U.S. Department
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Research and
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Administration

400 Seventh Street, S.W.
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THE UMOT MODEL

A Progress Report on the Development and Application of a Policy-Oriented Model of Transportation and Land Use Interactions

Page

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Summary

A new urban travel/land use model will be available for policy analysis in late 1981. Unlike conventional models, the UMOT uses a multi-loop feedback design in which all travel components interact simultaneously, producing many outputs from few inputs. The usual costly calibration to observed choices is completely elimimated by the use of constraints that are transferable over time and space. Having very modest data needs, the model has been programmed on an Apple II microcomputer. Both daily and hourly (24 hour) travel are computed interactively. In its finished form, the model will also compute land use interactively with travel. Transparency and user interaction are provided by self-contained instructions, graphic displays and alpha-numeric readouts. Presented here, in addition to a description of the model, are several examples of policy analysis involving automobile costs, transit fares and transit speed.

A. The UMOT Model Description

1. The development and application of the UMOT model as a policy analysis tool is being sponsored by the Research and Special Programs Administration with the cooperation of UMTA, FHWA and FRA. It has been conceptualized and developed by Yacov Zahavi of Mobility Systems, Inc.*

   The principal advantages to the user are a) far more realistic representations of urban travel and land use, including their interactions, than are available from conventional approaches, and b) a model that is not data hungry, does not require calibration to the observed choices, and can therefore be run quickly and inexpensively on a low-priced microcomputer.

2. Among the unique features of the UMOT model are:

   (1) All components of travel such as car ownership, travel demand and mode choice are unified under one operating mechanism, and not determined separately by independent submodels as in conventional approaches. This single mechanism ensures consistency among all parts of the model.

   2. All model components are linked through behavioral and physical constraints which have been found to be transferable over time and space. this means that the model's outputs are never calibrated to observed choices; the outputs are compared to observations for the model's validation, not calibrated to them.

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(3) The model computes hourly travel over the day, by mode and by trip purpose. This is linked to constraints on average daily travel to maintain consistency.

(4) There are no assumptions about unilateral causality. In the UMOT model all travel components are linked in a feedback process, and thus can be either cause or effect, depending on the step of the analysis.

3. In the fully completed form the UMOT will handle information in at least five dimensions: household number and size, income distribution, travel modes, time of day, and spatial location. In addition the model will be dynamic so that the time trajectories of change can be explored.

In its present stage of development the model integrates the first four dimensions. The spatial dimension (and therefore land use) is now under development and the model contains no dynamics, as yet. Even so, with prudence and understanding the model shows great power even now to indicate the effects of both policy actions and external factors such as gasoline price. Further improvements, even in the dimensions now modeled, are planned. Its application to intercity travel is also being undertaken.

4. The model is capable of exploring the effects of both policy actions and external factors. Typical issues, some of which may involve both policy and external factors are:

(1) Changing bus fares.

(2) Changing bus speeds.

(3) Introducing (or curtailing) rapid transit.

(4) Changing car costs through tolls, parking fees, taxes, etc.

(5) Auto use restrictions.

(6) Road network expansion or closings.

(7) Changes in household income, or income distribution.

(8) Change in household size.

(9) Changes in population.

(10) Changes in the price or availability of fuel.

(11) The effects of policy or external factors on fuel consumption.

(12) The effects of policy or external factors on the hourly distribution of travel.

5. The model has a number of built-in relationships that were found to be transferable both between cities and over time. The first four of these are behavioral, and the last two physical.

(1) The average daily travel time per traveler. This is the so-called "time budget". However, it is not a constraint, but rather a statistical relationship having a mean that is a function of travel speed and a stable coefficient of variation.

(2) The average daily travel money per household, the "money budget". Again, this is a relationship that is a function of income and car ownership.

(3) The average number of travelers per household, as a function of household size and car ownership.

(4) The threshold of car daily travel distance which justifies owning a car.

(5) The unit cost of owning and operating a car. This is a function of many factors, including average travel speed and the initial cost of the car (from FHWA records).

(6) The speed/flow relationships for road categories.

6. The model requires rather few inputs, while its outputs are many.

The inputs are:

(1) The number of households and the household sizes in the urban area under investigation.

(2) The income distribution of households by income group. Any number of groups can be handled but for purposes of policy exploration five groups are typically used.

(3) The unit costs of travel by mode. At present the model handles three modes, but the capability for a greater number will be incorporated.

In addition, the number of miles of road network can be accepted as an input, or it can be derived as an output, depending on the particular policy exploration being performed.

The model is now programmed to give the following outputs:

(1) Car ownership per household by income group.

(2) Proportions of households owning 0, 1 and 2+ cars within each income group.

(3) Class of car purchased by income group.

(4) Number of travelers per household.

(5) Daily travel distance per household, by mode.

(6) Modal split by passenger travel distance.

(7) Network travel speed.

(8) Door-to-door travel speed by income group.

(9) Minimum and maximum network sizes for which travel budgets can be fully utilized.

(10) Daily travel time and money expenditures per household and per traveler by mode, and hence also the expected revenues for public transport systems.

(11) Daily trip rate, trip distance and travel time by mode and by trip purpose, per average traveler and per household type.

(12) Hourly person trip rate, distance, time and speed by mode and by trip purpose.

(13) Hourly car trip rate, distance, time and speed by mode and by trip purpose.

(14) Hourly person and vehicle total travel distance and travel time (PMT, PHT, VMT, VHT), by mode.

(15) Car occupancy rates by trip purpose.

(16) The spread of peak hour travel into peak period travel under congested conditions.

(17) Daily and hourly fuel consumption, by mode, per household type.

It is important to understand that these outputs are all functions of the inputs. In general, all outputs will vary as any one of the inputs is changed; e.g., the unit cost of travel (gasoline price), the speed of travel (new freeways or subways), income distribution, number of households, or household size. As the model is developed further, an even greater number of outputs will be provided.

Furthermore, the inherent structure of the model plus the generous use of computer graphics enables the user to see the step-by-step process of convergence, thus making the model transparent as opposed to the typical "black box". In its present form it is programmed on an Apple II microcomputer.

7. The steps of the UMOT urban travel process, in a simplified way, are:

(1) The daily spatial and economic opportunities per household, presently represented by the daily travel distance, are maximized within the travel time and money constraints by the optimal combination of available or planned modes;

(2) The demand for car travel distance generates car ownership;

(3) The assignment of the estimated number of cars on the road network results in new unit costs of travel, which are then introduced as new inputs and

(4) The process is iterated until the outputs of consecutive runs converge to preferred levels of accuracy.

For instance, convergence is reached in examples that follow when the values of two consecutive interations are less than: (i) a speed of 1 kph for door-to-door speed, (ii) 0.05 cars per household, and (iii) one percent in the total number of cars. Even under such strict requirements convergence is very fast.

8. The ranking of choices within the UMOT's algorithm is:

(1) Car ownership, to satisfy the demand for car travel;

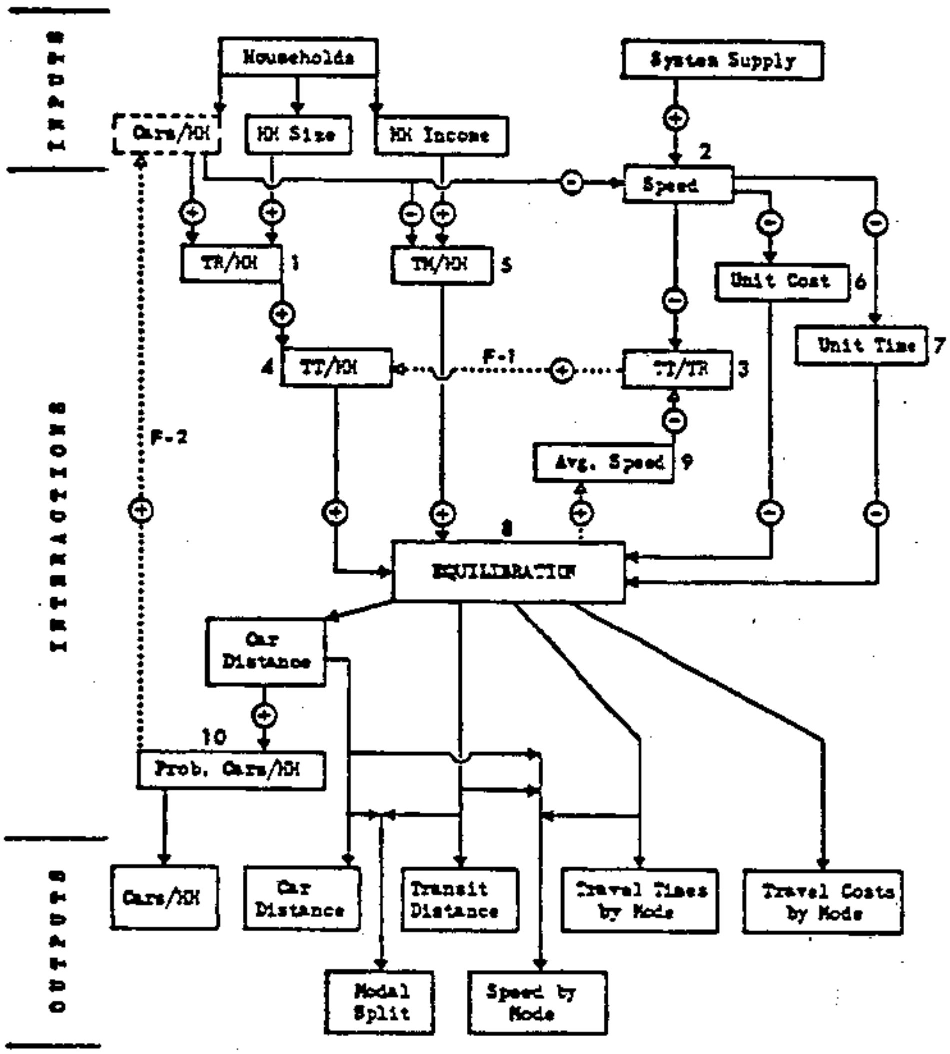
(2) Class of car below, at, or above a standard compact car. The UMOT model produces a continuous range of car costs, to signify different classes of cars, such as second-hand cars, standard new cars, or expensive new cars. Thus, households at different income levels and travel conditions can still satisfy their travel budgets by operating different classes of cars;

(3) Road network: when the households' travel parameters cannot reach convergence at an assumed road network (either too high or too low), the road network is adjusted automatically until convergence is reach.

Thus, the planner or policy maker can start with two extreme assumptions of road networks, and find the range of networks that would satisfy the travel system under given household characteristics and travel costs. Examples of this process are detailed below.

9. Since car ownership is an integral part of the UMOT model, the outputs of the model should be regarded as representing medium and long-term household decisions. For example, continuous increases in car travel costs would not necessarily result in a shift from car to transit travel as long as households would shift their preferences from large, gas-consuming cars to small gas-efficient cars.

The UMOT model is sensitive to such issues, and it can assist the policy maker in the evaluation of a wide range of alternative options. Several examples follow.



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

B. The UMOT Urban Daily Travel Model: Simplified Numerical Illustrations

1. Introduction

One way of showing the power of the UMOT model is by very simple illustrations. In the following examples a hypothetical city of 100,000 households is represented by two income groups, medium-high and medium-low. Identified respectively as groups I and II, they have average incomes of \$ 35,000 and \$ 15,000. For further simplification, all households are assumed to have three members. The model runs that follow show how the output variables react to various changes in the characteristics of the transportation system.

Since in its present stage of development the UMOT can deal with three modes simultaneously, the three modes in the following examples are car, bus and walk. (As walking is found to be a relatively small proportion of travel, it can be replaced by another mode, such as rapid transit.) Subsequent development of the UMOT model will allow the simultaneous addition of several more modes. The unit costs of the three modes in the initial runs are those of 1979/80.

2. The Initial Runs

The initial runs of the UMOT model are designed to find the range of road networks that would satisfy convergence of the travel system.

Table 1 shows the basic outputs of these two runs: starting the analysis with a very small arterial road network (10 km length) results in a minimum required length of 285 km, while starting with a very large arterial road network (1,000 km length) results in a maximum useful length of 492 km. Namely, 285-492 km is the range within which the two household groups can reach equilibrium (i.e., utilize their two travel budgets to their full effect). All subsequent runs were made for an intermediate road network, 350 km in length, and the first run is shown in Table 1.

As expected, car ownership levels, total travel distance, and speeds, all increase with increases in the length of road network. However, there are also several results which suggest a better insight into the travel system: First, high income households can take better advantage of an increased road network, increasing both their car ownership levels and total travel distance appreciably more than low income households.

Second, and contrary to conventional beliefs, congested travel conditions do not necessarily result in increases in bus travel; it is rather bus travel which suffers first. Since the total daily travel distance per household decreases when congestion increases, bus travel becomes even less attractive than before, and is the first to suffer a loss of travel (modal split in the UMOT model is measured by travel distance, and not by trips).

Lastly, when speed increases, and high income households increase their car ownership levels, the car factor (representing car class) decreases,

Table 1 : Basic Outputs of the UMOT Model

Starting Assumptions: 50,000 households at $ 35,000
50,000 households at $ 15,000
Household size = 3
Arterial road network: 10, 350 and 1,000 km respectively

10 km

============ PROGRAM OUTPUTS ===PAGE 1

CATAGORY	GROUP 1	GROUP 2
CARS/HH	1.26	.95
CAR FACTOR	1.6	.91
TR/HH	2.03	1.88
TIME/TR(HR)	1.14	1.15
TIME/HH(HR)	2.31	2.16
TM/HH($)	12.03	5
TM/HH(%)	11	10.66
SPEED NET.(KPH)	34.35	
SPEED D-D	20.87	17.35
ROAD NET.(KM)	285	
CAR DIST.	44.73	29.65
BUS DIST.	2.97	6.27
WALK DIST.	.49	1.61
TOT. DIST.	48.19	37.52
MOD. SPLIT(%)	6.22	17.46

============= PROGRAM OUTPUTS ===PAGE 2

CATEGORY	GROUP 1	GROUP 2
NO. OF CARS	63192	47561
% OF CARS	57.06	42.94
% HH:0 CARS	8.01	14.44
% HH:1 CAR	59.69	81.2
% HH:2+ CARS	32.3	4.36
CAR COST($)	.26	.15
BUS FARE($)	.09	.09
EXPEND. CAR($)	11.76	4.42
EXPEND. BUS($)	.27	.56
EXPEND. WALK($)	0	.02
TM/HH($)	12.03	5
EXPEND. CAR(MIN)	117.14	77.64
EXPEND. BUS(MIN)	15.54	32.84
EXPEND. WALK(MIN)	5.88	19.3
TT/HH (MIN)	138.56	129.78

350 km

JPR$0========== PROGRAM OUTPUTS ====PAGE 1

CATAGORY	GROUP 1	GROUP 2
CARS/HH	1.44	.99
CAR FACTOR	1.48	.91
TR/HH	2.12	1.9
TIME/TR(HR)	1.12	1.14
TIME/HH(HR)	2.38	2.17
TM/HH($)	12.03	5.13
TM/HH(%)	11	10.94
SPEED NET.(KPH)	38.36	
SPEED D-D	23.48	19.11
ROAD NET.(KM)	350	
CAR DIST.	52.26	32.48
BUS DIST.	3.33	7.31
WALK DIST.	.41	1.63
TOT. DIST.	56	41.43
MOD. SPLIT(%)	5.99	18.38

============= PROGRAM OUTPUTS ===PAGE 2

CATEGORY	GROUP 1	GROUP 2
NO. OF CARS	72090	49576
% OF CARS	59.25	40.75
% HH:0 CARS	6.51	12.58
% HH:1 CAR	47.67	79.14
% HH:2+ CARS	45.82	8.28
CAR COST($)	.22	.14
BUS FARE($)	.09	.09
EXPEND. CAR($)	11.73	4.45
EXPEND. BUS($)	.3	.66
EXPEND. WALK($)	0	.02
TM/HH($)	12.03	5.13
EXPEND. CAR(MIN)	122.56	76.18
EXPEND. BUS(MIN)	15.62	34.31
EXPEND. WALK(MIN)	4.92	19.57
TT/HH (MIN)	143.1	130.06

1,000 km

JPR$0========== PROGRAM OUTPUTS ====PAGE 1

CATAGORY	GROUP 1	GROUP 2
CARS/HH	1.81	1.01
CAR FACTOR	1.23	.91
TR/HH	2.3	1.91
TIME/TR(HR)	1.11	1.13
TIME/HH(HR)	2.55	2.15
TM/HH($)	12.03	5.16
TM/HH(%)	11	11
SPEED NET.(KPH)	46.48	
SPEED D-D	29.31	21.73
ROAD NET.(KM)	492	
CAR DIST.	70.87	34.83
BUS DIST.	3.63	10
WALK DIST.	.13	1.91
TOT. DIST.	74.63	46.75
MOD. SPLIT(%)	4.87	22.31

============= PROGRAM OUTPUTS ===PAGE 2

CATEGORY	GROUP 1	GROUP 2
NO. OF CARS	90617	50564
% OF CARS	64.19	35.81
% HH:0 CARS	4.35	11.35
% HH:1 CAR	28.36	76.3
% HH:2+ CARS	67.29	12.35
CAR COST($)	.17	.12
BUS FARE($)	.09	.09
EXPEND. CAR($)	11.7	4.24
EXPEND. BUS($)	.33	.9
EXPEND. WALK($)	0	.02
TM/HH($)	12.03	5.16
EXPEND. CAR(MIN)	137.15	67.41
EXPEND. BUS(MIN)	14.03	38.71
EXPEND. WALK(MIN)	1.62	22.94
TT/HH (MIN)	152.8	129.06

signifying an increased proportion of less expensive cars. Conversely, under congested travel conditions car ownership levels go down for all income groups, resulting in high income households purchasing less cars of a higher quality; e.g., in highly congested Manhattan the rich buy few but expensive cars.

Figure 1 shows the iterations of the basic travel components for each income group until convergence is reached: cars per household, car factor, road network length, and network and door-to-door speeds. The convergence steps are done at two levels: convergence for each separate household group, and convergence for all household groups together. It should be noted that the number of iterations can be reduced appreciably by relaxing the conditions for convergence.

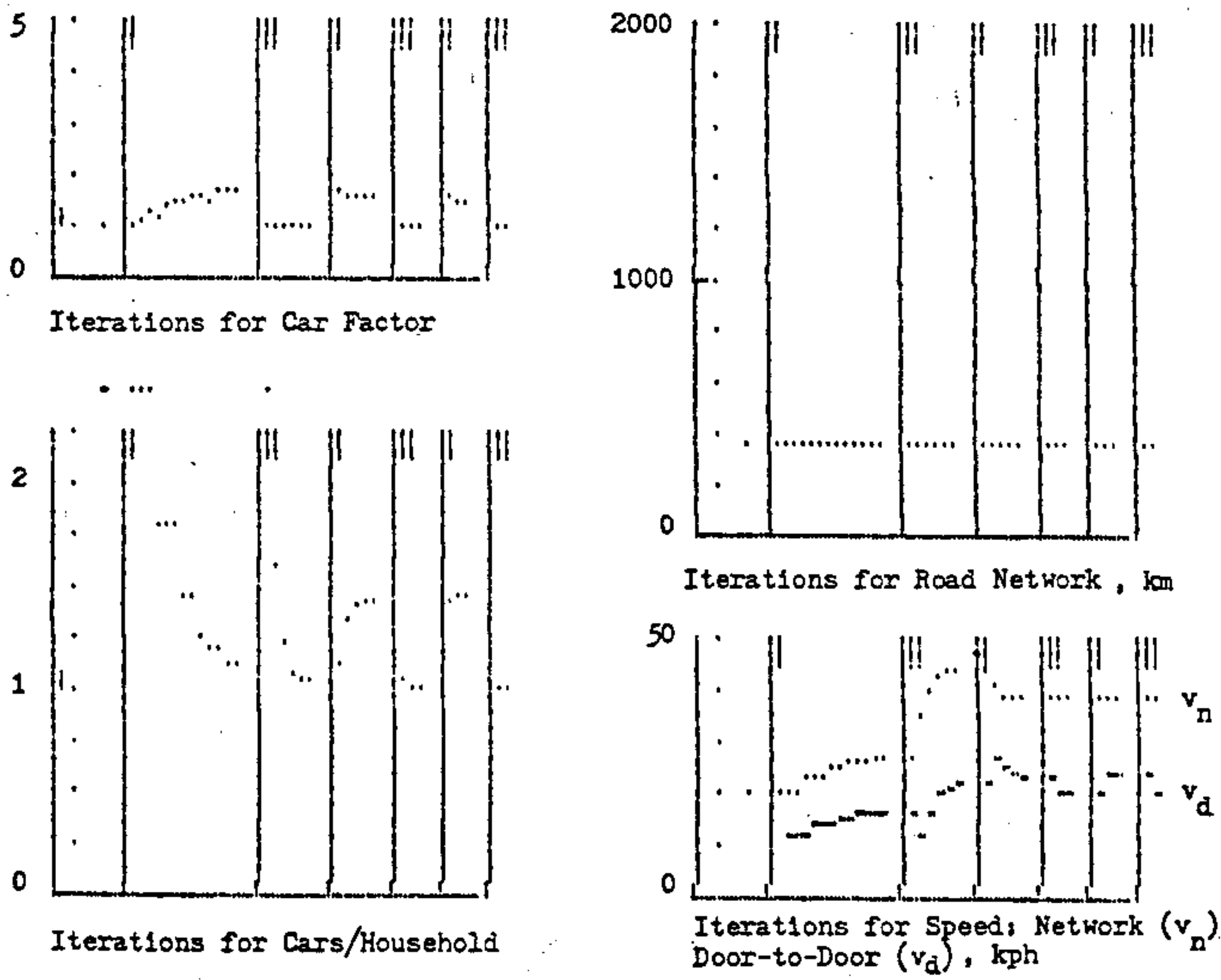


Figure 1 : Iterations to convergence of Income Groups I and II
Arterial Road Network = 350 km

3. Increases in Car Travel Costs

Figures 2 to 7 show some of the effects of increases in car travel costs on the various travel components. It is to be noted that the diagrams display partial results of a complex system and, therefore, they have to be interpreted simultaneously. Car travel cost should be interpreted as being relative to household income. In this simple illustration income has been held constant, therefore absolute and relative costs are the same.

