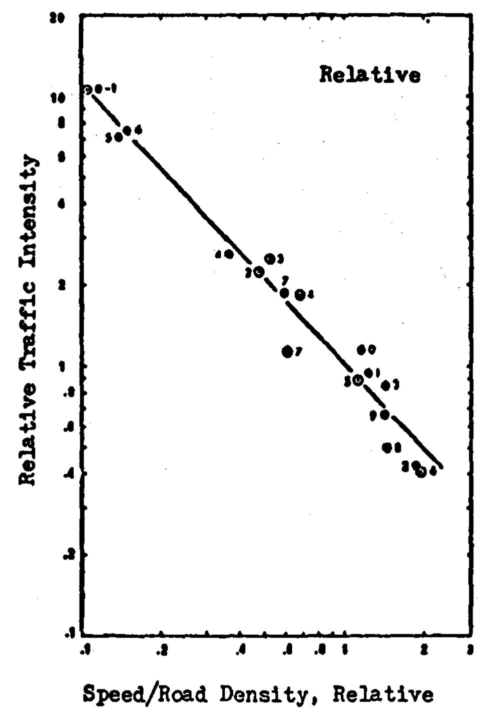


Figure 4.12-4: The Alpha-Relationship for the Arterial Networks of London and Pittsburgh, in Relative Values

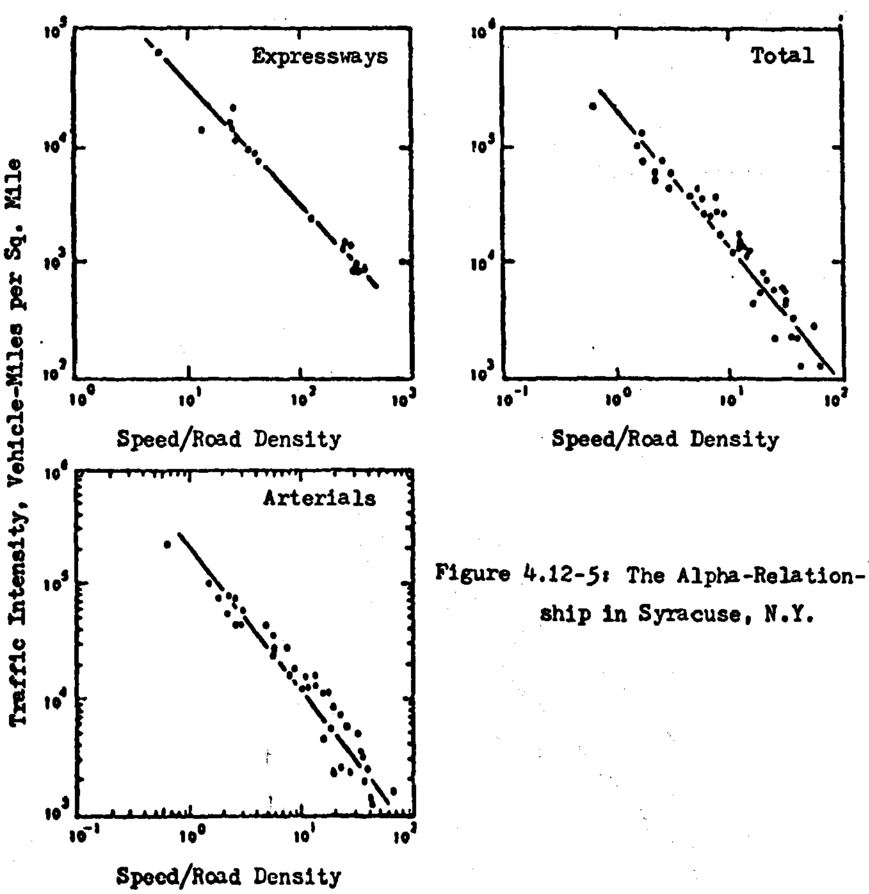


Figure 4.12-5: The Alpha-Relationship in Syracuse, N.Y.

It is noteworthy that, although the Alpha value may be different in different cities, depending on such factors as category of road, traffic composition or traffic regulations, the relationship between road density, traffic intensity and speed is consistent in all cases. Thus, when identified by observations for a sample of road sections in a given city, the relationship can then be applied as a useful tool for many purposes, such as the evaluation of alternative road plans or traffic assignments by rapid procedures (Zahavi, 1979-b).

Multiplying both I and RD in formula (4.12-5) by the respective ground area of each traffic zone results in the average traffic flow, q, so that

$$q\ v = \alpha \qquad (4.12\text{-}6)$$

for the range of values found in the cases studied.

Since the flow of traffic equals the concentration of traffic, C , multiplied by its space-mean speed, v , namely

$$q = C\ v \qquad (4.12\text{-}7)$$

it follows that formula (4.12-6) my be written in the form of

$$\alpha = q\ v = C\ v^2 \qquad (4.12\text{-}8)$$

By considering the concentration C as representative of the mass of the traffic, it can be concluded that Alpha may represent the "kinetic Energy" of the traffic, by being similar in form to $\frac{1}{2}mv^2$, where m is the physical mass. Furthermore, the Alpha-value represents the <u>product of flow and speed</u>, and indicates the ability of a specific road section, or a complete road network, to "produce" a certain "output" of vehicle-kilometers per unit distance. More specifically, if q is the average flow per kilometer of the road network per unit time, then

$$\alpha = q\ v = \text{Vehicles} \times \frac{\text{Distance}}{\text{Time}} = \frac{\text{Vehicle-kilometers}}{\text{Time}} \text{ per kilometer}$$

of the road network. And for the total road network:

$$\alpha_{total} = \frac{\text{Vehicle-kilometers}}{\text{Time}} \times \text{Kilometers} = \frac{(\text{Distance})^2}{\text{Time}} \qquad (4.12\text{-}9)$$

Hence, the higher Alpha is, the higher is the "productivity" of the road network in vehicle-kilometers. Of special interest is the indication that the Alpha value is proportional to $(\text{Distance})^2$, namely to a measure of Area, thus serving as a link with the accessibility provided by a given road network.

The Alpha-value may characterize, therefore, the quality and performance of a road network which, in a sense, coincides with the level of mobility that a road network can supply to its users. It is suggested, therefore, that Mobility of a road network be defined as the total vehicle-kilometers per unit time that the network can supply. It is a maximum value for a given road network, that can be increased only by specific improvements to the system supply.

The measure of Mobility from the travelers' point of view is developed below upon theoretical considerations. The remarkable result is that the travelers' demand for mobility is found to be identical in form and units to the mobility provided by system supply, thus unifying demand and supply by a common denominator.

It should be noted at this stage that while the supply of mobility by a road network is an upper value, depending on the characteristics of the given road network, the demand for mobility may vary with the socioeconomic characteristics of the travelers, as further discussed below.

3. Mobility Measure of Travelers

The development of a mobility measure from the travelers' point of view follows reference (McLynn, 1972), which deals specifically with transit travelers. However, the same considerations apply equally well to all travelers, using all other modes.

As transit mobility has to reflect the system's performance from the travelers' point of view, the descriptors have to cover all the components of transit travel from origin to destination. For example, the time duration of a trip usually includes several components, such as:

t_a - <u>Access time</u> to the transit stop, depending on the spatial distribution of origins and the spacing of transit stops;

t_w - <u>Wait time</u>, depending on the service frequency of the transit system;

t_t - <u>Travel time</u>, or in-vehicle time, depending on the trip distance and speed;

t_x - <u>Transfer time</u>, if the traveler has to transfer between transit lines in order to complete his trip from origin to destination;

t_e - <u>Egress time</u>, from the transit stop to the destination, depending on the spatial distribution of destinations and the spacing of transit stops.

Thus, the door-to-door - or "effective" - speed of transit will have to take into account all the components of distances, d , and times, t , namely:

$$v_{effective} = \frac{d_a + d_t + d_x + d_e}{t_a + t_w + t_t + t_x + t_e} \quad ; \qquad (4.12\text{-}10)$$

Hence, the effective speed, similar to the case of road traffic, is the space-mean speed, but with the addition of all the distance and time components to and from the transit stops, as well as between the transit lines if a transfer is required. (The same considerations also apply to vehicular travel when analyzing travel demand, as discussed below).

The development of a mobility measure is then based on the following 5 assumptions/requirements:

(1) The Mobility measure M will be a function of the variables:

P - number of trips;

d - average trip distance;

t - average trip time.

(2) For fixed values of the remaining two variables, the Mobility measure M is such that:

(a) an increase in P increases M;
(b) an increase in d increases M, and
(c) an increase in t decreases M.

(3) The Mobility measure M has the property that relative magnitudes are independent of the units of measure, namely: $M_1/M_2 = M_1'/M_2'$, where M_1 and M_2 are the mobilities before and after an improvement in the transit system measured in, say, metric units, while M_1' and M_2' are the mobilities for the same case measured in Imperial units.

The three above assumptions suggest already at this stage what the genral form of the mobility function must be. From Assumption (1) it follows that M depends only on P, d and t; Assumption (3) implies that M must be in the form of:

$$M = P^a d^b t^c \quad ; \tag{4.12-11}$$

where a, b and c are real numbers. And Assumption (2) requires that a and b must be positive numbers and that c must be a negative number. In other words, Assumption (1) determines the number of variables in the equation, Assumption (3) determines the functional form, and Assumption (2) signifies the algebraic signs of the constants in the equation. However, to the above assumptions we must add also the following requirements:

(4) Additivity: if M_A is the mobility associated with a group of trips A, and M_1 is the mobility associated with any single trip having a speed equal to the average speed of the trips of A, then:

$$M_C = M_A + M_1 \quad ; \tag{4.12-12}$$

where M_C is the mobility of the group of trips consisting of the trips of A and the single trip;

(5) Accessibility: in an idealized transit system, that operates in all directions with uniform speed, the mobility function is directly proportional to the area defined by the equal-time lines from the origin; i.e., mobility is also directly proportional to the accessibility to opportunities distributed uniformaly throughout the urban area.

The effect of Assumption (4) is the elimination of the first two constants in the general form of the mobility function shown in Eq.(-11) while the effect of Assumption (5) is that the mobility function can be expressed as

$$M = Pdv^k \quad ; \qquad (4.12\text{-}13)$$

where k is a positive number and v is the average speed d/t, and that k = 1.

Thus, the mobility function that has to satisfy all five assumptions simultaneously is found to be a simple one, in the form of:

$$M = Pdv \quad ; \qquad (4.12\text{-}14)$$

As (P)(d) is the passenger-kilometers of travel carried by the transit system, it follows that:

$$M = (\text{Passenger-kilometers}) \times (\text{Speed}) \quad ; \qquad (4.12\text{-}15)$$

Namely, the theoretical derivation of the mobility function is identical with the one derived by emprical analysis of vehicular travel on road networks, since expressing speed as distance over time results in:

$$M = \frac{(\text{Distance})^2}{\text{Time}} \quad ; \qquad (4.12\text{-}16)$$

measured in the same units as Eq.(-9) . Furthermore, it is also clear that the units of vehicles, such as cars, can be transformed into passengers, by multiplying the vehicle units by their passenger occupancy rates, thus making the two mobility functions completely identical by their measurement units.

An additional interesting characteristic of the mobility measure, M = Pdv, is that the variables P, d and v are not necessarily independent of each other. For example, if it is assumed that a traveler is willing to allocate for his daily travel a certain stable time, then an increase in speed will also result in an increase in the traveler's trip distance, or trip rate, or both. As an example, let us assume that the effective speed of a transit line, carrying 50 travelers, each making 2 trips per day at a trip distance of 5 kilometers, is increased from 10 to 15 kph. If it is then found that the mobility measure increased by the same proportion, it means that the travelers traded-off the new potential mobility for saved time only. However, if it is found that the mobility measure increased by more than 50 percent, it shows that the potential mobility was actually realized. Namely:

(a) Base Mobility : $M_{base} = Pdv = (50x2)(5)(10) = 5{,}000$;

(b) New Potential Mobility: $M_{pot.} = (50x2)(5)(15) = 7{,}500$;

(c) New Observed Mobility : $M_{obs.} = \quad = 9{,}000$.

At this stage, however, we have a problem, since the difference between the new observed mobility and the new potential mobility, namely 9,000 - 7,500 = 1,500, could have been achieved by various possibilities, such as:

(i) the original 50 travelers increasing their daily average trip rate from 2 to 2.4;

(ii) the original 50 travelers increasing their daily average trip distance from 5 to 6 kilometers;

(iii) the original 50 travelers increasing both their trip rate and trip distance in various proportions to result in the observed increased mobility;

(iv) although part of the observed increase in mobility is attributed to the original 50 travelers, the other part is attributed to new travelers, attracted to the improved transit line.

4. The Alpha Relationship in Germany

1. Referring back to the Alpha relationship, as described in Section 4.12 a special test was conducted to test the relationship under travel conditions in Germany.

Figure 4.12-6 shows the Alpha relationship for the arterial road system in the Nuremberg region, based on a selction of districts, and compared with similar relationships in Rotterdam and London.

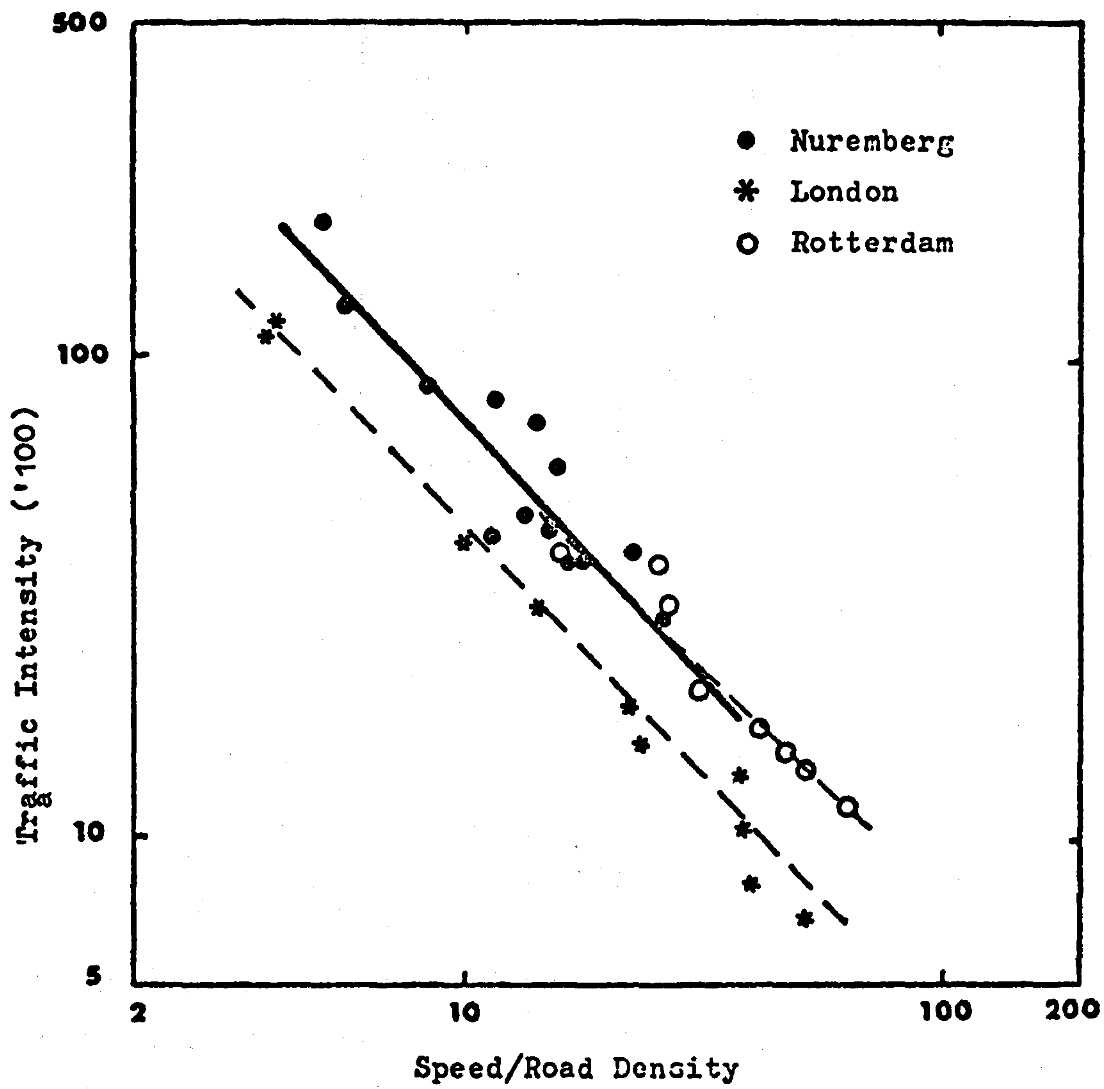


Figure 4.12-6: The Alpha-Relationship for Arterial Roads in the Nuremberg Region, Rotterdam and London

The relationships can be expressed by:

Nuremberg: $I = 892,915 \left(\frac{V}{D}\right)^{-1.066}$; $(r^2 = 0.851)$; (4.12-17)

Rotterdam: $I = 622,296 \left(\frac{V}{D}\right)^{-0.935}$; $(r^2 = 0.901)$; (4.12-18)

London: $I = 484,916 \left(\frac{V}{D}\right)^{-1.028}$; $(r^2 = 0.964)$; (4.12-19)

Three important conclusions may be inferred from these relationships. First, the exponent is practically unity in all three cases, thus confirming the theoretical requirement of the mobility measure, as descriebed in Section 4(3). Second, the travel characteristics of system supply in the Nuremberg region follow those observed in other cities. And third, the efficiency of the arterial road network in the Nuremberg region is higher than in the urban areas of Rotterdam and London.

The next test was carried out with the data from the City of Hagen. The data presented a unique opportunity for developing the Alpha relationship on the basis of roads widths, as the data included the widths of all roads. The relationship is shown in Figure 4.12-7 for a selection of zones, and it can be expressed by:

Hagen: $I_{(1)} = 41,235 \left(\frac{V}{D}\right)^{-1.065}$; $(r^2 = 0.851)$; (4.12-20)

As the above relationship is per meter width of the roads, it can be transformed into a relationship similar to the previous ones, namely by multiplying it by the average road width, which is 10.42 meters. Thus,

Hagen: $I_{(2)} = 428,840 \left(\frac{V}{D}\right)^{-1.065}$; (4.12-21)

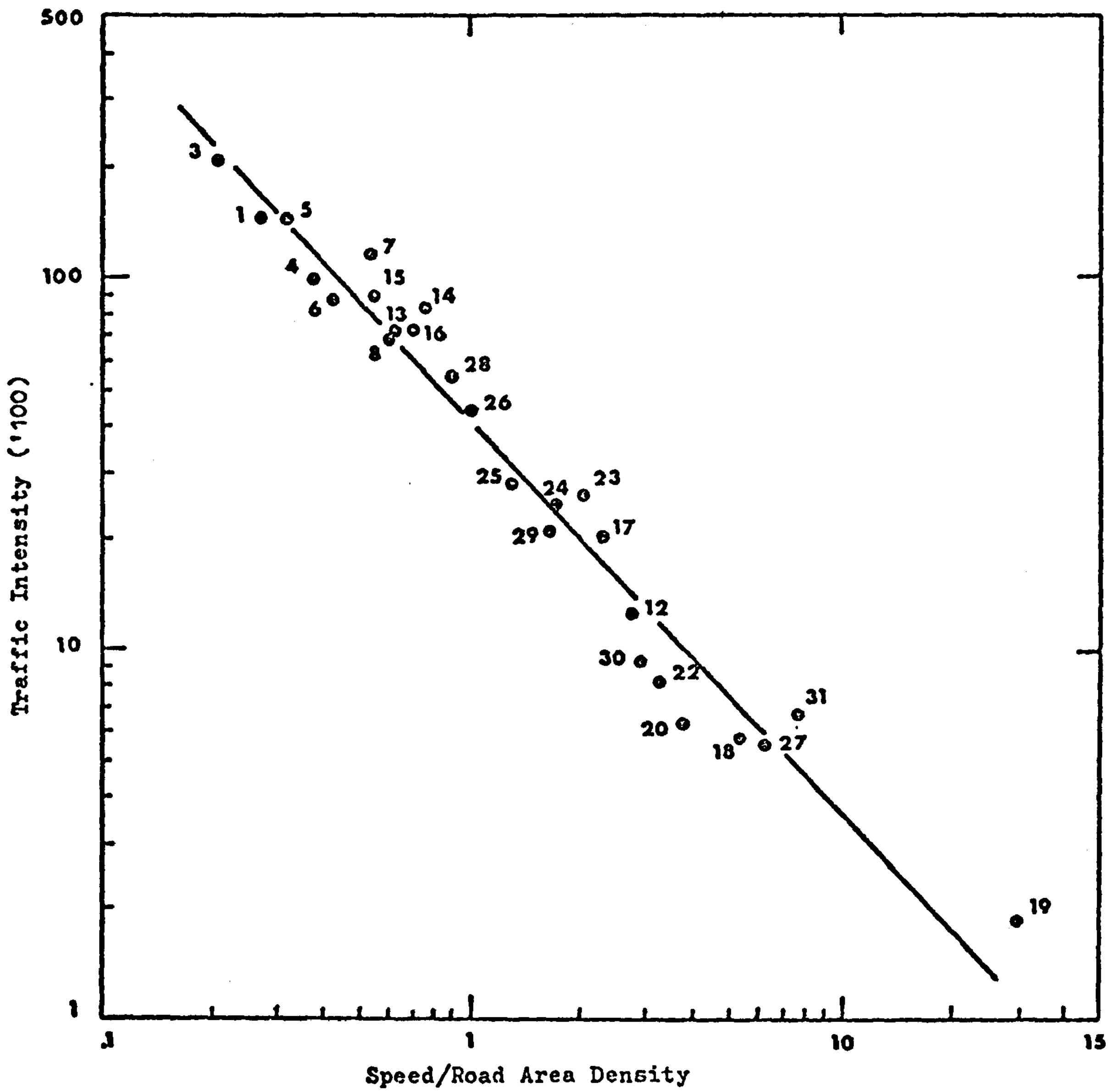


Figure 4.12-7 : The Alpha-Relationship per 1 meter width of Arterial Roads in the Hagen Region

It may be inferred from the above relationship that (i) the power of the function is, once again, practically unity, similar to the previous cases, and (ii) the efficiency of the arterial network in the Hagen region is appreciably lower than the one in the Nuremberg region, and is closer to the value of the arterial network in London.

Thus the Alpha value can serve as a quantified value for expressing the performance level of the road network, by its ability to supply a 'kinectic capacity' (product of flow and speed), as well as a measure for the mobility level from the point of view of the travelers, which can then be compared with their need for mobility. Thus, the need for, and the supply of, mobility can be based on the same units of measurements.

5. Mobility in the Nurenberg Region

The mobility levels per traveler, by household size and car ownership, versus the travel money expenditures in the Nurenberg region are detailed in Table 4.12-1 and shown in Figure 4.12-8. The relationship can be expressed by

$$\text{Mobility} = 141.21 + 56.85(\text{Expenditure, DM}), \quad (R^2 = 0.945) \quad (4.12\text{-}22)$$

This relationship suggests that the mobility level per traveler increases linearly with the expenditure on travel. This result is quite expected, as higher expenditures on travel mean higher travel speeds.

Table 4.12-1: Mobility per Traveler vs. Expenditure on Travel, the Nurenberg Region 1975

HH Size	Cars/HH	Distance per Traveler, km.	Speed kph.	Mobility	Expenditure per Traveler, DM
1	0	15.76	11.3	178	1.53
	1	29.41	24.1	709	12.36
2	0	18.22	12.7	231	1.77
	1	28.65	23.0	659	8.81
	2+	37.56	27.0	1,014	13.93
3	0	18.80	13.8	259	1.82
	1	25.59	20.2	517	7.43
	2+	31.80	24.5	779	11.31
4+	0	20.37	15.1	308	1.97
	1	24.82	19.7	489	6.20
	2+	31.24	24.0	750	9.21

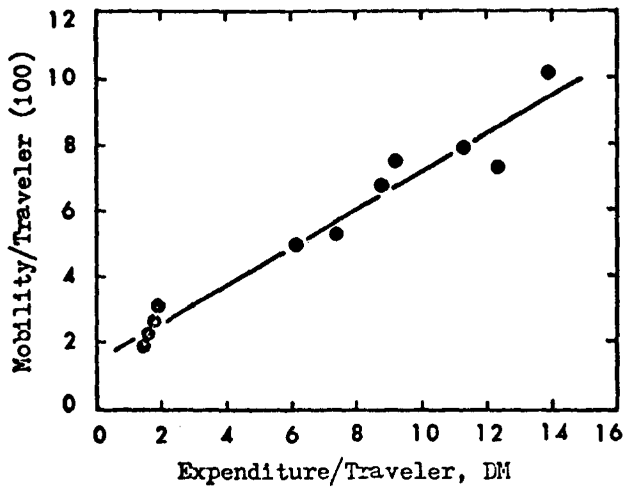


Figure 4.12-8: Mobility per Traveler, by Household Size and Car Ownership, vs. Expenditure, the Nurenberg Region 1975

Of special interest is the value of mobility at zero expenditure on motorized travel; refering back to Eq.(4.12-16), the value of mobility can be regarded as a measure of the area that can be accessible during a day while spending one hour on walking. Hence, the radius of accessibility at zero expenditure is about 6.7 km., which is in rough agreement with the 7.7 km. mentioned in Table 4.6-1.

It is also possible to divide the mobility level into components by mode and estimate the money expenditures required to increase the mobility-accessibility by alternative modes. Thus, the measure of mobility has the potential of being a scale by which the accessibilities of different population segments can be compared, as well as a tool for the economic evaluation of alternative policy options.