Figure 2 shows that cars per household decreases monotonically for the low income group. Of special importance is the appearance of a critical threshold, at about +60 percent increase in car travel cost, after which car ownership levels drop sharply. Cars per household for the high income group show mixed results (suggesting an indeterminate trend in the car market), which are affected by several factors: a decrease in the number of cars belonging to the low income group (as shown in Figure 3) thus increasing network speed, which compensates in part the increased car travel costs; a decrease in the required road network, as shown in Figure 4; and changes in mode choice, as shown in Figures 6-7.

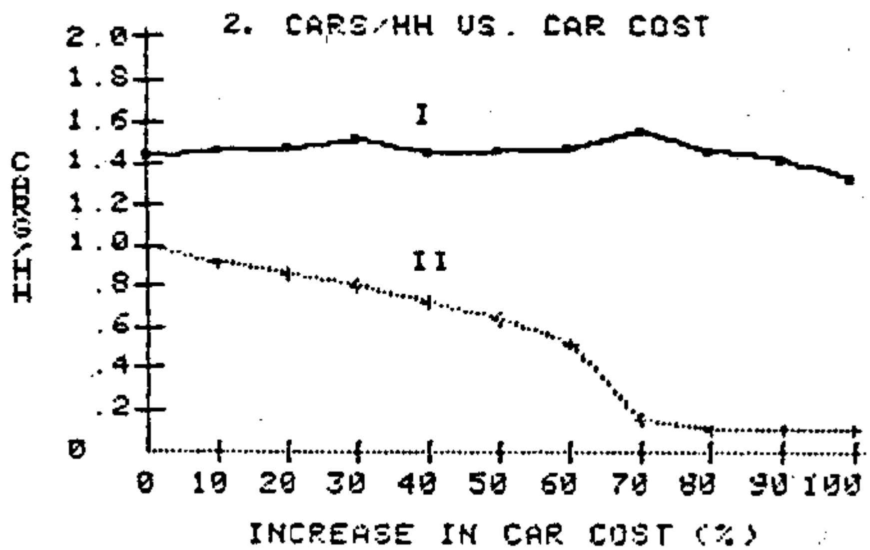


Figure 3 shows that the total number of cars using the road network decreases monotonically, although with fluctuations. Thus, there is less demand for the road network, as shown in the next figure.

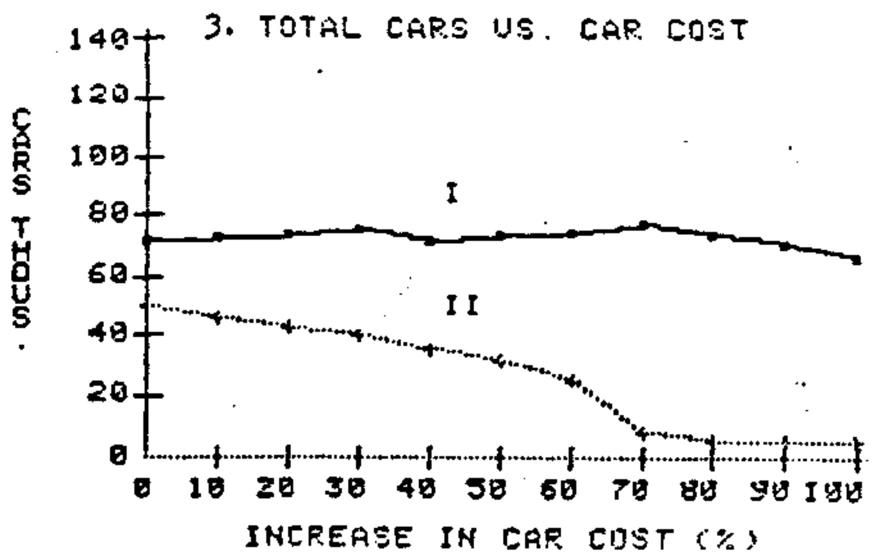


Figure 4 shows that the use of the available road network decreases, thus suggesting redistribution of travel patterns; e.g., shorter shopping trips and less trips for social-recreation purposes, or even changes in residence-job locations.

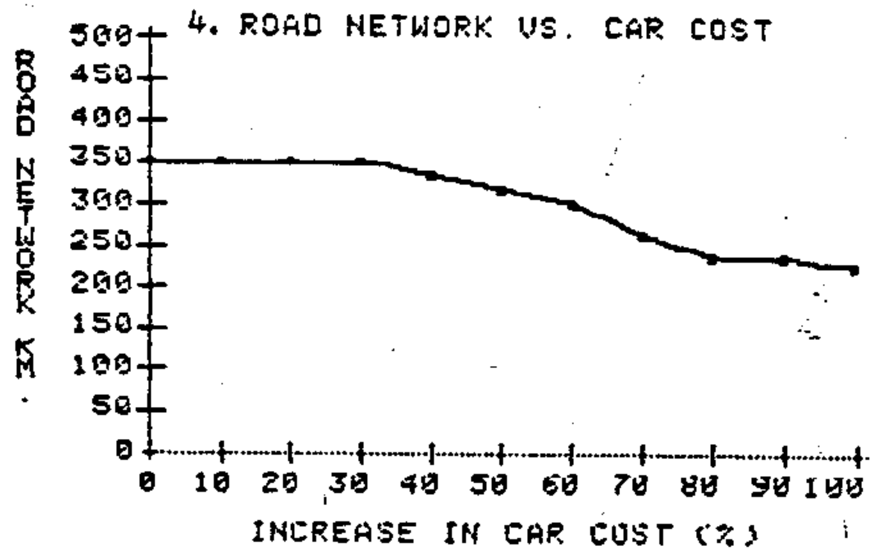
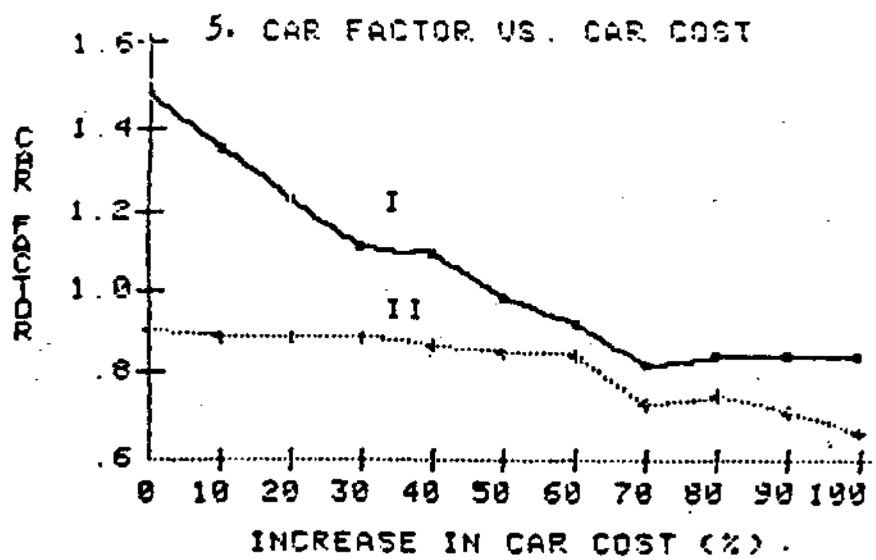


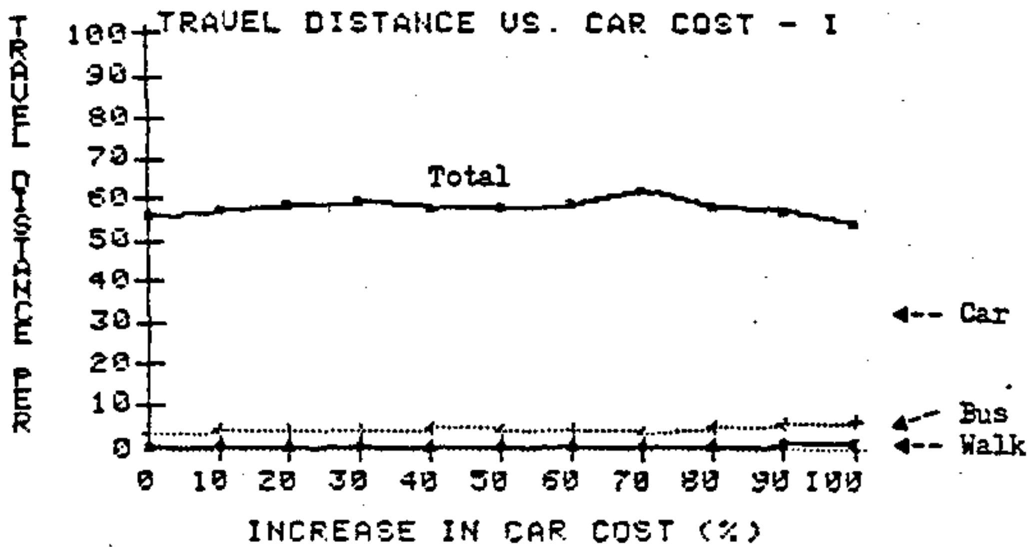
Figure 5 shows that appreciable changes in the car factor become apparent. These changes suggest a significant change in household choices associated with car classes; a shift towards smaller and more gas-efficient cars. The highest rate of choice-change is noted for the high income group; these households have wider range for, and more flexibility in, changing their choices than low income households.

(Note: In the short term both low and high income households may have to increase their travel money expenditures to use the cars they now own, but in the medium and long-term a shift to smaller and more efficient cars appears to be inevitable if gasoline price relative to incomes remain at an increased level.)



<u>Figures 6-7</u> suggest that significant changes in modal choices are expected for low income households: a significant loss of car travel, with only a marginal increase in bus travel; altogether there is a loss of travel, which emphasizes that modal shifts by trips, conventionally regarded as a one-to-one transfer, may convey a false, too optimistic, shift to bus travel. The modal choices of high income households, on the other hand, are barely affected.

6.



7.

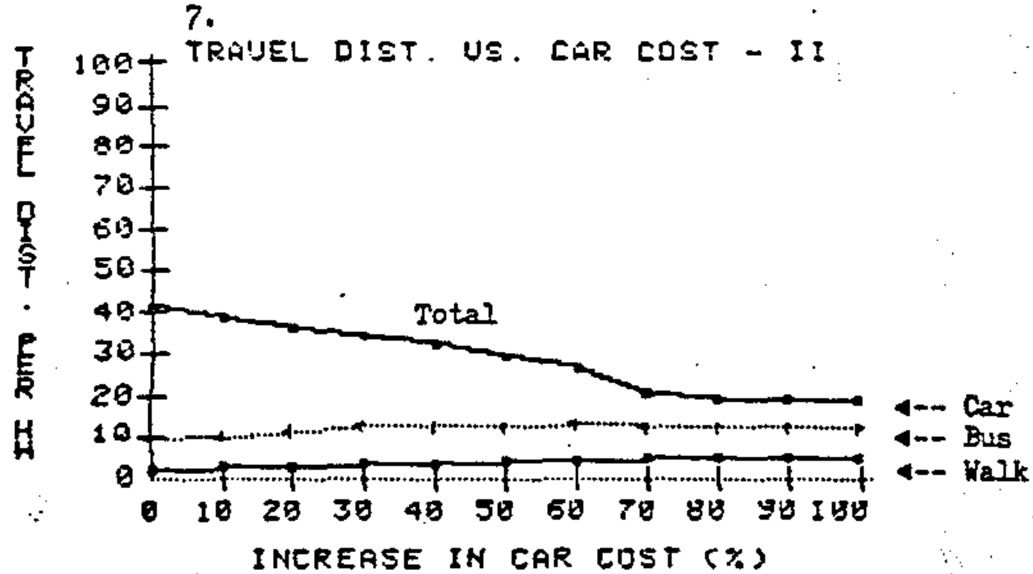
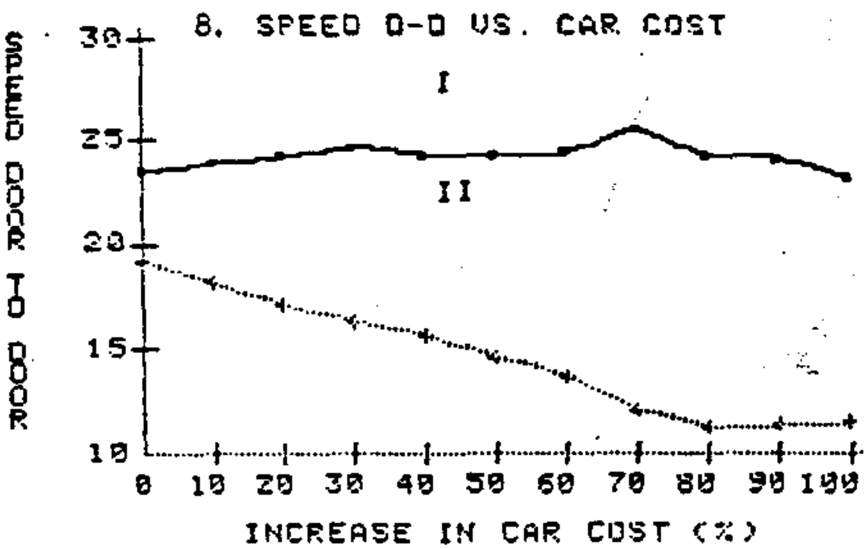


Figure 8 reveals part of the explanation of the loss of travel by low income households: a transfer from car to bus travel results in a reduction of door-to-door speed, which then inhibits travel. The door-to-door speed of high income households, on the other hand, is barely affected.

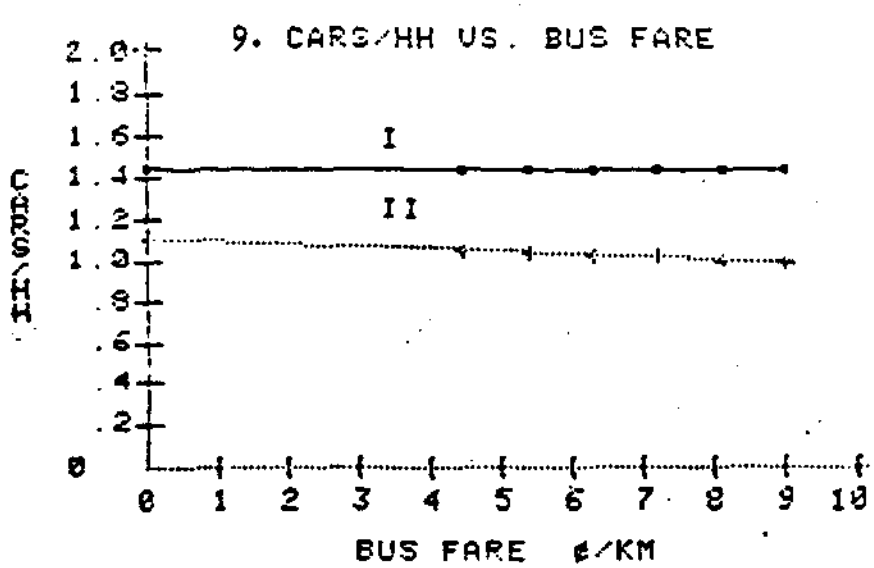


4. Decreases in Bus Fares

Following are some sample policy analyses.

Figure 9 shows the effects of bus fare reductions. The conventional consensus is that the demand function for bus travel is negatively sloped, namely that a decrease in bus fares should result in increased bus travel, and vice versa. Indeed, short term observations tend to support a negatively sloped demand function, although an inelastic one.

The UMOT model, being a medium and long-term model, suggests results which, at first sight, appear to be counterintuitive. Figure 9 suggests that a decrease in bus fares, down to zero fare (free bus travel) increases car ownership levels for low income households, as well as decreases the demand for bus travel.



In this case the "Giffen effect" becomes apparent: a decrease in the price of an inferior good allows the consumer to divert monies to a superior - though more expensive - good; e.g., repeating the classical example, if potatoes become very cheap, or completely free, a low income household would purchase in the long run more steaks -- not more potatoes. The Giffen effect, however, depends on several factors, including the initial consumption quantities of inferior vs. superior goods. Indeed, Figure 9 suggests that the high income households are indifferent to changes in bus fares; it is the low income group which benefits from lower bus fares, by employing the money thus made available to enable some of the members of the household to travel by the (superior) car.

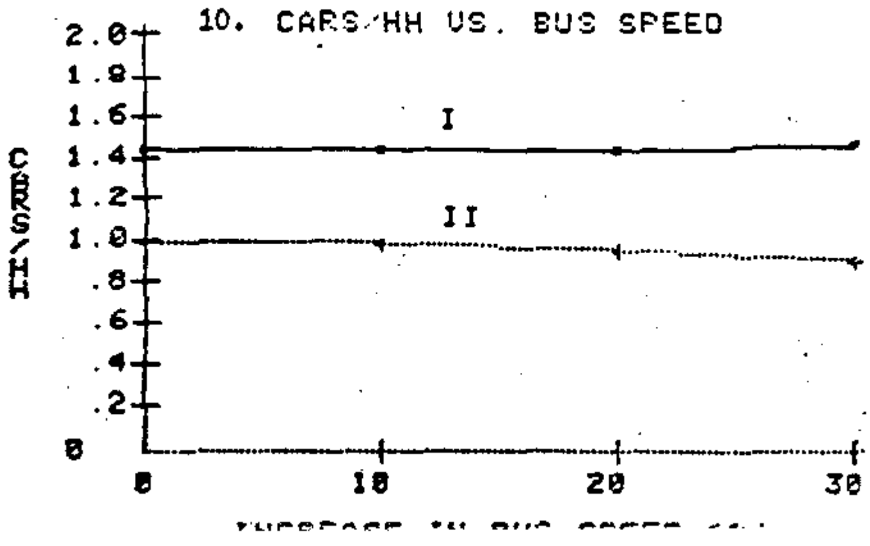
(Note: The short-term increase in the number of bus passengers when bus fares decrease substantially is due mostly to a transfer from walking to bus travel, as well as an increase of sightseeing trips, and trips by the disadvantaged. The latter category of travel can also be accomodated by means other than a general reduction in bus fares.)

5. Increases in Bus Speeds

Low bus fare is the superior quality of bus travel, while low speed is its inferior quality. Thus, improving its already superior quality - fares - does not seem to be the way to attract travel to buses. However, improving its inferior quality - speed - appears to have the desired effect.

Figure 10 suggests that increases in bus travel speeds make buses a partial substitute for car travel for low income households, thus lowering their car ownership levels. High income households, on the other hand, are affected only marginally, and in the opposite direction; less cars of low income households on a given road network results in increased travel speeds and, hence, increased car ownership levels for high income households. Thus, while improving transit patronage, increasing bus speeds may be a mixed-blessing from the standpoint of, say, energy consumption.

(Note: The effects of a rapid transit system on travel will be analyzed and reported in the future.)



C. The UMOT Hourly Travel Model

1. The UMOT hourly travel model is complementary to the UMOT daily travel model. Its purpose is to distribute the daily travel, by purpose, over 24 hours. In its final form it will be interconnected to the daily travel model through a feedback link, where only selected information will flow between the two models (i.e., structured programming modules).

2. At this initial stage of development, as presented below, the hourly model requires only four exogenous inputs for each travel purpose:

   (1) The mean starting hour of travel;

   (2) Duration of the activity;

   (3) Coefficient of variation for the starting hour of travel; and

   (4) Proportions of travel purposes.

   Two additional inputs are endogenous, coming from the daily travel model and specifying the total daily car travel distance (Vehicle Kilometers of Travel, or VKT), and the road network. The hourly travel model then distributes the VKT over 24 hours, including both outbound from, and inbound to home, as well as the non-home based travel.

   In addition, the model estimates the hourly network speeds and travel times for each travel purpose and total purposes, based on hourly speed/flow relationships. The average daily travel speed and travel times are then fed back into the daily travel model and iterations are carried out until the outputs of the two models converge.

   If the exogenous inputs result in travel congestion, where travel speeds decrease and travel times increase appreciably, the ranking of choices within the algorithm are:

   (1) Increases in the coefficients of variation, and thus a spread of peak-hour travel into peak-period travel; and

   (2) Changes in the proportions of trip purposes, based on previously observed relationships relating to the ranking of trip purposes by the travelers.

   For example, if travelers use up all their travel time and money budgets during congested periods for their essential travel purposes, such as work and business, none remain for discretionary travel, such as social and recreation. Thus, the planner and policy maker can evaluate and assess the effects of alternative transportation plans and regulations on the activity levels in the urban area which require travel to and from the activity locations.

3. In the following examples the UMOT hourly travel model operates independently. Figures 1-5 show sample outputs of the hourly travel model, presented as percent of the total daily VKT.

Figures 1 and 2 show the outbound and inbound hourly travel, respectively, for five travel purposes, and their total: Work, Business, Shopping, Social-Recreation and Other (the inbound travel, back home, is calculated automatically). Detailed output tables and diagrams will be shown during the program display.

Figure 3 shows total outbound, total inbound and grand total of all travel.

Figure 4 shows the hourly distribution of travel times.

Figure 5 shows the hourly distribution of speeds.

4. Of particular interest is Figure 3, which shows the hourly distribution of total travel in an urban area. Although three of the four exogenous inputs are assumed ones (due to lack of required data), both the shape and the scale of the resulting hourly distribution of total travel are remarkably similar to observed distributions in urban areas.

FIG. 1 VKT OUTBOUND, BY PURPOSE & TOTAL

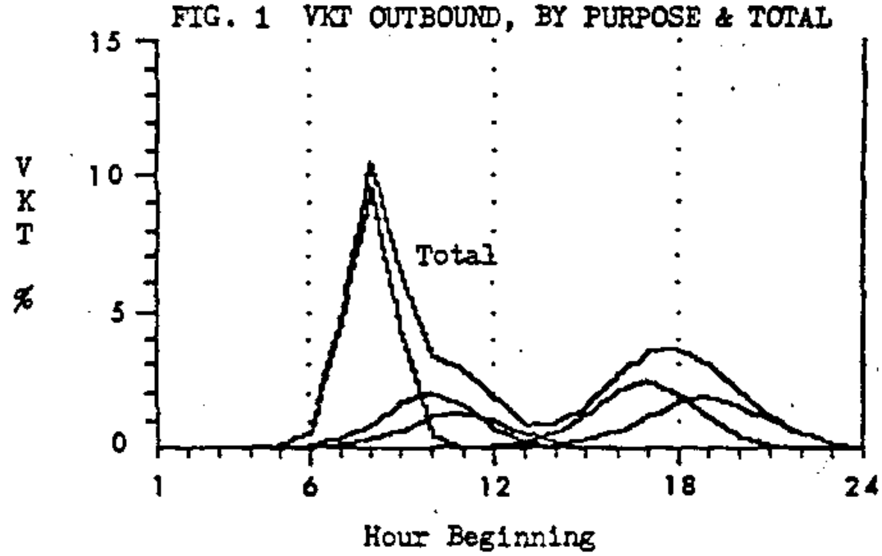


FIG. 2 VKT INBOUND, BY PURPOSE & TOTAL

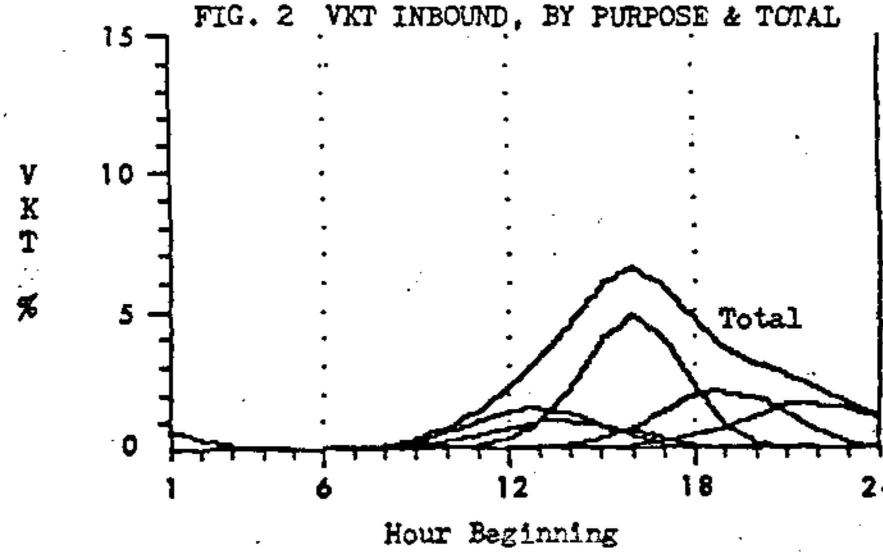


FIG. 3 VKT TOTALS

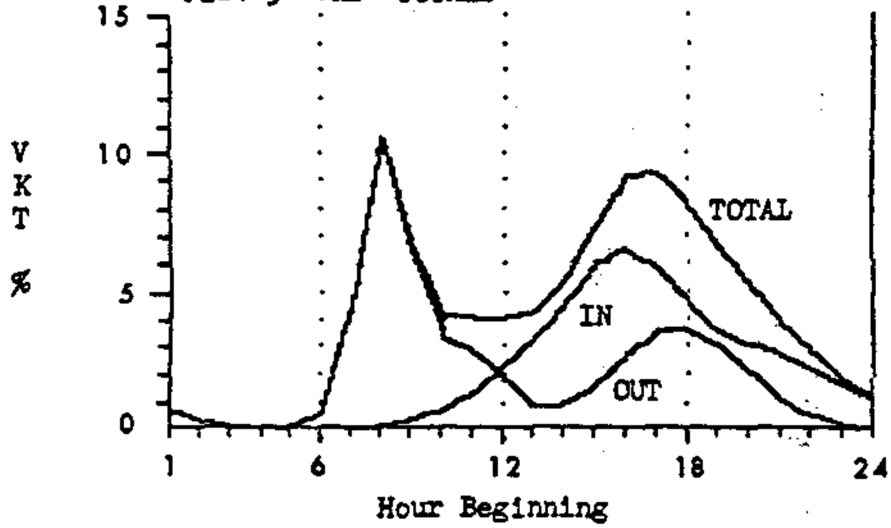


FIG. 4 DISTRIBUTION OF TRAVEL TIME

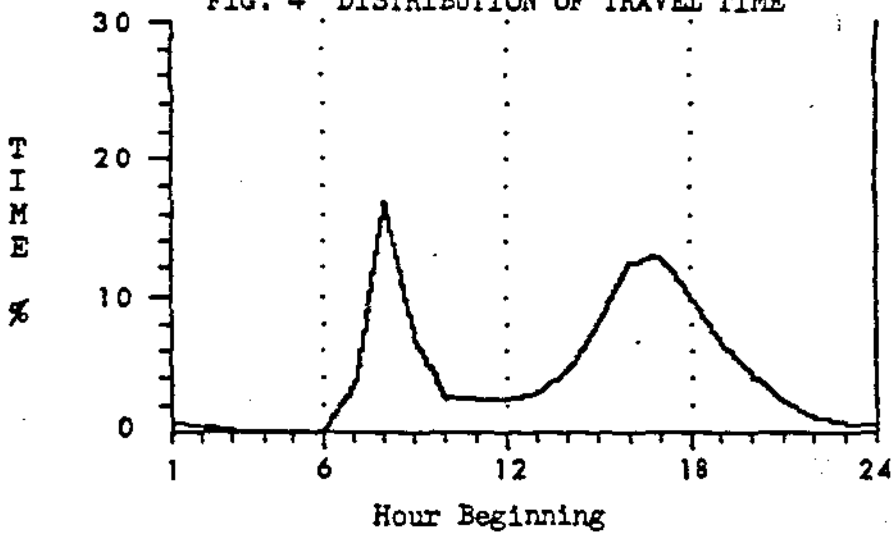
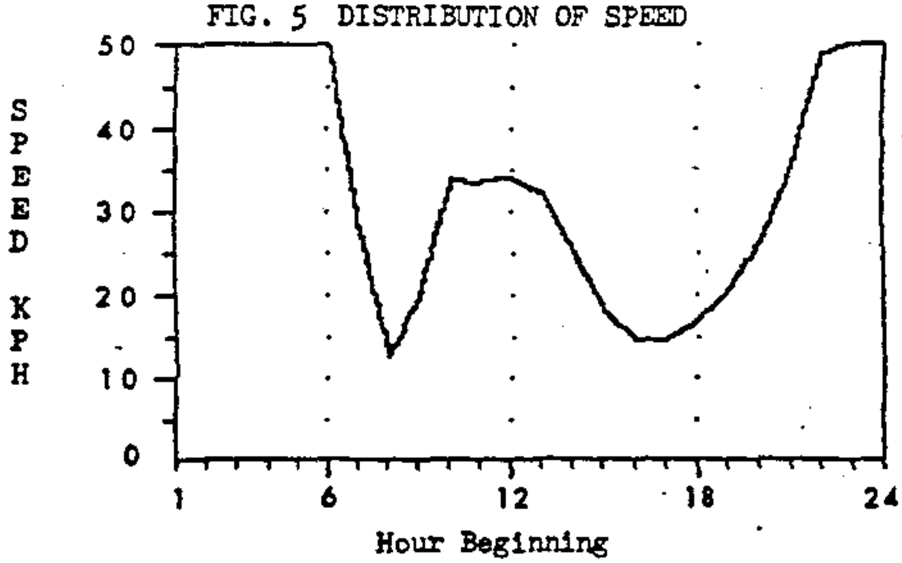


FIG. 5 DISTRIBUTION OF SPEED



D. The UMOT Intercity Travel Model

1. Introduction

The UMOT travel model can be appreciated best when applied to intercity travel, where differences between modes can be more pronounced (say, car vs. airplane) than in urban travel, and trip distances are not confined by the boundaries of an urban study area.

All currently operational intercity models, like urban models, have to be calibrated to the observed travel choices which they are required to estimate, and their validity hinges on their ability to reproduce the choices to which they were fitted. The UMOT process, on the other hand, is based on the constraints under which travel choices are made, and the predicted travel choices are then compared with the observed choices for the model's validation.

The inputs required for the UMOT model are: (i) the time and money budgets allocated to intercity travel by households of different population segments, and (ii) the operational characteristics of the modes, assumed in this case to be three: car, rail and airplane.

While there is a rapidly increasing amount of data on the time and money budgets that households allocate to their urban travel, not much data have yet been summarized for intercity travel. Therefore, the following examples can be regarded as sensitivity tests for the intercity UMOT process, where intercity travel is generated under a wide range of assumed money and time budgets.

For the simulations detailed below, the range of the money budgets is limited to \$ 15 to \$ 225, and the range of the daily time budgets is 1.5 to 6.7 hours, as detailed in Table 1.

It is to be noted at this stage that the above travel money and time budgets are not allocated to travelers with specific incomes or other socioeconomic characteristics. Such an allocation still awaits data from actual surveys. Furthermore, in the following simulations no assumptions are made about the frequency of travel; e.g., a traveler could either spend \$ 50 on each of four trips during a certain period, say, a year, or save and spend \$ 200 on one trip. Thus, the simulations deal with a range of trips, without specifying their frequency per traveler.

The matching of time budgets to money budgets of travelers is based on the reasonable assumption that there is an increasing reluctance to spend more time on intercity travel as money expenditures increase, with an upper limit of about 8 to 10 hours during one day. Thus, the travel time budget is assumed to increase with money budgets at decreasing rates, following a decreasing marginal utility trend, expressing known trends of the "value" of travel time.

2. The Assumptions

Three modes are considered here, car, rail and airplane. The operational characteristics of the three modes are based on actual travel experience during the period late 1978 to early 1979.

Because of the access-egress costs in time and money terms, the unit trip time and cost depend on distance and, therefore, the exercises have to be iterated: (1) the first run of the UMOT process is based only on the networks' unit costs, and (2) the iteration is carried out on the basis of the generated travel distances by mode, resulting from the first run, with the addition of the access-egress times and costs, which affect the new costs and, hence, also the new travel distances.

3. Basic Results

Applying the UMOT travel-distance maximization process results in the following outputs:

(1) Total travel distance using available modes within the travel time and money budgets and, as a result, simultaneous mode shares;

(2) Allocation of travel time and money to each mode and, therefore, the expected revenues for the operators of the public modes; and

(3) Average travel speed.

Table 1 summarizes the outputs of travel distance, total and by mode, and Figure 1 shows the maximum travel distance, by mode and total, that can be generated within the travel budgets.

Table 1

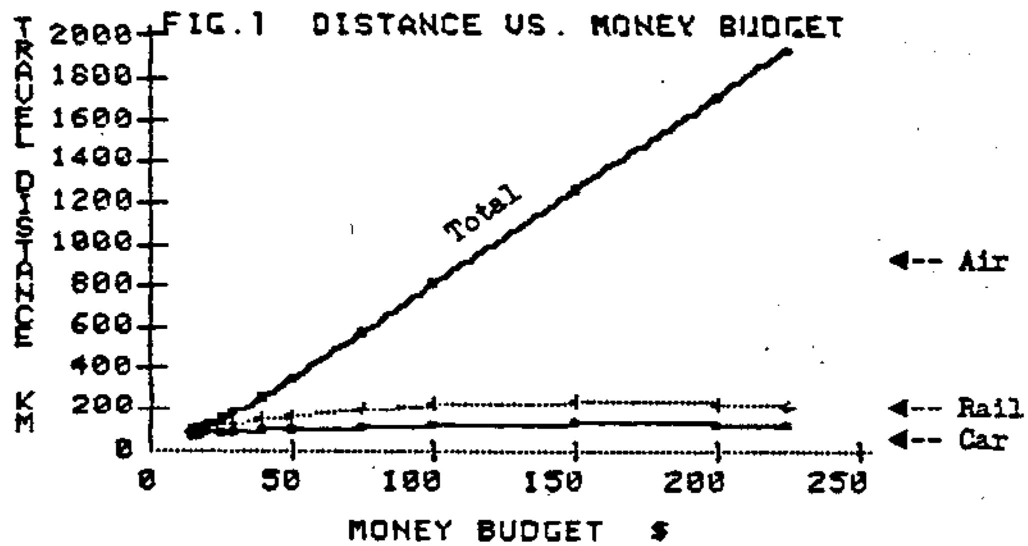
JFR#0============= DATA SUMMARY =============

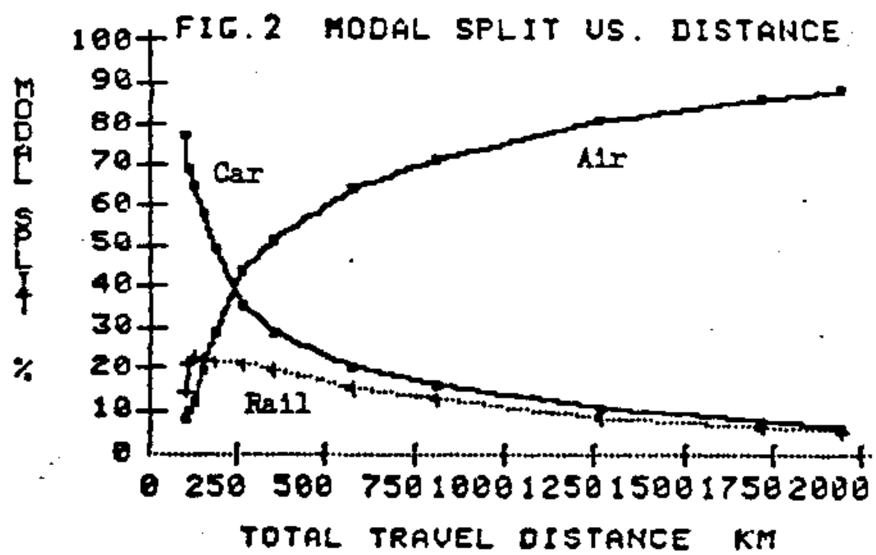
MM	TT	TOT.KM	CAR%	RAIL%	AIR%
15	1.54	97	77.19	14.56	8.25
17.5	1.83	112	68.67	21.08	10.25
20	2.08	127	64.4	23.07	12.53
25	2.5	155	58.02	22.26	19.73
30	2.85	184	49.15	21.69	29.16
40	3.39	260	35.55	20.9	43.56
50	3.82	350	28.85	19.64	51.52
75	4.58	580	20.41	15.67	63.92
100	5.13	810	15.95	12.65	71.41
150	5.89	1266	10.66	8.54	80.8
200	6.44	1720	7.57	6	86.43
225	6.66	1947	6.42	5.04	88.54

MM - travel money budget, $
TT - travel time budget , hrs.

There is nothing unusual in Figure 1, but if the proportions of travel distance by mode are related to the total travel distance, a remarkable transformation takes place, as shown in Figure 2, which is the well known relationship of trip modal split vs. trip distance.

The last result is of special interest for the understanding of travel behavior. The proportions of trip modal split by trip distance is an observed relationship, to which other models are calibrated. In the UMOT model, on the other hand, it is an output from a model of behavior, thus suggesting a behavioral rationale for the observed relationship.





4. Responses of the Travel System to Changes

The UMOT process is responsive to changes in the inputs relating to either the operational characteristics of the modes or the travelers. For instance, it is well known from experience that the mode choices of travelers traveling as a group, and sharing the same travel money budget (such as members of the same household) can be significantly different from the mode choice of a single traveler. The UMOT process treats such cases readily.

In the following example car travel costs are being increased steadily, while the travel costs of rail and air are kept unchanged. The results, for a travel money budget of $ 50, are shown graphically in Figures 3 and 4.

Figure 3 shows the effects of increases in car travel costs on the travel distance, by mode and total. While the total travel distance tends to decrease monotonically, there is a marked shift in modal shares within it; rail gains travel, while air loses travel. Car travel, on the other hand, shows mixed trends. A better representation of these trends are shown in Figure 4.

FIG.3 DISTANCE VS. CAR COST

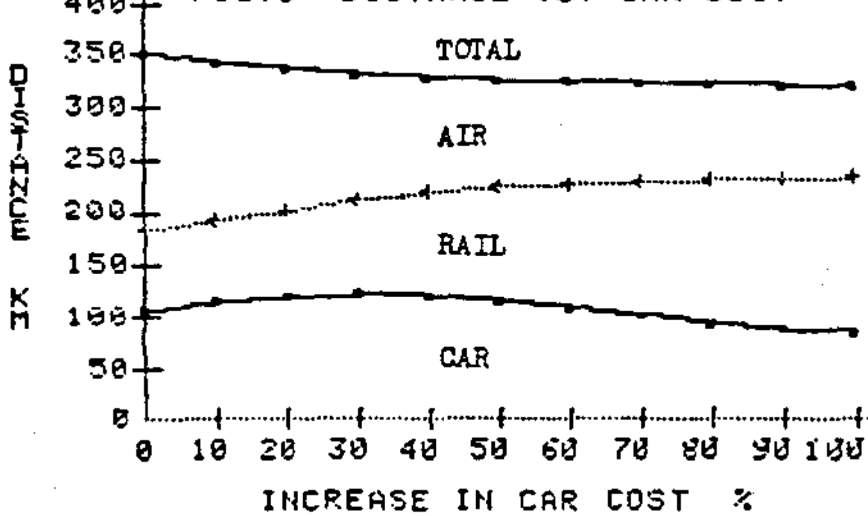
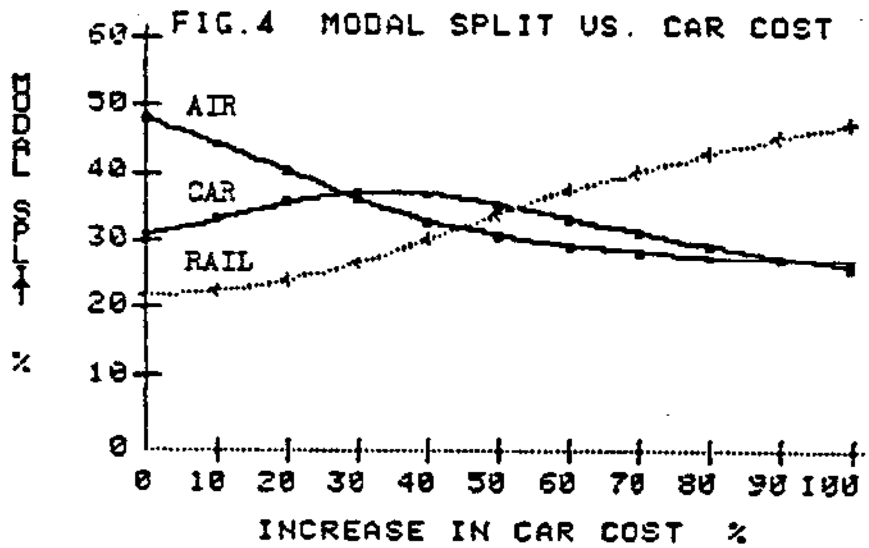


Figure 4 shows the modal splits of the three modes within the total travel distance, where rail gains travel monotonically and air loses travel monotonically. These are expected results. However, there is also an unexpected result, counterintuitive, which suggests that car travel increases with modest increases in car costs (up to about +40 percent).



When referring back to Figure 2 the counterintuitive result is resolved; higher travel costs, by whatever mode, result in less <u>total</u> travel distance, namely a shift towards the left-hand side of Figure 2. In the analyzed case, $ 50 and a total travel distance of about 350 km, a slight shift to the left results in a rapid increase in car modal split, thus increasing the share of car travel within the total travel distance.

The point to note at this stage is that conventional mode-choice models, which deal with <u>trips</u>, are not structured to display such trends. The UMOT model, which deals directly with travel distance (within which travelers can trade off trip rates vs. trip distances) is able to illuminate the complexity and richness of the travel system from a new viewpoint, as well as suggest travel trends which cannot be foreseen by intuition alone.

Traffic Engineering and Control
Oct 1981

The Unified Mechanism of Travel Model should be available for policy analysis by the end of the year

The UMOT urban travel/land-use model has been conceptualised and developed by Yacov Zahavi*, and its development and application as a policy analysis tool sponsored by the U.S. DoT's Research and Special Programs Administration with the co-operation of UMTA, FHWA and FRA. In summary, its principal advantages for the user are: (*a*) far more realistic representations of urban travel and land use, including their interactions, than are available from conventional approaches; and (*b*) a model that is not data-hungry, does not require calibration to the observed choices, and can therefore be run quickly and inexpensively on a low-priced microcomputer.

Unlike conventional models, UMOT uses a multi-loop feedback design in which all travel components interact simultaneously, producing many outputs from few inputs – costly calibration to observed choices is completely eliminated by the use of constraints that are transferable over time and space. Both daily and hourly (24 hour) travel are computed interactively, and in its finished form the model will also compute land use interactively with travel.

Transparency and user interaction are provided by self-contained instructions, graphic displays and alpha-numeric read-outs. Having very modest data needs, the model has been programmed on an Apple II microcomputer.

In London last month, Mr Zahavi gave presentations on UMOT to the DTp, TRRL, the GLC and London Transport. Among the unique features of the UMOT model, he said, are:

(*1*) All components of travel, such as car ownership, travel demand and mode choice, are unified under one operating mechanism, and not determined separately by independent sub-models as in conventional approaches. This single mechanism ensures consistency among all parts of the model.

(*2*) All model components are linked through behavioural and physical constraints which have been found to be transferable over time and space. This means that the model's outputs are never calibrated to observed choices; the outputs are compared to observations for the model's validation, not calibrated to them.

(*3*) The model computes hourly travel over the day, by mode and by trip purpose. This is linked to constraints on average daily travel to maintain consistency.

(*4*) There are no assumptions about unilateral causality. In the UMOT model all travel components are linked in a feedback process, and thus can be either cause or effect, depending on the step of the analysis.

In its fully-completed form UMOT will handle information in at least five dimensions: household number and size, income distribution, travel modes, time of day and spatial location. In addition, the model will be dynamic, so that the time trajectories of change can be explored.

In its present stage of development the model integrates the first four dimensions. The spatial dimension (and therefore land use) is now under development and the model contains no dynamics, as yet. Even so, with prudence and understanding the model shows great power even now to indicate the effects of both policy actions and such external factors as the price of petrol. Further improvements, even in the dimensions now modelled, are planned. Its application to inter-city travel is also being undertaken.

The model is capable of exploring the effects of both policy actions and external factors. Typical issues, some of which may involve both policy and external factors, are:

(*i*) changing bus fares;
(*ii*) changing bus speeds;
(*iii*) introducing (or curtailing) rapid transit;
(*iv*) changing car costs through tolls, parking fees, taxes, etc.;
(*v*) auto use restrictions;
(*vi*) road network expansion or closings;
(*vii*) changes in household income, or income distribution;
(*viii*) change in household size;
(*ix*) changes in population;
(*x*) changes in the price or availability of fuel;
(*xi*) the effects of policy or external factors on fuel consumption; and
(*xii*) the effects of policy or external factors on the hourly distribution of travel.