4.13 Proportions of Households Generating Travel During an Average Weekday, the Nurenberg Region

As the home-interview survey in the Nurenberg region was carried out for only one day per household, it is of importance to know what are the proportions of households that generated at least one motorized trip during an average weekday. Based on the data in Appendix 2, Table 4.13-1 summarizes these proportions by household size and car ownership.

The proportion of households that generate motorized travel per weekday is an increasing function of both household size and car ownership, as shown in Figure 4.13-1. Assuming that practically every household generates some motorized travel during an extended period, Table 4.13-1 suggests the expectation of a household type to generate such travel during an average weekday.

Table 4.13-1 : The Proportions of Households Generating Motorized Travel During an Average Weekday, the Nurenberg Region

HH Size	Cars/HH	Households	Households Traveled	Proportion of HH Traveled/Total HH
1	0	104,226	47,146	0.452
	1	34,515	28,088	0.814
2	0	56,754	33,586	0.592
	1	107,017	95,342	0.891
	2+	7,729	7,524	0.973
3	0	15,804	12,832	0.812
	1	49,206	46,197	0.939
	2+	14,149	13,715	0.969
4+	0	10,797	9,709	0.899
	1	36,894	35,552	0.964
	2+	19,460	19,216	0.987
Total/Average		456,551	348,907	0.764

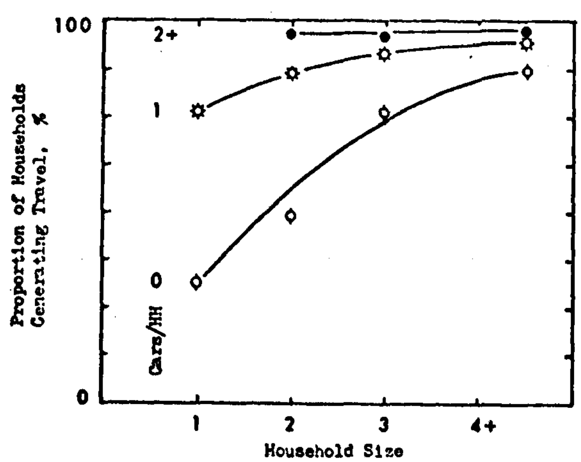


Figure 4.13-1: Proportion of Households Generating Motorized Travel per Average Weekday by Household Size and Car Ownership the Nurenberg Region 1975

4.14 Travelers per Household

In any behavioral travel model there is some uncertainty as to what should be regarded as the decision unit; should it be the individual decision-maker, or the household, within which several decision makers may have to compromise, such as about the use of one available car ? The problem is compounded when considering the travel time and money budgets, since the former is allocated by, and affecting the behavior of, individual travelers, while the latter is being shared by all travelers belonging to the same household.

As it is uncertain what ranking-order should the travel model follow, namely from the household to the traveler, or vice versa, the problem is solved in most conventional models by a compromise; trip rates are generated by household characteristics, while modal choice is based on the travelers' single trips. In the UMOT approach this problem is solved by having a complete feedback process between the two, where each one both affects, and is affected by, the other until an equilibrium condition between the travelers and their household is reached, or at least approached. While the defintion and process of this equilibrium condition are detailed in the following chapter, let us see here a simple example.

Although the number of travelers per household (or traveler rate, for short) can be a function of many factors, such as household size, income, occupation, age, sex, travel modes availability, transportation system supply and costs, urban structure and residence location, the question is whether we can capture the effects of such varied factors by the minimum number of variables, especially when considering that such variables have to be forecast if the model is to be applied for prediction purposes. Therefore, we start with only two variables, namely household size and car ownership. The point to note, however, is that car ownership in the UMOT process is an output from a feedback process between such factors as income, system supply and travel costs. Thus, we may start the process by assuming that each household in the study area ownes, say, five cars and, nonetheless, the final car ownership levels will converge to the observed ones, as detailed in Section 5.2 . Thus, although the estimation of the traveler-rate is based on only two independent variables, household size and car ownership, it actually interacts through the car ownership component with many other factors. Put another way, the reliability and sensitivity of the model is tested not by calibrating it to many independent variables, but rather by its ability to converge to the observed values by the feedback process when based on a minimum number of independent variables, and when starting the process with even absurd assumptions about some of the variables, such as car ownership.

At this stage, however, we deal with the direct estimation of the traveler rate, as a function of household size and car ownership, while the feedback process is discussed in Section 5.1.

The first analysis is carried out on the basis of the Munich data, as detailed in Appendix 1. Two regressions were run on the following model:

$$\text{Travelers/HH} = a + b_1(\text{HH Size}) + b_2(\text{Car Ownership}) \ ;$$

In the first model run all 118 observations, of three days, were used. In the second model run observations with fewer than two data points were eliminated. It would have been desirable that each data point had at least 20 observations to reduce the sampling variance. The cut-off point of two was decided on pratical grounds as nearly every 1 and 2 observation data point was an outlier (i.e., outside the two standard deviation confidence interval of the regression). The results are summarized in Table 4.14-1.

Table 4.14-1 : Number of Travelers per Household as a Function of Household Type, Munich

Model	a (Std. Error)	b_1 (Std. Error)	b_2 (Std. Error)	R^2	Std. Error of Est.	Coeff. of Var.	Percent of Outliers
1	0.248 (0.174)	0.573 (0.058)	0.156 (0.084)	0.50	0.59	0.29	6.8
2	0.069 (0.141	0.709 (0.048)	0.102 (0.709)	0.72	0.46	0.21	5.2

It is noted that the R^2 of the second regression is quite high, and much better than that of the first regression. The results show clearly the detrimental effect that large sampling variation can have on regression coefficients. It may also be inferred from Table 4.14-1 that the traveler rate is affected predominantly by household size.

The second analysis was carried out on the basis of the much richer data set of Nurenberg, as detailed in Appendix 2, and the results of the regression can be expressed by (Figure 4.14-1):

$$\text{Travelers/HH} = 0.205 + \underset{(14.06)}{0.547}(\text{HH Size}) + \underset{(3.67)}{0.275}(\text{Cars/HH}) \; ; \quad (4.14\text{-}1)$$

where the numbers in paretheses are the t-statistic and the coefficent of multiple correlation is 0.938. It becomes evident that: (i) once again, the traveler rate is affected predominantly by household size, and (ii) the relationships for Nurenberg and Munich are similar.

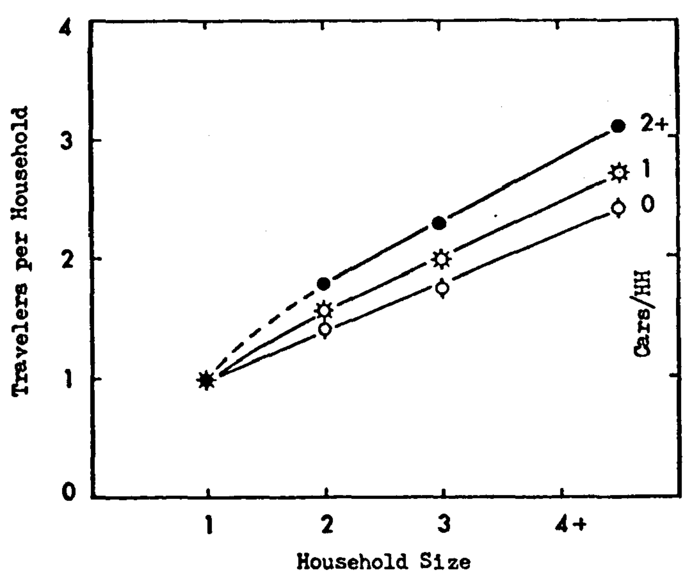


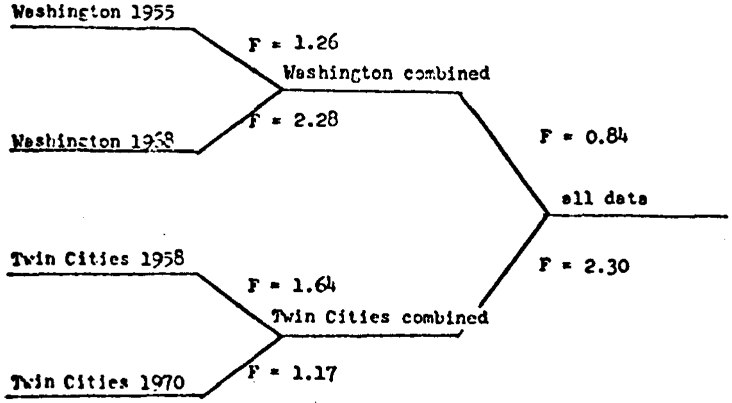
Figure 4.14-1: Travelers per Household, by Household Size and Car Ownership, Nurenberg 1975

It might be of interest to add here an additional set of relationships from Washington, D.C. and Twin Cities, as shown in Table 4.14-2 (Zahavi, 1979-a). These relationships are different from those of Munich and Nurenberg by being based on district averages, and the travelers are above 5 years. Furthermore, the analysis was done for four cases, namely for the two cities and for two periods, both separately and combined. Even so, all relationships were found to be similar.

The close similarity between such relationships in one country suggests that more attention should be given to generalize them both between cities and over time.

Table 4.14-2: Travelers per Household, by Household Size and Car Ownership Washington, D.C. and Twin Cities

City	Year	Constant	HHSIZE	CPHH	R^2	F	Σe_j^2
Washington	1955	0.9169	0.1921 (3.23)	0.4712 (3.79)	0.81	20.75	0.0810
Washington	1968	0.643	0.2309 (4.50)	0.5031 (7.62)	0.94	81.93	0.0607
Twin Cities	1958	0.024	0.3248 (5.28)	0.8701 (5.74)	0.95	128.51	0.0502
Twin Cities	1970	0.210	0.2791 (5.23)	0.7764 (6.35)	0.95	133.36	0.0621
Washington	both	0.6487	0.2771 (6.96)	0.4176 (6.46)	0.85	69.06	0.2243
Twin Cities	both	0.1186	0.3677 (11.07)	0.6339 (8.50)	0.94	214.03	0.1514
both	all	0.4029	0.3366 (12.90)	0.4896 (9.69)	0.91	279.77	0.4750



CHAPTER 5. THE UMOT PROCESS

5.1 Introduction

1. Several of the theoretical aspects of the UMOT process were already discussed in the Chapter 2, where it was indicated that it answers the basic economic utility maximization requirements, as well as passes its sign tests. This chapter summarizes several of the operational aspects of the UMOT process, with special emphasis on the interactions between the demand for travel - car ownership - system supply. As urban structure is not yet fully integrated within this framework, the schematic presentation of the model is preliminary at this stage, for the purpose of testing the UMOT interactions and their convergence.

2. Figure 5.1-1 is a flow chart of the principal interactions in the UMOT process, and Table 2.1 summarizes their characteristics. As the flow chart and the table are self-explanatory, the following comments refer only to the special features of the process. They can be summarized as follows:

   (1) The inputs to the process are minimal. They probably will be further elaborated and expanded in the operational model, but for the sake of simplicity and clarity, they are limited in number at this stage.

   Perhaps this is the place to note that adding many independent variables to a calibrated model may increase its ability to pass statistical validation tests on base-year data, but not necessarily its forecasting ability for new or future scenarios; first, it is very difficult to project many independent variables into the future, and while they may add to the model's base-year accuracy, they also increase the uncertainty of its forecasts; second, it may be theoretically preferable to ensure the sensitivity of, and responsiveness between, the travel components with a minimum number of inputs, than to calibrate many unrelated models, each with many independent variables. For instance, developing separate models for car ownership and trip generation, or even separate models for the trip purposes, each with several variables which often differ (as in the current practice), does not ensure the feedback between the travel components; and third, many of the seemingly independent variables, such as household income, household size, household location, household car ownership, profession and age, are all interrelated in some way and, hence, adding too many of them may not add much to the confidence in forecasts of the model, due to confounding of the order of cause and effect.

In short, if a behavioral model is conceptually right, it should be able to estimate observed travel and urban phenomena, when based on a minimum number of inputs, without being calibrated to the same observations.

In our case, only two household characteristics are required at this stage for deriving travel demand, namely household income and household size. They are used for defining the time and money constraints. Another input is an initial estimate of cars per household. This estimate is changed through the operation of the feedback process; one test for the model's validity is its ability to produce the observed car ownership levels in the final equilibrium, without being calibrated on them.

(2) The second set of inputs into the model is the observed, or planned, transportation system supply, which is required for the convergence of travel demand with system supply.

The road network is the principal component at this stage, for deriving network speeds of both cars and buses, where the transit speeds are proportional to the car speeds. Unit travel costs are then derived from speeds, in both time and money units (bus fares are an exogenous input).

The network travel speeds are derived at this stage by the Alpha relationship, which is explained in Section 4.12.

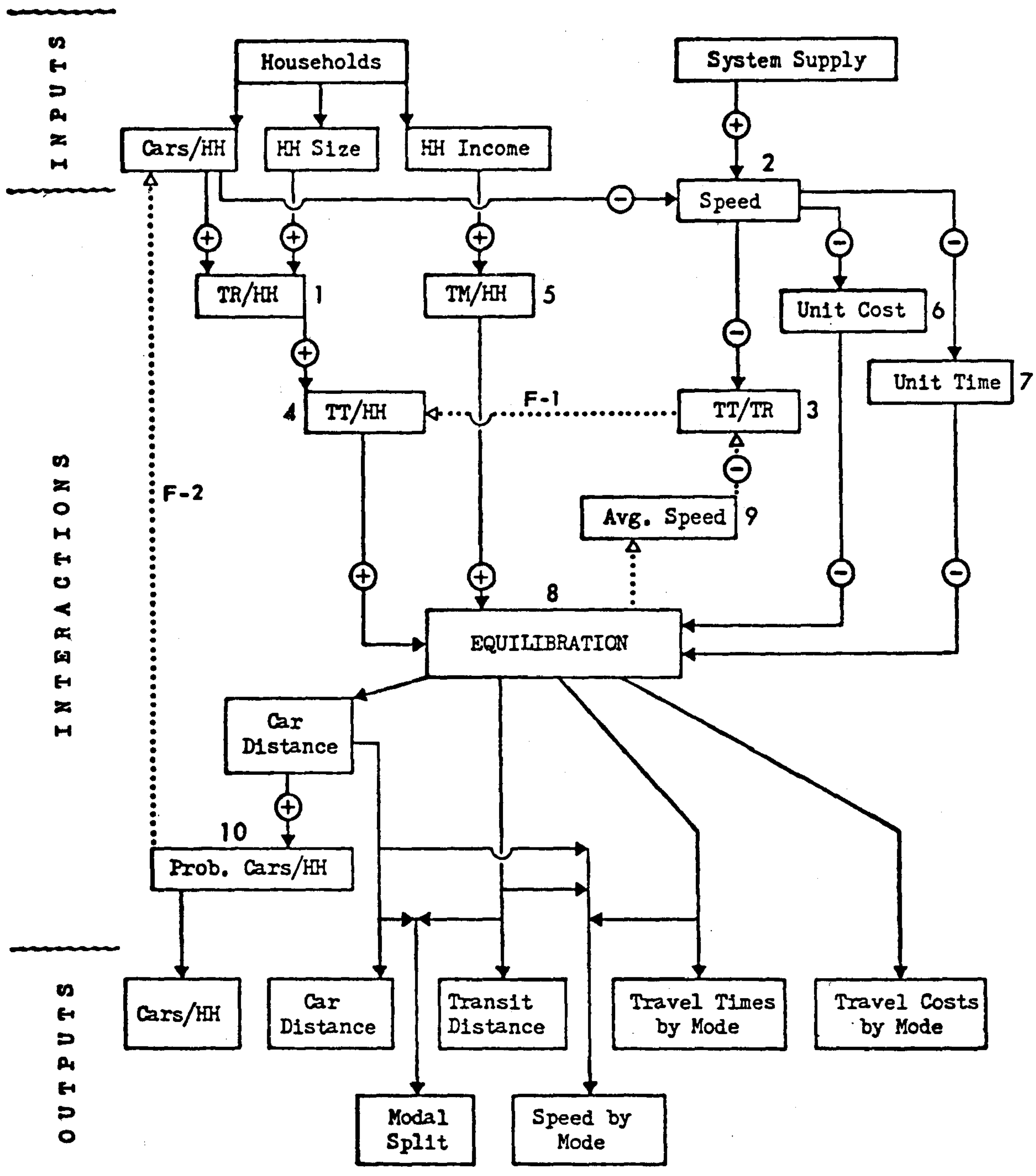


Figure 5.1-1 : Flow Chart of the Interactions between Travel Demand, System Supply and Car Ownership, the UMOT Model

⟶ Input/Output flow

5 Interaction. Effect of Input on Output is expressed by ⊕ or ⊖

⋯▷ Feedback

Table 5.1-1: Interactions between Travel Demand, Car Ownership and System Supply, 2-mode Case (Relationships and unit costs are for Washington, D.C. 1968)

INTER-ACTION	INPUT	PROCESS	OUTPUT
1	1. Household Size (HS) 2. Cars/Household (MOT)	$TR/HH = 0.403 + 0.337(HS) + 0.490(MOT)$;	Number of Travelers per Household (TR/HH)
2	1. Cars/HH (MOT) 2. No. of HH (N) 3. Daily Travel Time per Car (H) 4. α - Alpha value of the road network; Arterials ≃ 400,000 (α) 5. Road Network Length (L)	$v_n = \sqrt{\frac{(\alpha)(L)}{(MOT)(N)(H)}}$;	Daily Average Network Speed (v_n)
3	1. Network Speed (v_n) 2. Door-to-Door Speed: about 0.67 & 0.33 the network speed for car and transit respectively. Average d-d speed per HH has to be assumed and then iterated by feedback, as explained in Interaction F-1.	$TT/TR = 1.03 + \frac{2.18}{v_{avg.}}$;	Daily Travel Time per Traveler (TT/TR)
4	1. TR/HH 2. TT/TR	$T = (TR/HH)(TT/TR)$;	Daily Travel Time per Household (T). Regarded as a constraint on the amount of generated travel per household.
5	1. Daily Average Income per Household, as Annual Income/312 days of Travel (I/HH)	$M = 0.11(I/HH)$;	Daily Household Expenditure on Travel (M). Regarded as a constraint on the amount of generated travel per household.
6	1. Network Speed (v_n) 2. Car Occupancy (CO)	$c_c = \frac{1.494\, v_n^{-0.75}}{CO}$;	Cost/km of Car Passenger Travel (c_c) Given: Cost/km of Transit Passenger(c_t).
7	1. Network Speed (v_n)	$v_c = 0.67(v_n)$; (1) $v_t = 0.33(v_n)$; (2) $t_c = 60/v_c$; (3) $t_t = 60/v_t$; (4)	(1) Car Passenger d-d Speed (v_c); (2) Transit Passenger d-d Speed (v_t); (3) Car Passenger Travel Time/km. Minutes (t_c); (4) Transit Passenger Travel Time/km. Minutes (t_t).

Cont.

INTER-ACTION	INPUT	PROCESS	OUTPUT
8	1. The Time Constraint (T) 2. The Money Constraint (M) 3. Unit Costs (c_c, c_t) 4. Unit Times (t_c, t_t)	Solving two equations with two unknowns, D_c and D_t. $D_c c_c + D_t c_t = M$; $D_c t_c + D_t t_t = T$; $T_c = (D_c)(t_c)$; $T_t = (D_t)(t_t)$; $M_c = (D_c)(c_c)$; $M_t = (D_t)(c_t)$; $MS = \frac{D_t}{D_c + D_t} 100$;	(1) Daily Pass.Km. by Car (D_c) (2) Daily Pass.Km. by Transit (D_t) (3) Time Allocated for Car Travel (T_c) (4) Time Allocated for Transit Travel(T_t) (5) Money Allocated for Car Travel(M_c) (6) Money Allocated for Transit Travel (M_t) (7) Modal Split (MS)
9	1. D_c, D_t ; 2. t_c, t_t ;	$v_{avg.} = \frac{D_c + D_t}{t_c + t_t}$;	Average d-d Speed per Household $(v_{avg.})$
F-1	1. $v_{avg.}$ assumed in (3); 2. $v_{avg.}$ resulting from (9)	FEEDBACK The average speed assumed in Interaction 3 has to correspond with the average speed resulting from Interaction 9. If there is a significant difference between the two, say above 5 percent, substitute the later speed in (3) and iterate. Convergence is rapid.	
10	1. $D_c = \mu$; 2. Standard Deviation of $D_c = \sigma$; 3. Threshold of D_c for Car Ownership; 1, 2, 3+ (S_1).	$Prob(S_1) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{1}{2}\left[\frac{S_1 - \mu}{\sigma}\right]^2}$	(1) Probability of a Household to own 0, 1, 2, 3+ cars; (2) Product of Car Ownership Probability and Number of HH = Total Number of Cars.
F-2		FEEDBACK The estimated total number of cars interacts with system supply to result in speed. The whole process is repeated until travel demand, system supply and car ownership reach equilibrium. Convergence is rapid.	

The Alpha relationship expresses the basic interaction between speed and flow, but any other speed/flow relationship can be used instead. Nonetheless, the Alpha relationship appears to be preferable as it is based on the daily travel times of cars on the road network, which depend on the constraint of the daily travel time of car travelers.

It is to be noted at this stage that a distinction is made in the UMOT process between network time/speed, and door-to-door time/speed, the latter being based on the travel times reported by the respondents. The reason for this distinction is that travel behavior is based on the perceived door-to-door travel times (including access, waiting, in-vehicle, and egress times), while system performance is expressed by the measured, physical, speed.

(3) The equilibrium process is based on the assumption that travelers in representative households strive to maximize their utility from travel under their explicit constraints on travel. Only two constraints are considered at this stage, of time and of money. While these two constraints appear to explain a major part of travel behavior, it is quite possible that additional constraints will have to be added at a later stage. For instance, in many cities of developing countries a minimum daily travel distance per representative household/traveler appears to override the time and money constraints that are observed in cities of developed countries. (See Section 4.11).

The utility from travel may be expressed in various ways. Possibly the best way to express it is by the spatial opportunities that can be reached within the constraints. This involves both the number and variety of opportunities. A somewhat less satisfactory, but more practical, way may be to measure it by the maximum daily travel distance that can be generated within the constraints; the daily travel distance is not only easily measurable, but it is also the only common denominator for both travel demand and system supply, a prerequisite for the interactions between, and convergence of, travel demand and system supply. The fact that the model using travel distance maximization can reproduce observed relationships appears to provide strong evidence that this representation can be used as a surrogate for one based on opportunities.

Further advantages of using the daily travel distance is that the maximization process results in travel demand by distance, modal splits by distance, and the demand for car ownership, thus unifying three separate models within one process. Hence, the daily travel distance is used at this stage to express and measure the utility of travel.

(4) Perhaps the most unique characteristic of the UMOT process is the high ratio between the outputs and the inputs. This characteristic will become more obvious in the following exercises, but it can also be observed in Figure 5.1-1, where many different outputs, which in the current transportation models have to be derived by different models, are the results of one, integrated, process.

A principal concept behind the UMOT process is that travel demand, within the travel constraints, generates the demand for car ownership which, after interacting with the available system supply, results in speeds and unit costs of travel that affect travel demand, resulting in a closed system in an equilibrium condition. An additional loop, not yet shown in Figure 5.1-1, is the interactions of the above factors with urban structure, as discussed in Section 5.5.

The point to note, therefore, is that all the above factors interact by feedback within a closed system, thus making all factors sensitive and responsive to each other, as well as to exogenous policy options.

Although the policy options are not directly defined in Figure 5.1-1, they can enter the process through many doors. For instance, they can affect system supply, unit costs of travel, and availability of land for development. Furthermore, each major policy option can be further stratified, such as by affecting the unit costs of travel through changes in the car rest/operating costs, or the transit fares. The same also applies to travel speeds and land use regulations, all of which will affect the chain of travel demand - car ownership - system supply - urban structure - travel demand.

It is most useful now to move from general descriptions of the process to practical examples of its application.

The first, and perhaps the most important, part is the car ownership model, as it serves as a link between the demand for travel and system supply. Following the car ownership model are tests for the convergence of the UMOT process.

5.2 The UMOT Car Ownership Model

1. Introduction

This section presents an approach to, and the basic components of, a new car ownership model, which is closely interlinked with travel demand. A numerical exercise illustrates the technique for car ownership estimation, and several aspects and problems of the model are discussed. The Memorandum starts with a short overview of car ownership models (Fowkes, 1977).

One reason for the special interest in car ownership is that forecasts of the number of cars are required for several different purposes, which affect the choice of the models' underlying assumptions and techniques. For instance, car manufacturers want to know the potential market for sales and the car models which are likely to sell best. The approach in this case, therefore, is basically market research. Government agencies, on the other hand, are concerned primarily with the total number of vehicles, for which gasoline and road space have to be provided. The approach in this case is aggregate in nature, even if stratified by vehicle types or regions. Local authorities, however, want to know future car ownership down to the level of traffic zones, in order to estimate the demand for local road networks. The approach in this case is micro in nature and, as such, is the most demanding of all three approaches. This Memorandum deals specifically with the last approach.

The procedures for modeling car ownership can be divided into two broad approaches. The first is the extrapolation of past trends into the future under some constraints, as exemplified by the logistic or similar 'S' shaped functions. This approach leans heavily on time-series data, and is represented by the work of J.C. Tanner (1974).

The second approach is economic in nature, seeking the causal relationships that explain the household's decision to purchase a car, mostly on the basis of cross-sectional data. The techniques used in this case are many, including the derivation of demand functions through utility maximization under explicit constraints, as exemplified by the work of M.J. Beckmann (1972), or using maximization where the constraints are only implied through the use of variables such as income, as exemplified by the work of M. Ben-Akiva (1976).

In all these techniques, the variables and parameters are established by calibration to observed data, on the basis of multiple regression or category analysis. The variables considered in the causal relationships can be grouped under three main groups: (i) Socio-economic variables, such as income, household size, age and profession; (ii) Spatial variables, such as location, population density, transportation system supply and accessibility; and (iii) Taste variables, which are difficult to quantify and usually incorporate those influences on car ownership not accounted for by the former two variable groups (e.g., index of social status, which depends in part on the first two groups). A major problem in this approach is the multicollinearity between the many variables in the three groups.

In most urban travel demand model systems, the level of car ownership is estimated first by a separate model, and then introduced as an exogenous variable into the travel demand models, assuming that car ownership determines to a large extent the number of generated trips per household. In more advanced models, using disaggregate joint-choice formulations, car ownership and mode to work are estimated together, and are regarded as a 'medium-term' decision, which is then introduced into the 'short-term' trip-generation models as one of the variables.

It is agreed by many, however, that the order of cause-and-effect in all the available car ownership models is not yet fully resolved, as there are several possibilities: (i) car ownership affects trip rates; (ii) trip rates affect car ownership; (iii) socio-economic factors affect jointly the need for all trip generation and car ownership.

At this stage another problem becomes evident: trip rates represent travel demand in all travel demand models, although they may not be the best measure for the demand for travel. The problem is aggravated even more when introducing modal choice into the picture; in most models modal choice is strongly dependent on car ownership, but it could well happen that the reverse is true. Namely, if there is a certain amount of activity or travel which needs to be satisfied, and if 'n' hypothetical modes are available, the question is what are the proportions of mode usage that would satisfy the travel need of travelers in an 'optimal' way ?. Whatever the definition of 'optimal' is, travel, mode and car ownership choices have to be sensitive to each other within one framework, as the availability of only 'm' actual modes out of 'n' potential modes may affect the modal split and travel demand by a feedback process. However, this two-way effects is missing in most, if not all, operational car ownership models. Therefore, special attention to this problem is given in the following sections.

2. The Car Ownership Process

The starting assumptions and the required data for this model are relatively few, as follows:

(1) It is postulated that car ownership is affected, first and foremost, by the demand for car travel-distance. Hence, the UMOT car ownership is interlinked with the UMOT travel demand model.

This approach simplifies the car ownership model, both conceptually and computationally, since there is no duplication of variables in the car ownership and travel demand models : In operational models most of the variables in a separate car ownership model are also the variables in a travel demand model, while car ownership is then introduced as an additional variable into the travel demand model. Such car ownership models can rapidly become very cumbersome, and a recent disaggregate model includes 21 independent variables, which are used in different combinations for different population segments (Ben Akiva, 1976).

In the UMOT car ownership model, on the other hand, there is no duplication of variables, as it is based on the demand for travel resulting from the travel demand model, which also includes all travel cost variables. Thus, higher travel demand tends to increase the number of cars; which may increase travel costs; resulting in a reduced demand for cars. This feedback between travel demand and car ownership is further elaborated in Section 5.3.

(2) The second requirement for the UMOT car ownership model is the threshold of car travel-distance that will justify the purchase of a car. Eqs. (2.11-38 and 39) suggest that such a threshold can be identified explicitly on the basis of economic considerations. Since the coefficients in the above equations have not yet been finalized, some indications of its value have been derived empirically from the Nurenberg data, as detailed in Section 4.11.

It can be inferred from this figure that there are significant differences in the daily travel distance per household, even for households with the same size, of about 17-27 passenger-kilometers between 0-1 cars and 48-58 passenger-kilometers between 1-2+ cars. Thus, if the demand of a given household for car travel, as derived from the UMOT travel demand model, is within one of the three ranges, the household will be expected to behave accordingly. The problem, however, is that not all households, even of the same type, behave in exactly the same way, as discussed in the next section.

(3) The third requirement of the UMOT car ownership model is the distribution of travel behavior of individual households around their group's mean, as already mentioned in Section 3.7. Hence, the introduction of such distributions into the UMOT car ownership model (as well as into the travel demand model) defines the probability of a single household, on a disaggregate level, to behave in a certain way.

The only known fact about the travel time and distance distributions at this stage is that the coefficients of variation for different population segments are similar, and within a range of 0.5 - 1.0. It is also evident that these coefficients can be reduced to a large extent by further stratification of households, as mentioned above.

The last point is of special interest, as it can enable the analyst to test, by such techniques as discriminant analysis of the travel variables, which of household characteristics are significant in explaining travel behavior.

It can also be inferred that the distributions would be skewed to some extent, as there can be no negative values of time, money and distance, while there are no restrictions, at least not theoretically, on the positive values. Such distributions could probably be expressed by a Gamma function, or similar functions.

As can be seen from the above considerations, the requirements for the UMOT car ownership model are relatively few: (i) the demand for car travel, as an output from the travel demand model; (ii) the thresholds of car travel distance that would justify 0-1-2+ cars; and (iii) the coefficient of variations around the mean values of travel demand and, possibly, also around the mean thresholds.

Following is an exercise of car ownership estimation in Washington, D.C. 1968, based on the above information requirements, while the implications of this exercise and suggestions for further development of this type of model are presented in Chapter 6.

3. An Example

The data and assumptions for the exercise are as follows:

(1) The demand for car travel, by income levels, is as detailed in Table 4.10-1, and repeated here as Table 5.2-1.

(2) The thresholds for car ownership are assumed to be 14 passenger-kilometers per household for 1 car, and 55 pass.-km. per household for 2+ cars. As the coefficients in Eq.(2.11-38 and 39) are not yet known, the above values were borrowed from the Nurenberg data (Section 4.11) and adjusted to Washington, D.C..

Table 5.2-1 : Summary of Estimated Travel Demand per Household, by Income, Washington, D.C. 1968 (Times and speeds are door-to-door)

Annual Income, $	4,000	5,000	6,000	7,000	8,000	9,000	10,000	11,000
Cars/HH	-	(0.1)	0.35	0.71	1.02	1.29	1.54	1.76
TM-budget, $	0.51	0.75	1.24	2.01	2.82	3.17	3.53	3.88
TT-budget, hr.	2.02	2.02	2.09	2.20	2.29	2.41	2.53	2.63
CAR: v, kph.	13.5	15.0	16.0	19.0	21.0	24.0	26.0	28.0
c, $/km.	0.104	0.096	0.092	0.081	0.075	0.068	0.064	0.060
D, km.	0.02	2.39	8.40	19.74	34.14	42.38	50.81	60.59
TRANSIT: v, kph.	6.8	7.5	8.0	9.5	10.5	12.0	13.0	14.0
c, $/km.	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
D, km.	13.63	13.96	12.52	11.02	6.97	7.73	7.45	6.56
Total Distance	13.65	16.35	20.92	30.76	41.11	50.11	58.26	67.15

(*) The outputs in the case of two constraints and two modes result from a straightforward solution of two equations with two unknowns, without having to apply the maximization process.

(3) The coefficient of variation for the mean values of travel demand is 0.5 at all income levels. (Changing the coefficient from 0.5 to 0.8 changed the estimate of the first threshold negligibly, from 14 to 15 pass.km.);

(4) The variations follow a normal distribution (in order to simplify the calculations). Hence, the probability of a household owning a car can be estimated from the normal probability density function:

$$p(x) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{1}{2}\left[\frac{x-\mu}{\sigma}\right]^2} \quad ; \qquad (5.2\text{-}1)$$

where μ is the mean value and σ is the standard deviation. Thus, the probability of a household to own 1 car or more is the area under the probability density function between $x = 14$ and $x = \infty$.

The relevant data, assumptions and results, by income groups, are summarized in Table 5.2-2 for the case of Washington, D.C. 1968, and shown graphically in Figure 5.2-1.

Table 5.2-2 also includes the observed levels of car ownership for the same income groups, and it is evident that the estimated values follow closely the observed ones.

Table 5.2-2:
Car Ownership (based on a Normal Distribution), by District, Washington 1968

Annual Income, $	6,000	7,000	8,000	9,000	10,000
Car Pass.Km. (μ)	8.40	19.74	34.14	42.38	50.81
S.D. (σ) = $\frac{1}{2}(\mu)$	4.20	9.87	17.07	21.19	25.41
Prob. 1+ car (1)	0.10	0.72	0.881	0.910	0.926
Prob. 0 Car	0.90	0.28	0.119	0.090	0.074
Prob. 2+ Cars (2)	0.0	0.0	0.111	0.275	0.434
Prob. 1 car only	0.10	0.72	0.770	0.635	0.492
Avg. Car Ownership (3)	0.10	0.72	1.014	1.240	1.447
Observed Car Ownership	0.35	0.71	1.02	1.29	1.54

(1) Assuming 14 pass.km. as the minimum threshold for 1 car;
(2) Assuming 55 pass.km. as the minimum threshold for 2+ cars;
(3) Avg. car ownership = (Prob. 1 car) + 2.2(Prob. 2+ cars).

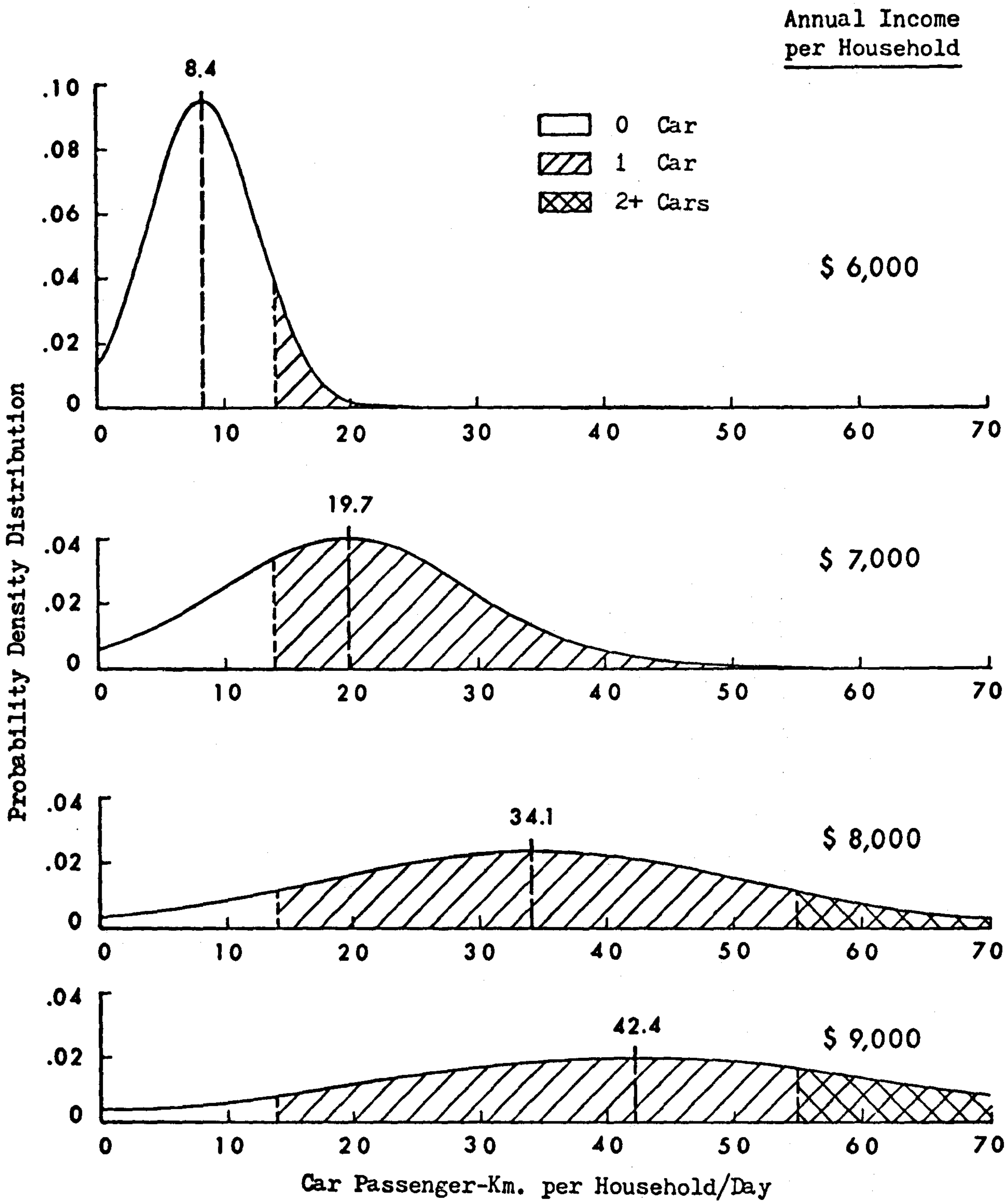


Figure 5.2-1 : Probability of Car Ownership per Household vs. Income, by District, Washington, D.C. 1968

Figure 5.2-2 shows how the estimated proportions of households owning 0-1-2+ cars change with income, a trend well known from observations.

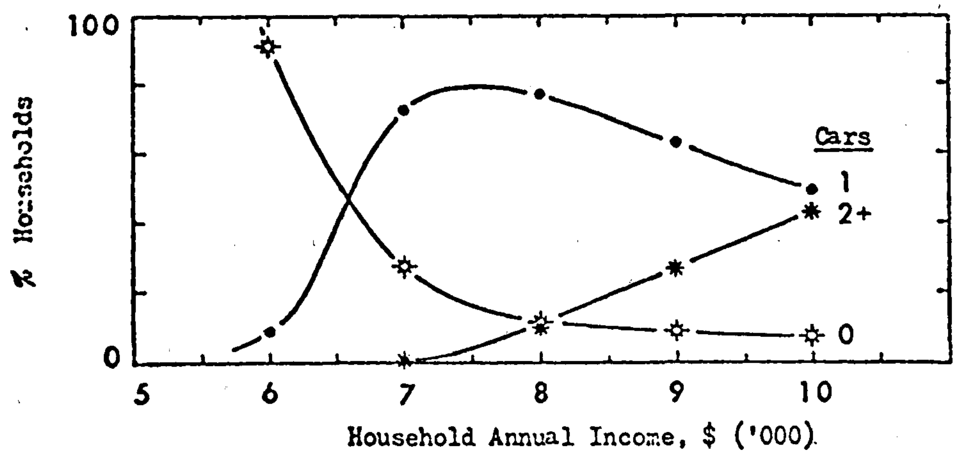


Figure 5.2-2 : Car Ownership vs. Household Income, by District, as Estimated by the UMOT Process, Washington, D.C. 1968

Although the above exercise appears to be very simple, based on a minimum amount of data and assumptions, it touches upon the basic foundation of travel understanding. The reason is that calibrating a model to the same observations that it is asked to reproduce is a self-fulfilling process, and practically every model which is even mildly reasonable will reproduce the observations. Thus, the ability of this type of model to reproduce the observations cannot be used as proof for its validity. A more promising approach for testing the validity of a behavioral model is by basing it upon the constraints under which decisions are made, and testing whether the estimated choices correspond with the observed ones.

Indeed, the above exercise is based on the constraints, and not on the final choices: (i) the behavioral constraints of time and money, interacting with the exogenous unit costs of travel (representing the modes and their system supply) resulted in the expected demand for the total travel distance and its split by mode; (ii) the estimated demand for car travel was then used to derive the expected car ownership levels. The validity of the model can then be tested by comparing its estimated choices of travel demand and car ownership with the observed ones.

It is quite obvious that one simple exercise is far from proving the correctness of the approach. Nonetheless, when coupled with the theoretical tests of the model for its validity by economic criteria, as detailed in Chapter 2, the exercise suggests that the the approach is sound and promising.

It should be noted at this stage that one important factor is still missing from the above exercise, namely the effects of system supply. System supply is one of the essential links for the feedback process between travel demand - car ownership - system supply - travel demand. As already noted above, travel demand and modal split, both expressed by travel distance, depend on the unit costs of travel and the travel constraints. Let us now assume that income increases, thus also increasing the travel money budgets, generating more demand for travel-distance by car, resulting in more cars. If, however, system supply will not be increased in concert, it is obvious that congestion - and unit costs of travel - will increase as well, thus serving as a restraining factor on travel demand and, hence, on car ownership. This process is evident not only from time-series data, but also from cross-sectional data; two households, with the same characteristics, will generate different amounts of travel demand and car ownership if one resides in the city center, while the other resides in the suburb, depending much on the different unit costs of travel in the two locations, as affected by system supply.

This point raises an interesting question with respect to the above exercise; the exercise was based on average incomes, without specifying the residence location of households. Hence, if the UMOT model is to be sensitive to locational factors, it has to include the housing-job factor as well, in addition to system supply, as there are strong indications to suggest that there is a trade-off between the travel and the housing money budgets. This part of the UMOT is discussed in Section 5.5.

One reflection on the above subject is worth mentioning at this stage; each probability density function shown in Figure 2.5-1 is a composite of households owning and not owning cars. However, once the probability of a household to own a car is estimated, the distribution of travel distance can be divided into two separate distributions, namely higher travel distance for car owning households and lower travel distance for non-car households (e.g., Figure 4.11-4). Thus, the households will strive to locate their residence at a spatial point in the city where they will be able to maximize their travel utilities, such as maximizing the spatial opportunities, within their travel distance. Put another way, part of the variations about the mean values of travel demand appear to reflect locational choice, which can then link travel demand, system supply and urban structure by a feedback process.

The last point of interest is the derived value of travel time, as estimated from the UMOT car ownership model. Eq.(2.11-38) in Chapter 2 is repeated again:

$$x_o \geqslant \frac{p}{\frac{\xi'(T)}{\psi'(Y)}\left(\frac{1}{v_2} - \frac{1}{v_1}\right) + (c_2 - \bar{c}_1)} \quad ; \qquad (5.2\text{-}2)$$

where: x_o - the distance traveled by car to justify car ownership;

p - fixed costs of owning a car;

v_2 - travel speed by transit;

v_1 - travel speed by car;

c_2 - travel cost by transit/km.;

$\bar{c}_1$ - travel cost by car/km.;

$\frac{\xi'(T)}{\psi'(Y)}$ - the (marginal) value of travel time.

It is now possible to derive the value of travel time from Eq.(5.2-2) by assuming that x_o = 14 passenger-km., as applied in the above exercise for Washington, D.C. 1968 (and based on empirical data from the Nurenberg region 1975). Table 5.2-3 details the results, showing that the value of travel time increases from $ 2.24 per hour at an annual household income of $ 6,000 to $ 3.03 per hour at an annual household income of $ 11,000, namely an increase in the value of time with income at a decreasing rate.

Table 5.2-3: The Value of Travel Time, as Derived from the UMOT Car Ownership Model, Washington, D.C. 1968 (1)

HH Annual Income $	Door-to-Door Speed, kph.		Operating Cost per km., ¢ (2)		Value of Time $/hr.	HH Daily Income $ (3)	Proportion of Value of Time vs. Daily Inc.%
	Car	Transit	Car	Transit			
6,000	16.0	8.0	9.2	3.73	2.24	19.2	11.7
7,000	19.0	9.5	8.1	3.73	2.45	22.4	10.9
8,000	21.0	10.5	7.5	3.73	2.59	25.6	10.1
9,000	24.0	12.0	6.8	3.73	2.79	28.9	9.7
10,000	26.0	13.0	6.4	3.73	2.98	32.1	9.3
11,000	28.0	14.0	6.0	3.73	3.03	35.3	8.6

(1) District averages;
(2) Cost per pass.km.; Daily fixed cost per car = $ 1.21;
(3) Based on 312 days/year.

It is of interest to compare these values with the average values derived by a sophisticated disaggregate model, calibrated for Washington, D.C. 1968 (Ben-Akiva, 1976).

Value of In-Vehicle Time = $ 2.75/hr.
Value of Out-of-Vehicle Time = $ 3.65/hr.

with the total average value being near the former than the latter.

Thus, the values of the two estimates are both within the same magnitude and similar to values derived by previous detailed mode choice models.

* * *

5.3 Convergence of the UMOT Process

A demanding test of the UMOT process is its ability to converge rapidly, especially if it is to be computerized. Such preliminary tests are carried out in this section.

The exercises relate at this stage to hypothetical cities, in order to test the interactions and their convergence under controlled conditions. Nonetheless, although the exercises relate to hypothetical cities, the values used are real, mostly based on the relationships observed in Washington, D.C. 1955 and 1968, and Twin Cities 1958 and 1970. It is to be noted that only the relationships that were found to be transferable both between the two cities and over time are applied in the exercises, such as the number of travelers per household, or the daily travel time per traveler, as detailed in Table 5.1-1. Household size in the exercises is assumed to be the same, at 3 persons per household.

The exercises are ranked by their complexity, as detailed below.

The convergence of travel demand - car ownership - system supply was tested by carrying out several exercises of increasing complexity, as convergence is an important attribute of this model. The first example is for a hypothetical city with the following starting assumptions:

Households - 100,000
Household annual income - $ 6,000
Household daily expenditure on travel - 11 percent of daily income (312 travel days per year)
Car ownership - 1.5 cars/HH
Car occupancy - 1.5
Arterial network length - 200 km.
Alpha value - 400,000
Daily average network speed - 40 kph.
Car TT-budget - 0.80 hr.

Table 5.3-1 details the results of the calculations, where convergence is reached after three iterations. It becomes evident from the results that the starting assumptions of car ownership and speed, 1.5 and 40 kph. respectively, are too high, and that convergence is reached at about 0.8 cars/HH and a daily average speed of 34 kph.

The second test is similar to the above exercise, where the only difference is in the household annual income, this time $ 8,000. The results of this test are detailed in Table 5.3-1.where convergence is reached after two iterations. This time, however, equilibrium is reached at a car ownership level of 1.03 cars/HH and a network speed of 30 kph.

In the third test, the 100,000 households were divided into two equal groups, with annual incomes of $ 6,000 and $ 8,000. The convergence in this case (not shown in Table 5.3-1 was reached after 2 iterations, with car ownerships of 0.79 and 1.04 respectively, and a network speed of 32 kph.

In the fourth test the population in the above city was doubled; to 100,000 households with an annual income of $ 6,000, and 100,000 households with an annual income of $ 8,000, as detailed in Table 5.3-1. It was also assumed that households of both groups have equal opportunity for traveling at the same network average speed.

Convergence in this case was reached after 2 iterations, with car ownerships of 0.73 and 0.90 respectively, while the network speed dropped down to 24 kph. The implications of the above results are discussed in Section 5.4.

In the last test, the hypothetical city was expanded to include households of four income levels, as follows:

$ 4,000	- 50,000	households
$ 6,000	-100,000	"
$ 8,000	-100,000	"
$10,000	- 50,000	"
Total	300,000	households

and an arterial network of 400 km.

Table 5.3-1 : Convergence of Travel Demand and Car Ownership for a Given System Supply
Households = 100,000; Arterial Network = 200 km.

HH Income $	6,000				8,000			START			ITERATION 1			ITERATION 2		
Iteration	Start	1	2	3	Start	1	2	6,000	8,000	Total	6,000	8,000	Total	6,000	8,000	Total
Cars/HH	1.50	0.72	0.81	0.80	1.50	1.06	1.00	0.80	1.03	0.91	0.71	0.88	0.79	0.74	0.91	0.82
Cars	150,000	72,200	81,020	79,580	150,000	106,300	100,020	80,200	102,580	182,790	71,200	87,580	158,780	73,600	91,140	164,740
TR/HH	2.15	1.77	1.81	1.81	2.15	1.93	1.90	1.81	1.90		1.76	1.85		1.78	1.86	
$Speed_{net}$	40.00	36.11	34.08	34.39	40.00	29.76	30.68	22.69	22.69	22.69	24.35	24.35	24.35	23.90	23.90	23.90
$Speed_c$	26.67	24.07	22.72	22.93	26.67	19.84	20.45	15.13	15.13		16.23	16.23		15.93	15.93	
$Speed_t$	13.33	12.03	11.36	11.47	13.33	9.92	10.23	7.57	7.57		8.12	8.12		7.97	7.97	
$Speed_{avg.}$	17.3	18.0	17.0	17.1	20.7	17.4	18.1	12.0	13.7		13.0	15.0		12.7	14.7	
$Time_c$, min.	2.25	2.49	2.64	2.62	2.25	3.02	2.93	3.97	3.97		3.70	3.70		3.77	3.77	
$Time_t$, min.	4.50	4.99	5.28	5.23	4.50	6.05	5.87	7.93	7.93		7.39	7.39		7.53	7.53	
$Cost_c$, $	0.063	0.068	0.071	0.070	0.063	0.078	0.076	0.096	0.096		0.091	0.091		0.092	0.092	
$Cost_t$, $	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037		0.037	0.037		0.037	0.037	
TT/TR, hr.	1.16	1.15	1.16	1.16	1.14	1.16	1.15	1.20	1.20		1.20	1.18		1.20	1.18	
TT/HH, hr.	2.49	2.04	2.10	2.10	2.45	2.24	2.19	2.19	2.28		2.11	2.18		2.14	2.20	
TC/HH, $	2.12	2.12	2.12	2.12	2.82	2.82	2.02	2.12	2.82		2.12	2.82		2.12	2.82	
$Dist._c$	19.84	24.44	23.53	23.84	36.04	33.56	34.58	19.43	28.16		20.50	29.89		20.24	29.55	
$Dist._t$	23.21	12.38	12.13	12.18	14.58	5.48	5.11	6.85	3.16		6.88	2.75		6.92	2.74	
$Dist._{tot.}$	43.05	36.82	35.66	36.02	50.62	39.04	39.69	26.28	31.32		27.38	32.64		27.16	32.29	
Prob. Car 0	0.278	0.197	0.209	0.204	0.111	0.121	0.117	0.288	0.159		0.264	0.145		0.268	0.147	
Prob. Car 1	0.722	0.797	0.787	0.791	0.744	0.778	0.764	0.712	0.812		0.736	0.808		0.732	0.810	
Prob. Car 2+	-	0.006	0.004	0.005	0.145	0.101	0.119	-	0.029		-	0.047		-	0.043	
Cars	72,200	81,020	79,580	80,200	106,300	100,020	102,580	71,200	87,580	158,780	73,600	91,140	164,740	73,200	90,460	163,660
Cars/HH	0.72	0.81	0.80	0.80	1.06	1.00	1.03	0.71	0.88	0.79	0.74	0.91	0.82	0.73	0.90	0.82
$Speed_{net}$	36.11	34.08	34.39	34.26	29.76	30.68	30.29			24.35			23.90			23.98

Convergence in this case was reached after 3 iterations, as detailed in Table 5.3-2. The rapid convergence to equilibrium conditions suggest the robustness of the process. Of special interest is the significant divergence of the four household groups by car ownership, daily average speed, daily travel distance, and modal splits by distance within the equilibrium condition.