The model has a number of built-in relationships that were found to be transferable both between cities and over time. The first four of these are behavioural, and the last two physical:

(*1*) The average daily travel time per traveller. This is the so-called 'time budget'. However, it is not a constraint, but rather a statistical relationship having a mean that is a function of travel speed and a stable coefficient of variation.

(*2*) The average daily travel money per household, the 'money budget'. Again, this is a relationship that is a function of income and car ownership.

(*3*) The average number of travellers per household, as a function of household size and car ownership.

(*4*) The threshold of car daily travel distance which justifies owning a car.

(*5*) The unit cost of owning and operating a car. This is a function of many factors, including average travel speed and the initial cost of the car (from FHWA records).

(*6*) The speed/flow relationships for road categories.

The model requires rather few inputs, while its outputs are many. The *inputs* are:

(*1*) The number of households and the household sizes in the urban area under investigation.

(*2*) The income distribution of households by income group. Any number of groups can be handled, but for purposes of policy exploration five groups are typically used.

(*3*) The unit costs of travel by mode. At present the model handles three modes, but the capability for a greater number will be incorporated.

In addition, the number of miles of road network can be accepted as an input, or it can be derived as an output, depending on the particular policy exploration being performed.

The model is now programmed to give the following *outputs*:

(*1*) Car ownership per household by income group.
(*2*) Proportions of households owning 0, 1 and 2+ cars within each income group.
(*3*) Class of car purchased by income group.
(*4*) Number of travellers per household.
(*5*) Daily travel distance per household, by mode.
(*6*) Modal split by passenger travel distance.
(*7*) Network travel speed.
(*8*) Door-to-door travel speed by income group.
(*9*) Minimum and maximum network sizes for which travel budgets can be fully utilised.
(*10*) Daily travel time and money expenditures per household and per traveller by mode, and hence also the expected revenues for public transport systems.
(*11*) Daily trip rate, trip distance and travel time by mode and by trip purpose, per average traveller and per household type.
(*12*) Hourly person trip rate, distance, time and speed by mode and by trip purpose.
(*13*) Hourly car trip rate, distance, time and speed by mode and by trip purpose.
(*14*) Hourly person and vehicle total travel distance and travel time (PMT, PHT, VMT, VHT), by mode.
(*15*) Car occupancy rates by trip purpose.
(*16*) The spread of peak-hour travel into peak-period travel under congested conditions.
(*17*) Daily and hourly fuel consumption, by mode, per household type.

It is important to understand that these outputs are all functions of the inputs. In general, *all* outputs will vary as any one of the inputs is changed, e.g. the unit cost of travel (petrol price), the speed of travel (new freeways or subways), income distribution, number of households, or household size. As the model is developed further, an even greater number of outputs will be provided.

Furthermore, the inherent structure of the model, plus the generous use of computer

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* Further information can be obtained from Mr Zahavi at Mobility Systems, Inc., 7304 Broxburn Court, Bethesda, Maryland 20034, USA.

graphics, enables the user to see the step-by-step process of convergence, thus making the model transparent as opposed to the typical "black box".

The steps of the UMOT urban travel process, in a simplified way, are:

(*1*) the daily spatial and economic opportunities per household, presently represented by the daily travel distance, are maximised within the travel time and money constraints by the optimal combination of available or planned modes;

(*2*) the demand for car travel distance generates car ownership;

(*3*) the assignment of the estimated number of cars on the road network results in new unit costs of travel, which are then introduced as new inputs; and

(*4*) the process is iterated until the outputs of consecutive runs converge to preferred levels of accuracy (Fig 1).

For instance, convergence can be reached when the values of two consecutive iterations are *less* than: (*i*) a speed of 1 km h for door-to-door speed; (*ii*) 0·05 cars per household; and (*iii*) 1 per cent in the total number of cars. Even under such strict requirements convergence is very fast.

The ranking of choices within the UMOT's algorithm is:

(*1*) *Car ownership:* to satisfy the demand for car travel.

(*2*) *Class of car:* below, at or above a standard compact car. The UMOT model produces a continuous range of car costs, to signify different classes of cars, such as second-hand cars, standard new cars, or expensive new cars. Thus, households at different income levels and travel conditions can still satisfy their travel budgets by operating different classes of cars.

(*3*) *Road network:* when the households' travel parameters cannot reach convergence at an assumed road network (either too high or too low), the road network is adjusted automatically until convergence is reached.

Thus, the planner or policy-maker can start with two extreme assumptions of road networks, and

```
DATE: AUG. 20. 1981
INPUT ROAD NETWORK (KM) =350
INPUT CAR COST, %       =100
MODES : CAR, BUS AND WALK
```

1. HOUSEHOLDS, CARS, ROAD & SPEEDS

HH INCOME	10.00K	25.00K	50.00K
HH SIZE	3.00	3.00	3.00
NO. OF HHS	33.00K	33.00K	34.00K
CARS/HH	0.73	1.50	1.79
CAR FACTOR	0.73	1.10	1.77
HH: 0 CARS, %..	29.15	6.23	4.39
HH: 1 CAR, %..	70.84	45.23	28.70
HH: 2+ CARS %..	0.01	48.55	66.91
NO. OF CARS ...	24.16K	49.64K	60.91K
NO. OF CARS %..	17.94	36.85	45.22
ROAD NETWORK KM	350.00	350.00	350.00
SPEED NET. KPH.	44.08	44.08	44.08
SPEED DOOR-DOOR	16.25	25.47	28.62

find the range of networks that would satisfy the travel system under given household characteristics and travel costs.

Since car ownership is an integral part of the UMOT model, the outputs of the model should be regarded as representing medium and long-term household decisions. For example, continuous increases in car travel costs would not necessarily result in a shift from car to transit travel as long as households would shift their preferences from large 'gas guzzlers' to small energy-efficient cars. The UMOT model is sensitive to such issues, and it can assist the policy-maker in the evaluation of a wide range of alternative options.

2. TRAVEL TIME & MONEY BUDGETS

TT/HH: CAR.....	39.37	110.23	143.64
TT/HH: BUS.....	43.37	25.00	8.12
TT/HH: WALK....	41.18	9.96	----
TT/HH: TOTAL ..	123.15	143.64	151.77
TM/HH: CAR	1.92	8.03	17.01
TM/HH: BUS	0.96	0.55	0.18
TM/HH: WALK....	0.03	0.01	----
TM/HH: TOTAL $.	2.91	8.59	17.19
TM/HH: TOTAL %.	9.31	11.00	11.00

3. TRAVEL DISTANCE & MODAL SPLIT

DIST./HH: CAR .	19.29	54.02	70.39
DIST./HH: BUS .	10.63	6.13	1.99
DIST./HH: WALK.	3.43	0.83	----
DIST./HH: TOTAL	33.35	60.97	72.38
M/S: P.T. %....	35.52	10.19	2.75
M/S: BUS %....	----	----	----
M/S: WALK %....	----	----	----

4. UNIT COSTS & UNIT TIMES

UNIT COST: CAR.	0.10	0.15	0.24
UNIT COST: BUS.	0.09	0.09	0.09
UNIT COST: WALK	0.01	0.01	0.01
UNIT COST: AVG.	0.09	0.14	0.24
UNIT TIME: CAR	2.04	2.04	2.04
UNIT TIME: BUS	4.08	4.08	4.08
UNIT TIME: WALK	12.00	12.00	12.00
UNIT TIME: AVG.	3.69	2.36	2.10

5. TRAVELLERS & GROUP EXPENDITURE

TRAVELERS/HH...	1.77	2.15	2.29
TR/GROUP	58.50K	70.98K	77.92K
TT/TR, HR......	1.16	1.11	1.10
TM/TR, $.......	1.64	4.00	7.50
DIST./TR, KM...	18.81	28.35	31.58
GROUP EXP.:CAR.	63.30K	265.12K	578.28K
GROUP EXP.:BUS.	31.56K	18.20K	6.09K
GROUP EXP.:WALK	1.13K	0.27K	----
GROUP EXP.:TOT.	95.99K	283.59K	584.38K

6. FUEL CONSUMPTION

GAL./HH: CAR...	0.53	0.98	1.46
GAL./HH: BUS...	0.10	0.06	0.02
GAL./HH: WALK..	----	----	----
GAL./HH: TOT...	0.63	1.04	1.48
GAL./GR: CAR ..	17.44K	32.28K	49.55K
GAL./GR: BUS...	3.40K	1.96K	0.66K
GAL./GR: WALK..	----	----	----
GAL./GR: TOT...	20.85K	34.24K	50.21K

```
SUMMARY
=======
TOTAL CARS=134703.99
TOTAL PKT=4812551.85
TOTAL MONEY BUDGET=963961.18
TOTAL GAL. CAR=99270552.5
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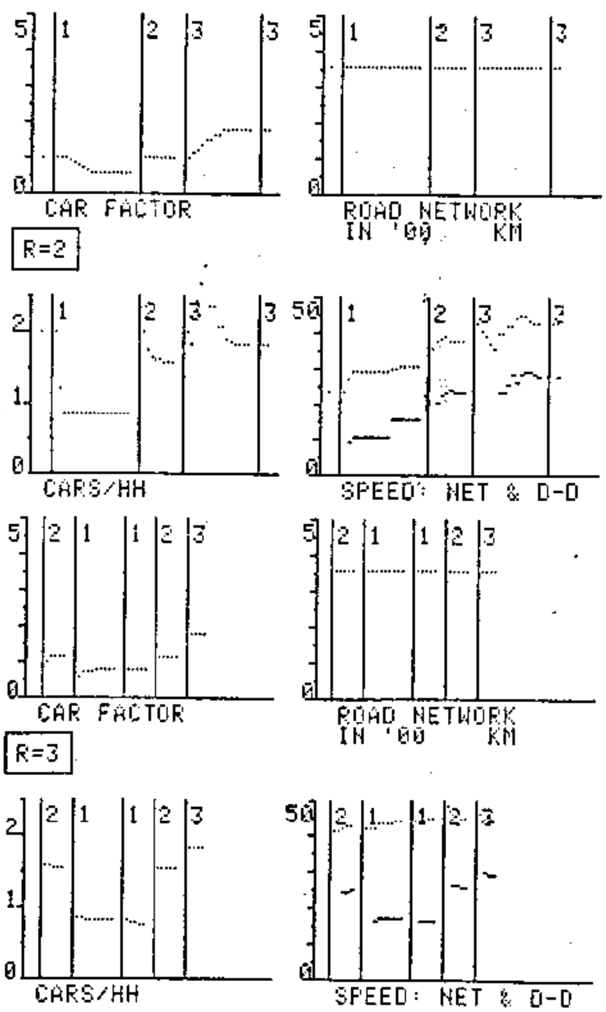

Fig 1. Three full iterations of the UMOT model, from start to final convergence, for 100 000 households divided equally between three income groups 1, 2, 3 ($10 000, $25 000 and $50 000 p.a.) and where the arterial road network is 350 km. The Car Factor describes the type of car purchased by a household in relation to a standard compact car. Speeds shown are network and door-to-door.

MOBILITY SYSTEMS, INC.

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TRAVEL REGULARITIES IN BALTIMORE, WASHINGTON, LONDON AND READING

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MOBILITY SYSTEMS, INC.

TRAVEL REGULARITIES IN BALTIMORE, WASHINGTON, LONDON AND READING

CONTENTS

MOBILITY SYSTEMS, INC.

7304 BROXBURN CT.
BETHESDA, MD. 20034

(301) 229-7762

December 15, 1981

TECHNICAL MEMORANDUM(*)

TO : Robert W. Crosby
Chief, Systems Analysis Division, U.S. DOT

FROM : Yacov Zahavi
Mobility Systems, Inc.

SUBJECT: TRAVEL REGULARITIES IN BALTIMORE, WASHINGTON, LONDON AND READING

1. INTRODUCTION

1.1 As part of the work under a contract with the U.S. DOT, data from a U.S. city were examined for travel regularities and compared with findings from sources outside the U.S. The many relationships tested are shown in the table of Contents.

Progress Report No.7 reported on some of the travel regularities observed in London and Reading, U.K. This report summarizes the travel characteristics derived from the home interview survey conducted in Baltimore, Maryland in 1977, and compares them with those of Washington, D.C., London and Reading.

The Baltimore and Washington tables for analysis were provided by the U.S. DOT, while the London and Reading tables were provided with the assistance and cooperation of U.K. authorities.

1.2 The travel relationships derived from the Baltimore data, as well as their comparison with similar relationships from the other three cities, are presented in this report at two different levels. Relationships analyzed in depth are those basic to the UMOT model, such as the daily travel time expenditure per traveler. A more general analysis was made of other relationships that emerged when examining the travel data of widely different cities.

1.3 This report includes three principal parts. The first part presents the basic relationships derived from the Baltimore data. The second part presents a comparison between the Baltimore and the other three cities' relationships, while the last part includes appendices detailing the data sets upon which the relationships are based. It should be noted that some parts of a previous report are repeated here for clarity reasons, as well as for the benefit of those who have not read the previous report.

1.4 The results of this report strongly indicate that travel characteristics in a city are related through a system of interactions. The report further shows that certain important travel characteristics dis-

(*) An attachment to Progress Report No.8, The UMOT Travel Model-2 play regularities which are transferable among the four cities tested. These travel regularities include the daily travel time per traveler frequency distributions and their derivative relationships, such as that between daily travel distance per traveler and speed. These results corroborate those in other cities that have previously been examined.

The findings in this report add further support to the underlying principles of the UMOT model, which treat all travel components as interacting within a single system that also includes urban structure.

2. TRAVEL CHARACTERISTICS IN BALTIMORE

2.1 Introduction

(1) The Baltimore 1977 home interview survey is one of the most recent in-depth travel surveys conducted in a U.S. City. It is a so-called disaggregate survey, based on a relatively small sample size; after screening households for the required data for analysis only 664 households remained, representing more than half-a-million households in the survey area, thus limiting to some extent the ability to explore in depth all relationships.

The Baltimore raw data were stratified by three principal dimensions: household annual income, household size, and household car ownership level. Because of the small sample size six income groups were defined for analysis: $ 0-4K, 4-8K, 8-12K, 12-19K, 19-25K, and 25K+. Household size was stratified into five groups: 1,2,3,4,5+ persons per household, and car ownership included four groups: 0,1,2,3+ cars per household. Thus, the 664 households were stratified into 6*5*4 = 120 cells.

The data in each cell were further stratified by the travel characteristics by four modes: car, bus, taxi and motorcycle. The travel characteristics selected were: travelers per household, daily travel time and distance per traveler/household, trip rate per traveler, trip distance and trip time. Additional tables were prepared for travel time and distance frequency distributions per traveler. The raw data permitted the examination of only internal travel characteristics, namely where both origin and destination were inside the study area. The data, from which the relationships were derived, are detailed in the appendices.

(2) Since 664 households were stratified into 120 cells many of the cells were either empty or included too few households for deriving meaningful relationships. Therefore, most of the relationships are based on three data sets, grouped by the three principal socioeconomic characteristics, namely household income, household size, and household car ownership level; altogether 15 data points, which are shown simultaneously in some of the diagrams.

Two comments should be noted at this stage. First, although the best-fit equations shown with the composite diagrams are based on least-squares regression, this technique is used for presentation purposes only, and not for statistical tests. Second, the close similarity between the plotted three data sets indicates that the shown relationships are robust and consistent enough to emerge whichever way the data are stratified. It may also be inferred that it would be advisable to verify relationships derived from a small sample by using the same data in various combinations. The point is that multiple regression in this particular case is not fully satisfactory since not only sample size is very small but income, household size and car ownership are highly correlated with each other.

(3) An additional reason for deriving the basic relationships from grouped data is the high variability of travel characteristics observed at the disaggregate level. Travel characteristics of two travelers can differ not only because of their different socioeconomic characteristics but also because of the daily variations in travel behavior of each traveler. While a weekly travel diary could solve part of the latter problem, the Baltimore data (as well as the data from the other three cities) are based on a one-day survey, thus making it impossible to isolate the sources of data variations.

One possible way to minimize the effects of daily variations was already proposed in a previous report(*), where it was noted that travel characteristics, stratified by household socioeconomic characteristics, tended to stabilize whenever the sample size of each group was about 30. Thus, the general relationships shown in this report are based on grouped data, where each data-point represents at least 30 households. Nonetheless, when analyzing relationships crucial to the UMOT model, such as travel time expenditures, they are also tested statistically at disaggregated levels.

(4) No causal relationships are suggested at this stage, and each relationship is limited to one independent variable. However, the relationships are presented in a sequential order, leading to a better understanding of the feedback interactions between all travel components.

In some cases the relationships are shown versus both income and car ownership levels. The latter serves as a common denominator for the comparison of relationships from different cities. It should also be noted that "cars per household" applies to households stratified by car ownership levels, namely 4 data points (0,1,2,3+ cars/HH), while "average cars per household" applies to households stratified by income level, namely 6 data-points.

(*) The UMOT/Urban Interactions, Report DOT/RSPA/DPB-10/7, January 1981.

(5) The relationships were derived from households and travelers that generated at least one motorized trip during the survey day. They are shown graphically, with minimum text, in order to save space and following the saying that " a diagram is worth a thousand words". As already mentioned above, the data upon which the relationships are based, as well as the tests, are detailed in the appendices.

2.2 Proportions of Households Generating Travel

Figure 1 (Appendix 1) shows the proportions of households generating at least one motorized trip during the survey day versus household income. It is quite obvious that the proportion of households generating travel is much larger at higher income levels.

FIG. 1 % HH TRAVELING VS. HH INCOME

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====================
SPILLMAN : Y=LIMIT-A*B^X

LIMIT   =100
A...... =68.2104574
B...... =.774204788
COD(R^2)=.957693704
C.O.C.  =.978618263
S.E.E.  =.578828168
====================
```
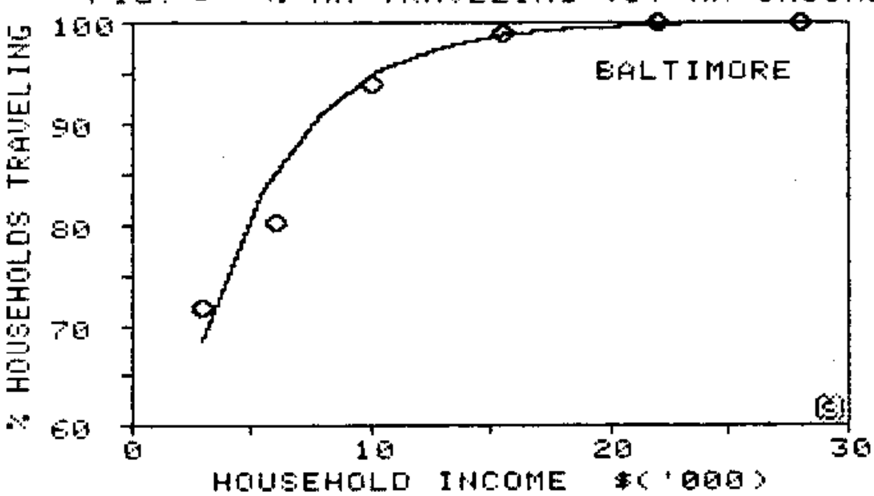
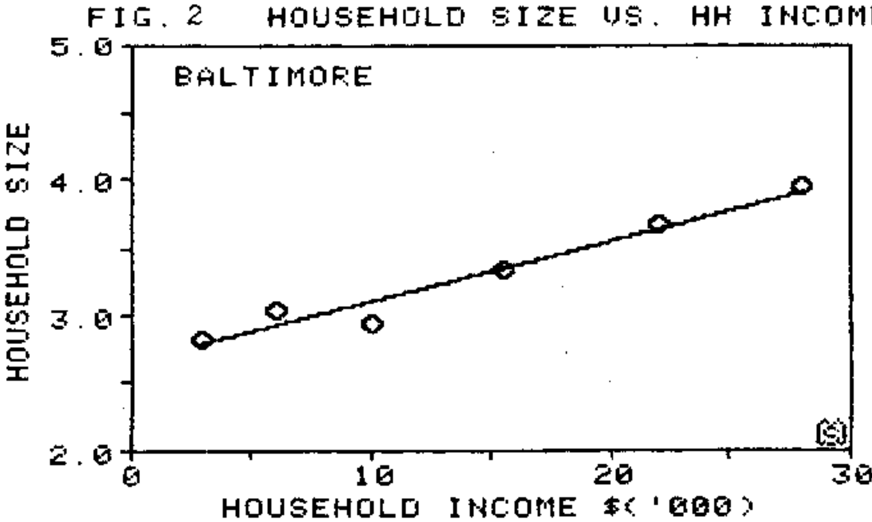



2.3 Household Size vs. Household Income

Figure 2 indicates that household size is related linearly to household income.