The convergence of the total number of cars versus network speed is shown in Figure 5.3-1 This figure also shows iteration number 4, although the numerical difference between iteration 4 and 3 is insignificant, at about 1 percent only.

It is to be noted at this stage that the results of all the above exercises are intermediate only, as they do not yet relate to urban structure. This subject is discussed in Section 5.5 .

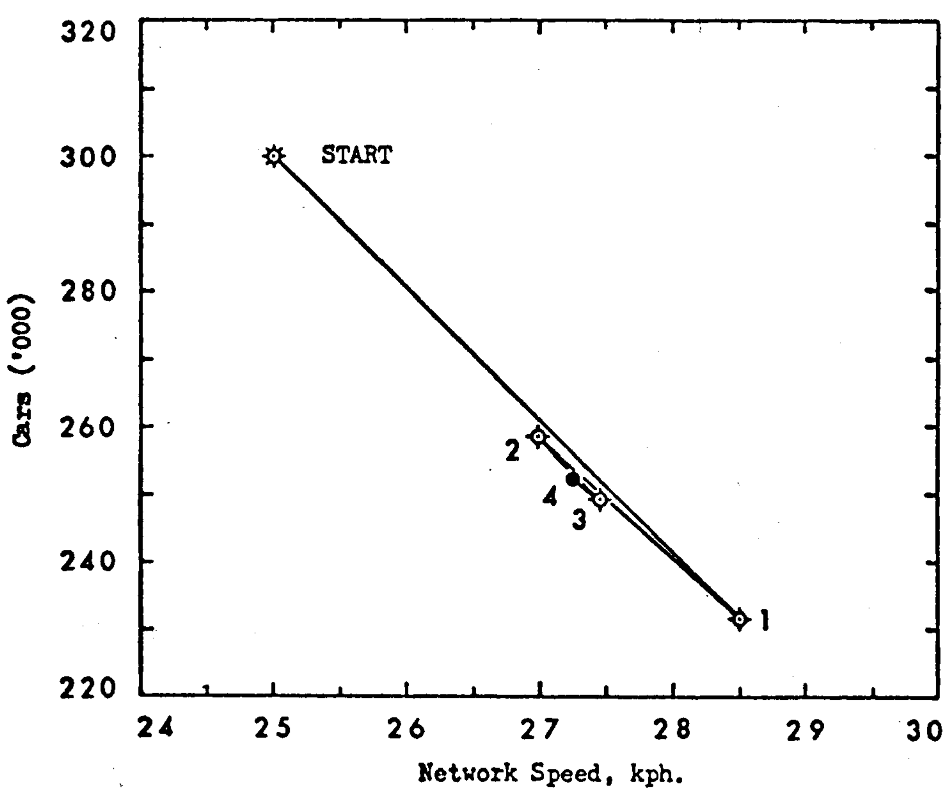


Figure 5.3-1 : Convergence by Iterations, Number of Cars vs. Speed for a Given Arterial Network

Table 5.3-2 : Convergence of Travel Demand and Car Ownership for a Given System Supply

Arterial Network = 400 km.

Iteration	START					ITERATION 1				
HH Income $	4,000	6,000	8,000	10,000	Total	4,000	6,000	8,000	10,000	Total
Households	50,000	100,000	100,000	50,000	300,000	50,000	100,000	100,000	50,000	300,000
Cars/HH	1.00	1.00	1.00	1.00		0.17	0.73	0.92	1.17	
Cars	50,000	100,000	100,000	50,000	300,000	8,650	72,600	91,920	58,360	231,530
TR/HH	1.90	1.90	1.90	1.90		1.50	1.77	1.87	1.99	
$Speed_{net.}$					25.05					28.51
$Speed_c$					16.70					19.01
$Speed_t$					8.35					9.51
$Speed_{avg.}$	10.35	12.75	15.17	16.70		12.95	14.80	17.09	19.01	
$Time_c$, min.					3.59					3.16
$Time_t$, min.					7.19					6.31
$Cost_c$, $					0.0890					0.0810
$Cost_t$, $					0.0373					0.0373
TT/TR, hr.	1.25	1.20	1.17	1.16		1.20	1.18	1.16	1.15	
TT/HH, hr.	2.38	2.28	2.22	2.20		1.80	2.09	2.17	2.28	
TC/HH, $	1.41	2.12	2.82	3.53		1.41	2.12	2.82	3.53	
$Dist._c$	9.51	20.04	30.25	39.66		12.39	22.14	32.92	43.58	
$Dist._t$	15.11	9.02	3.42	-		10.92	8.80	4.16	-	
$Dist._{tot.}$	24.62	29.06	33.67	39.66		23.31	30.94	37.08	43.58	
Prob. Car 0	0.83	0.27	0.14	0.10		0.60	0.13	0.13	0.09	
Prob. Car 1	0.17	0.73	0.81	0.68		0.40	0.77	0.79	0.61	
Prob. Car 2+	-	-	0.05	0.22		-	-	0.09	0.30	
Cars	8,650	72,600	91,920	58,360	231,530	19,850	77,040	98,300	63,710	258,900
Cars/HH	0.17	0.73	0.92	1.17	0.77	0.40	0.77	0.98	1.27	0.86
$Speed_{net.}$					28.51					26.96

Iteration	ITERATION 2					ITERATION 3				
HH Income $	4,000	6,000	8,000	10,000	Total	4,000	6,000	8,000	10,000	Total
Households	50,000	100,000	100,000	50,000	300,000	50,000	100,000	100,000	50,000	300,000
Cars/HH	0.40	0.77	0.98	1.27	0.86	0.34	0.76	0.95	1.23	0.83
Cars	19,850	77,040	98,300	63,710	258,900	16,850	75,800	95,440	61,420	249,510
TR/HH	1.61	1.79	1.89	2.04		1.58	1.79	1.88	2.02	
$Speed_{net.}$					26.96					27.47
$Speed_c$					17.97					18.31
$Speed_t$					8.99					9.16
$Speed_{avg.}$	11.94	14.02	16.17	17.89		12.25	14.32	16.56	18.31	
$Time_c$, min.					3.28					3.28
$Time_t$, min.					6.55					6.55
$Cost_c$, $					0.0830					0.0830
$Cost_t$, $					0.0373					0.0373
TT/TR, hr.	1.21	1.19	1.17	1.15		1.21	1.18	1.16	1.15	
TT/HH, hr.	1.95	2.13	2.21	2.35		1.91	2.11	2.18	2.32	
TC/HH, $	1.41	2.12	2.82	3.53		1.41	2.12	2.82	3.53	
$Dist._c$	11.57	21.50	31.79	41.93		11.78	21.77	32.28	42.53	
$Dist._t$	11.71	8.36	3.93	0.12		11.61	8.44	3.82	-	
$Dist._{tot.}$	23.28	29.86	35.72	42.05		23.39	30.21	36.10	42.53	
Prob. Car 0	0.66	0.24	0.13	0.09		0.65	0.24	0.13	0.09	
Prob. Car 1	0.34	0.76	0.80	0.64		0.35	0.76	0.79	0.63	
Prob. Car 2+	-	-	0.07	0.27		-	-	0.08	0.28	
Cars	16,850	75,800	95,440	61,420	249,510	17,700	76,200	96,700	62,300	252,900
Cars/HH	0.34	0.76	0.95	1.23	0.83	0.36	0.76	0.97	1.25	0.84
$Speed_{net.}$					27.47					27.28

5.4 Demand versus Supply

1. The convergence of travel demand and car ownership in the above exercises is for a given system supply. Hence, the iterations move along the supply curve, as shown in Figure 4.1. The two examples are the two separate cases detailed in Section 5.3 for households with annual incomes of $ 6,000 and $ 8,000 respectively.

The supply curve is for an arterial network of 200 km., as derived from the relationship:

$$v_n = \frac{\alpha L}{K} \quad ; \qquad (5.4\text{-}1)$$

where:

v_n - daily average network speed, kph. (Shown as $t = \frac{1}{v_n} 60$ in Figure 5.4-1).

L - road network length, km.;

α - Alpha value; for arterials = 400,000;

K - daily Car-Kilometers.

Figure 5.4-1 is based on the unit cost of time per kilometer.

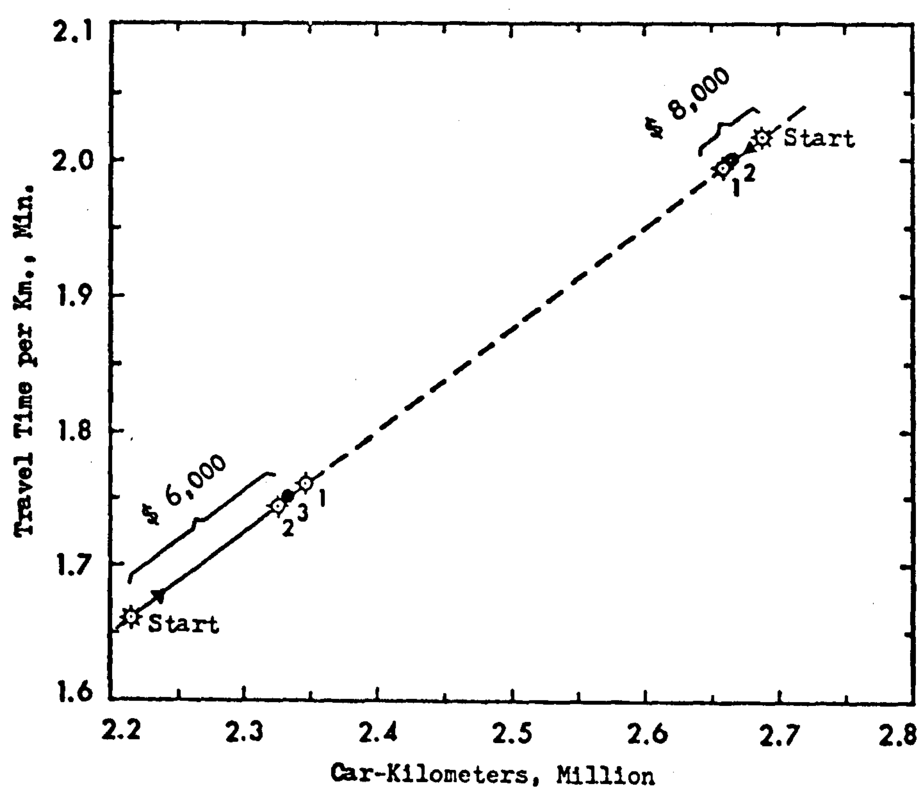


Figure 5.4-1 : Two examples of the Convergence of Travel Demand with System Supply. The system supply relationship is for an arterial network of 200 km. The two examples are of 100,000 households with an annual income of $ 6,000 and $ 8,000.

It can be inferred from Figure 5.4-1 that the equilibrium point of the supply curve is the point where travel demand is in equilibrium with system supply. Thus, while the demand curve is not yet calculated, the iterations search for the intersection point between travel demand and system supply along the supply curve.

2. The demand curve can be derived by changing system supply for a given household group. Such an exercise is summarized in Table 5.4-1 and shown in Figure 5.4-2.

Table 5.4-1: The Effect of System Supply on Travel Demand. Households - 100,000; Household Annual Income - $ 8,000; Arterial Road Network - 50 to 400 km.

Road Network Length, km.	Cars/HH	Cars	Network Speed, kph	Minutes per km.	Car-Km. ('000)	Km. per Car per Day	Daily TT/Car 30 km., hr.
50	0.79	79,200	17.24	3.48	1,160.1	14.6	2.05 (*)
100	0.91	91,320	22.70	2.64	1,762.1	19.3	1.55 (*)
200	1.03	102,580	30.29	1.98	2,641.1	25.8	1.17
300	1.09	109,100	35.97	1.67	3,336.1	30.6	0.98
400	1.15	114,720	40.50	1.48	3,949.6	34.4	0.87

(*) See comments in Section (3)

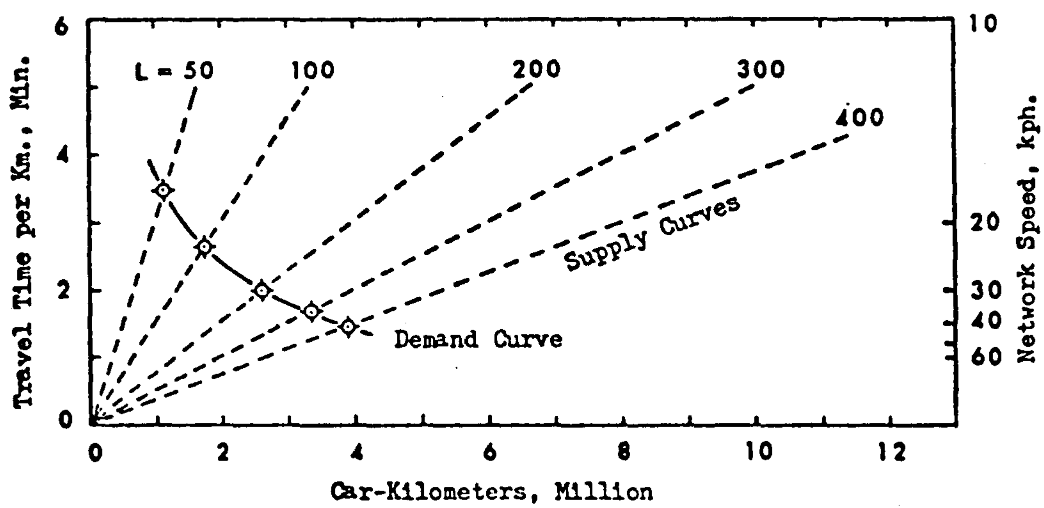


Figure 5.4-2 : Travel Demand vs. System Supply. 100,000 households with an annual income of $ 8,000.

It becomes evident from Figure 5.4-2 that the travel demand curve is of the conventional downward-sloping form, suggesting that the demand for car travel-distance increases with a decrease in travel time. Of particular interest is the result that the elasticity of car travel distance vs. travel time is above unity; a one percent reduction in travel time generates about 1.4 percent increase in travel distance, thus suggesting that there is a strong incentive to increase travel distance when speeds increase (*).

One way of taking advantage of a better road network is to increase the travel opportunities, and it appears that this can be achieved best - within the households' travel constraints - by increasing their car ownership levels. For example, and as detailed in Table 5.4-1, increasing the arterial network from 50 to 400 km. results in an increase in network speed from 17.2 to 40.5 kph., and in an increase in car ownership from 0.79 to 1.15 cars/HH respectively.

The interrelationships between the above factors are shown in Figures 5.4-3 to 5.4-5: Figure 5.4-3 shows how speed increases with system supply. The speed increases at decreasing rates, since each speed increment encourages car ownership, resulting in more cars, which then inhibit speed. The same basic trends are also apparent in Figure 5.4-4 for car ownership vs. system supply, and in Figure 5.4-5 for car ownership vs. speed.

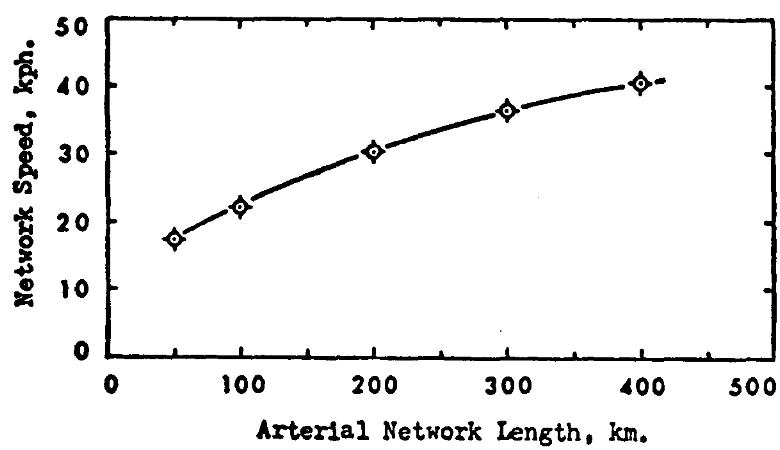


Figure 5.4-3 : Network Speed vs. System Supply, 100,000 household with an annual income of $ 8,000

(*) e.g., a decrease in travel time from 3.48 to 1.48 minutes/km. resulted in an increase in car-kilometers from 1.16 to 3.95 million.

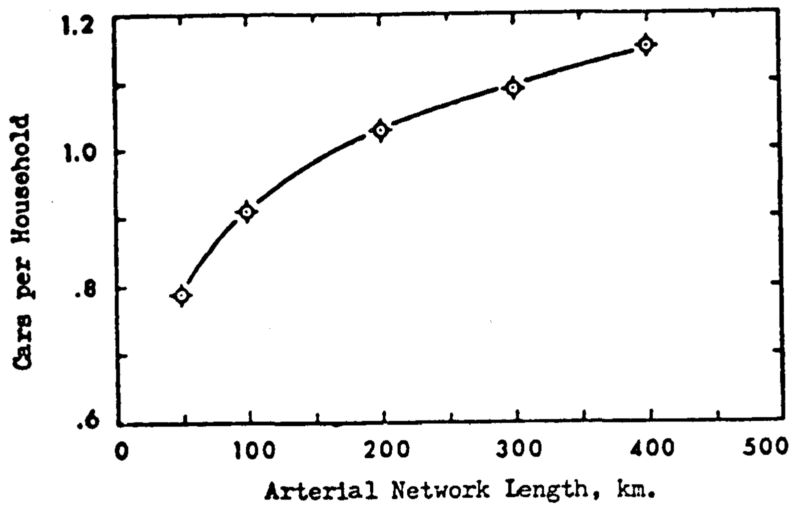


Figure 5.4-4 : Car Ownership vs. System Supply, 100,000 households with an annual income of $ 8,000

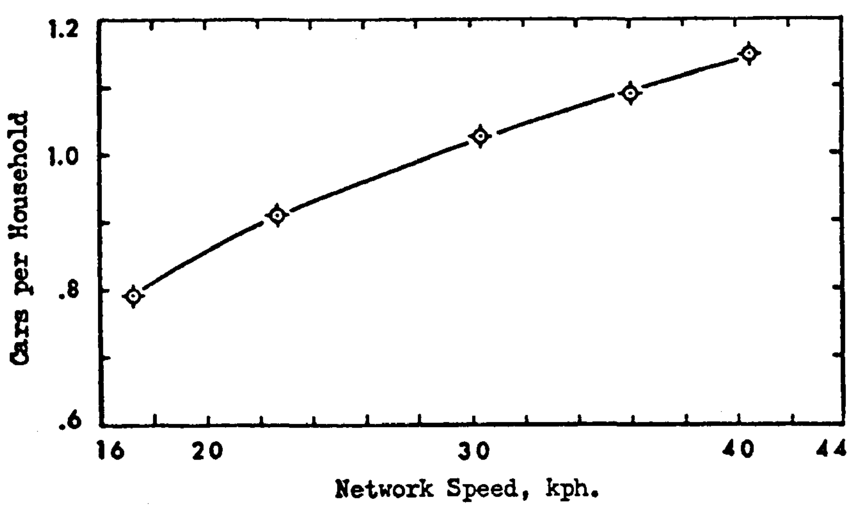


Figure 5.4-5 : Car Ownership vs. Network Speed. Household annual income $ 8,000.

While the above relationships are well known qualitatively, it is significant to note that they may be derived quantitatively through the UMOT process.

3. Table 5.4-1 also includes the daily travel distance per average car, which increases from 14.6 km. to 34.4 km. for alternative system supply. However, it was already noted that the daily travel distance per average car is very stable, at about 30 km., in a wide range of cities, small and large, compact and dispersed (Sec. 4.11). It may, therefore, be inferred

that the results of the cases of system supply of 50 and 100 km. are not practical; either the estimated car ownership levels are too high, or car travelers will spend more time and money than assumed. For instance, the daily travel times per average car required to travel 30 km. are shown for the above cases in the last column in Table 4.1, where it becomes evident that the travel times for the first two cases are beyond those actually observed in cities.

These results suggest that an important factor/s is still missing in the above exercises, such as urban structure and/or an additional constraint on car ownership. This subject is further discussed in Section 5.5.

This discussion provides a preliminary exploration of the possible interaction of the travel demand and system supply characteristics with urban structure, utilizing a new approach to the subject of population distributions in urban areas.

5.5 Urban Structure

1. One of the assumptions in the above exercises was that all households, at all income levels, have equal speed opportunities. However, this assumption has to be amended now, by introducing the following consideration: as shown in Table 5.3-2, the probability of a household in income group $ 4,000 to own a car is 0.36. Namely, 64 percent of all households in this group will not own a car and, hence, they will have to depend on modes other than a car, such as transit and walking. These households then change the starting assumptions in several ways. First, their money expenditure on travel will be far less than the assumed upper-level of 11 percent, since their allocated time for travel will be spent much before they reach even half of the money constraint. This factor will lower the average money constraint for the $ 4,000 group, thus further reducing car ownership. Because of this factor, an additional iteration process may have to be introduced into the model.

Second, the average speed of households not owning a car will be appreciably lower than the average speed of households owning a car; they no longer have the same opportunities as high income households for travel speeds.

Third, as a result from the above factors, such households will tend to locate their residence at locations that have high densities of opportunities, or travel to and from locations which are served by relatively good transit service. As both the above two requirements are best met at or near the city center, the residence location of such households will tend to be located near the city center. Put another way, low income households, with low car ownership levels, have less choice of residence location than high income households, as they either have to depend on the availability of public transport for their travel, or reside at a location where there is less need for motorized travel. Car owning households, on the other hand, have a wider freedom of residence location choice.

The above considerations are tested in the following exercises, which relate to cities under equilibrium conditions, mostly in developed countries. It is to be noted that the exercises are based on travel considerations only, while the housing market and bid-rent functions are beyond the scope of this study.

2. Referring back to the exercise detailed in Table 5.3-2, it was shown that the household average door-to-door speed depends on income, namely:

$ 4,000 - 12.3 kph;
$ 6,000 - 14.3 kph
$ 8,000 - 16.6 kph
$10,000 - 18.3 kph

The average speeds result from different proportions of car and transit travel, where each mode has its own area-wide constant speed, regardless of location within the city. However, speeds do change by location, depending on such factors as road-network and car-travel densities.

In the following exercise, based on simplified assumptions - some of which are borrowed from actual observations in various cities - a test of the spatial differentiation of households by their travel characteristics is made. The two starting assumption are:

(1) The road density decreases as a negative power function of distance from the city center;

(2) The accumulation of car travel distance is a linear function of distance from the city center within the urban area. (Zahavi, 1979-b).

Thus, by dividing the city into rings, the network speed in each ring can be derived by the Alpha relationship. The results of this procedure are shown in Figure 5.5-1, where the network speed increases with distance from the city center. The door-to-door speeds of car and transit travelers are then derived from the network speed, based on the proportions mentioned in Interaction 3 in Table 5.2-1.The average door-to-door speed by distance from the center can then be derived from the last two speed curves, assuming that households residing near the center travel mostly by transit, while households residing at the edge of the urban area travel mostly by car.

The last step is to superimpose the households' average door-to-door speeds of each income group, as derived and detailed in Table 5.2-1,on the average door-to-door speed curve in Figure 5.5-1, based on the assumption that households tend to locate their residences at the point on the speed gradient which equals their average speed.

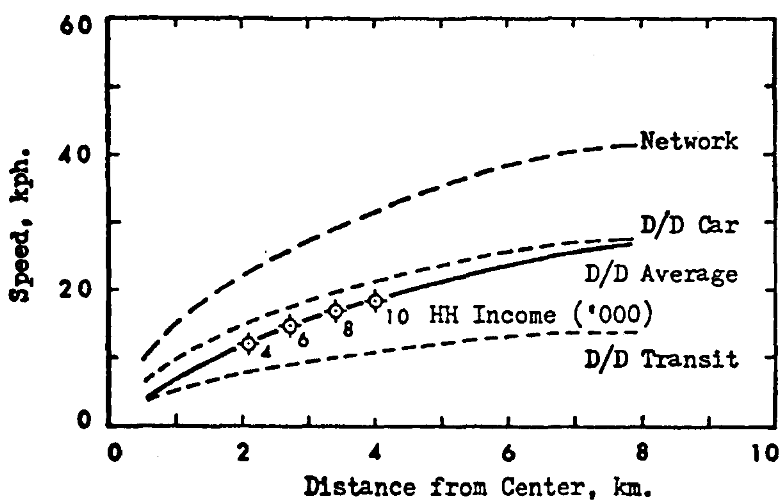


Figure 5.5-1: Household Location from the City Center, by Annual Income, after Superimposing the Daily Average (D/D) Speed on the Average Speed Gradient

Thus, households with different incomes will tend to reside at different distances from the city center under equilibrium conditions. However, not all households, even within each income group, are exactly the same, as they differ by household size and structure, car ownership, and personal tastes and preferences, all of which may affect residence location. As these factors, especially the personal ones, are difficult to capture and express in the car ownership and travel demand models, distributions around the mean values are utilized and assumed to vary in the same way as they were applied in the car ownership model. (Put another way, the distributions of travel distance, as described in Section 5.2 , already represent the influence of such factors). Hence, it is assumed that the same coefficient of variation relating to the distribution of travel distances - namely, 0.5 - also applies to residence location.

The results of these assumptions are summarized in Table 5.5-1 and shown in Figure 5.5-2.

Table 5.5-1: Probability Density Distributions of Household Location from the City Center, by Annual Income

Annual Income, $	4,000	6,000	8,000	10,000	Total	Avg. Income
μ	2.10	2.70	3.40	4.00		
σ	1.05	1.35	1.7	2.00		
Distance, km.	P R O B A B I L I T I E S					
0 - 1	.1190	.0783	.0548	.0432	.2952	6,360
1	.3227	.1991	.1257	.0913	.7388	6,210
2	.3533	.2923	.2040	.1506	1.0002	6,480
3	.1562	.2479	.2343	.1934	.8318	7,060
4	.0279	.1215	.1904	.1934	.5332	7,750
5	.0020	.0344	.1094	.1506	.2964	8,350
6		.0056	.0445	.0913	.1414	8,840
7		.0005	.0128	.0431	.0564	9,210
8			.0026	.0159	.0185	9,510
9 - 10			.0004	.0045	.0049	9,700

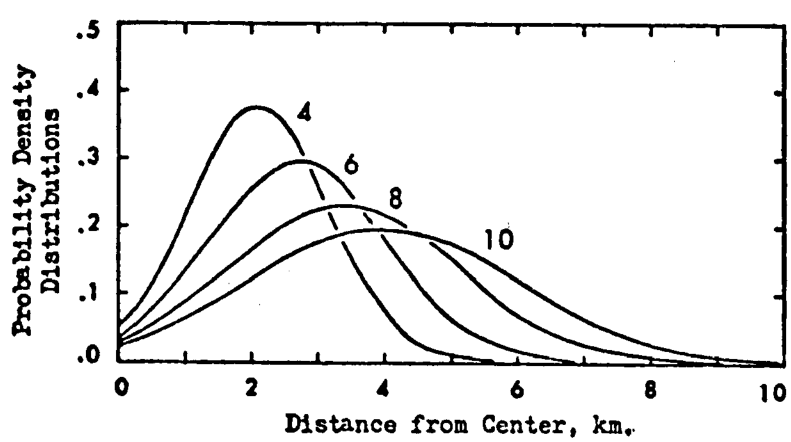


Figure 5.5-2 : Probability Density Distribution of Household Location, by Annual Income ($ '000) vs. Distance from the City Center (Example 1)

The curves represent the probability density distributions of households with different income levels to reside at different distances from the city center. Figure 5.5-3 shows the sum of the probability curves by distance, expressing the total (unweighted) population distribution in the city.

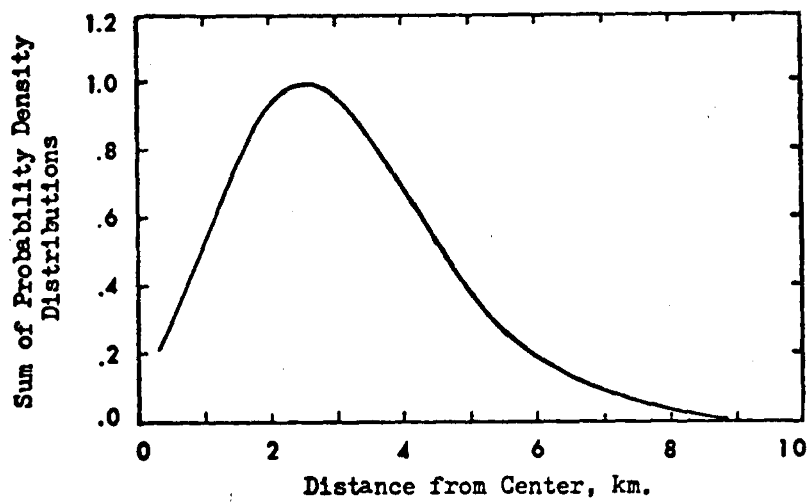


Figure 5.5-3 : Probability Density Distribution of all Households vs. Distance from the City Center (Example 1)

The two last figures are of special interest, as they touch upon a basic issue of population distributions in an urban area. For instance, it can be inferred from Figure 5.5-2 that the low income households have less freedom of residence location choice than high income households. Furthermore, Figure 5.5-3 suggests that population density (as the quotient of population over area), as a function of distance from the city center, can be derived by UMOT (*).

An additional interesting result from Figure 5.5-2 is the gradient of average income in a city; the average income in the above exercise, as detailed in Table 5.5-1 and shown in Figure 5.5-4, is lowest at a certain distance from the center, similar to observations in many cities, two of which are shown in Figure 5.5-5.

(*) Population density in cities of developing countries can be expressed by a negative exponential function, while in cities of developed countries it can be expressed by a Gamma function.

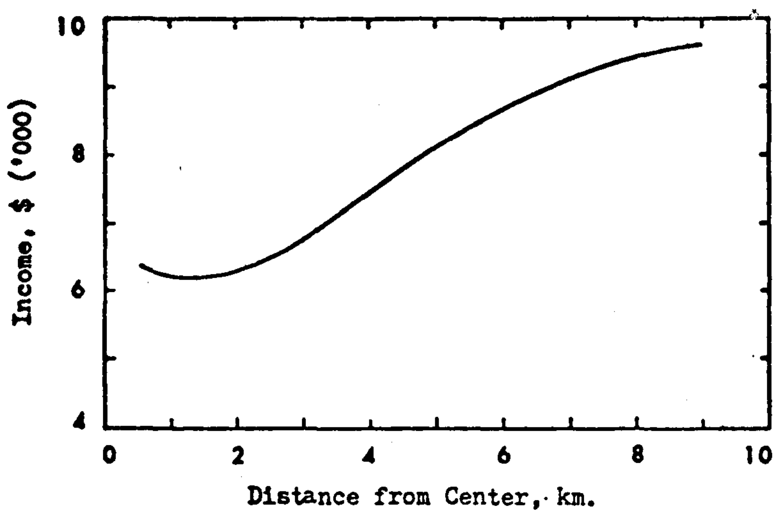


Figure 5.5-4 : Average Household Annual Income vs. Distance from the City Center

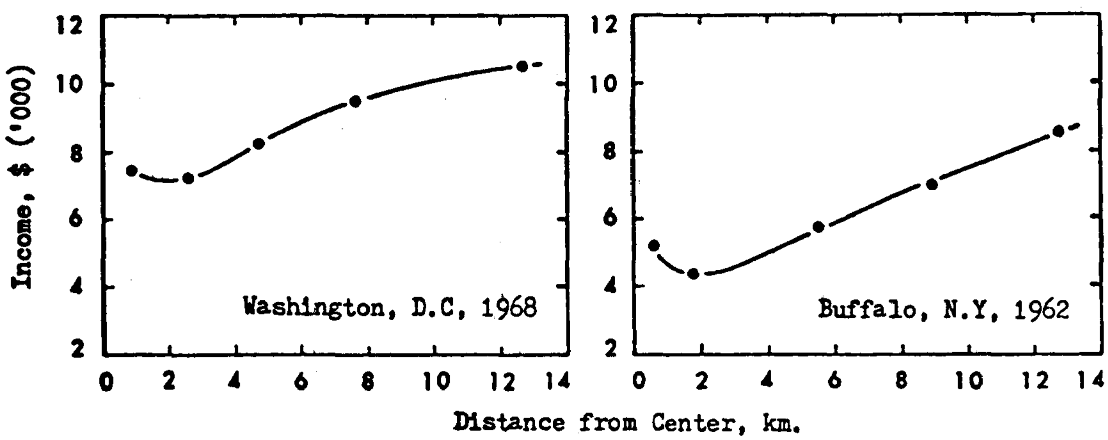


Figure 5.5-5 : Average Household Annual Income vs. Distance from the City Center, Washington, D.C. 1968 and Buffalo, N.Y. 1962

It can also be inferred that variations in the population distributions, such as shown in Figure 5.5-2, may lead to new (polycentric) development at a certain distance from the city center, as shown in Figures 5.5-6 and 5.5-7. It is also evident that a beltway, which will increase travel speeds above those assumed for the arterial network in Figure 5.5-2, will encourage and accelerate such development.

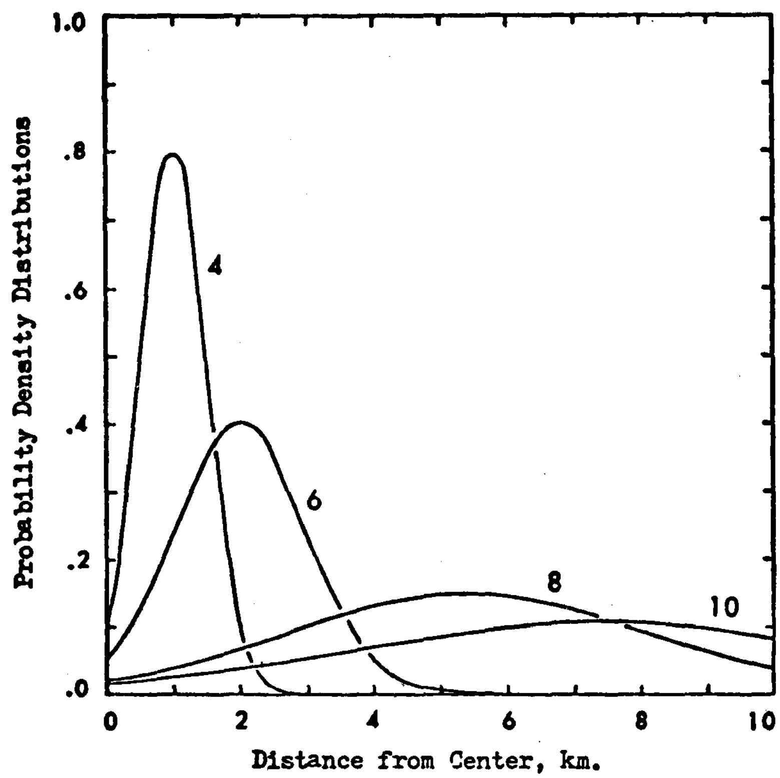


Figure 5,5-6 : Probability Density Distribution of Household Location, by Annual Income ($ '000) vs. Distance from the City Center (Example 2)

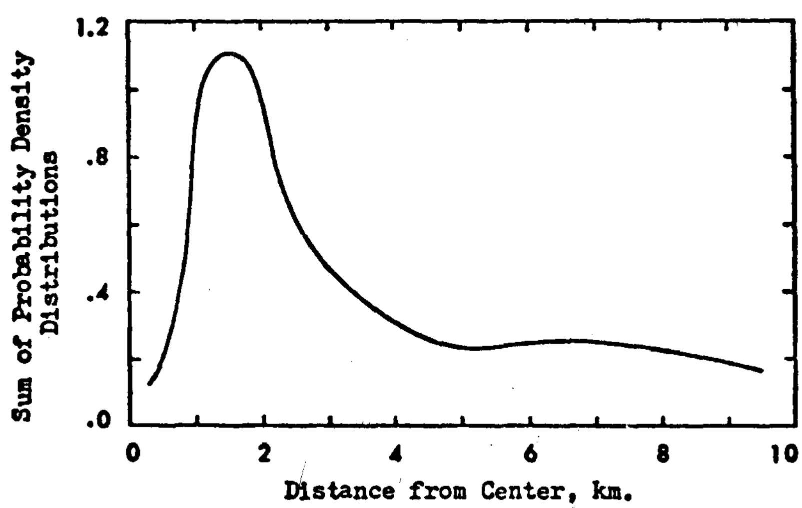


Figure 5.5-7 : Probability Density Distribution of all Households vs. Distance from the City Center (Example 2)

3. It has to be mentioned again at this stage that while the above phenomena in urban areas are well known, they do not lend themselves to easy theoretical formulation or to numerical analysis by the conventional models. The procedure described in this report, while only an exercise at this stage, suggests a new approach to the problem, by showing that travel demand, system supply, car ownership and urban structure may be unified within one framework.

Of special importance are the following indications:

(1) The constraints on travel, when applied in a certain and consistent way, can reproduce known travel and urban phenomena with no, or with minimum, calibrations;

(2) Travel distance, being a common denominator for both travel demand and system supply, makes the former sensitive and responsive to the latter;

(3) Although car ownership in conventional models is regarded and treated as one of the causes for travel demand, it now appears that it both results from, and affects, travel demand through its interaction with system supply. Thus, car ownership is an important link between travel demand, system supply and urban structure;

(4) The interactions between travel demand, car ownership and a given system supply under equilibrium conditions can generate the household distributions in an urban area.

'Equilibrium conditions' may be defined in this case as the situation where households can maximize their benefits, including residence location, car ownership and travel demand, within their constraints. For instance, low income households will tend to locate their residence near the city center if given the opportunity. However, adjustments of population distributions within an urban area take time, and it can well happen that exogenous factors may disrupt the internal process of adjustment. For example, cities in many developing countries grow rapidly by the migration of poor families, that are forced to settle down at the periphery of the urban area. The members of such poor households have to spend more time and money on travel to and from jobs than high income households. Thus, if the city continues to grow by poor newcomers at a greater rate than its ability to absorb the newcomers and adjust its structure accordingly, the urban system can be regarded as being in a disequilibrium condition.

It may, therefore, be concluded that a dynamic model has to consider the reaction-time, or relaxation time, of the various endogenous interactions (such as the adjustment of population distributions) and exogenous factors (such as population migration, or policy decisions that affect system supply, travel costs, and urban structure).

It appears that simulations may assist in a better understanding of such dynamic interactions over time, as well as in defining the critical thresholds along a time scale for different policy decisions to be most effective.

5.6 The Differential Accumulation Process

The Differential Accumulation process, or D/A process for short, considers the simultaneous interaction between the spatial distributions of workers and jobs in an urban/regional area, and expresses the accumulated difference between them from the area's center (Zahavi, 1976).

In more precise terms, the D/A process assumes, as a starting point, that workers try to minimize the travel distance between their residence and job locations under certain constraints and, hence, the difference between the numbers of workers and jobs is accumulated by distance, starting from the urban fringe towards the city center. Namely, it is assumed that workers prefer to find a job near their home, and if there are more workers than jobs in a certain area, the rest of the workers will have to travel further in the search of a job. As a result of this assumption, no travel to work is required when the two spatial distributions are completely equal, while maximum travel, both in amount and distance, is generated when all jobs are concentrated in the center while all workers reside at the fringe of the city. Furthermore, it is also clear that whatever the actual spatial distributions are, the D/A process would then reflect the minimum possible amount of travel to work.

In spite of these simplifying assumptions, it was found that the weighted average distance of the D/A curve to the city center approximates with remarkable regularity the observed average trip distance in the city, as derived from a comprehensive transportation study. Thus, a link between urban structure and average trip distance can be established, with effects spreading to trip rates; trip rate and trip distance interact by trade-offs within the total daily travel distance.

Figure 5.6-1 presents examples of the D/A curves in Bangkok and Washington, D.C., where the spatial distributions of population (representing workers) and jobs were normalized in percent and, hence, the D/A curves express the differential accumulation of the percent-difference between the two distributions. The summarized data are detailed in Table 5.6-1.

Table 5.6-1: The D/A Process in Bangkok and Washington, D.C.

Characteristic	BANGKOK	WASHINGTON, D.C.	
Year	1972	1955	1968
Population	3,567,700 (1)	1,425,320	2,380,480
Jobs	762,500	736,000	1,120,320
Trip Distance by D/A, km.	7.30	6.64	10.10
Trip Distance Observed, km.	7.40	6.68	10.59

(1) Within the urbanized area

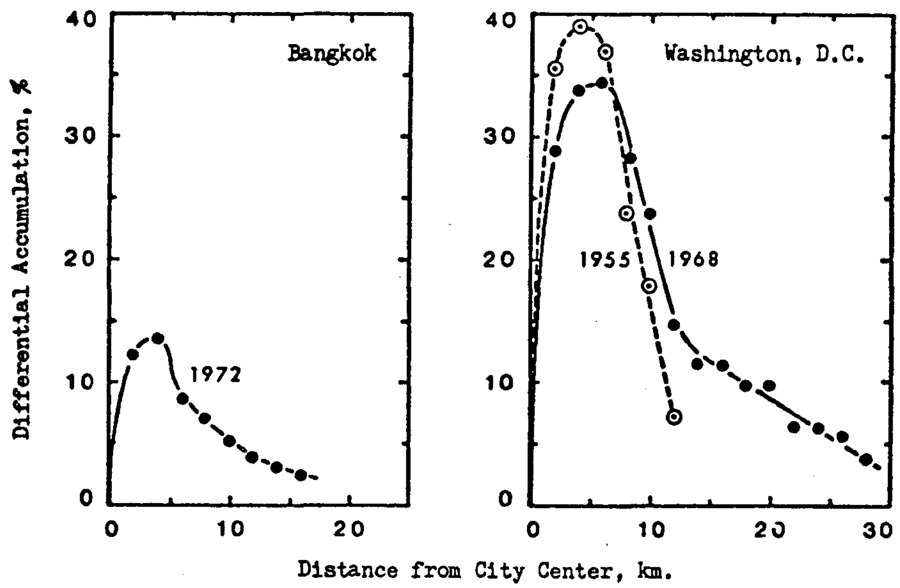


Figure 5.6-1: Differential Accumulation of Population vs. Jobs by Distance from the City Center, Bangkok and Washington, D.C.

It becomes evident from Figure 5.6-1 that the spatial distributions of population and jobs in Bangkok are more evenly distributed than in Washington, D.C., thus requiring less travel to work, the reasons being low speeds and low motorization levels.

In Washington, D.C., on the other hand, the strong differentiation between the two distributions generates about three times more travel to work. Furthermore, the differentiation between the two distributions even increased substantially during 1955-1968, signifying a strong dispersion force.

The point to note at this stage is that cities where speeds are low tend to be compact, and the population and job distributions evenly dispersed. However, if speeds increase and land use is uncontrolled, the city will start to expand from within, since travelers will then have better spatial opportunities, including their residence-job locations, within their travel constraints such as the travel-time budget.

Cities in developing countries, on the other hand, mostly expand from the outside by poor new-comers who settle at the fringe of the urban area, while travel speeds continuously decrease under ever-increasing traffic congestion.

The D/A process was also applied to the Nurenberg data, as detailed in Table 5.6-2 and shown in Figure 5.6-2.

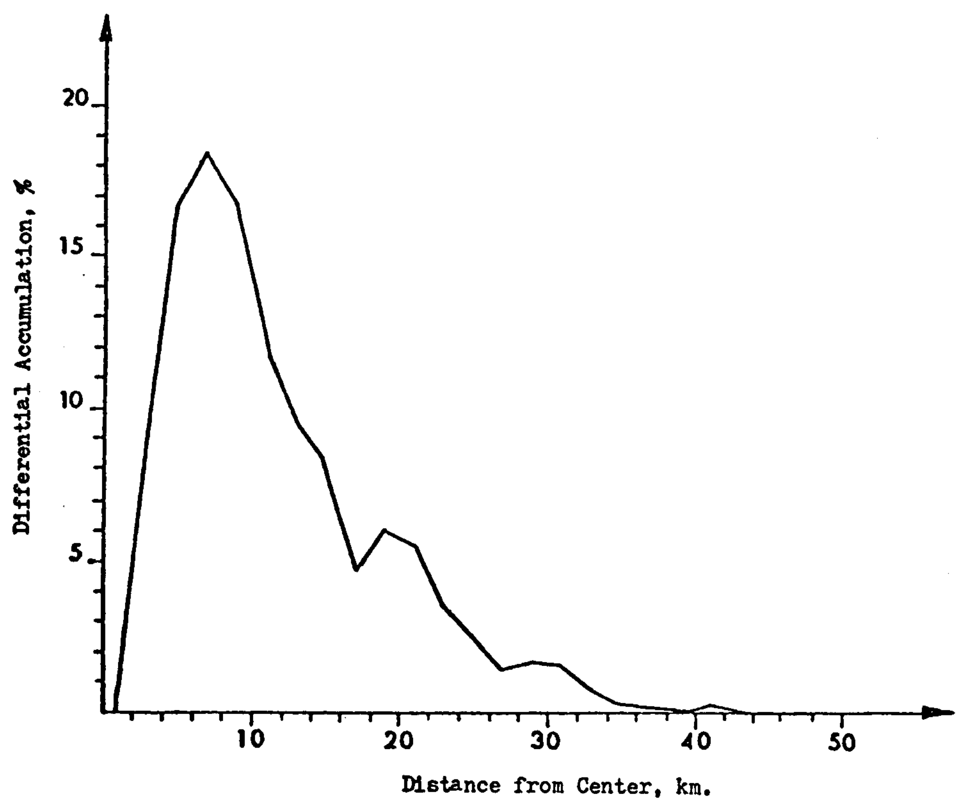


Figure 5.6-2: The Differential Accumulation of Population vs. Jobs, in Percent, vs. Distance from the Nurenberg Region's Center, 1975

Table 5.6-2: Differential Accumulation of Population vs. Jobs by Distance from the Center of the Nurenberg Region

Distance to Center	Population	Jobs	Population Percent	Jobs Percent	Accumulated Differences
0 - 2	181.532	139.471	15,6	23,5	-
2 - 4	145.911	127.118	12,6	21,4	7,9
4 - 6	107.671	65.832	9,3	11,1	16,7
6 - 8	99.882	37.778	8,6	6,4	18,5
8 - 10	95.062	20.629	8,2	3,5	16,3
10 - 12	47.520	11.558	4,1	1,8	11,6
12 - 14	63.293	24.445	5,4	4,1	9,3
14 - 16	103.762	33.014	8,9	5,6	8,0
16 - 18	87.563	51.489	7,5	8,7	4,7
18 - 20	28.752	11.702	2,5	2,0	5,9
20 - 22	48.041	12.976	4,1	2,2	5,4
22 - 24	32.372	11.074	2,8	1,9	3,5
24	27.578	7.783	2,4	1,3	2,6
26	9.035	6.287	0,8	1,1	1,5
28	7.836	2.906	0,7	0,5	1,8
30	28.570	8.985	2,5	1,5	1,6
32	24.126	9.220	2,1	1,5	0,6
34	3.923	1.518	0,3	0,3	-
36	5.227	2.554	0,4	0,4	-
38	-	-	-	-	-
40	5.162	2.259	0,4	0,4	-
42	-	-	-	-	-
44	-	-	-	-	-
46	3.432	1.648	0,3	0,3	-
48 - 50	6.072	2.800	0,5	0,5	-
Total	1.162.322	593.046	100,0	100,0	115,9

Distance of D/A centroid to center of the region $= \frac{\Sigma \text{ D/A x Distance}}{\Sigma \text{ D/A}} = \frac{1,364.9}{115.9} = 11.78$ km.

Observed Car Average Trip Distance = 11.2 km.

As can be seen in Table 5.6-2, the distance of the D/A curve to the region's center is 11.78 km., while the observed average car trip distance is 11.2 km., or a difference of only + 5.2 percent. Table 5.6-3 compares similar data of all available cases, where it becomes apparent that the D/A relationship is transferable between cities and regions.

Table 5.6-3: Average Trip Distance by the Differential Accumulation Process vs. Observed, in a Selection of Cities

City	Year	Trip Distance, km.		Difference
		Estimated	Observed	Est./Obs.%
Athens	1962	5.5	5.6	- 1.8
Baltimore	1962	9.0	9.3	- 3.2
Bangkok	1972	7.3	7.4	- 1.4
Kuala Lumpur	1972	5.1	5.3	- 3.8
Tel Aviv	1965	4.1	4.1	0.0
Washington, D.C.	1955	6.6	6.7	- 1.5
Washington, D.C.	1968	10.1	10.6	- 4.7
Nurenberg Region	1975	11.8	11.2	+ 5.2

In conclusion, it appears that the D/A process, which is one of the links between urban structure and the travel estimates derived by the UMOT process, seems to apply equally well to the Nurenberg region as to a wide selection of cities in different countries.

5.7 Travel Probability Fields

1. Introduction

It has been shown in Chapter 4 that the daily travel distance per average traveler is strongly related to the door-to-door speed. It is evident, therefore, that the trip rate and the trip distance have to be inversely related to each other within the total daily distance. For instance, if the density of destinations is high and trip distances short, then the trip rate will be high.

It may, therefore, be expected that the spatial distributions of trip destinations will be affected by the density of destinations and the speed. For example, since transit speeds are usuallv lower than car speeds, it is to be expected that the spatial distributions of transit trip destinations will be more compact than of car trip destinations. A test of this expectation is detailed in the following sections.

2. The Travel Fields

A travel field is defined in this report as the area where about 2/3 (one standard deviation) of all destinations are expected to terminate. It is further assumed at this stage, for the sake of simplification and as a first-approximation, that the distribution of destinations about the mean follows a normal distribution.

The technique for defining such travel fields is as follows:

(1) List all trips originating from a zone and terminating at the destination zones;

(2) List the coordinates of all zones;

(3) Find the centroid of destinations from each origin zone, i, as:

$$\bar{x}_j = \frac{\sum T_i x_j}{\sum T_i} \quad ; \qquad (5.7\text{-}1)$$

$$\bar{y}_j = \frac{\sum T_i y_j}{\sum T_i} \quad ; \qquad (5.7\text{-}2)$$

where T_i is the number of trips originating from zone i and terminating at each destination zone j, and x_j and y_j are the coordinates of the destination zones;

(4) Find the angle between the origin zone and the centroid of destinations by:

$$tg\alpha_{i-j} = \frac{y_i - \bar{y}_j}{x_i - \bar{x}_j} \quad ; \qquad (5.7\text{-}3)$$

where x_i, y_i are the coordinates of the origin zone i and $\bar{x}$, $\bar{y}$ are the coordinates of centroid of destinations j;

(5) Transform the coordinates of all i-j zones by the angle

$$\left.\begin{aligned} x' &= x \cos\alpha + y \sin\alpha \\ y' &= y \cos\alpha - x \sin\alpha \end{aligned}\right\} \qquad (5.7\text{-}4)$$

where x', y' are the new coordinates;

(6) Repeat the calculation for the centroid of all destinations j from an origin zone i in accordance with step (2), based on the new coordinates x', y';

(7) Calculate $\sigma_{x'}$ and $\sigma_{y'}$:

$$\left.\begin{aligned} \sigma_{x}' &= \sqrt{\frac{\sum T_i \, (x'_j - \bar{x}_j')^2}{\sum T_i}} ; \\ \sigma_{y}' &= \sqrt{\frac{\sum T_i \, (y'_y - \bar{y}'_y)^2}{\sum T_i}} ; \end{aligned}\right\} \qquad (5.7\text{-}5)$$

(8) Draw $\sigma_{x'}$ and $\sigma_{y'}$ along the axes x', y', centered on the centroid of destinations x'_j, y'_j. The area thus defined (which can be approximated by a rough ellipsoid) will include about 2/3 of all destinations.