FIG. 2 HOUSEHOLD SIZE VS. HH INCOME

```
====================
LINEAR : Y=A+B*X

A...... =2.65512728
B...... =.0448430333
COD(R^2)=.9583626
C.O.C.  =.978959959
S.E.E.  =.100584264
====================
```

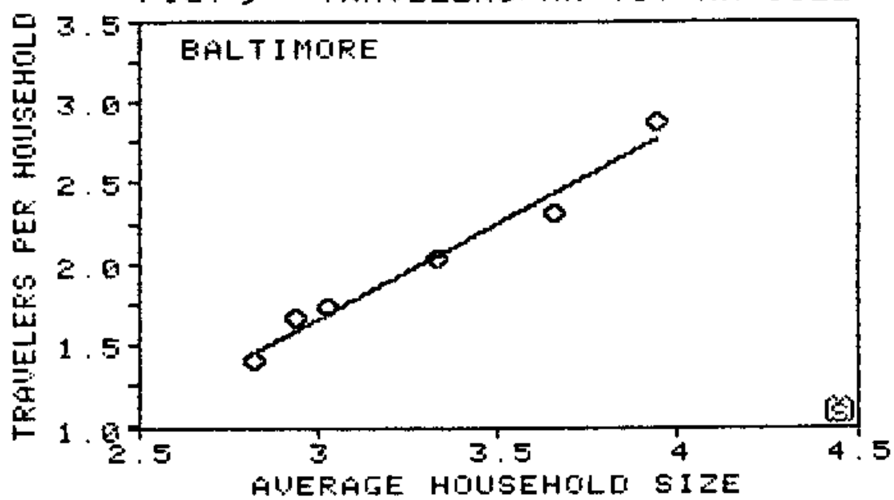


2.4 Travelers per Household

Figure 3 shows the relationship between the number of travelers per household and household size. This relationship explains in part the one shown in Figure 1: high income households generate more travel than low income households not only because they may have more money available for travel, but also because their household size and, therefore, their number of travelers, is higher.

```
===================
LINEAR : Y=A+B*X

A...... =-1.87650206
B...... =1.178956
COD(R^2)=.971551644
C.D.C.  =.985673194
S.E.E.  =.0994446634
===================
```

FIG. 3 TRAVELERS/HH VS. HH SIZE

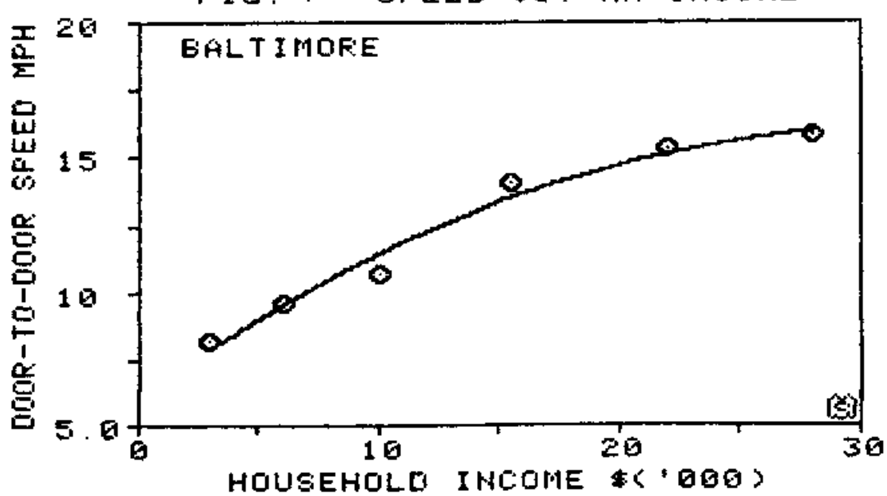


2.5 Speed vs. Income

Figure 4 shows that the travelers' door-to-door speed is greater at decreasing increments with respect to larger household income.

```
===================
NTH ORDER :

DEGREE  =2
CONSTANT=6.16119262
1 DEG.C =.624797542
2 DEG.C =-9.77622741E-03
COD(R^2)=.979146843
C.D.C.  =.989518491
S.E.E.  =.598934457
===================
```

FIG. 4 SPEED VS. HH INCOME

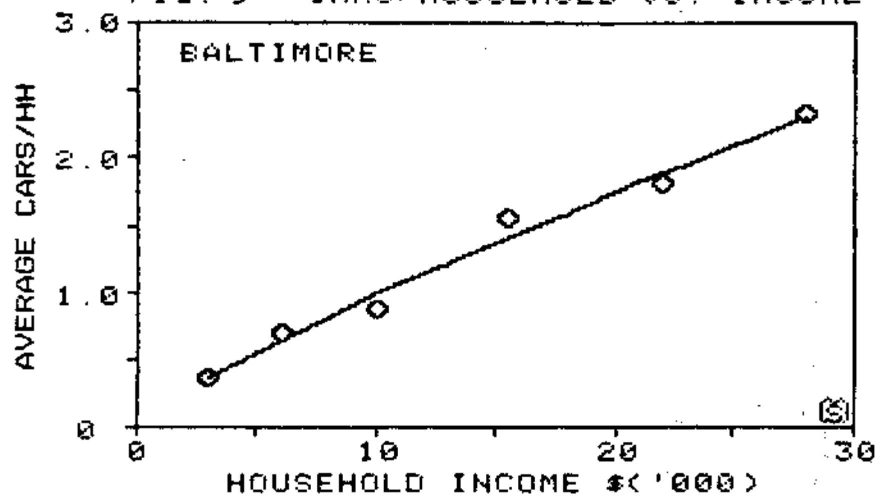


2.6 Cars per Household vs. Income

Figure 5 shows the relationship between car ownership per household and income.

```
====================
GEOMETRIC(POWER) : Y=A*X^B

A...... =.149030059
B...... =.820718588
COD(R^2)=.987585398
C.O.C.  =.993773313
S.E.E.  =.0865100662
====================
```

FIG. 5 CARS/HOUSEHOLD VS. INCOME

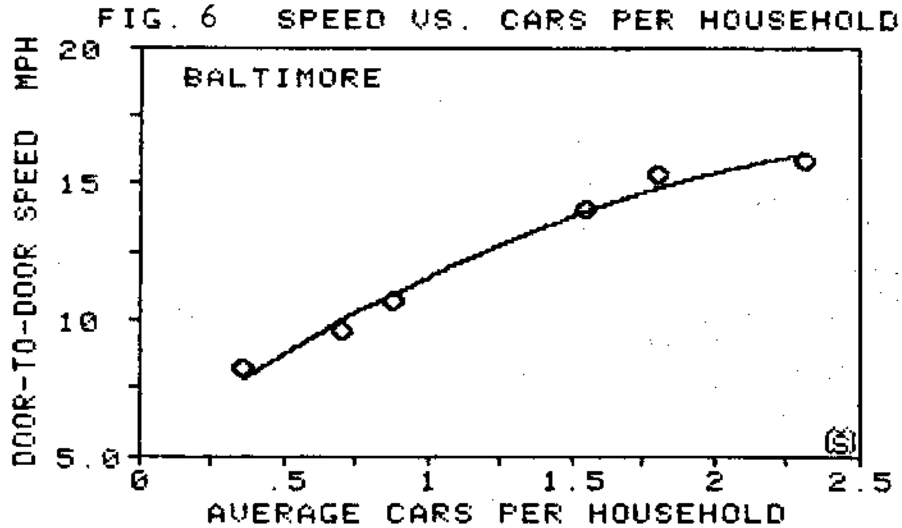


2.7 Speed vs. Car Ownership

Figure 6 shows a correlation between travelers' door-to-door speed and their respective households' car ownership levels.

```
====================
NTH ORDER :

DEGREE  =2
CONSTANT=5.31081573
1 DEG.C =7.45598903
2 DEG.C =-1.20823671
COD(R^2)=.986807057
C.O.C.  =.993381627
S.E.E.  =.476391762
====================
```

FIG. 6 SPEED VS. CARS PER HOUSEHOLD

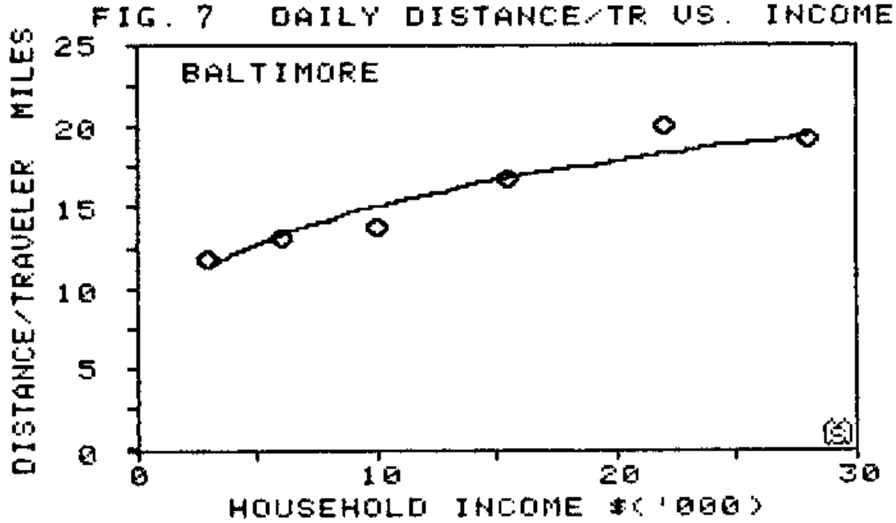


2.8 Daily Travel Distance per Traveler vs. Income

Figure 7 shows that the daily travel distance per traveler is greater for higher income. However, it is not immediately clear whether the longer travel distances are due to higher travel speeds or to more time allocated to travel. This is a basic issue that is clarified in the following sections.

FIG. 7 DAILY DISTANCE/TR VS. INCOME

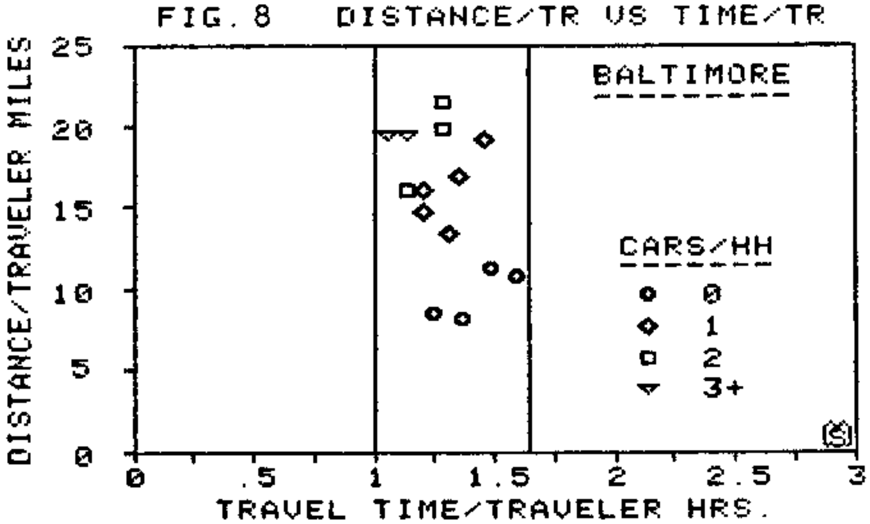
```
====================
GEOMETRIC(POWER) : Y=A*X^B

A...... =8.58056006
B...... =.245679163
COD(R^2)=.912390702
C.D.C.  =.955191448
S.E.E.  =.0715725187
====================
```



2.9 Daily Travel Distance vs. Daily Travel Time

Figure 8 indicates that the daily travel time is not larger for greater daily travel distance per traveler when the data are grouped by cars per household (the narrow range of values is bordered by the two vertical lines). It may, therefore, be inferred that longer travel distance is linked to higher travel speed than to more travel time.

FIG. 8 DISTANCE/TR VS TIME/TR



2.10 Daily Travel Time by Mode vs. Income

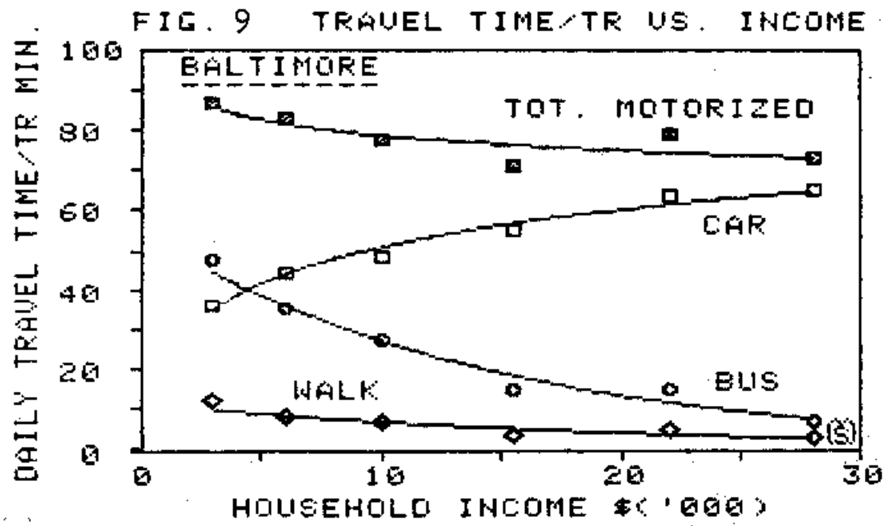
Figure 9 shows the daily travel time per traveler, by mode, vs. income. Three conclusions may be inferred from this figure:

(1) The daily travel time per traveler tends to be lower with greater income.

(2) The travel times allocated to car and bus are inversely related.

(3) Walking by travelers who made at least one motorized trip during the survey day does not appear to be a principal mode; it comprises only 6 to 12 percent of the total travel time of travelers belonging to high and low income households, respectively. Furthermore, the distance covered by walking is a small part of the daily travel distance. (Households that generated only walking trips are not discussed in this report.)

The remainder of the diagrams are based on the daily travel times allocated to motorized travel only.



2.11 Daily Travel Time and Distance per Traveler and per Household, by Mode, vs. Cars per Household

Figures 10 and 11 show the daily travel time and distance, by mode, vs. cars per household.

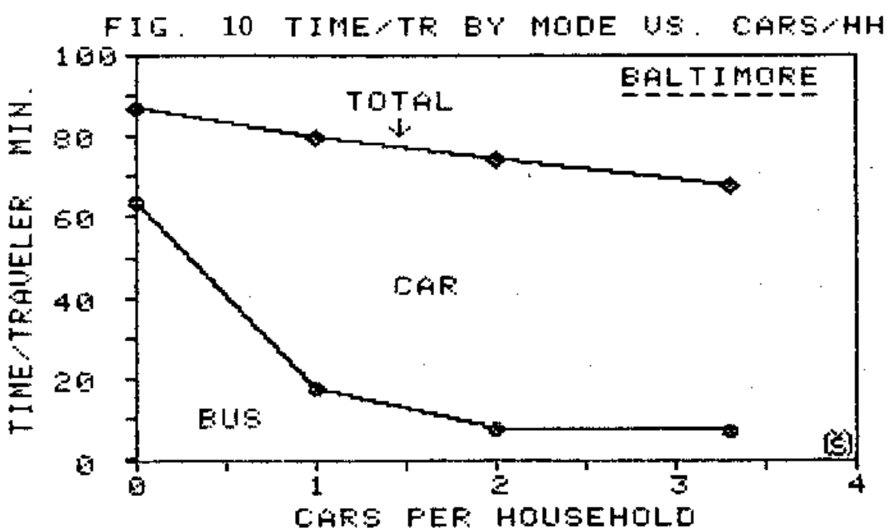
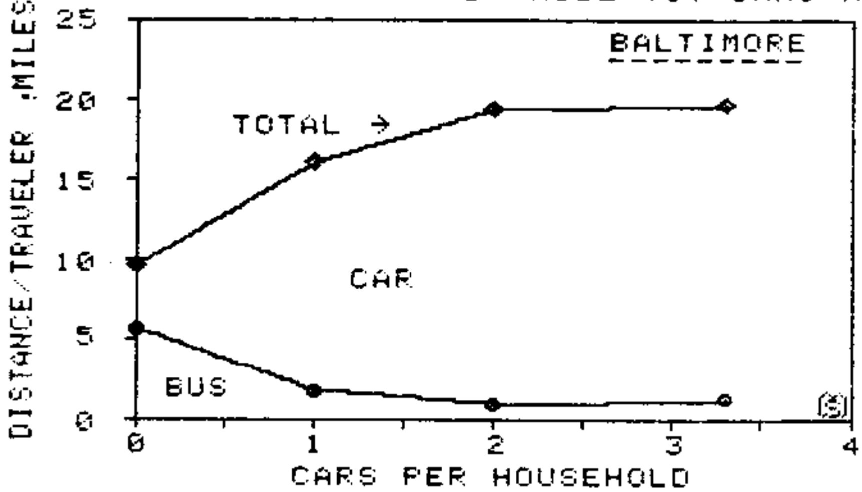


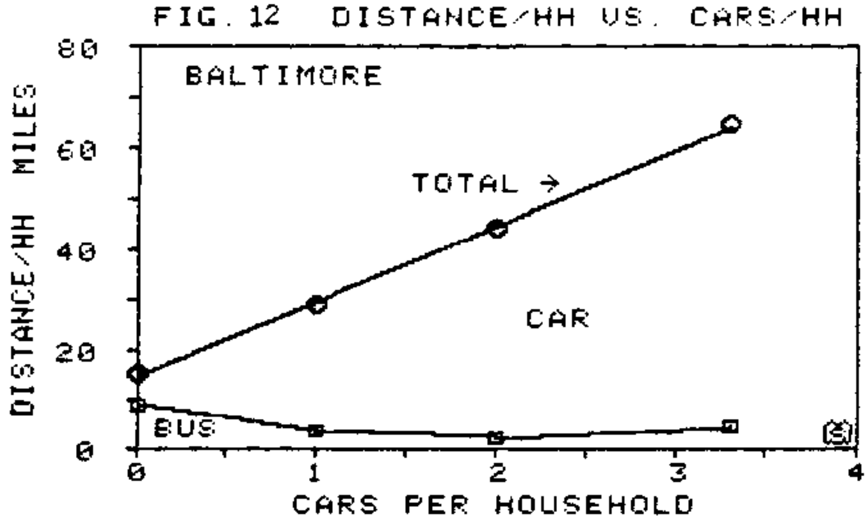
FIG. 11 DIST/TR BY MODE VS. CARS/HH



These diagrams suggest two seemingly contradictory trends; the availability of cars increases the daily travel distance per traveler while, at the same time, it requires less time for travel. This phenomenon can be explained by the increased travel speed available by car travel. Indeed, the two diagrams suggest how - and why - modal choice is affected by car ownership: cars can provide more travel distance for less travel time. (Locational choice is also involved in these decisions. This is treated elsewhere in the UMOT reports.)

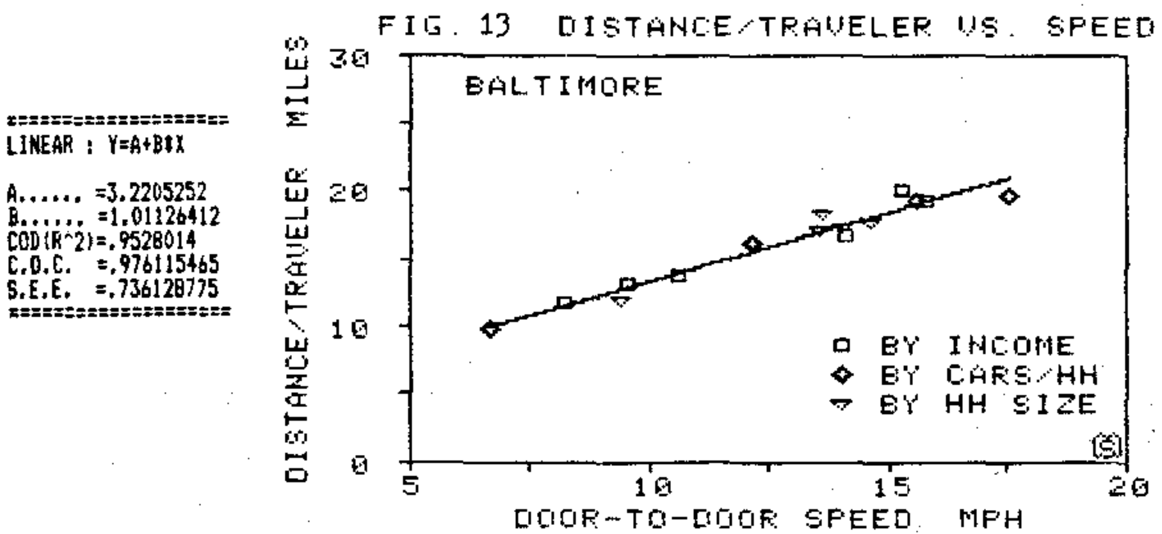
Figure 12 shows the corresponding relationship between the daily travel distance per household, by mode, and car ownership levels.

FIG. 12 DISTANCE/HH VS. CARS/HH



2.12 The Effect of Speed on Travel Distance

Figure 13 shows the relationship between the daily travel distance per traveler and door-to-door speed. The data have been stratified in three ways: by income, by cars per household and by household size. While three regression lines could have been drawn through each set of points, it is obvious that the single line shown in Figure 13 represents all three relationships fairly. This again indicates a strong relationship among the three variables. In practice, any one of the three can be used to show the relationship.



2.13 Travel Time Frequency Distributions

(1) The average daily travel time per traveler at an aggregate level may mask great variations across individual travelers. These variations can stem from many causes, such as from different socioeconomic characteristics of the travelers, or from daily variations by individual travelers. It is quite obvious, therefore, that there are many ways by which such travel times can be analyzed for their variations.

The conventional way is to stratify the data by such factors as sex, age and profession, and test the data sets for equivalency by the analysis of variance (ANOVA). In this report the data are stratified into time frequency distributions by income and by car ownership levels, as detailed in Appendix 2, and analyzed for equivalency by contingency table analysis (which is regarded as more stringent than the ANOVA test).

(2) Since the number of cases beyond a daily travel time of four hours were negligible, the data were stratified (by 10 minute intervals) up to 4 hours daily travel time per individual traveler. Even so, it becomes apparent from Appendix 2 that the few travelers who travel extremely long periods during the survey day, such as professional drivers and traveling salespersons,

do significantly affect both the mean time values or their variance. (A similar phenomenon was described in The UMOT/Urban Interactions.) Hence, the first step in the analysis of such frequency distributions is the determination of the effect of outlying travelers on the mean travel times and their variation.

(3) Table 1 summarizes several such tests, where the proportion of travelers at the long-end of the frequency distributions is reduced stepwise from 100 to 90 percent, thus excluding travelers who travel extremely long periods during the survey day.