Examples of such travel fields for a selection of zones in Washington, D.C., 1968 (all trips in this case) are shown in Figure 5.7-1.

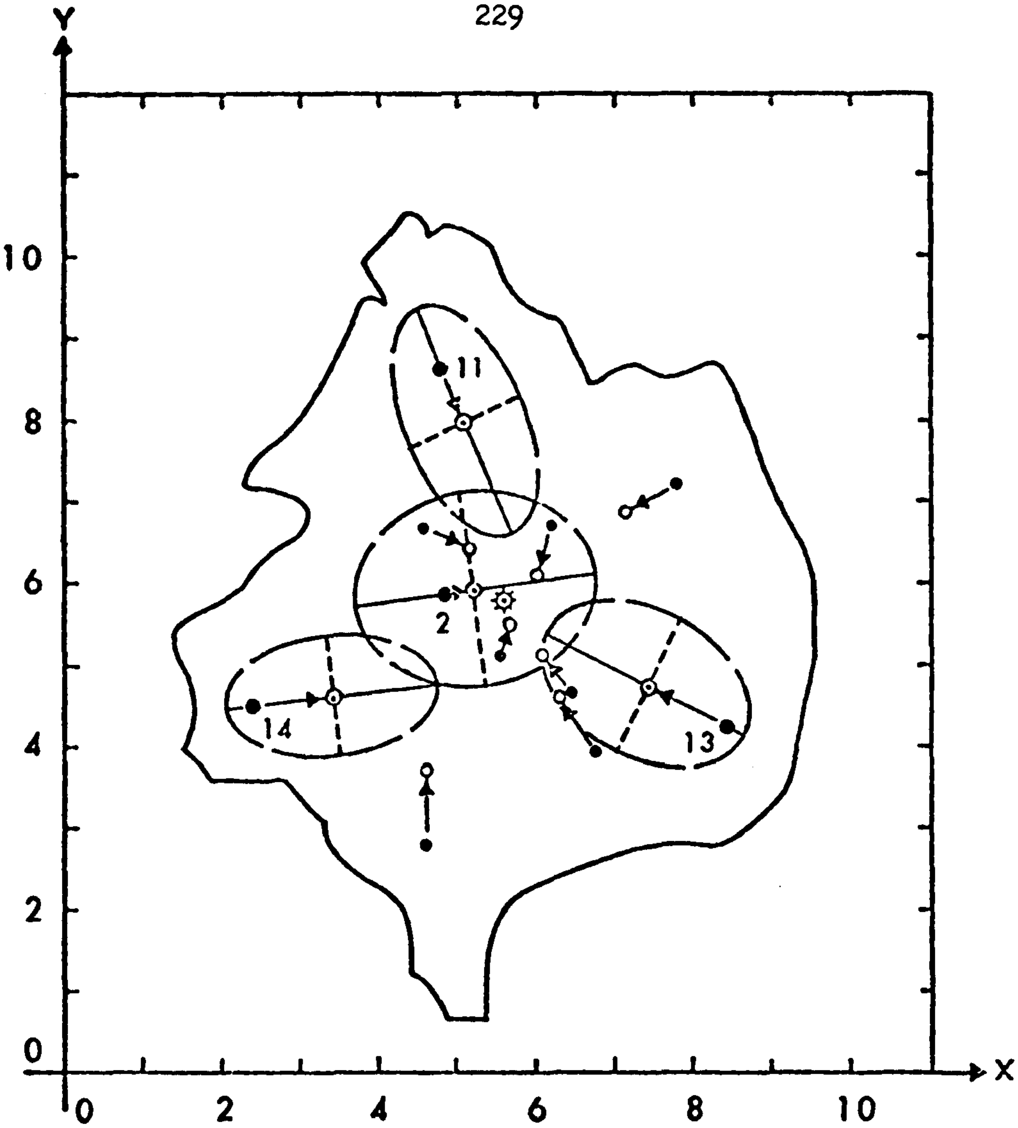


Figure 5.7-1 : Travel Fields for Selected Districts in Washington, D.C. 1968

5.3 Travel Fields in Nuremberg

The technique described above was applied to a selection of zones in the Nuremberg region, as shown in Figure 5.7-2 for car trips and in Figure 5.7-3 for transit trips.

The following indications may be inferred from the two figures:

(1) The direction of destinations tends to be towards the major urban areas in the region. For instance, the direction from zones 19 and 23 is towards the city of Nuremberg, in zone 1;, while the direction from zone 15 is slightly shifted from zone 1 due to the effect of the town of Erlangen;

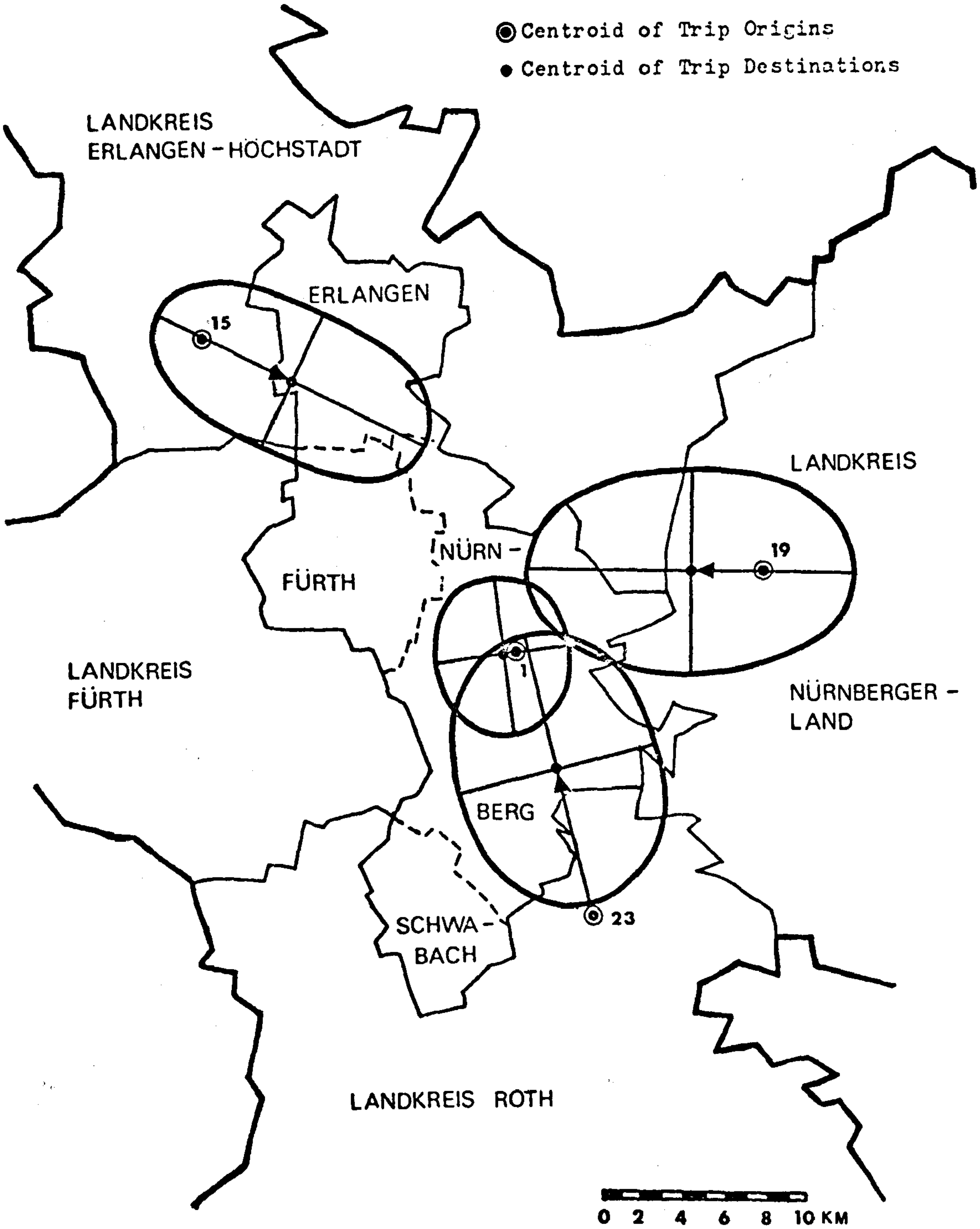


Figure 5.7-2 : Travel Fields of Car Travel for Selected Districts in the Nuremberg Region, 1975

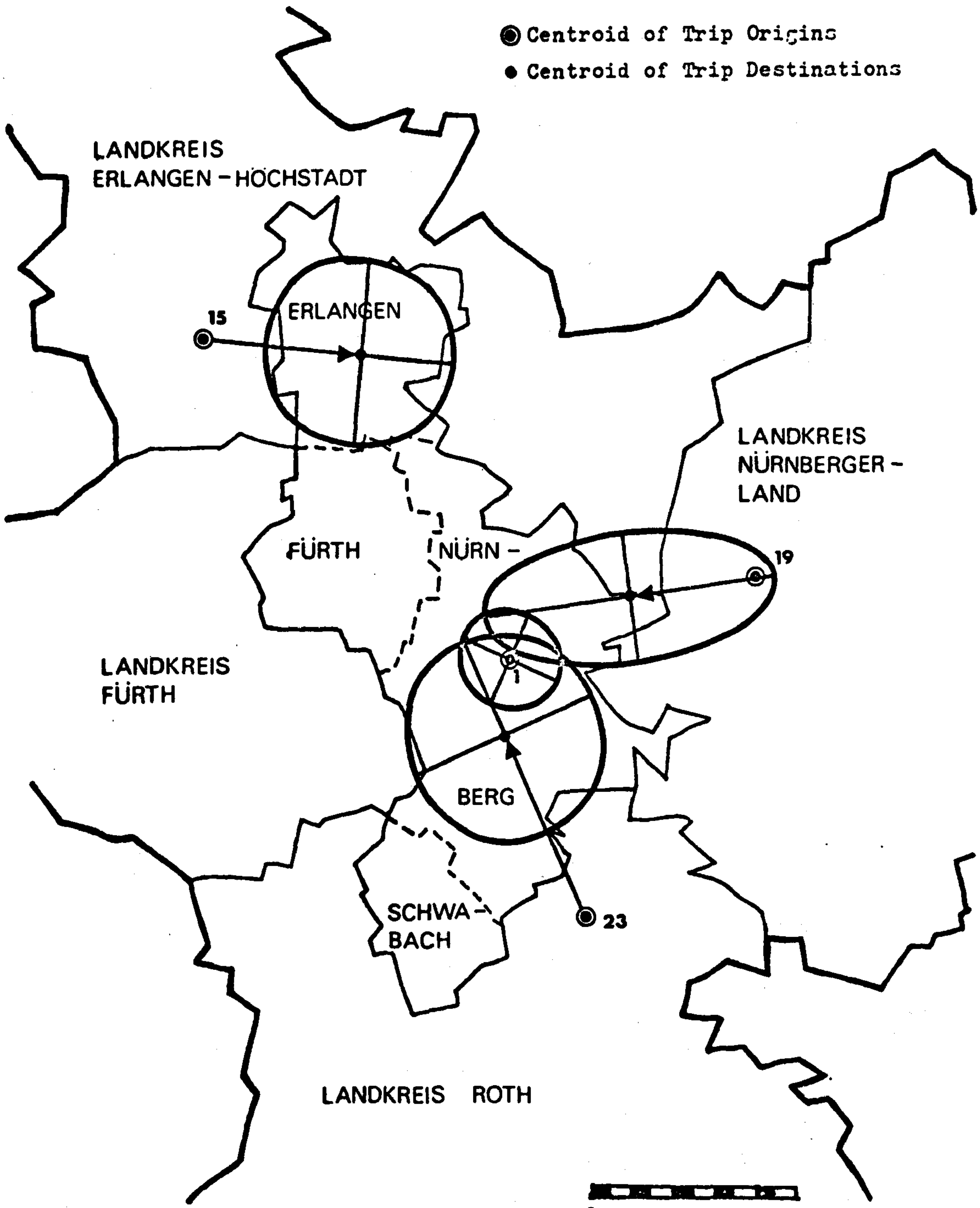


Figure 5.7-3 : Travel Fields of Transit Travel for Selected Districts in the Nuremberg Region, 1975

(2) The extension of the travel field tends to be proportional to the distance of the origin zone from the major urban areas in the region. For instance, the travel field of the city of Nuremberg is the most compact one, while the travel fields of the other zones are elongated.

(3) Car travel fields tend to be larger and more elongated than transit travel fields, thus suggesting a higher dispersion of destinations;

(4) The direction of the travel field is also affected by the available system supply. For instance, the transit travel field of zone 15 is predominantly directed to the town of Erlangen, following the transit system, while the car travel field is predominantly towards the city of Nuremberg.

While all the above indications reflect and follow the expected trends, as derived from standard procedures of origin-destination matrices, assignments and desire-lines, the advantage of the travel fields is that they concentrate the spatial distributions of many single trips into a simple geometrical visualization of a probability field, where the single trips are expected to terminate. Furthermore, the two measures of disperson, σ_x and σ_y, can be collapsed into a single measure, called 'the standard distance', and described by:

$$sd = \sqrt{\sigma_x^2 + \sigma_y^2} \qquad (5.7\text{-}6)$$

Thus, the standard distance and its direction are a simple measure of trip distribution characteristics, which may simplify the techniques of travel analysis. For instance, the travel field is a result from the interactions between travel demand, system supply and urban structure. Thus, it can serve as a direct link between the three factors, for a one-phase trip generation-distribution-assignment model.

It should,however, be noted at this stage, that the technique of travel fields is in its first stages of development, and that much research is still needed before it can be regarded as an approved tool for analysis.

* * *

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The purpose of the research reported in the previous chapters was twofold. First, to analyze the consistency of previously observed phenomena that travelers within urban areas appear to have average daily time and money expenditures on travel which are stable both between cities and over time in the same city. Second, if such expenditures are indeed found to be predictable, to explore and develop the conceptual framework of a transportation planning tool which takes advantage of such regularities in relating travel demand and transportation system supply to urban form.

The findings of this study were very encouraging and agreed with previous findings. They can be summarized as follows:

The Travel Time Budget (TT-budget)

(1) The mean daily TT-budget per motorized traveler of each of 55 different household types in Munich is stable over weekdays. Namely, although the travel time expenditure of each individual traveler within his group may vary between days, the group's mean value is stable over weekdays. Furthermore, the mean values are similar to the TT-budgets observed in other cities of developed countries.

(2) The variations around the mean value of daily TT-budgets by individual travelers within each population segment in Munich and Nurenberg are very stable for all population segments, and are similar to those found in other cities, including cities of developing countries (Coefficient of variation about 0.6).

(3) The mean daily TT-budget per traveler is an inverse function of speed, decreasing as speed increases, and vice versa.

(4) When low speeds increase, such as by transfer from bus to car travel, part of the "saved" time is actually saved, while the other part is traded-off for more travel distance. However,

at initially high speeds, practically all speed increases are traded-off for more travel distance.

(5) The minimum mean daily TT-budget per traveler in an urban area, at high travel speed, is just over 1 hour per day, and slightly higher in the Nurenberg region (including intra-regional travel). The maximum mean daily TT-budget per traveler, at low travel speeds, is about 1.5 hours per day in cities of developed countries. In large and/or fast expanding cities in developing countries, the mean daily TT-budget per traveler at low travel speeds can reach and pass the two-hour level per day.

(6) The mean TT-budget per traveler was found to be closely related to the household's income level, to the availability of cars and transportation system supply, and to urban structure. High income travelers, having better opportunities for traveling at higher speeds than low income travelers, can both travel more daily distance (i.e., and have better spatial and economic opportunities) than low income travelers, and still save travel time. Low income travelers, on the other hand, have to spend more time in order to travel less daily distance.

The reason for this difference is due to the travel money budget, as detailed below.

<u>The Travel Money Budget</u> (TM-budget)

(1) The mean TM-budget per household, for all households over time, is found to be a stable proportion of disposable income in Germany, the U.S., the U.K. and Canada. While the proportion may vary by definition and conditions between countries, the stability within one country remained unchanged even during the energy crisis and cost increases in 1973-75.

(2) The daily TM-budget per household in an urban area is strongly related to the household's disposable income level and car availability. It is about 11-12 percent of disposable income for car

owning households, and about 3-5 percent for non car owning households, stable at all income levels. Such results in the Nurenberg region are similar to those in Washington, D.C. and Twin Cities in the U.S.

(3) The significant gap, or "quantum-jump", in the TM-budget of car and carless households suggests that purchasing a car is a major household decision, closely related to other major decisions, such as residence location. However, the probability of a household to make such a decision increases rapidly with income.

(4) The daily variations around the mean TM-budgets per household within each segment of the 55 household types in the Nurenberg region (as reflected by the daily travel distance) are higher by about 50 percent than the variations around the mean TT-budgets. One possible explanation for this result is that it is easier to transfer money between days than to transfer travel time; daily travel times are constrained by 24-hours per day, while the travel money is constrained by the monthly or the yearly income. The point to note, however, is that the coefficient of variation of the TM-budget, similar to the case of the TT-budget, is very similar for all population segments.

In conclusion, the TM-budgets of car and carless households appear to be strongly related to income, and stable over time. Hence, the TM-budget, together with the TT-budget, can be applied as two simultaneous budgets under which all travel choices take place, as summarized below.

Implications of the TT and TM Budgets

Given the households' socioeconomic characteristics and the transportation system supply characteristics, the UMOT process proceeds along the following, simplified, steps:

(1) The Demand for Travel: Household income affects the upper limit of the TM-budget allocated to travel. Household size and income

level affect the number of travelers per household and, hence, the initial TT-budget per household.

Applying the travel-distance maximization process under the TM and TT budgets, and the unit costs of available or planned modes, in money and time terms, results in the demand for travel distance by each mode.

(2) The Car Ownership Model: The demand for car travel-distance generates car ownership, in order to satisfy the demand. No specific assumptions about cause and effect are necessary since the interaction between the estimated number of cars and a given road network results in new unit costs of travel. These new unit costs are fed back into the travel demand phase, affecting both the TT-budgets (which are sensitive to speed) and the demand for travel distance by mode, and the process is repeated by iteration until equilibrium between the demand for travel and system supply is reached.

Sensitivity tests have shown that convergence of the process is rapid, resulting in the observed travel characteristics.

The process gives equal attention to all modes, generating the demand for travel by all defined modes, such as walking, car, bus, urban and interurban train, all of which are expressed by their operational characteristics.

(3) Urban Structure: The UMOT process has the potentiality of combining both the urban strcture and travel aspects in one process. Preliminary tests suggest that the differential accumulation process, which expresses the interactions between the spatial distributions of population and jobs, and results in a measure of the average trip distance in the area, applies equally well to the Nurenberg region. Even so, more detailed analyses are still required in this specific area, as proposed in Section 6.2.

Theoretical Foundation of the UMOT

Special attention is given in this report to the theoretical foundation of the UMOT process. The travel behavior concepts of UMOT were developed with respect to a particular theory of human decision making called utility theory. While this is not the only theory capable of providing a basis for the analytical strcture of the proposed process, it is adequate to, and may in fact be, the best alternative currently available, particularly in light of its extensive and successful use in describing many types of consumer choices in microeconomics.

The particular forms of utility functions applicable to travel situations were formulated, and it was found that these forms predict the empirical regularities in travel decisions which form the bases of the UMOT process.

Forecasting individual travel demand can be accomplished by two alternative approaches. The current approach is to calibrate a demand model to individual travel behavior with an extensive number of independent variables in order to describe the variability of individual choices. This approach has the difficulty that each of the independent variables must be predicted separately for the future date.

The UMOT approach, on the other hand, is based on the observation that the variabilities in the travel budgets among individuals within groups are similar for all population segments. Therefore, assuming that such variabilities remain stable over time as well, it is necessary to forecast only the mean values of the budgets for each group. These mean values, together with the variabilities around them, provide the probabilities of individual travelers to behave in predicted ways.

One advantage of this process is that it needs only a few independent variables in order to predict individual travel behavior under new conditions. Furthermore, the relative stability of such relationships, as distance per traveler vs. speed, and their transferability between cities, ensures their stability over time as well.

Additional Results

Several additional concepts evolved during the conduction of this research study. Although they are still at a preliminary stage of development, it is worthwile to note them, as follows:

(1) Spatial Distributions of Population and Jobs: Preliminary tests suggest that the UMOT process can generate the probabilities of households of different types to reside in certain areas of a city, given system supply. Coupled together with the differential accumulation, the process can generate the population and job spatial distributions under alternative assumptions. One important advantage of the UMOT process in dealing with urban structure is the question of equilibrium. Practically all urban form models that deal with dynamic changes in urban structure are based on the principle of equilibrium between demand and supply, so that all tested alternative urban structures always reach, or at least approach, equilibrium conditions, such as between population and job spatial distributions. In the UMOT process, on the other hand, urban structure may impose on the population long trip distances or trip times which may become the binding constraint, overriding the TT and TM budgets. While conventional models regard such a case as being in equilibrium, based on the definition that observed demand is always in equilibrium with supply, the UMOT process measures the amount of disequilibrium between the stable TT and TM budgets under stable urban conditions and the TT and TM budgets that travelers will be forced to spend in order to satisfy their minimum demand for travel, such as nondisretionary travel. This is an especially important issue when increases in travel costs might cross a critical threshold, a possibility now in sight even in cities of developed countries.

(2) Travel Probability Fields: Changing conditions in an urban area can also change travel patterns, including trip rates, trip distances, mode choice and trip distribution. Current techniques of trip distribution depend on detailed trip origin-destination

matrices, dealing with a vast number of single trips that have to be distributed between a large number of traffic zones. Thus, any significant change in the study area, such as in urban structure, population socioeconomic characteristics, system supply, or travel costs, requires the redistribution of trips.

In The UMOT process, on the other hand, the distribution of trip destinations, generated by different population segments, can be viewed as a spatial probability distribution that can be analyzed by statistical techniques. More specifically, if a household can generate a certain amount of travel-distance, subject to its constraints on travel, each trip has a certain probability of terminating within a certain area, called a "travel field", which can be defined by one or two standard deviations. Thus, the daily demand for travel, as measured by the daily travel distance, can be transformed directly into an O-D matrix, serving as a link between the distribution/assignments phases of single trips and the UMOT process.

The point to note is that the UMOT process expresses the interaction between the demand for travel and system supply by a feedback process, where each factor both affects, and is affected by, the other. Thus, households with limited budgets of time and money will tend to search actively for accessibilities in order to maximize their spatial and economic opportunities, but by doing so on a given system supply, they will affect local accessibilities, thus also affecting their choices. Repeating this feedback process by iteration will result in the equilibrium condition (on a daily basis) between travel demand and its distribution within the urban area.

6.2 Recommendations

The recommendations emerging from this study can be summarized under the following major headings:

Data

Special attention should be given to the adequacy and consistency of data sets in subsequent data analyses. For instance, the lack of information on household incomes in the Nurenberg and Munich data required elaborate procedures for their estimation, and while the results appear to be reasonable and consistent with those observed in other cities, the question of uncertainty still remains open.

Furthermore, experience with available data suggests that careful screening is required before the data are analyzed. For example, home-interview results are usually checked for underreporting by comparing origin-destination matrices with screen-line volumes and, more often than not, they have to be amended by adjustment factors. The analyses in this report, however, are based on the original data and, hence, a certain underreporting is to be expected. While this factor is not critical in our case, since underreporting usually refers to short trips (i.e., short in time and distance) and, therefore, not affecting much the total daily travel times and distances, this problem should be looked into in subsequent research.

But perhaps the most important requirement for future research of travel budgets is the availability of two data sets in the same study area, at two points in time, in order to compare the stability and change of travel budgets versus changes in urban structure, system supply and travel characteristics. Hence, more thorough analyses than those carried out in Washington, D.C. and Twin Cities are still required, and recommended.

The UMOT Process

Further developments should be made to the UMOT process to improve its ability to explain small nuances in transportation choices. The most obvious improvements would include:

(a) As already mentioned above, further verification of the stability of the travel budgets over time.

(b) Determination of whether additional attributes besides travel time and money are needed to derive mode choice from the budgets. These attributes are allowed for in the utility functions of UMOT. A further part of this invstigation would determine what modal characteristics, such as comfort and safety, would be required.

(c) To further relate trip rate with trip distance for different purposes and modes, and to relate trip distances with urban structure.

(d) Further elaboration of the car ownership model, as a link to travel demand, system supply and urban structure.

(e) To integrate urban structure in the UMOT process, as detailed below.

Urban Structure

The relationship of travel and urban structure should be more fully developed. This would include the determination of aspects such as the probability distribution of residence and job locations. A goal of this work is to include the dynamic processes of urban development, including relaxation times, as an integral part of the model. In this case, however, the process will have to include the housing supply as an explicit component, and the travel utility functions will have to include money expenditures on housing. An additional link between travel, urban structure and system supply is the further development of the travel probability fields.

The UMOT Model

Even at this stage of development of the UMOT process, the multiple interactions among the travel components require its development into a computerized model. Such development would enable it to both be examined and checked under more complex situations, and to be tested on more data that vary over time, including at least one city for which comprehensive data at two points in time are available.

While some parts of the recommended developments, such as the probability distributions of population and jobs, and travel probability fields, can be carried out as separate phases, it appears that the complete range of interactions and feedback processes between the demand for travel, system supply and urban structure can be tested by a computerized model only.

The UMOT Interurban Model

After the completion of this research study, the UMOT process was also tested for its ability to generate interurban travel characteristics. Preliminary tests included the interactions between three principal modes, namely car, rail and air. A wide range of money and time expenditures was assumed, and the process generated estimates of mode choice by travel distance, based on the modes' operational characteristics. Comparisons between the UMOT outputs and observed mode-choice vs. distance relationships in Europe showed a very close agreement between the two[*]. Additional tests suggested that both mode choice and travel distance are very sensitive to the number of persons traveling together as a group (e.g., members of one family), sharing the same money budget. Such results may also reflect on urban travel (although probably to a lesser degree) and they should be checked carefully when developing the UMOT urban model. It was also noted that changes in the modes' operational characteristics (such as increasing rail speed) had significantly different effects of different group sizes. Thus, the UMOT process appears to be sensitive also to the number of persons who make a joint travel decision when sharing one - or more - of the travel budgets. This indication may have many important implications to travel behavior modeling.

Since the UMOT interurban process does not depend on urban structure, it can be further tested and developed directly into an operational model.

* * *

(*) "The Future of European Passenger Transport". Organisation for Economic Co-operation and Development (OECD), Paris 1977.

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APPENDICES

APPENDIX I-1. The Munich 3-day Data (KONTIV)

Travelers who made at least one motorized trip, per Household, by householf type and day

1st Day				2nd Day			
HTYPE	MOT.HH	MOT.TRAV.	TRAV./HH	HTYPE	MOT.HH	MOT.TRAV.	TRAV./HH
1	40	40	1.00	1	31	31	1.00
2	44	44	1.00	2	46	46	1.00
3	47	47	1.00	3	35	35	1.00
4	12	12	1.00	4	20	20	1.00
5	14	23	1.64	5	12	20	1.67
6	63	93	1.48	6	47	73	1.55
7	1	1	1.00	7	1	1	1.00
8	0	0	0.00	8	0	0	0.00
9	0	0	0.00	9	0	0	0.00
10	6	8	1.33	10	5	8	1.60
11	5	9	1.80	11	4	6	1.50
12	43	68	1.58	12	37	59	1.59
13	11	18	1.64	13	7	13	1.86
14	20	33	1.65	14	10	17	1.70
15	9	16	1.78	15	9	16	1.78
16	7	11	1.57	16	6	9	1.50
17	1	2	2.00	17	1	2	2.00
18	14	24	1.71	18	15	25	1.67
19	0	0	0.00	19	0	0	0.00
20	2	5	2.50	20	1	3	3.00
21	3	6	2.00	21	3	6	2.00
22	4	7	1.75	22	3	5	1.67
23	11	23	2.09	23	10	19	1.90
24	3	7	2.33	24	3	7	2.33
25	0	0	0.00	25	0	0	0.00
26	1	2	2.00	26	3	7	2.33
27	4	9	2.25	27	6	10	1.67
28	7	12	1.71	28	9	17	1.89
29	3	5	1.67	29	2	4	2.00
30	0	0	0.00	30	1	1	1.00
31	0	0	0.00	31	0	0	0.00
32	1	2	2.00	32	1	2	2.00
33	0	0	0.00	33	0	0	0.00
34	1	1	1.00	34	0	0	0.00
35	0	0	0.00	35	0	0	0.00
36	0	0	0.00	36	0	0	0.00
37	0	0	0.00	37	0	0	0.00
38	0	0	0.00	38	0	0	0.00
39	0	0	0.00	39	0	0	0.00
40	1	1	1.00	40	2	3	1.50
41	2	6	3.00	41	2	6	3.00
42	1	2	2.00	42	0	0	0.00
43	2	7	3.50	43	2	7	3.50
44	0	0	0.00	44	0	0	0.00
45	2	4	2.00	45	1	2	2.00
46	0	0	0.00	46	0	0	0.00
47	0	0	0.00	47	0	0	0.00
48	3	8	2.67	48	0	0	0.00
49	3	10	3.33	49	3	11	3.67
50	1	1	1.00	50	1	4	4.00
51	1	4	4.00	51	1	3	3.00
52	1	3	3.00	52	0	0	0.00
53	1	3	3.00	53	0	0	0.00
54	1	3	3.00	54	1	4	4.00
55	3	8	2.67	55	2	7	3.50
56	399	588	1.47	56	343	509	1.48

APPENDIX I-1.

3rd Day				Total			
HTYPE	MOT.HH	MOT.TRAV.	TRAV./HH	HTYPE	MOT.HH	MOT.TRAV.	TRAV./HH
1	35	35	1.00	1	106	106	1.00
2	51	51	1.00	2	141	141	1.00
3	50	50	1.00	3	132	132	1.00
4	21	21	1.00	4	53	53	1.00
5	13	22	1.69	5	39	65	1.67
6	74	109	1.47	6	184	275	1.49
7	0	0	0.00	7	2	2	1.00
8	1	1	1.00	8	1	1	1.00
9	0	0	0.00	9	0	0	0.00
10	6	9	1.50	10	17	25	1.47
11	5	9	1.80	11	14	24	1.71
12	49	85	1.73	12	129	212	1.64
13	11	17	1.55	13	29	48	1.66
14	14	25	1.79	14	44	75	1.70
15	11	16	1.45	15	29	48	1.66
16	3	6	2.00	16	16	26	1.63
17	2	2	1.00	17	4	6	1.50
18	15	27	1.80	18	44	76	1.73
19	1	2	2.00	19	1	2	2.00
20	4	10	2.50	20	7	18	2.57
21	2	4	2.00	21	8	16	2.00
22	6	12	2.00	22	13	24	1.85
23	11	24	2.18	23	32	66	2.06
24	3	6	2.00	24	9	20	2.22
25	0	0	0.00	25	0	0	0.00
26	2	3	1.50	26	6	12	2.00
27	4	7	1.75	27	14	26	1.86
28	11	24	2.18	28	27	53	1.96
29	2	4	2.00	29	7	13	1.86
30	1	2	2.00	30	2	3	1.50
31	1	2	2.00	31	1	2	2.00
32	1	3	3.00	32	3	7	2.33
33	0	0	0.00	33	0	0	0.00
34	1	2	2.00	34	2	3	1.50
35	0	0	0.00	35	0	0	0.00
36	0	0	0.00	36	0	0	0.00
37	0	0	0.00	37	0	0	0.00
38	0	0	0.00	38	0	0	0.00
39	0	0	0.00	39	0	0	0.00
40	1	1	1.00	40	4	5	1.25
41	2	7	3.50	41	6	19	3.17
42	2	5	2.50	42	3	7	2.33
43	2	7	3.50	43	6	21	3.50
44	0	0	0.00	44	0	0	0.00
45	1	2	2.00	45	4	8	2.00
46	1	4	4.00	46	1	4	4.00
47	0	0	0.00	47	0	0	0.00
48	2	5	2.50	48	5	13	2.60
49	3	11	3.67	49	9	32	3.56
50	2	6	3.00	50	4	11	2.75
51	1	4	4.00	51	3	11	3.67
52	0	0	0.00	52	1	3	3.00
53	0	0	0.00	53	1	3	3.00
54	1	2	2.00	54	3	9	3.00
55	2	8	4.00	55	7	23	3.29
56	431	652	1.51	56	1173	1749	1.49

<u>APPENDIX I-2</u>. The Munich 3-day Data (KONTIV)

Daily Travel Time per Traveler and Standard Deviation - 1st Day

CROSSTABULATION FOR TIME/MOT.TRAVELER — S.DEVIATION TIME

HHTYPE	CAR	TRANSIT	TOTAL	TOTAL
1	0.07	1.16	1.23	0.548
2	0.64	0.39	1.03	0.608
3	0.04	1.04	1.07	0.611
4	0.78	0.38	1.16	0.561
5	0.00	1.13	1.13	0.634
6	0.76	0.42	1.18	0.756
7	0.00	1.42	1.42	0.000
8	0.00	0.00	0.00	0.000
9	0.00	0.00	0.00	0.000
10	0.19	1.21	1.40	0.834
11	0.68	0.08	0.76	0.392
12	0.66	0.54	1.20	0.733
13	1.04	0.15	1.18	0.728
14	0.09	1.17	1.26	0.664
15	0.66	0.20	0.86	0.725
16	0.00	0.87	0.87	0.457
17	0.88	0.25	1.13	0.884
18	0.64	0.51	1.14	0.643
19	0.00	0.00	0.00	0.000
20	0.39	0.18	0.57	0.476
21	0.26	0.94	1.20	0.741
22	0.87	0.36	1.23	0.488
23	0.39	0.69	1.08	0.505
24	0.50	0.13	0.63	0.464
25	0.00	0.00	0.00	0.000
26	0.00	1.17	1.17	0.000
27	0.87	0.39	1.26	0.71[illegible]
28	0.96	0.42	1.38	0.735
29	0.10	0.98	1.08	0.177
30	0.00	0.00	0.00	0.000
31	0.00	0.00	0.00	0.000
32	0.00	0.75	0.75	0.000
33	0.00	0.00	0.00	0.000
34	0.75	0.58	1.33	0.000
35	0.00	0.00	0.00	0.000
36	0.00	0.00	0.00	0.000
37	0.00	0.00	0.00	0.000
38	0.00	0.00	0.00	0.000
39	0.00	0.00	0.00	0.000
40	0.25	0.00	0.25	0.000
41	1.11	0.46	1.56	0.482
42	0.67	0.00	0.67	0.236
43	0.14	1.44	1.58	0.937
44	0.00	0.00	0.00	0.000
45	0.29	0.75	1.04	0.083
46	0.00	0.00	0.00	0.000
47	0.00	0.00	0.00	0.000
48	0.18	0.99	1.17	0.504
49	0.27	0.91	1.17	0.881
50	2.65	0.00	2.65	0.000
51	0.69	0.52	1.21	0.350
52	0.00	1.31	1.31	0.529
53	0.56	0.78	1.33	0.289
54	0.50	0.92	1.42	0.300
55	0.71	0.46	1.17	0.611
TOT	0.49	0.66	1.15	0.657

APPENDIX I-3. The Munich 3-day Data (KONTIV)

Daily Travel Distance per Traveler and Standard Deviation - 1st Day

CROSSTAPULATION FOR DISTANCE/MOT.TRAVELER | S.DEVIATION DISTANCE

HHTYPE	1 CAR	TRANSIT	TOTAL	TOTAL
1	0.97	14.17	15.15	8.966
2	14.82	6.34	21.16	20.719
3	1.43	13.68	15.10	15.205
4	14.67	4.08	18.75	14.907
5	0.00	16.18	16.18	13.248
6	20.18	6.01	26.19	22.967
7	0.00	20.00	20.00	0.000
8	0.00	0.00	0.00	0.000
9	0.00	0.00	0.00	0.000
10	3.00	16.13	19.13	16.031
11	13.06	0.78	13.83	12.088
12	15.09	8.27	23.36	19.836
13	25.11	2.06	27.17	21.041
14	6.18	17.58	23.75	23.838
15	23.50	1.84	25.34	36.403
16	0.00	12.43	12.43	6.998
17	22.50	6.00	28.50	23.335
18	15.02	8.04	23.06	15.143
19	0.00	0.00	0.00	0.000
20	8.40	2.80	11.20	9.550
21	3.50	7.73	11.23	4.989
22	27.00	4.29	31.29	19.771
23	9.63	9.75	19.38	11.153
24	10.07	1.29	11.36	8.410
25	0.00	0.00	0.00	0.000
26	0.00	15.00	15.00	7.071
27	24.56	3.38	27.93	27.977
28	22.38	10.33	32.71	17.441
29	1.00	14.40	15.40	11.127
30	0.00	0.00	0.00	0.000
31	0.00	0.00	0.00	0.000
32	0.00	8.50	8.50	2.121
33	0.00	0.00	0.00	0.000
34	18.00	18.00	36.00	0.000
35	0.00	0.00	0.00	0.000
36	0.00	0.00	0.00	0.000
37	0.00	0.00	0.00	0.000
38	0.00	0.00	0.00	0.000
39	0.00	0.00	0.00	0.000
40	2.50	0.00	2.50	0.000
41	22.03	12.67	34.70	15.302
42	18.00	0.00	18.00	2.828
43	4.29	23.14	27.43	17.396
44	0.00	0.00	0.00	0.000
45	7.00	9.80	16.80	9.628
46	0.00	0.00	0.00	0.000
47	0.00	0.00	0.00	0.000
48	4.13	11.75	15.88	10.803
49	5.60	22.70	28.30	33.387
50	43.00	0.00	43.00	0.000
51	14.50	11.50	26.00	10.954
52	0.00	22.00	22.00	7.211
53	14.33	13.33	27.67	13.279
54	11.33	6.00	17.33	14.434
55	28.86	6.75	35.61	33.288
TOT	12.24	9.54	21.79	19.658

APPENDIX I-4. The Munich 3-day Data (KONTIV)

Daily Travel Time per Traveler and Standard Deviation - 2nd Day

CROSSTAPULATION FOR TIME/MOT.TRAVELER | S.DEVIATION TIME

2

HHTYPE	CAR	TRANSIT	TOTAL	TOTAL
1	0.03	1.32	1.35	0.606
2	0.63	0.53	1.16	0.735
3	0.03	1.26	1.29	0.890
4	0.45	0.61	1.05	0.335
5	0.04	1.20	1.24	0.682
6	0.60	0.50	1.10	0.576
7	0.00	1.42	1.42	0.000
8	0.00	0.00	0.00	0.000
9	0.00	0.00	0.00	0.000
10	0.00	1.16	1.16	0.698
11	0.62	0.32	0.94	1.175
12	0.68	0.42	1.10	0.623
13	0.98	0.15	1.13	0.549
14	0.00	0.95	0.95	0.460
15	0.64	0.52	1.17	0.540
16	0.00	1.15	1.15	0.699
17	0.92	0.21	1.12	1.002
18	0.69	0.49	1.17	0.728
19	0.00	0.00	0.00	0.000
20	0.59	0.28	0.87	1.065
21	0.18	0.81	0.99	0.232
22	0.75	0.40	1.15	0.454
23	0.49	0.67	1.16	0.702
24	1.05	0.20	1.25	0.814
25	0.00	0.00	0.00	0.000
26	0.21	0.88	1.10	0.450
27	0.98	0.22	1.20	0.761
28	0.80	0.40	1.20	0.440
29	0.00	0.96	0.96	0.323
30	1.50	0.00	1.50	0.000
31	0.00	0.00	0.00	0.000
32	0.00	1.96	1.96	0.530
33	0.00	0.00	0.00	0.000
34	0.00	0.00	0.00	0.000
35	0.00	0.00	0.00	0.000
36	0.00	0.00	0.00	0.000
37	0.00	0.00	0.00	0.000
38	0.00	0.00	0.00	0.000
39	0.00	0.00	0.00	0.000
40	0.78	0.33	1.11	0.922
41	0.54	0.76	1.29	0.454
42	0.00	0.00	0.00	0.000
43	0.07	1.52	1.60	0.735
44	0.00	0.00	0.00	0.000
45	0.00	0.96	0.96	0.059
46	0.00	0.00	0.00	0.000
47	0.00	0.00	0.00	0.000
48	0.00	0.00	0.00	0.000
49	0.28	0.77	1.05	0.434
50	0.82	0.00	0.82	1.050
51	0.69	0.97	1.67	0.722
52	0.00	0.00	0.00	0.000
53	0.00	0.00	0.00	0.000
54	0.94	0.25	1.19	1.139
55	0.67	0.44	1.11	0.535
TOT	0.48	0.68	1.16	0.646

APPENDIX I-5. The Munich 3-day Data (KONTIV)

Daily Travel Distance per Traveler and Standard Deviation - 2nd Day

CROSSTABULATION FOR DISTANCE/MOT.TRAVELER S.DEVIATION DISTANCE

HHTYPE	2 CAR	TRANSIT	TOTAL	TOTAL
1	0.26	17.11	17.37	11.137
2	16.00	9.10	25.10	23.076
3	0.83	13.49	14.31	11.169
4	9.95	5.53	15.48	11.551
5	0.50	13.45	13.95	8.196
6	16.12	6.70	22.82	17.632
7	0.00	20.00	20.00	0.000
8	0.00	0.00	0.00	0.000
9	0.00	0.00	0.00	0.000
10	0.00	15.63	15.63	14.966
11	7.75	5.00	12.75	17.192
12	15.29	7.26	22.55	16.523
13	23.12	2.69	25.81	16.023
14	0.00	11.97	11.97	7.281
15	18.66	4.81	23.47	16.897
16	0.00	13.52	13.52	10.024
17	21.50	6.50	28.00	21.213
18	18.86	6.24	25.10	17.377
19	0.00	0.00	0.00	0.000
20	20.67	2.67	23.33	35.233
21	2.33	8.25	10.58	4.716
22	20.80	4.80	25.60	15.388
23	9.84	8.71	18.55	11.344
24	24.93	1.29	26.21	22.338
25	0.00	0.00	0.00	0.000
26	5.93	10.57	16.50	12.626
27	21.20	2.20	23.40	22.589
28	19.79	8.53	28.32	13.582
29	0.00	14.75	14.75	13.150
30	26.00	0.00	26.00	0.000
31	0.00	0.00	0.00	0.000
32	0.00	14.00	14.00	5.657
33	0.00	0.00	0.00	0.000
34	0.00	0.00	0.00	0.000
35	0.00	0.00	0.00	0.000
36	0.00	0.00	0.00	0.000
37	0.00	0.00	0.00	0.000
38	0.00	0.00	0.00	0.000
39	0.00	0.00	0.00	0.000
40	18.50	2.67	21.17	27.705
41	13.20	8.10	21.30	12.491
42	0.00	0.00	0.00	0.000
43	0.86	26.14	27.00	18.556
44	0.00	0.00	0.00	0.000
45	0.00	12.60	12.60	10.465
46	0.00	0.00	0.00	0.000
47	0.00	0.00	0.00	0.000
48	0.00	0.00	0.00	0.000
49	6.55	10.73	17.27	11.064
50	18.00	0.00	18.00	24.000
51	23.33	15.33	38.67	28.024
52	0.00	0.00	0.00	0.000
53	0.00	0.00	0.00	0.000
54	21.25	2.00	23.25	27.342
55	18.86	7.86	26.71	23.824
TOT	11.69	8.99	20.68	16.520

APPENDIX I-6. The Munich 3-day Data (KONTIV)

Daily Travel Time per Traveler and Standard Deviation - 3rd Day

CROSSTABULATION FOR TIME/MOT.TRAVELER S.DEVIATION TIME

HHTYPE	3 CAR	TRANSIT	TOTAL	TOTAL
1	0.02	1.18	1.21	0.722
2	0.74	0.38	1.12	0.663
3	0.02	1.11	1.13	0.738
4	0.50	0.55	1.05	0.509
5	0.05	1.20	1.25	0.809
6	0.63	0.47	1.10	0.646
7	0.00	0.00	0.00	0.000
8	0.00	1.08	1.08	0.000
9	0.00	0.00	0.00	0.000
10	0.00	1.26	1.26	0.695
11	0.72	0.28	1.00	0.545
12	0.61	0.51	1.12	0.666
13	1.06	0.13	1.19	0.684
14	0.00	1.40	1.40	0.759
15	0.63	0.33	0.96	0.365
16	0.00	1.19	1.19	0.630
17	0.00	0.83	0.83	0.471
18	0.68	0.62	1.29	0.671
19	0.00	1.40	1.40	1.273
20	0.54	0.94	1.48	0.554
21	0.00	0.91	0.91	0.375
22	0.85	0.56	1.41	0.707
23	0.48	0.70	1.18	0.475
24	0.33	0.44	0.78	0.386
25	0.00	0.00	0.00	0.000
26	0.31	0.78	1.09	0.149
27	0.50	0.51	1.01	0.365
28	0.61	0.61	1.22	0.678
29	0.00	1.21	1.21	0.741
30	1.00	0.25	1.25	1.061
31	1.10	0.17	1.27	0.966
32	0.00	1.22	1.22	0.536
33	0.00	0.00	0.00	0.000
34	0.00	0.38	0.38	0.177
35	0.00	0.00	0.00	0.000
36	0.00	0.00	0.00	0.000
37	0.00	0.00	0.00	0.000
38	0.00	0.00	0.00	0.000
39	0.00	0.00	0.00	0.000
40	0.25	0.00	0.25	0.000
41	0.65	0.62	1.27	0.727
42	0.65	0.23	0.89	0.241
43	0.02	1.56	1.58	0.654
44	0.00	0.00	0.00	0.000
45	0.58	0.54	1.12	0.059
46	0.00	1.62	1.62	0.821
47	0.00	0.00	0.00	0.000
48	0.00	1.27	1.27	0.655
49	0.32	1.01	1.33	0.568
50	0.11	0.81	0.92	0.522
51	0.37	0.62	1.00	0.561
52	0.00	0.00	0.00	0.000
53	0.00	0.00	0.00	0.000
54	1.46	0.33	1.79	1.237
55	0.80	0.36	1.17	0.678
TOT	0.46	0.70	1.16	0.652

APPENDIX I-7. The Munich 3-day Data (KONTIV)

Daily Travel Distance per Traveler and Standard Distance - 3rd Day

CROSSTABULATION FOR DISTANCE/MOT.TRAVELER | S.DEVIATION DISTANCE

3

HHTYPE	CAR	TRANSIT	TOTAL	TOTAL
1	0.79	14.80	15.59	10.532
2	18.10	7.02	25.12	21.759
3	0.60	14.78	15.38	12.887
4	10.86	5.79	16.65	15.133
5	0.64	14.81	15.45	16.065
6	17.09	6.81	23.90	20.335
7	0.00	0.00	0.00	0.000
8	0.00	14.00	14.00	0.000
9	0.00	0.00	0.00	0.000
10	0.00	18.89	18.89	13.411
11	11.28	4.11	15.39	11.768
12	15.87	7.65	23.51	19.738
13	24.82	0.71	25.53	15.589
14	0.00	28.77	28.77	27.742
15	15.94	4.16	20.09	13.442
16	0.00	19.08	19.08	9.687
17	0.00	22.00	22.00	2.828
18	18.83	9.49	28.32	19.997
19	0.00	21.00	21.00	24.042
20	15.46	12.83	28.29	20.593
21	0.00	11.25	11.25	5.252
22	23.29	6.54	29.83	22.875
23	14.21	10.04	24.25	22.595
24	7.00	6.83	13.83	7.567
25	0.00	0.00	0.00	0.000
26	3.33	10.00	13.33	5.774
27	12.57	4.86	17.43	15.393
28	14.87	9.33	24.20	12.715
29	0.00	18.00	18.00	16.971
30	26.00	3.50	29.50	31.820
31	13.25	1.75	15.00	11.314
32	0.00	10.00	10.00	7.211
33	0.00	0.00	0.00	0.000
34	0.00	4.30	4.30	1.131
35	0.00	0.00	0.00	0.000
36	0.00	0.00	0.00	0.000
37	0.00	0.00	0.00	0.000
38	0.00	0.00	0.00	0.000
39	0.00	0.00	0.00	0.000
40	2.50	0.00	2.50	0.000
41	15.70	8.86	24.56	20.738
42	15.22	2.72	17.94	5.108
43	0.36	26.50	26.86	7.290
44	0.00	0.00	0.00	0.000
45	14.00	8.00	22.00	8.485
46	0.00	26.50	26.50	11.619
47	0.00	0.00	0.00	0.000
48	0.00	13.50	13.50	9.407
49	7.91	15.18	23.09	10.222
50	5.33	10.33	15.67	5.125
51	11.00	11.50	22.50	16.442
52	0.00	0.00	0.00	0.000
53	0.00	0.00	0.00	0.000
54	31.00	2.00	33.00	35.355
55	20.75	5.75	26.50	25.545
TOT	11.78	10.20	21.98	18.288

APPENDIX I-8. The Munich 3-day Data (KONTIV)

Daily Average Speed

CROSSTAPULATION FOR SPEED

HHTYPE	1st Day TOTAL	2nd Day TOTAL	3rd Day TOTAL
1	12.33	12.87	12.92
2	20.54	21.71	22.48
3	14.05	11.06	13.58
4	16.17	14.70	15.89
5	14.26	11.27	12.34
6	22.14	20.70	21.72
7	14.12	14.12	0.00
8	0.00	0.00	12.92
9	0.00	0.00	0.00
10	13.68	13.44	15.04
11	18.22	13.50	15.39
12	19.49	20.49	21.05
13	22.98	22.80	21.47
14	18.84	12.63	20.58
15	29.53	20.08	20.99
16	14.34	11.72	15.98
17	25.33	24.89	26.40
18	20.18	21.36	21.88
19	0.00	0.00	15.00
20	19.53	26.92	19.07
21	9.36	10.73	12.33
22	25.51	22.26	21.16
23	17.89	16.05	20.49
24	18.00	20.97	17.79
25	0.00	0.00	0.00
26	12.86	15.07	12.24
27	22.18	19.50	17.22
28	23.69	23.54	19.88
29	14.22	15.39	14.90
30	0.00	17.33	23.60
31	0.00	0.00	11.84
32	11.33	7.15	8.18
33	0.00	0.00	0.00
34	27.00	0.00	11.47
35	0.00	0.00	0.00
36	0.00	0.00	0.00
37	0.00	0.00	0.00
38	0.00	0.00	0.00
39	0.00	0.00	0.00
40	10.00	19.05	10.00
41	22.19	16.45	19.35
42	27.00	0.00	20.23
43	17.38	16.93	16.96
44	0.00	0.00	0.00
45	16.13	13.15	19.56
46	0.00	0.00	16.31
47	0.00	0.00	0.00
48	13.61	0.00	10.66
49	24.09	16.52	17.42
50	16.23	21.82	17.09
51	21.52	23.20	22.50
52	16.85	0.00	0.00
53	20.75	0.00	0.00
54	12.24	19.58	18.42
55	30.52	24.13	22.71
TOT	18.99	17.83	18.91