Table 1 : **TIME FREQUENCY DISTRIBUTION STATISTICS : BALTIMORE**

TRAVELERS CLASSIFIED BY HH INCOME AND CAR OWNERSHIP

GROUP	INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	0 CAR	1 CAR	2 CARS	3+ CARS	TOTAL
100% OF TRAVELERS											
TR. OBSERVED	62	145	148	318	258	325	198	408	421	229	1256
MAX. TT (MIN)	235	235	225	235	235	225	235	225	225	205	225
AVG. TIME/TR.	67.42	66.67	71.99	64.41	70.92	65.61	73.67	66.51	69.7	59.12	67.36
S.D. OF TIME	52.4	49.75	47.45	44.04	46.86	47.72	45.92	47.51	48.86	42.88	47.08
S.E. OF TIME	6.65	4.13	3.9	2.47	2.92	2.65	3.26	2.35	2.38	2.83	1.33
COEFF. OF VAR	.78	.75	.66	.68	.66	.73	.62	.71	.7	.73	.7
ALPHA	1.66	1.8	2.3	2.14	2.29	1.89	2.57	1.96	2.04	1.9	2.05
BETA	.02	.03	.03	.03	.03	.03	.03	.03	.03	.03	.03
GAMMA	.9	.93	1.17	1.07	1.16	.96	1.4	.98	1.02	.96	1.02
99% OF TRAVELERS											
TR. OBSERVED	62	144	148	316	257	322	197	404	417	228	1246
MAX. TT (MIN)	215	205	225	195	205	205	205	205	215	195	205
AVG. TIME/TR.	67.42	65.57	71.99	63.46	70.32	64.15	72.96	64.96	68.21	58.48	66.12
S.D. OF TIME	52.4	48.13	47.45	42.5	45.95	45.48	44.91	45.12	46.65	41.86	45.17
S.E. OF TIME	6.65	4.01	3.9	2.39	2.87	2.53	3.2	2.24	2.28	2.77	1.28
COEFF. OF VAR	.78	.73	.66	.67	.65	.71	.62	.69	.68	.72	.68
ALPHA	1.66	1.86	2.3	2.23	2.34	1.99	2.64	2.07	2.14	1.95	2.14
BETA	.02	.03	.03	.04	.03	.03	.04	.03	.03	.03	.03
GAMMA	.9	.95	1.17	1.12	1.2	1	1.47	1.03	1.07	.98	1.07
95% OF TRAVELERS											
TR. OBSERVED	59	138	143	305	248	311	191	390	404	218	1201
MAX. TT (MIN)	185	155	175	165	165	165	165	165	175	145	165
AVG. TIME/TR.	60.25	60.16	67.13	59.2	65.92	59.43	69.18	60.45	64.01	53.08	61.44
S.D. OF TIME	42.51	41.18	40.23	36.71	40.36	38.52	40.05	38.91	40.93	33.96	38.8
S.E. OF TIME	5.53	3.51	3.36	2.1	2.56	2.18	2.9	1.97	2.04	2.3	1.12
COEFF. OF VAR	.71	.68	.6	.62	.61	.65	.58	.64	.64	.64	.63
ALPHA	2.01	2.13	2.78	2.6	2.67	2.38	2.98	2.41	2.45	2.44	2.51
BETA	.03	.04	.04	.04	.04	.04	.04	.04	.04	.05	.04
GAMMA	1	1.06	1.66	1.43	1.51	1.23	1.97	1.25	1.28	1.28	1.34
90% OF TRAVELERS											
TR. OBSERVED	56	134	135	290	237	299	179	369	379	207	1141
MAX. TT (MIN)	155	145	145	125	145	135	135	135	135	115	135
AVG. TIME/TR.	54.29	57.33	61.33	54.49	61.61	55.73	63.48	55.2	57.66	48.68	56.6
S.D. OF TIME	34.46	38.32	33.22	30.95	35.84	34.41	34.47	32.94	33.53	28.74	33.34
S.E. OF TIME	4.6	3.31	2.86	1.82	2.33	1.99	2.58	1.71	1.72	2	.99
COEFF. OF VAR	.63	.67	.54	.57	.58	.62	.54	.6	.58	.59	.59
ALPHA	2.48	2.24	3.41	3.1	2.96	2.62	3.39	2.81	2.96	2.87	2.88
BETA	.05	.04	.06	.06	.05	.05	.05	.05	.05	.06	.05
GAMMA	1.31	1.13	3.01	2.2	1.92	1.45	2.95	1.69	1.92	1.78	1.8

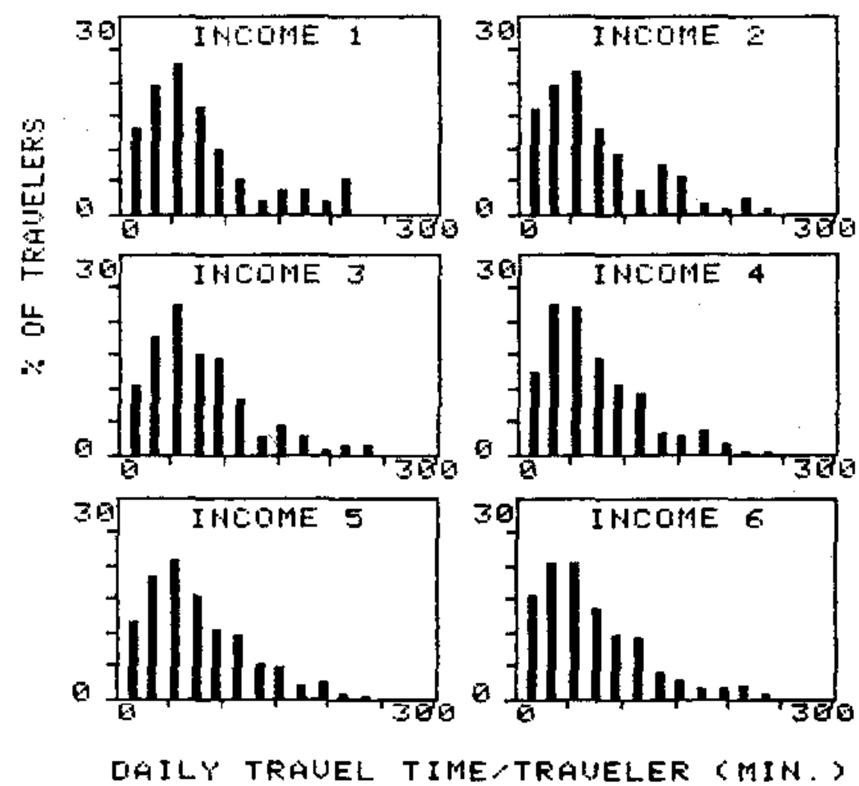
It is evident from Table 1 that both the means and the variations are strongly affected by a few outlying travelers. For instance, deducting 5 percent of the extreme-end travelers in each income group has the following effects on the total values: the maximum observed travel time decreases by 21 percent; the mean travel time decreases by 9 percent; and the coefficient of variation (standard deviation over mean) decreases by 10 percent. Furthermore, both the means and coefficient of variation are stabilized for the major part of travelers' groups.

Nonetheless, the tests between groups, detailed in the next section, show equivalency even when all travelers are included in the analyses.

(4) The travel time frequency distribution diagrams by income and by car ownership (grouped by 20 minutes for clarity of presentation, as detailed in Appendix 3) are shown in Figure 14, while the total, for all travelers, is shown in Figure 15. Figure 15 shows also a Gamma function fitted to the travel time frequency distribution for all travelers. (The α and β parameters for each and all groups are detailed in Appendix 3.)

Fig. 14

BALTIMORE DATA
DAILY TRAVEL TIME PER TRAVELER
MOBILITY SYSTEMS, INC.
NOVEMBER 81



Cont.

Fig. 14

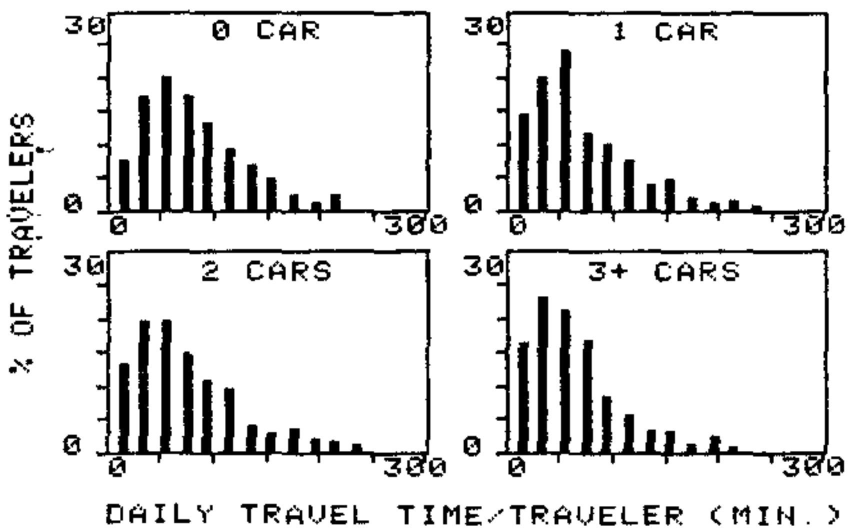
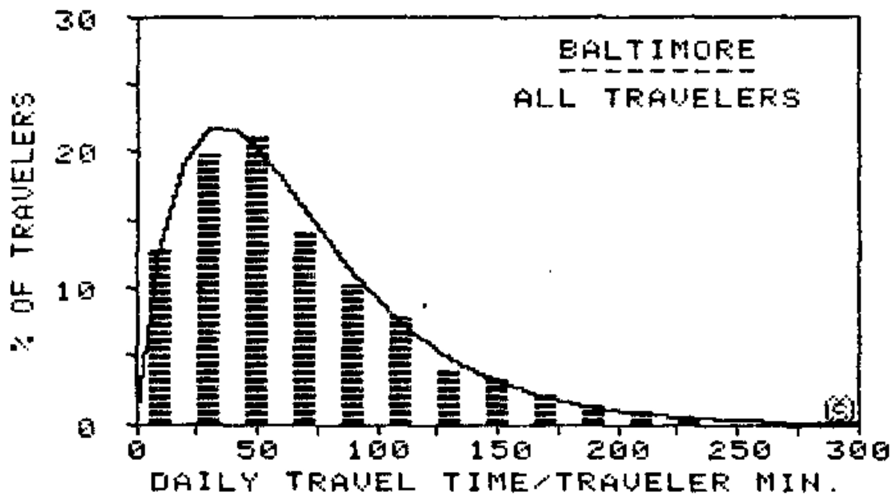


FIG. 15 TRAVEL TIME/TR DISTRIBUTIONS



2.14 <u>Travel Time Frequency Distributions: Tests for Equivalency</u>

The travel time frequency distributions detailed in Appendix 2 were tested for equivalency by contingency table analysis. Since the test requires at least 5 observations in each cell, some time-intervals had to be grouped. Because of the small number of total cases in income group 1, the tests were carried out twice: once for income groups 2-6 based on 11 time-intervals, and once for all income groups based on 7 time-intervals, as detailed in Table 2. The null-hypothesis for equivalency of the time frequency distributions is accepted in both cases (the test for acceptance was at a 95 percent confidence level). In other words, the travel time frequency distributions per traveler by income can be regarded as equivalent.

Table 2

BALTIMORE: TEST FOR EQUIVALENCY, BY INCOME

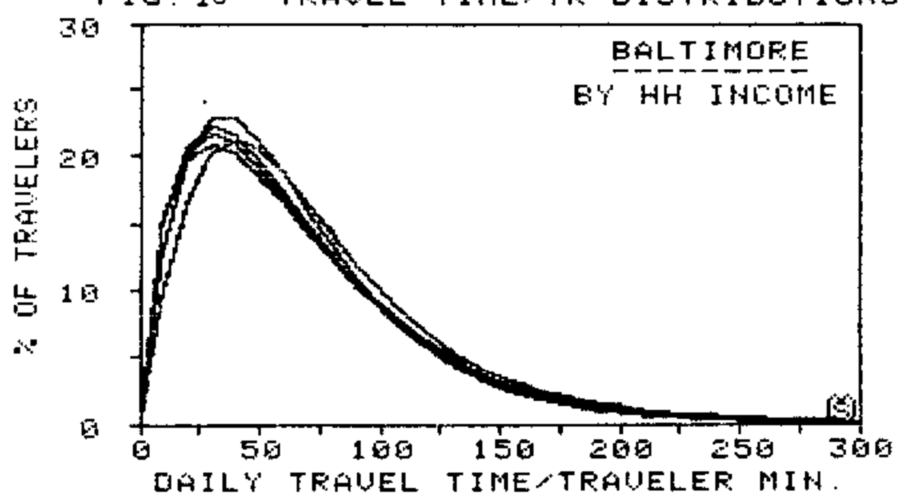
INCOME GROUPS	TIME(MIN.) MAXIMUM	# OF TIME INTERVALS	DEGREES OF FREEDOM	OBSERVED CHI SQR.	CRITICAL VAL.(.05)
2 - 6	235	11	40	35.37	55.76
1 - 6	235	7	30	25.37	43.77

BALTIMORE: TEST FOR EQUIVALENCY, BY CAR OWNERSHIP

CAR GROUPS	TIME(MIN.) MAXIMUM	# OF TIME INTERVALS	DEGREES OF FREEDOM	OBSERVED CHI SQR.	CRITICAL VAL.(.05)
1 - 3+	235	15	28	36.53	41.34

Figure 16 shows the six Gamma functions fitted to the six income groups (based on Appendix 3). The closeness of the six distributions is quite evident.

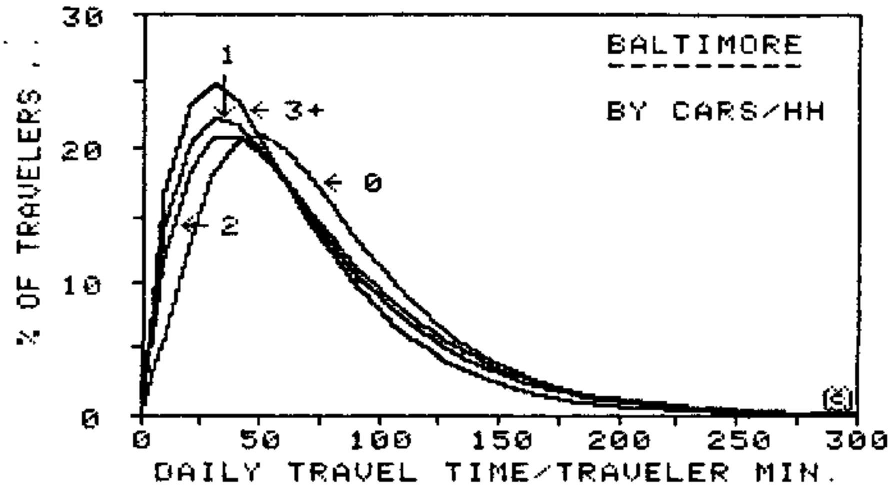
FIG. 16 TRAVEL TIME/TR DISTRIBUTIONS



Since it was already noted in Section 2.11 (i.e. Figure 10) that the daily travel time per traveler is less for higher car ownership levels, additional tests were carried out by car ownership levels, as detailed in Appendix 2.

The first test, encompassing all four car ownership groups, resulted in a significant difference between the groups. However, when the travelers belonging to households owning 1,2,3+ cars (i.e., excluding 0-car households) are tested, the null-hypothesis of equivalency is accepted. This result suggests that travelers of non-car households behave differently from travelers of car-owning households; the former travelers spend appreciably more time for travel than the latter travelers. This result can be seen clearly in Figure 17, where the Gamma function fitted to 0-car travelers is shifted to the right of the other three curves.

FIG. 17 TRAVEL TIME/TR DISTRIBUTIONS



Two principal conclusions can be drawn from the above tests. First, the travel time expenditures of travelers stratified by income can be regarded as statistically equivalent. Second, stratification by car ownership is more sensitive than stratification by income, where the travel time expenditures of 0-car travelers are significantly higher than those of car-owning travelers. In other words, not only can travelers owning cars be regarded as belonging to the same class regardless of car ownership level, but there is a significant quantitative (and, therefore, probably also qualitative) gap between the two classes of travelers.

Comparisons between the travel time frequency distributions of Baltimore and Washington, D.C./London/Reading are detailed in Section 3.8. The following sections present several additional general relationships derived from the Baltimore data set.

2.15 Trip Rate and Trip Distance vs. Daily Travel Distance per Traveler

The definition of a trip has always been quite ambiguous, since trips can be linked/chained and grouped into tours in various ways, and thus dependent more on the analysts' preferences than on the data. Trip rates and trip distances may thus vary widely from one analyst to the next. However, one measure of travel not affected by the definition of a trip is the product of trip rate and distance, or total daily travel distance. Thus, while the exploration of trip rates and trip distances as isolated variables is often unsatisfactory, this can be done meaningfully within the context of total daily travel distance per traveler, as shown below. (The avoidance of using elasticities in this case is intentional, as will be discussed in the final report.)

Figures 18 and 19 show how trip rates and trip distances in Baltimore are related to the total daily travel distance per traveler.

FIG. 18 TRIP RATE/TR VS. DISTANCE/TR

```
====================
NTH ORDER :

DEGREE =2
CONSTANT=-.313094889
1 DEG.C =.376034494
2 DEG.C =-8.46533761E-03
COD(R^2)=.952897233
C.O.C. =.976164552
S.E.E. =.0946494998
====================
```

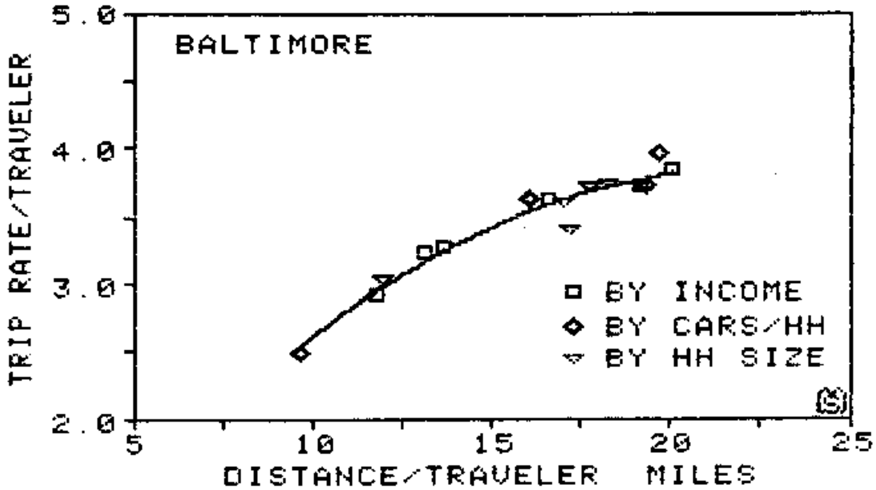
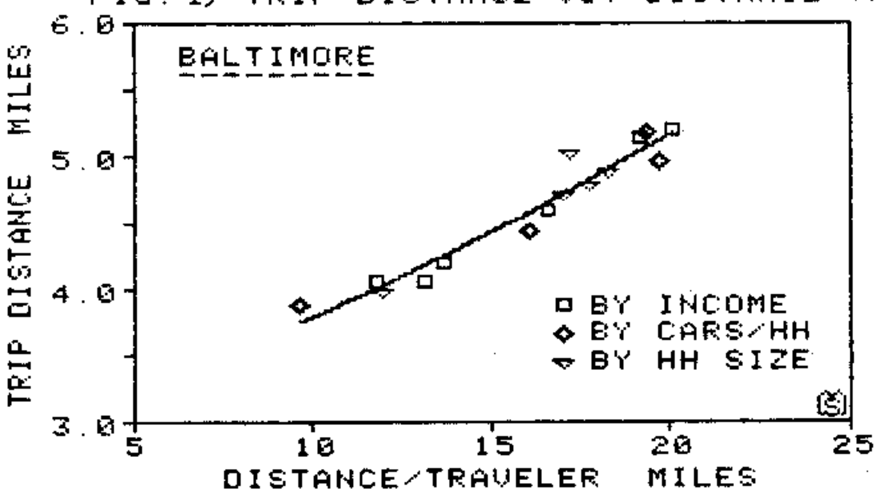


FIG. 19 TRIP DISTANCE VS. DISTANCE/TR

```
====================
EXPONENTIAL : Y=A*EXP(B*X)

A...... =2.77479483
B...... =.0311583299
COD(R^2)=.937819366
C.O.C. =.968410742
S.E.E. =.0271851283
====================
```



It may be inferred from Figure 18 that trip rates are greater at a decreasing rate with longer daily travel distance. Trip distances, on the other hand, appear to be longer at increasing increments with greater daily travel distance, as shown in Figure 19.

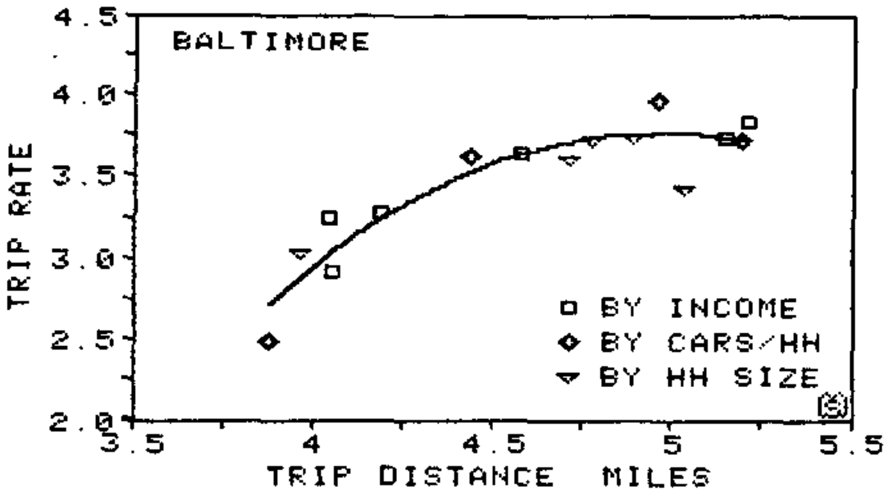
The above indicators suggest two very important conclusions: First, there are trade offs between trip rates and trip distances within the total daily travel distance. Thus, a travel model should consider such interactions explicitly. Second, the trade offs are far from being simple, where trip rates take precedence over trip distances at low daily travel distances (i.e., when travel speeds are low; see Figure 13), while trip distances take precedence over trip rates at high daily travel distances.

The above interrelationships can be also expressed directly, by relating trip rates to trip distances, as shown in Figure 20; trip rates (and, hence, also proportions of trip purposes) tend to increase rapidly at low values, and then approach gradually what appears to be a saturation level of trip rates.

FIG. 20 TRIP RATE VS. TRIP DISTANCE

NTH ORDER :

DEGREE =2
CONSTANT=-19.2009884
1 DEG.C =9.30300527
2 DEG.C =-.942104393
COD(R^2)=.854190022
C.D.C. =.924224011
S.E.E. =.166528561



Nonetheless, numerical values of the above relationships should be regarded cautiously since they depend much on the definition of a trip. In other words, numerical values are not expected to be transferable between cities as long as trips are not measured by a fully transferable and compatible yardstick.

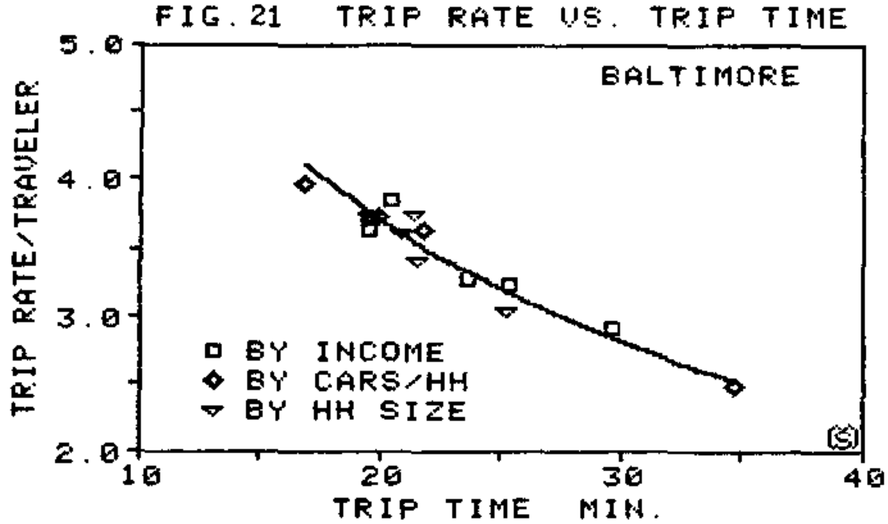
2.16 Trip Rate vs. Trip Time

Figure 21 shows an inverse relationship between trip rate and trip time. This type of relationship is an expected one since the product of trip rate and trip time = total daily travel time per traveler.

FIG. 21 TRIP RATE VS. TRIP TIME

INVERSE : Y=1/(A+B*X)

A...... =.100150034
B...... =8.50660327E-03
COD(R^2)=.946249875
C.D.C. =.972753759
S.E.E. =9.57673041E-03



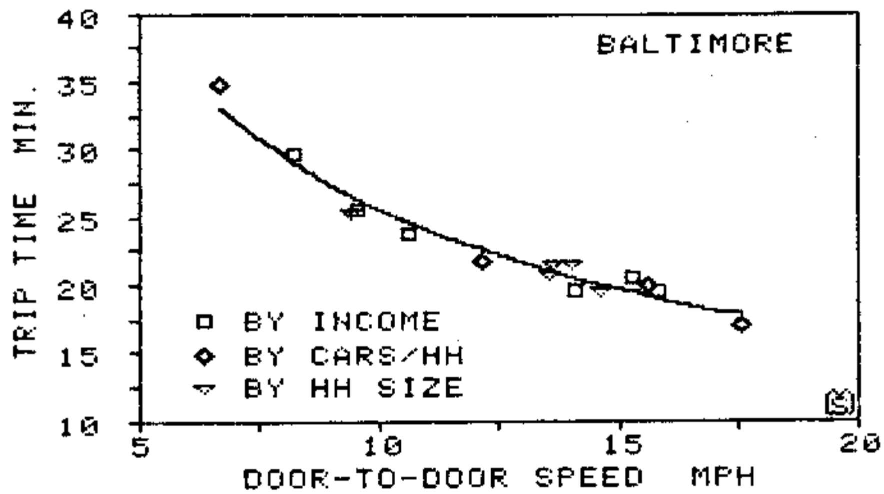
2.17 Trip Time vs. Speed

Figure 22 shows an inverse relationship between trip time and door-to-door speed. In a way, this figure closes the circle, where all travel components are not only related to each other, but also interact with the speed offered by the transportation system. Such relationships serve as the conceptual foundation of the UMOT travel/urban structure model.

FIG. 22 TRIP TIME VS. SPEED

====================
GEOMETRIC(POWER) : Y=A*X^B

A...... =113.440322
B...... =-.647527345
COD(R^2)=.953416558
C.D.C. =.976430519
S.E.E. =.0409995082
====================



3. THE COMPARISONS

3.1 Introduction

This chapter details a number of important and useful comparisons among the four cities that were studied.

The comparisons of travel data and relationships from different cities must be approached with caution because of a lack of standardized definitions for travel components. In our case, the following principal differences between the data sets could be identified:

(1) The Baltimore and Washington, D.C. data refer to internal travel only, namely where both trips' origins and destinations are within the study area. The Reading data, on the other hand, include internal and external travel generated by the residents. In the London case trips are internal plus trips to external zones of a length less than 60 km (37 miles); thus, the London travel can be regarded as regional in nature and scope. Furthermore, rail travel in Reading refers to intercity travel only, while rail travel in London refers to both the urban and the regional underground and overground rail system.

(2) The Baltimore, London and Reading data refer to travel generated by all households within the study area. The Washington data, on the other hand, refer in this report to travel generated by households within a North corridor, starting from the CBD and including parts of Georgetown, Chevy Chase, Bethesda and Potomac.

(3) Travel distance in Baltimore is the network distance. In Washington, D.C. it is the X-Y coordinate distance (i.e., sum of the differences in the Xs and differences in the Ys), which is about .95 the network distance. In London and Reading, on the other hand, travel distance is air-line distance. While no adjustment was made in the case of Washington, D.C., the London and Reading travel distances were adjusted to network distances by the following factors (based on TRRL Report 749 (1977) by Oldfield): Car, motorcycle and taxi - 1.23; bus - 1.26; rail - 1.40.

(4) The Baltimore, Washington and London data include information on trips, namely trip rates, distances and times. The Reading data, on the other hand, are for total travel only.

(5) The Baltimore, London and Reading travel distances, times and speeds are by mode. In Washington, D.C. travel is total, by all modes.

(6) The Washington, D.C., London and Reading travel time frequency distributions extend up to 500 minutes per traveler (8.3 hrs.), while in Baltimore they extend to 250 minutes (4.2 hrs.). Furthermore, in the former cases the time intervals are 0-9.99, 10-19.99, 20-29.99,..., minutes, while in the latter case the time intervals are 0-4.99, 5-14.99, 15-24.99,..., minutes, in order to capture the most-often reported trip times (in most cases rounded to 10,20,..., minutes) within the interval ranges.

In addition to the above differences the four cities are also intrinsically different, both in size and structure. Table 3 summarizes several of the principal characteristics of the cities. (The travel distances in London and Reading, measured in kilometers, were converted to miles in order to be comparable with travel distances in Baltimore and Washington, D.C.)

Nonetheless, these differences did not prohibit the emergence of a number of useful comparisons, as noted in the sections following.

Table 3

THE FOUR CITIES: SUMMARY (*)

CITY.....................:	BALTIMORE	WASHINGTON	WASHINGTON	LONDON	READING
YEAR.....................:	1977	1955	1968 (**)	1977	1977
ALL POPULATION ('000)....:	1794.21	1425.32	1592.60	6558.30	143.20
ALL HOUSEHOLDS ('000)....:	535.59	450.68	547.22	2615.90	57.02
HH SIZE (ALL HHS)........:	3.35	--	--	2.51	2.51
HH SIZE (TRAVELING HHS)..:	3.40	3.16	2.91	2.70	2.73
SAMPLE SIZE - % (***)...:	0.12	5.79	2.73	0.27	2.34
TRAVELERS/HOUSEHOLD......:	2.14	1.92	1.87	1.95	1.86
CARS PER HOUSEHOLD.......:	1.49	.87	1.13	.78	.81
TRAVEL TIME/TR HR.......:	1.26	1.19	1.21	1.33	1.29
C.O.V. OF TIME..........:	0.64	--	--	0.69	--
DISTANCE/HOUSEHOLD.......:	36.74	22.37	27.30	25.70	40.60
DISTANCE/TRAVELER........:	17.20	11.63	14.56	13.18	21.83
D-D SPEED MPH...........:	13.66	9.75	12.05	9.88	16.86
TRIP RATE/TRAVELER.......:	3.59	2.90	2.97	2.85	--
TRIP DISTANCE............:	4.79	4.01	4.90	4.62	--
TRIP TIME MIN............:	21.03	24.69	24.42	28.10	--

(NOTE: DISTANCES ARE IN MILES)

* : TRAVEL RELATES TO HHS GENERATING AT LEAST ONE MOTORIZED TRIP DURING THE SURVEY DAY.
** : HOUSEHOLDS LOCATED WITHIN THE 1955 STUDY AREA GENERATING TRAVEL WITHIN THE EXTENDED 1968 STUDY AREA.
*** : FINAL SAMPLE IN TABELS, AFTER SCREENING.
-- : NOT AVAILABLE

There are also other differences between the data sets which could not be identified explicitly, such as the definition of a trip; in some cases it might refer to each leg of one trip made by different modes, while in other cases it might refer to the linked legs and associated with the mode by which the longest leg-distance was traveled. In order to avoid such differences, all trips in the following comparisons were tabulated by the latter definition.

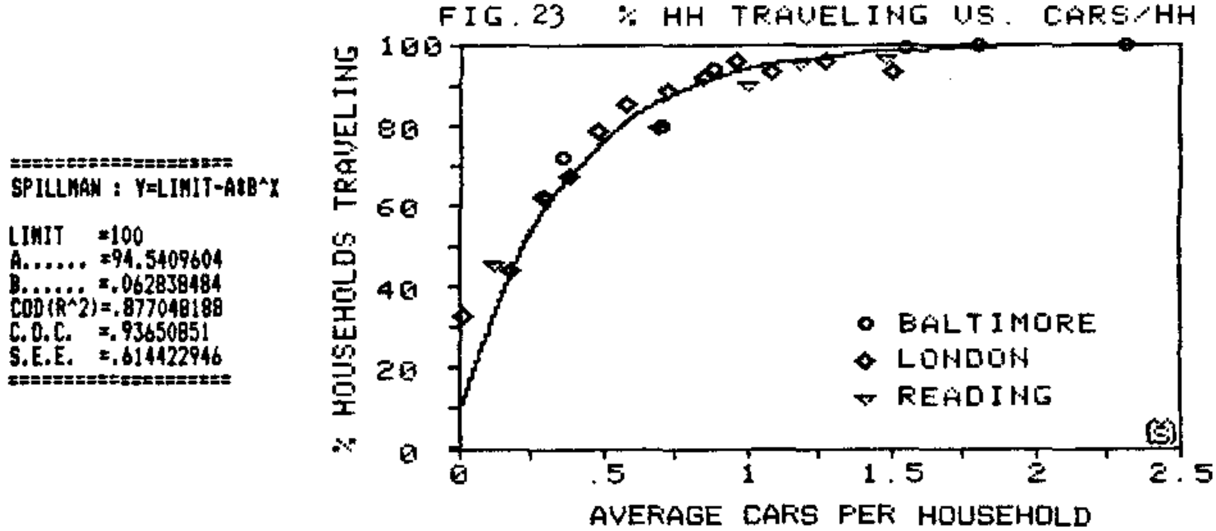
The most-often used common denominator in the following comparisons is car ownership. Even so, it should be noted that there are three groups (0,1,2+ cars/HH) in London and Reading, and four groups (0,1,2,3+ cars/HH) in Baltimore and Washington, D.C. Furthermore, in some cases the comparisons are based on the average car ownership level by income group. It should also be noted that the terms 'per traveler' and 'per household' refer to an average traveler/household representing their group.

The data upon which the following relationships are based are detailed in Appendices 1 and 4.

3.2 Proportions of Households Generating Travel

Figure 23 shows the proportions of households generating at least one motorized trip during the survey day versus car ownership levels in Baltimore, London and Reading. The similarity between the three relationships is noteworthy, especially when considering the intrinsic differences between the cities, and their data.

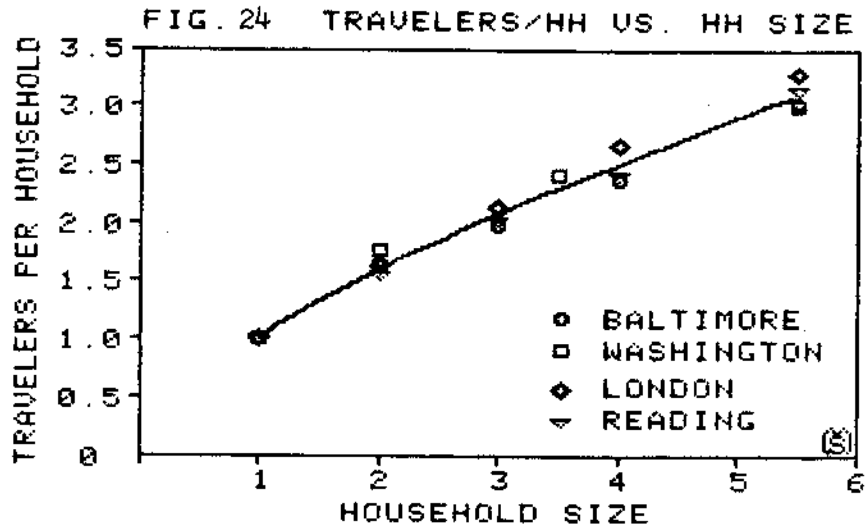
FIG. 23 % HH TRAVELING VS. CARS/HH



3.3 Travelers per Household

Figure 24 suggests that the number of travelers is correlated predominantly with household size, and is similar in the four cities. This result is precisely what we would expect, but it is not usually used in conventional travel models.

```
====================
GEOMETRIC(POWER) : Y=A*X^B

A...... =1.01216572
B...... =.656978896
COD(R^2)=.988529434
C.O.C.  =.994248176
S.E.E.  =.0450154498
====================
```

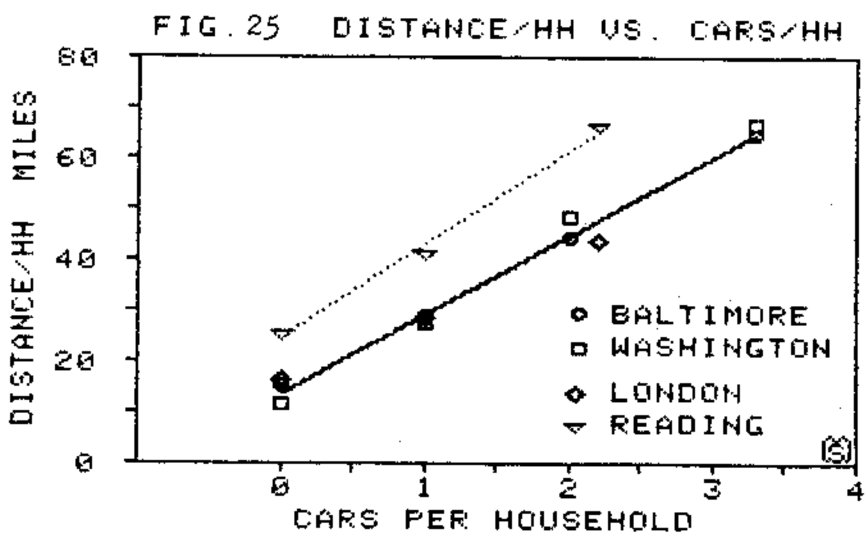


3.4 Travel Distance per Household vs. Car Ownership

Figure 25 shows the daily travel distance per household vs. car ownership. While the urban travel in Baltimore and Washington, D.C., as well as the regional travel in London, show similar regularities, the effect of intercity travel in the case of Reading sets this city apart. As shown in the following sections, speed per traveler appears to be the missing link for making travel distance fully transferable between all four cities.

Reading
```
====================
LINEAR : Y=A+B*X

A...... =24.051004
B...... =18.5838763
COD(R^2)=.993388135
C.O.C.  =.996688585
S.E.E.  =2.36076607
====================
```

Three Cities
```
====================
LINEAR : Y=A+B*X

A...... =13.5111312
B...... =15.5013325
COD(R^2)=.984767473
C.O.C.  =.99235451
S.E.E.  =2.48202013
====================
```



3.5 Door-to-Door Speed

Figure 26 shows how door-to-door speeds (daily travel distances over reported daily door-to-door travel times) differ in the four cities. Once again, Reading is significantly apart from the other cities, and Figure 27 suggests one possible reason for this difference: the intercity travel by both car and rail is carried out at relatively high speeds.

FIG. 26 SPEED VS. CARS/HOUSEHOLD

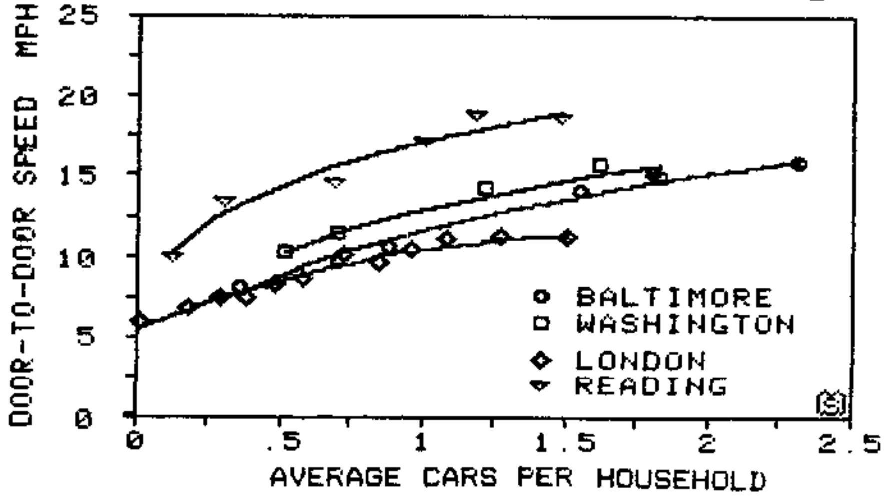
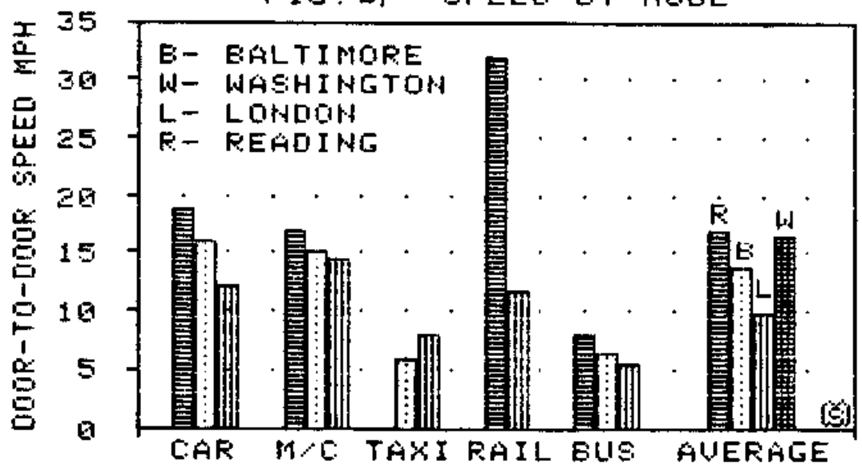


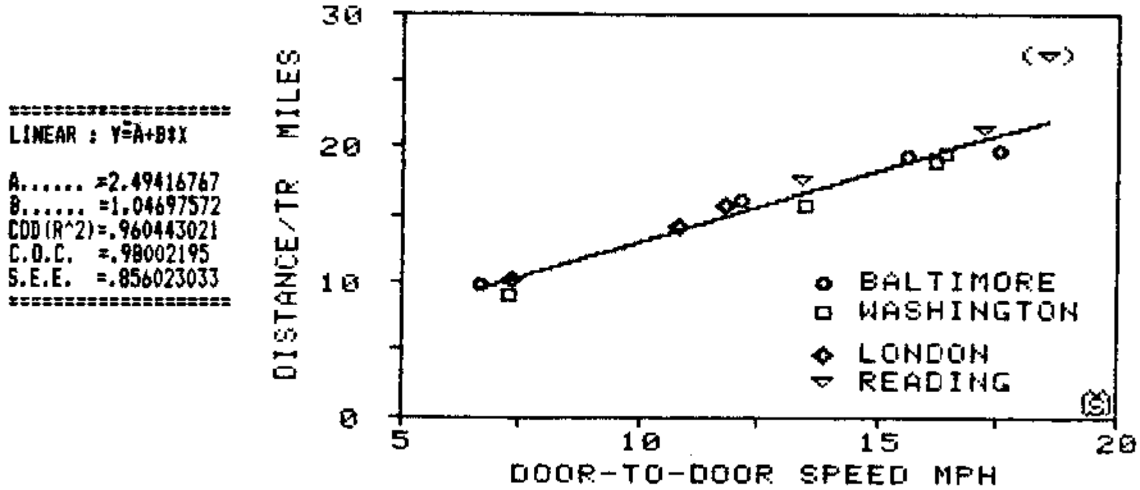
FIG. 27 SPEED BY MODE



3.6 Daily Travel Distance per Traveler

Perhaps the most remarkable relationship in this report is shown in Figure 28, namely the daily travel distance per traveler vs. speed, by car ownership (0,1,2,3+ in Baltimore and Washington, D.C., and 0,1,2+ in London and Reading), a relationship which can be regarded as fully transferable between all four cities (see also Figure 13 in this report, as well as Figure 14 in the previous report). (The only outlier in Figure 28 is the group of households in Reading owning 2+ cars; not only is their sample size small, but their share of inter-city travel is highest. This one outlier is excluded from the best-fit estimation.)

FIG. 28 DISTANCE/TRAVELER VS. SPEED

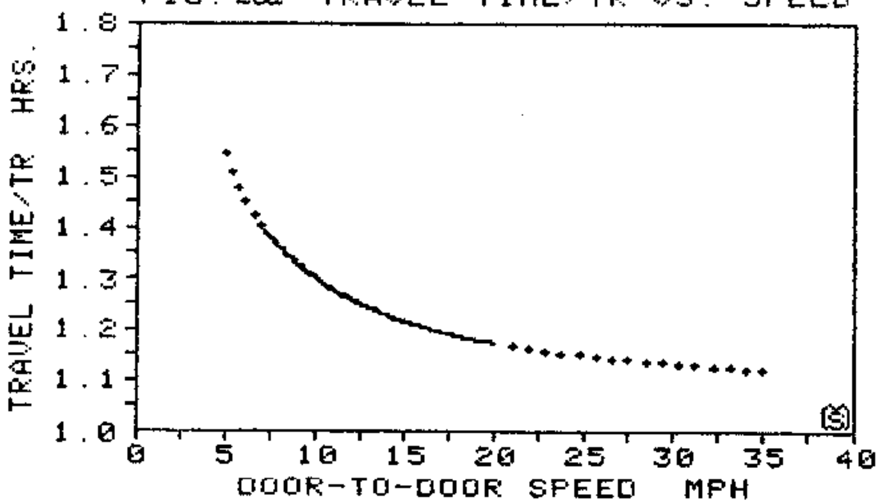


The relationship shown in Figure 28 appears to be a cornerstone for a transferable urban travel model, since passenger-miles of travel can be estimated directly from travel speeds.