APPENDIX II-1. The Nurenberg Data - Travelers per Household

HTYPE	HOUSEHOLDS	HH-MOTORIZED TRAV.	TRAVELERS/HH
1	38738	22526	0.58
2	26941	22785	0.85
3	65488	24620	0.38
4	7574	5303	0.70
5	17564	12083	0.91
6	44536	39621	1.29
7	542	412	1.02
8	415	374	1.40
9	72	53	1.44
10	13849	10573	1.17
11	9788	9115	1.54
12	40221	37741	1.60
13	7657	7471	1.79
14	24799	10518	0.65
15	12057	8491	1.16
16	5322	3950	1.30
17	5073	4581	1.64
18	7600	7240	1.92
19	2956	2802	2.02
20	3077	2989	2.32
21	3326	2784	1.55
22	3964	3764	1.93
23	11638	11074	2.11
24	3215	3153	2.43
25	4372	3778	1.58
26	2940	2752	1.79
27	9814	9215	1.91
28	6733	6531	2.19
29	2784	2320	1.32
30	1878	1737	1.43
31	2788	2519	1.44
32	555	513	1.66
33	1124	1042	1.90
34	928	816	1.94
35	1597	1499	2.33
36	1427	1376	2.48
37	438	426	2.90
38	1068	1045	2.89
39	3187	2978	2.42
40	2388	2279	2.71
41	8194	7989	2.78
42	6935	6845	3.15
43	2261	2021	2.08
44	2183	2088	2.42
45	3969	3839	2.56
46	2394	2312	2.90
47	2432	2419	3.25
48	2434	2127	2.26
49	2103	2025	2.61
50	5886	5714	2.90
51	2736	2708	3.41
52	1987	1767	2.14
53	1685	1634	2.22
54	4630	4371	2.33
55	6289	6199	2.93
TOT.	456553	348904	1.35

Households - Total Households
HH-Motorized - Households generating at least one motorized trip
Travelers/HH - Travelers per Total Households

APPENDIX II-2. The Nurenberg Data - Time per Traveler

CROSSTABULATION FOR TIME/MOT.TRAVELER — S.DEVIATION TIME

GRAND TOTAL

MHTYPE	CAR	TRANSIT	TOTAL	TOTAL
1	0.19	1.20	1.39	0.930
2	1.13	0.10	1.22	0.901
3	0.13	1.29	1.42	0.922
4	1.05	0.18	1.23	0.871
5	0.23	1.17	1.40	0.926
6	1.01	0.26	1.26	1.023
7	0.22	1.15	1.36	0.864
8	0.73	0.65	1.37	0.824
9	1.13	0.09	1.22	0.691
10	0.25	1.10	1.36	0.932
11	0.80	0.32	1.12	0.944
12	0.99	0.27	1.25	0.990
13	1.35	0.03	1.38	1.050
14	0.11	1.40	1.51	0.988
15	1.03	0.24	1.27	0.883
16	0.23	1.18	1.41	0.961
17	0.74	0.55	1.29	1.096
18	0.76	0.53	1.29	1.060
19	0.67	0.58	1.25	0.878
20	1.07	0.26	1.33	0.909
21	0.24	1.08	1.32	0.838
22	0.63	0.50	1.13	0.855
23	0.77	0.51	1.28	0.974
24	1.11	0.23	1.34	1.019
25	0.25	1.10	1.35	0.902
26	0.66	0.45	1.11	0.795
27	0.79	0.54	1.33	1.045
28	1.09	0.17	1.27	1.035
29	0.17	1.17	1.34	0.792
30	0.77	0.50	1.26	1.047
31	0.85	0.45	1.31	0.683
32	0.82	0.56	1.39	1.036
33	1.06	0.18	1.23	0.936
34	0.24	1.05	1.29	0.925
35	0.54	0.66	1.20	0.905
36	0.60	0.63	1.23	0.844
37	0.66	0.69	1.35	0.992
38	0.97	0.43	1.40	1.052
39	0.24	1.12	1.36	0.909
40	0.51	0.70	1.22	0.947
41	0.58	0.69	1.28	0.957
42	0.90	0.41	1.30	1.018
43	0.24	1.12	1.35	0.833
44	0.60	0.64	1.23	1.009
45	0.62	0.71	1.33	1.016
46	0.54	0.68	1.22	0.810
47	0.85	0.42	1.27	0.866
48	0.23	1.08	1.32	0.840
49	0.52	0.69	1.21	0.923
50	0.59	0.68	1.27	0.887
51	0.90	0.48	1.38	0.979
52	0.32	1.09	1.42	0.895
53	0.61	0.54	1.15	0.959
54	0.74	0.52	1.27	1.002
55	0.99	0.25	1.24	0.976
TOT	0.72	0.58	1.30	0.966

APPENDIX II-3. The Nurenberg Data - Distance per Traveler

CROSSTABULATION FOR DISTANCE/MOT.TRAVELER S.DEVIATION DISTANCE

GRAND TOTAL

HHTYPE	CAR	TRANSIT	TOTAL	TOTAL
1	4.37	12.52	16.89	15.580
2	28.22	1.27	29.49	24.803
3	2.60	12.12	14.71	13.513
4	26.89	2.15	29.04	30.370
5	5.50	13.96	19.46	18.700
6	26.72	3.40	30.12	26.614
7	3.56	14.21	17.78	16.565
8	22.32	10.47	32.79	24.533
9	33.45	1.08	34.53	28.052
10	5.99	12.63	18.62	18.661
11	19.73	4.76	24.49	23.516
12	25.12	3.76	28.87	24.611
13	36.93	0.48	37.41	28.491
14	2.70	13.69	16.40	15.840
15	23.93	2.44	26.38	22.857
16	4.92	14.89	19.81	20.104
17	18.03	7.36	25.40	24.964
18	18.94	6.82	25.76	24.279
19	18.40	6.64	25.04	22.309
20	29.67	3.45	33.12	27.652
21	5.75	12.69	18.43	19.725
22	14.75	6.74	21.48	19.326
23	19.37	6.35	25.72	23.820
24	30.53	3.19	33.72	27.149
25	4.62	14.07	18.69	17.253
26	16.38	7.41	23.79	20.873
27	19.47	7.19	26.65	24.475
28	27.67	2.58	30.25	25.116
29	2.87	14.27	17.14	17.351
30	19.01	7.12	26.13	24.306
31	24.07	5.55	29.61	26.159
32	24.09	7.94	32.03	27.666
33	28.59	2.04	30.63	27.304
34	4.53	16.32	20.85	21.993
35	16.19	11.03	27.22	33.767
36	17.05	8.35	25.39	24.287
37	15.96	9.26	25.22	19.692
38	28.11	5.84	33.94	30.287
39	5.18	15.18	20.36	19.662
40	13.64	10.91	24.54	25.238
41	15.66	9.85	25.51	26.307
42	24.54	6.62	31.16	28.336
43	6.20	14.77	20.97	22.026
44	15.71	9.16	24.87	23.864
45	15.76	9.28	25.04	25.490
46	14.37	8.48	22.85	21.035
47	23.23	5.69	28.92	24.143
48	5.13	13.29	18.41	18.510
49	12.28	8.65	20.93	19.834
50	15.03	8.89	23.93	24.100
51	25.56	6.94	32.50	29.863
52	7.22	14.86	22.08	23.106
53	16.41	8.51	24.92	26.383
54	18.63	8.62	27.25	25.445
55	26.92	4.21	31.13	26.528
TOT	18.51	7.24	25.76	24.401

APPENDIX II-4. The Nurenberg Data - Daily Average Speed

CROSSTABULATION FOR SPEED

GRAND TOTAL

HHTYPE	CAR	TRANSIT	TOTAL
1	23.42	10.44	12.19
2	25.06	13.09	24.10
3	20.59	9.37	10.37
4	25.69	11.73	23.61
5	23.88	11.94	13.90
6	26.58	13.29	23.88
7	16.33	12.41	13.03
8	30.71	16.16	23.85
9	29.63	12.50	28.41
10	23.65	11.44	13.71
11	24.66	14.64	21.77
12	25.48	14.06	23.05
13	27.32	14.83	27.02
14	24.75	9.76	10.84
15	23.25	9.98	20.71
16	21.70	12.59	14.06
17	24.29	13.37	19.64
18	24.87	12.80	19.90
19	27.64	11.38	20.05
20	27.71	13.46	24.96
21	24.19	11.75	14.00
22	23.44	13.52	19.06
23	25.23	12.40	20.09
24	27.48	13.64	25.07
25	18.52	12.80	13.86
26	24.71	16.42	21.36
27	24.80	13.24	20.07
28	25.28	14.99	23.88
29	16.58	12.20	12.77
30	24.85	14.38	20.73
31	28.27	12.20	22.67
32	29.20	14.10	23.08
33	27.04	11.50	24.80
34	18.65	15.56	16.14
35	30.08	16.69	22.70
36	28.53	13.17	20.62
37	24.22	13.39	18.68
38	29.04	13.52	24.26
39	21.44	13.56	14.96
40	26.51	15.55	20.18
41	26.87	14.23	20.01
42	27.36	16.28	23.91
43	26.40	13.21	15.50
44	26.32	14.37	20.15
45	25.31	13.04	18.77
46	26.80	12.39	18.73
47	27.27	13.50	22.71
48	22.12	12.25	13.99
49	23.49	12.60	17.30
50	25.66	13.06	18.89
51	28.42	14.42	23.54
52	22.32	13.57	15.57
53	26.93	15.65	21.61
54	25.05	16.46	21.50
55	27.17	16.63	25.03
TOT	25.78	12.54	19.88

APPENDIX II-5. The Nurenberg Data - Daily Time per Household

CROSSTABULATION FOR TIME/MOT.HH

GRAND TOTAL

HHTYPE	CAR	TRANSIT	TOTAL
1	0.19	1.20	1.39
2	1.13	0.10	1.22
3	0.13	1.29	1.42
4	1.05	0.18	1.23
5	0.30	1.55	1.85
6	1.46	0.37	1.83
7	0.29	1.54	1.84
8	1.13	1.00	2.13
9	2.20	0.17	2.37
10	0.39	1.70	2.09
11	1.32	0.54	1.86
12	1.68	0.45	2.13
13	2.48	0.06	2.54
14	0.17	2.15	2.31
15	1.70	0.40	2.11
16	0.40	2.07	2.47
17	1.35	1.00	2.34
18	1.53	1.07	2.60
19	1.42	1.24	2.66
20	2.56	0.61	3.17
21	0.44	2.00	2.44
22	1.28	1.01	2.29
23	1.71	1.14	2.85
24	2.75	0.58	3.33
25	0.46	2.02	2.47
26	1.27	0.86	2.13
27	1.60	1.10	2.70
28	2.47	0.39	2.86
29	0.27	1.85	2.13
30	1.18	0.77	1.95
31	1.36	0.73	2.09
32	1.48	1.01	2.49
33	2.17	0.36	2.53
34	0.54	2.32	2.86
35	1.34	1.64	2.98
36	1.54	1.63	3.17
37	1.97	2.06	4.03
38	2.86	1.27	4.13
39	0.62	2.89	3.52
40	1.46	1.99	3.45
41	1.66	1.97	3.63
42	2.86	1.30	4.16
43	0.55	2.61	3.15
44	1.51	1.61	3.13
45	1.65	1.88	3.53
46	1.61	2.05	3.66
47	2.78	1.38	4.16
48	0.60	2.81	3.41
49	1.42	1.86	3.28
50	1.75	2.03	3.78
51	3.10	1.66	4.75
52	0.78	2.63	3.41
53	1.39	1.24	2.64
54	1.84	1.29	3.13
55	2.95	0.75	3.70
TOT	1.27	1.02	2.30

APPENDIX II-6. The Nurenberg Data - Daily Distance per Household

CROSSTABULATION FOR DISTANCE/MOT.HH

GRAND TOTAL

HHTYPE	CAR	TRANSIT	TOTAL
1	4.37	12.52	16.89
2	28.22	1.27	29.49
3	2.60	12.12	14.71
4	26.89	2.15	29.04
5	7.27	18.45	25.72
6	38.74	4.94	43.68
7	4.80	19.14	23.94
8	34.60	16.23	50.83
9	65.21	2.11	67.32
10	9.21	19.43	28.63
11	32.54	7.85	40.39
12	42.74	6.39	49.13
13	67.85	0.89	68.74
14	4.14	20.94	25.08
15	39.57	4.04	43.60
16	8.62	26.09	34.71
17	32.68	13.35	46.03
18	38.08	13.72	51.80
19	39.17	14.14	53.30
20	70.92	8.25	79.17
21	10.63	23.48	34.12
22	29.99	13.71	43.70
23	43.05	14.12	57.17
24	75.56	7.88	83.44
25	8.47	25.80	34.27
26	31.26	14.15	45.42
27	39.57	14.61	54.18
28	62.55	5.83	68.38
29	4.55	22.61	27.15
30	29.44	11.03	40.48
31	38.43	8.86	47.29
32	43.19	14.23	57.42
33	58.62	4.19	62.81
34	10.02	36.08	46.10
35	40.25	27.41	67.65
36	43.84	21.47	65.31
37	47.61	27.61	75.22
38	82.99	17.23	100.22
39	13.39	39.25	52.64
40	38.69	30.95	69.64
41	44.63	28.08	72.71
42	78.39	21.14	99.53
43	14.47	34.43	48.90
44	39.81	23.21	63.01
45	41.67	24.54	66.21
46	43.17	25.46	68.63
47	75.88	18.57	94.45
48	13.27	34.40	47.67
49	33.28	23.43	56.71
50	44.87	26.54	71.41
51	88.02	23.90	111.93
52	17.37	35.74	53.11
53	37.56	19.46	57.02
54	45.98	21.29	67.27
55	80.04	12.50	92.54
TOT	32.81	12.83	45.64

APPENDIX III-1. The Munich Data, the Complete 1-day Sample (KONTIV)
Summary Table per Traveler

HTYPE	MOT.HH	MOT.TRAV.	TRAV./HH	TIME/MOT. TRAVELER	DISTANCE/MOT. TRAVELER	SPEED	S.DEVIATION TIME
1	298	298	1.00	1.36	17.02	12.50	0.655
2	522	522	1.00	1.12	24.58	21.88	0.663
3	236	236	1.00	1.41	17.11	12.13	0.792
4	116	116	1.00	1.16	19.57	16.94	0.750
5	127	194	1.53	1.38	17.95	12.98	0.735
6	441	679	1.54	1.15	23.29	20.18	0.690
7	15	22	1.47	1.21	20.27	16.82	0.721
8	13	19	1.46	1.15	23.71	20.68	0.689
9	3	3	1.00	0.58	9.17	15.71	0.464
10	85	141	1.66	1.36	17.81	13.14	0.645
11	20	32	1.60	1.06	18.38	17.27	0.608
12	396	702	1.77	1.17	22.52	19.23	0.622
13	128	233	1.82	1.16	25.65	22.05	0.625
14	84	142	1.69	1.25	15.33	12.26	0.649
15	101	173	1.71	1.25	20.75	16.63	0.816
16	35	68	1.94	1.16	14.55	12.50	0.653
17	36	63	1.75	1.17	16.77	14.30	0.643
18	60	124	2.07	1.19	19.53	16.43	0.604
19	38	84	2.21	1.20	21.20	17.61	0.707
20	30	69	2.30	1.16	22.86	19.69	0.611
21	28	61	2.18	1.19	16.07	13.52	0.608
22	6	13	2.17	1.07	17.35	16.26	0.797
23	83	195	2.35	1.19	19.83	16.69	0.664
24	39	94	2.41	1.02	20.38	20.00	0.561
25	15	28	1.87	1.19	19.38	16.23	0.635
26	5	12	2.40	0.90	11.68	13.04	0.600
27	43	92	2.14	1.20	18.34	15.26	0.664
28	31	72	2.32	1.16	21.53	18.32	0.692
29	8	16	2.00	1.60	25.01	15.60	0.852
30	2	4	2.00	1.42	34.50	24.28	1.180
31	11	20	1.82	1.22	19.50	15.92	0.635
32	2	4	2.00	1.10	30.55	27.88	0.439
33	5	11	2.20	1.33	31.36	23.66	1.004
34	4	12	3.00	1.08	15.51	14.39	0.806
35	4	8	2.00	1.10	15.29	13.85	0.685
36	7	15	2.14	1.14	16.87	14.80	0.447
37	1	4	4.00	1.06	15.32	14.42	0.533
38	8	20	2.50	1.52	25.64	16.91	0.910
39	7	22	3.14	1.13	14.64	12.91	0.556
40	4	10	2.50	1.12	15.76	14.01	0.543
41	21	62	2.95	1.39	20.07	14.43	0.741
42	16	52	3.25	0.92	15.77	17.15	0.534
43	8	17	2.13	1.17	15.94	13.66	0.646
44	9	19	2.11	1.36	22.73	16.75	0.663
45	25	56	2.24	0.99	16.57	16.74	0.643
46	33	84	2.55	1.08	18.54	17.16	0.641
47	11	30	2.73	1.17	22.49	19.20	0.765
48	9	32	3.56	1.08	12.90	11.94	0.701
49	7	24	3.43	1.10	17.19	15.66	0.520
50	32	93	2.91	1.44	22.70	15.76	0.681
51	15	53	3.53	1.29	25.00	19.33	0.661
52	3	9	3.00	1.02	11.24	11.04	0.714
53	1	4	4.00	0.56	8.92	15.87	0.410
54	8	22	2.75	1.14	23.82	20.96	0.548
55	9	25	2.78	1.35	32.17	23.84	0.887
TOT.	3304	5215	1.58	1.21	20.80	17.26	0.680

APPENDIX III-2. The Munich Data, the Complete 1-day Sample (KONTIV)
Summary Table per Household

CROSSTABULATION FOR DISTANCE/MOT.HH | CROSSTABULATION FOR TIME/MOT.HH

GRAND TOTAL

HHTYPE	CAR	TRANSIT	TOTAL	CAR	TRANSIT	TOTAL
	CROSSTABULATION FOR DISTANCE/MOT.HH			CROSSTABULATION FOR TIME/MOT.HH		
1	2.02	14.99	17.02	0.09	1.27	1.36
2	20.35	4.23	24.58	0.79	0.33	1.12
3	1.26	15.85	17.11	0.05	1.36	1.41
4	13.05	6.52	19.57	0.55	0.61	1.16
5	3.93	23.49	27.42	0.19	1.92	2.11
6	26.14	9.72	35.85	1.05	0.73	1.78
7	15.17	14.56	29.73	0.56	1.21	1.77
8	22.19	12.46	34.65	0.63	1.05	1.68
9	9.17	0.00	9.17	0.58	0.00	0.58
10	7.35	22.20	29.55	0.36	1.89	2.25
11	18.65	10.55	29.40	0.88	0.82	1.70
12	26.63	13.29	39.92	1.08	1.00	2.08
13	38.28	8.42	46.69	1.44	0.67	2.12
14	4.69	21.23	25.92	0.19	1.92	2.11
15	21.02	14.52	35.54	0.78	1.36	2.14
16	8.54	19.72	28.26	0.33	1.93	2.26
17	11.11	18.24	29.35	0.59	1.46	2.05
18	24.28	16.08	40.37	1.04	1.42	2.46
19	29.61	17.26	46.86	1.14	1.52	2.66
20	36.50	16.08	52.58	1.38	1.29	2.67
21	5.84	29.16	35.00	0.28	2.31	2.59
22	21.17	16.42	37.58	1.03	1.28	2.31
23	25.47	21.12	46.59	1.06	1.73	2.79
24	37.22	11.89	49.11	1.45	1.00	2.46
25	12.10	24.07	36.17	0.53	1.70	2.23
26	11.80	16.24	28.04	0.53	1.62	2.15
27	17.71	21.52	39.23	0.74	1.83	2.57
28	34.74	15.27	50.02	1.46	1.27	2.73
29	8.50	41.52	50.02	0.40	2.81	3.21
30	50.50	18.50	69.00	1.50	1.34	2.84
31	18.64	16.82	35.45	0.92	1.30	2.23
32	61.10	0.00	61.10	2.19	0.00	2.19
33	64.20	4.80	69.00	2.32	0.60	2.92
34	11.00	35.52	46.52	0.49	2.74	3.23
35	17.07	13.50	30.57	0.81	1.40	2.21
36	19.43	16.71	36.14	0.72	1.73	2.44
37	44.00	17.30	61.30	1.75	2.50	4.25
38	45.85	18.25	64.10	2.41	1.37	3.79
39	12.21	33.80	46.01	0.52	3.04	3.56
40	13.15	26.25	39.40	0.85	1.96	2.81
41	23.76	35.50	59.26	1.04	3.07	4.11
42	35.49	15.75	51.24	1.67	1.32	2.99
43	13.05	20.82	33.87	0.52	1.96	2.48
44	30.56	17.42	47.98	1.28	1.59	2.86
45	19.55	17.58	37.13	0.76	1.45	2.22
46	29.54	17.65	47.19	1.22	1.53	2.75
47	42.25	19.09	61.35	1.62	1.58	3.20
48	19.11	26.76	45.87	0.85	2.99	3.84
49	26.43	32.50	58.93	1.01	2.75	3.76
50	29.59	36.39	65.98	1.25	2.94	4.19
51	63.67	24.67	88.33	2.46	2.11	4.57
52	2.83	30.90	33.73	0.25	2.81	3.06
53	7.70	28.00	35.70	0.42	1.83	2.25
54	33.75	31.75	65.50	1.38	1.75	3.12
55	72.81	16.56	89.37	2.48	1.27	3.75
TOT	19.09	13.74	32.83	0.77	1.13	1.90

APPENDIX IV. Travel Time and Money Budgets per Household, by Type, the Nurenberg Region 1975 and Munich 1976

Type	Size	Cars	THE NURENBERG REGION				MUNICH	
			TT, hr.	M, DM	Inc/Day	M % Inc.	TT, hr.	M, DM
1	1	0	1.39	1.63	42.08	3.9	1.36	1.68
2		1+	1.22	12.36	72.85	(17.0)	1.12	12.08
3		0	1.42	1.44	42.08	3.4	1.41	1.70
4	1	1+	1.23	12.37	72.85	(17.0)	1.16	11.76
5	2	0	1.85	2.49	75.33	3.3	2.11	2.70
6		1+	1.81	13.80	112.72	12.2	1.78	13.36
7		0	1.84	2.33	75.33	3.1	1.77	2.79
8		1	2.13	15.01	112.72	13.3	1.68	13.39
9		2+	2.37	25.43	-	-	(0.58)	20.21
10		0	2.09	2.75	75.33	3.7	2.25	2.87
11		1	1.86	13.66	112.72	12.1	1.70	12.84
12		1	2.13	14.35	112.72	12.7	2.08	13.90
13		2+	2.54	25.49	-	-	2.12	23.95
14		0	2.31	2.45	75.33	3.3	2.11	2.53
15	2	1+	2.11	13.75	112.72	12.2	2.14	13.58
16	3	0	2.47	3.37	106.41	3.2	2.26	2.72
17		1	2.34	14.45	129.25	11.2	2.05	13.23
18		1	2.60	14.97	129.25	11.6	2.46	14.09
19		1	2.66	15.13	129.25	11.7	2.66	14.73
20		2+	3.17	26.80	-	-	2.67	24.86
21		0	2.44	3.29	106.41	3.1	2.59	3.43
22		1	2.29	14.26	129.25	11.0	2.31	13.86
23		1	2.85	15.47	129.25	12.0	2.79	14.90
24		2+	3.37	27.15	-	-	2.46	24.34
25		0	2.47	3.33	106.41	3.1	2.23	3.47
26		1	2.13	14.43	129.25	11.2	2.15	13.01
27		1	2.70	15.23	129.25	11.8	2.57	14.27
28		2+	2.86	25.72	-	-	2.73	24.60
29		0	2.13	2.66	106.41	2.5	3.21	4.90
30		1	1.95	13.83	129.25	10.7	2.84	16.73
31		1	2.09	14.32	129.25	11.1	2.23	13.69
32		1	2.49	15.49	129.25	12.0	2.19	15.08
33	3	2+	2.53	25.15	-	-	2.92	25.72
34	4+	0	2.86	4.49	121.94	3.7	3.23	4.52
35		1	2.98	17.08	141.79	12.1	2.21	13.09
36		1	3.17	16.57	141.79	11.7	2.44	13.75
37		1	4.03	17.76	141.79	12.5	4.25	15.99
38		2+	4.13	29.11	-	-	3.79	25.99
39		0	3.52	5.11	121.94	4.2	3.59	4.45
40		1	3.45	17.43	141.79	12.3	2.81	14.54
41		1	3.63	17.56	141.79	12.4	4.11	16.76
42		2+	4.16	29.26	-	-	2.99	24.73
43		0	3.15	4.71	131.94	3.9	2.48	3.23
44		1	3.13	16.45	141.79	11.6	2.86	14.83
45		1	3.53	16.81	141.79	11.9	2.22	13.88
46		1	3.66	17.06	141.79	12.0	2.75	14.77
47		2+	4.16	28.68	-	-	3.20	25.79
48		0	3.41	4.61	121.94	3.8	3.84	4.36
49		1	3.28	15.91	141.79	11.2	3.76	16.58
50		1	3.78	17.37	141.79	12.3	4.19	17.39
51		2+	4.75	30.50	-	-	4.57	28.45
52		0	3.41	5.10	121.94	4.2	3.06	3.34
53		1	2.64	15.73	141.79	11.1	2.25	14.30
54		1	3.13	16.73	141.79	11.8	3.12	17.12
55	4+	2+	3.70	28.19	-	-	3.75	28.13

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