This relationship implies two underlying principles: First, it implies regularity in the allocation of time for daily travel and, second, it implies that since speed has to be purchased, high income travelers travel more distance than low income travelers (i.e., 0-car travelers are located at the lower-left corner of the diagram, while 2+ and 3+ car travelers are located at the upper-right corner of the diagram). Put another way, this relationship can be regarded as the end-result of four interacting factors: the expenditures of time and money allocated to travel, the supply of the transportation system, and the costs of using its various parts/modes. This type of transferable relationship is one of the cornerstones of the UMOT travel model.

The relationship shown in Figure 28 can be transformed into a time-speed relationship, as shown in Figure 28a. The two relationships indicate that travelers traveling at high speeds spend less travel time for more travel distance than at low speeds. In other words, the times saved by speed increases are saved, as such, only in part; another part is traded-off for more travel distance (e.g., see also Figures 10-11).

FIG. 28a TRAVEL TIME/TR VS. SPEED



The above results suggest two interesting possibilities: (i) the relationships appear to be the key to the understanding of "induced travel", and (ii) the benefit derived from increased speed (namely, the "value" of saved time) is <u>at least</u> the additional cost required to purchase the increases in speed and travel distance.

An additional possibility, suggested by the Reading data, is that part of the saved time at high speeds within the urban area is reallocated to intercity travel. This possibility will be tested and reported in a forthcoming progress report.

3.7 Daily Travel Time per Traveler by Mode

Since different modes provide different travel speeds, it is to be expected that high income travelers would tend to allocate more of their travel time to fast - but more expensive - modes than low income travelers. This expectation has already been borne out in Figures 9,10 and 11. Figures 29,30 and 31 repeat the allocation of travel time by principal mode vs. cars per household in Baltimore, London and Reading.

CAR

GEOMETRIC(POWER) : Y=A*X^B

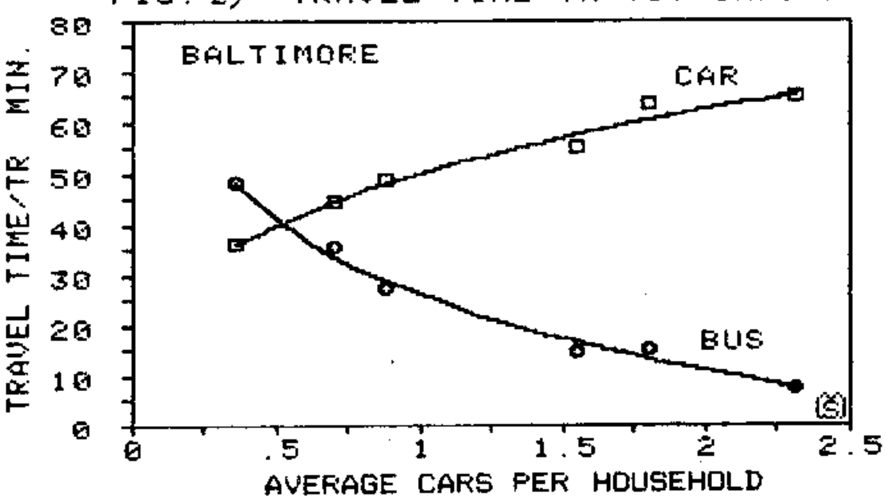
A...... =49.9418638
B...... =.324121165
COD(R^2)=.981199951
C.O.C. =.990555375
S.E.E. =.0348344026

BUS

LOGARITHMIC : Y=A+B*LOG(X)

A...... =25.7886426
B...... =-21.9445918
COD(R^2)=.990488789
C.O.C. =.995233032
S.E.E. =1.66963249

FIG. 29 TRAVEL TIME/TR VS. CARS/HH



CAR

GEOMETRIC(POWER) : Y=A*X^B

A...... =37.8017172
B...... =.477023826
COD(R^2)=.987074804

RAIL

NTH ORDER :

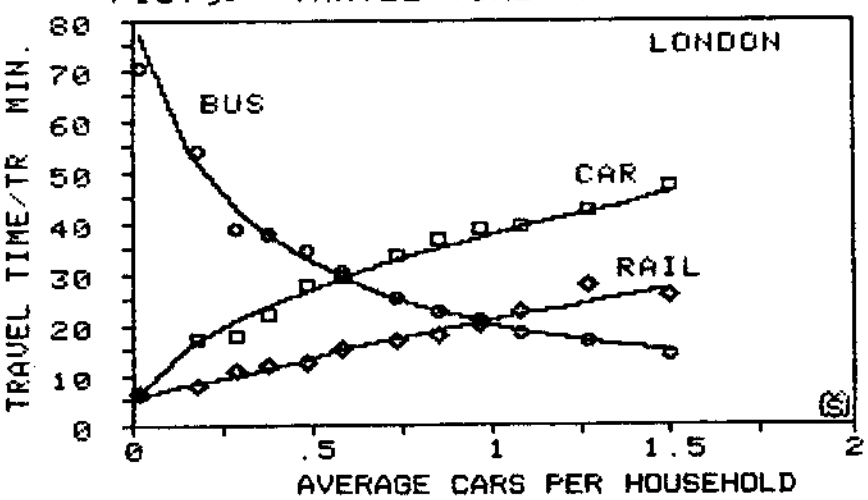
DEGREE =2
CONSTANT=5.00460642
1 DEG.C =18.1704851
2 DEG.C =-2.24456254
COD(R^2)=.965975059

BUS

INVERSE : Y=1/(A+B*X)

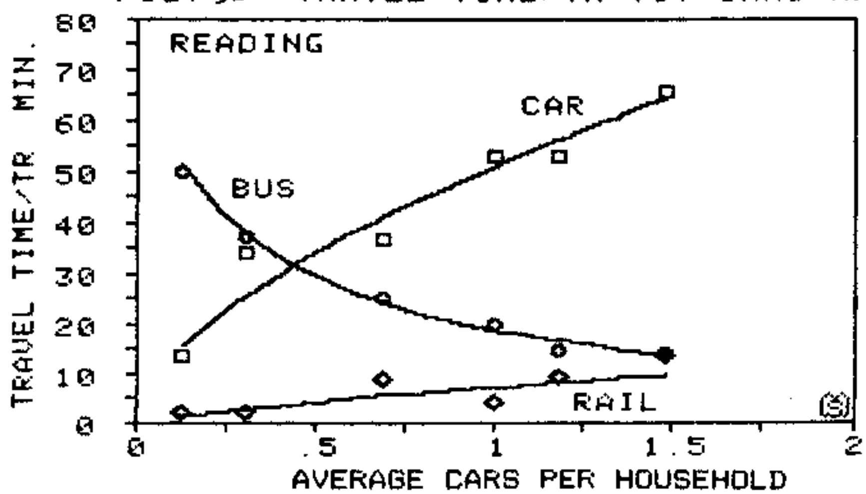
A...... =.0121743245
B...... =.0386075117
COD(R^2)=.994484847

FIG. 30 TRAVEL TIME/TR VS. CARS/HH



```
CAR
====================
GEOMETRIC(POWER) : Y=A*X^B

A...... =51.2481544
B...... =.588421927
COD(R^2)=.927330494
C.O.C.  =.962980007
S.E.E.  =.171339749
====================
RAIL
====================
GEOMETRIC(POWER) : Y=A*X^B

A...... =7.23125798
B...... =.77547594
COD(R^2)=.708041036
C.O.C.  =.841451743
S.E.E.  =.517976987
====================
BUS
====================
INVERSE : Y=1/(A+B*X)

A...... =.0143573398
B...... =.0398377122
COD(R^2)=.969036923
C.O.C.  =.984396731
S.E.E.  =4.1337332E-03
====================
```

FIG. 31 TRAVEL TIME/TR VS. CARS/HH



The first result emerging from Figures 30-31 is that although rail travel is conventionally regarded as public transport, similar to bus travel, its relationship between the time allocated by mode and car ownership levels is similar to the relationship of car travel, rather than of bus travel. This result may have far reaching implications not only to step-wise mode-choice forecasts (e.g., when the first split is done between private vs. public modes, and the second split between bus vs. urban rail), but also to conventional car ownership and trip generation models. For instance, one possible implication is that high-speed rail is a partial substitute for cars; lower car ownership levels in a city having a rapid transit system may be due not only to higher congestion costs but also to the availability of a relatively high-speed mode that can serve as a partial substitute for car travel. (It should be noted that the emphasis here is on the speed that the mode provides, and not on the mode's name.)

An additional implication, quite contradictory to conventional beliefs, is that high income travelers appear to derive more benefits from an urban rail system than low income travelers. In London, where the underground rail system covers both rich and poor areas, this factor may not be regarded as critical, but it can raise some difficult issues in the planning of routes of a new rapid transit system in U.S. cities; should the priority of routes be directed toward rich or poor areas ? Such a question is not easy to answer as it touches upon two - and often contradicting - requirements; equity for the population, and revenue for the system. A travel model should, therefore, be able to deal explicitly with, and be sensitive to, such requirements.

Since Baltimore did not have an urban rail system during the survey year, Figures 32 and 33 compare the allocation of travel time to bus and car modes in the three cities (as already mentioned above, no stratification by mode is available in the Washington, D.C. tables). As can be seen in these figures, the low income travelers (i.e., mainly at low car ownership levels) also benefit from a rail system: the allocation of travel time to both the bus and the car modes in London and Reading are lower than in Baltimore; the difference is allocated to rail travel. An additional interesting observation is that the intercity travel by car by the Reading travelers becomes a dominant factor at high car ownership levels (i.e., high income levels), a phenomenon which may explain the outlier point in Figure 28. Thus, this outlier may become a pivot point for the analysis of intercity travel, a subject to be covered in a forthcoming progress report.

FIG. 32 TRAVEL TIME/TR BY BUS

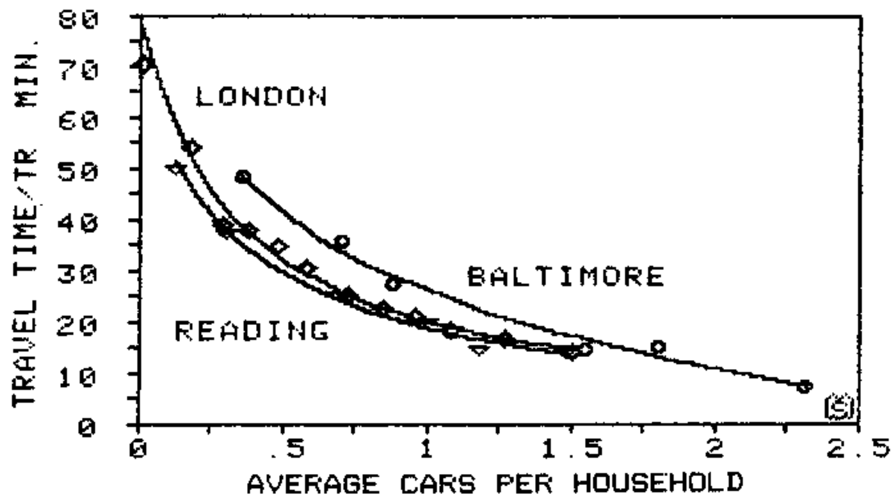
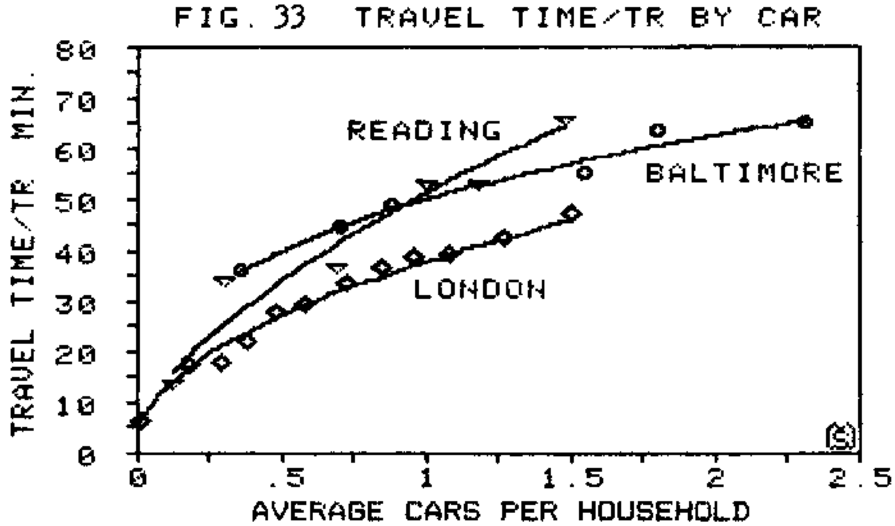


FIG. 33 TRAVEL TIME/TR BY CAR



The attention is now turned to a more thorough analysis of the daily travel time per traveler at disaggregate levels.

3.8 Travel Time Frequency Distributions

The travel time frequency distributions in Baltimore have already been shown in Figures 14-17. The same distributions in Washington, D.C., London and Reading are detailed below.

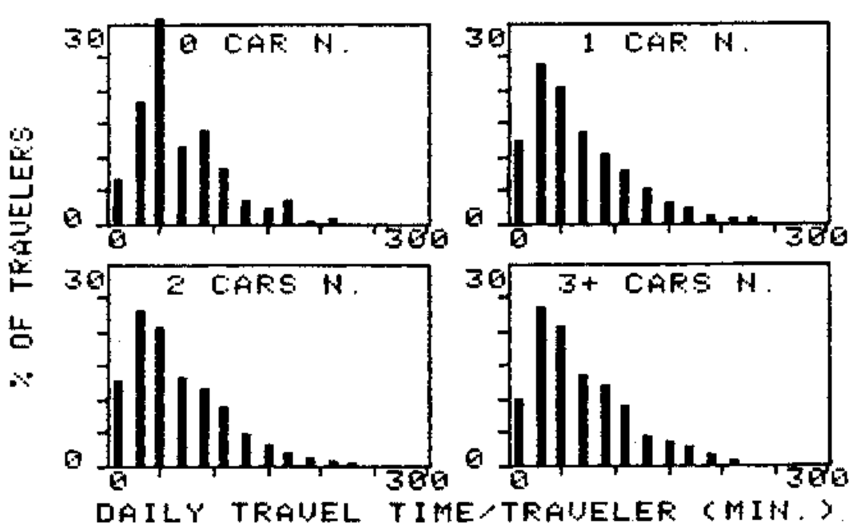
The test for equivalency within Baltimore has already been described in Section 2.14. The tests for equivalency in Washington, D.C., London and Reading are detailed below, followed by comparisons between the four cities.

(1) Washington, D.C.

The available tables for Washington include travel time frequency distributions for two corridors; a North corridor, including parts of Georgetown, Chevy Chase, Bethesda and Potomac, and a South corridor, including parts of Arlington, Falls Church and Fairfax. Figures 34-37 (Appendix 5) show the frequency distributions, by car ownership levels, in the two corridors, and Table 4 summarizes the test for equivalency. As can be seen, the null-hypothesis of equivalency is accepted. Hence, only the North corridor is tested for equivalency with the other cities in the following comparisons.

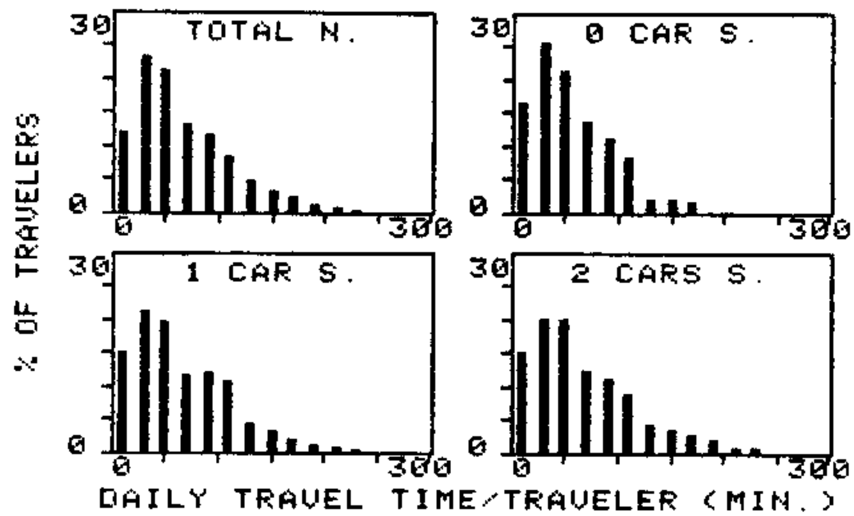
Fig. 34

WASHINGTON D.C. DATA
DAILY TRAVEL TIME PER TRAVELER
MOBILITY SYSTEMS, INC.
NOVEMBER 81



Cont.

WASHINGTON D.C. DATA
NORTH & SOUTH CORRIDORS
DAILY TRAVEL TIME PER TRAVELER
MOBILITY SYSTEMS, INC.
NOVEMBER 81



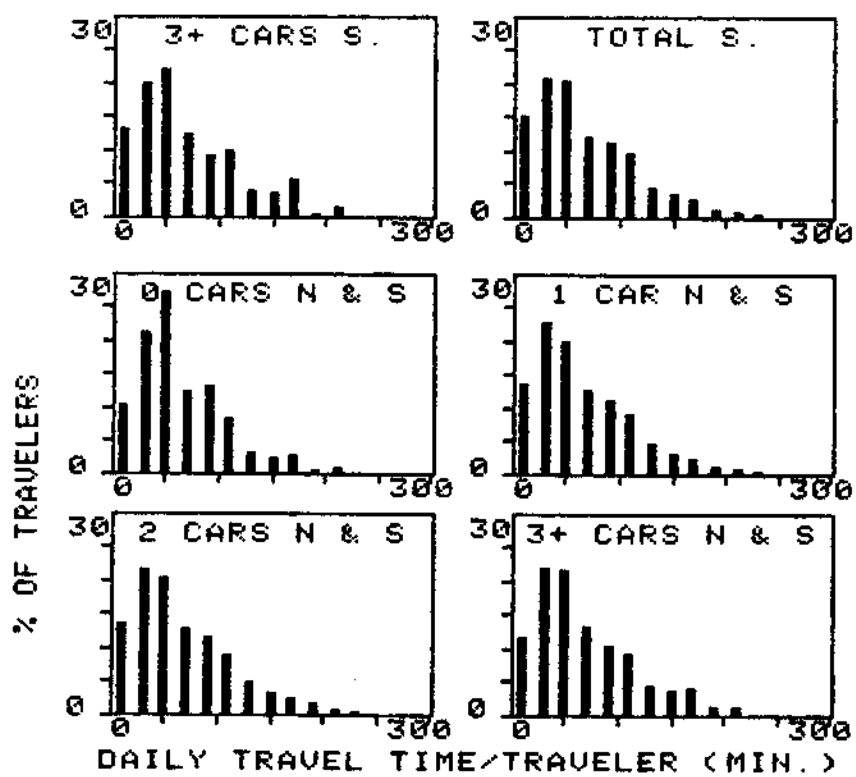


FIG. 35 TRAVEL TIME/TR DISTRIBUTIONS

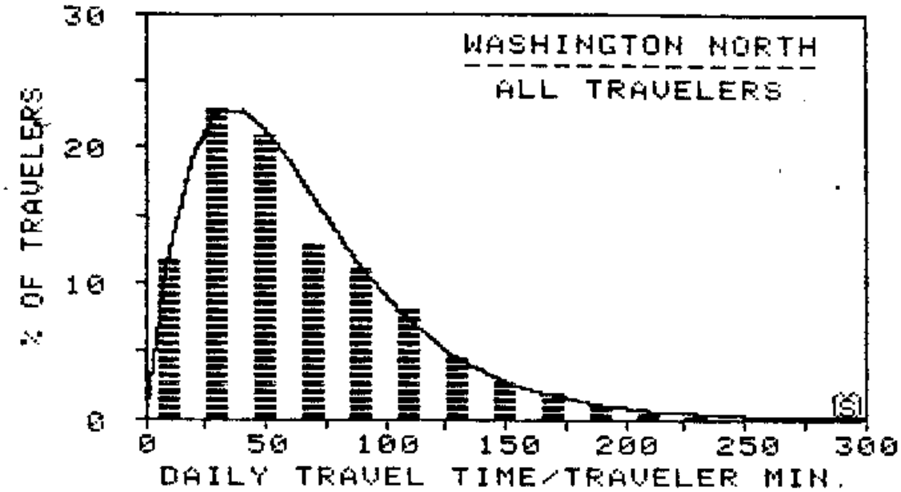


FIG. 36 TRAVEL TIME/TR DISTRIBUTIONS

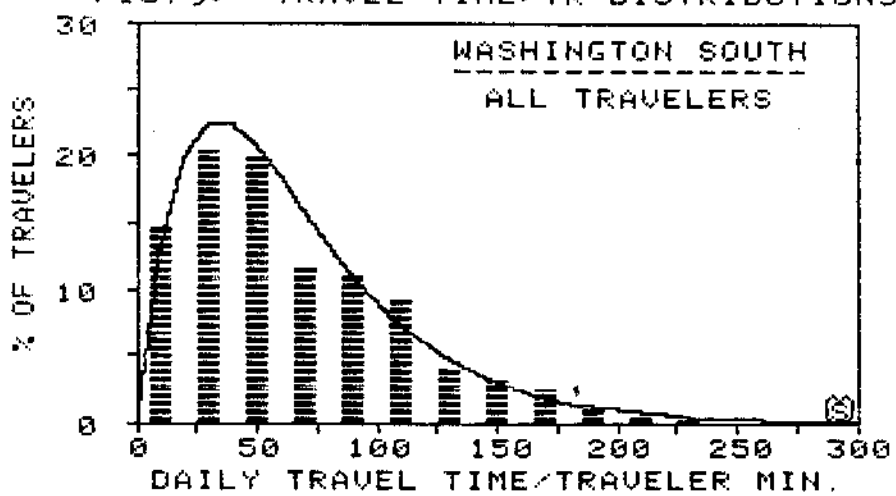


FIG. 37 TRAVEL TIME/TR DISTRIBUTIONS

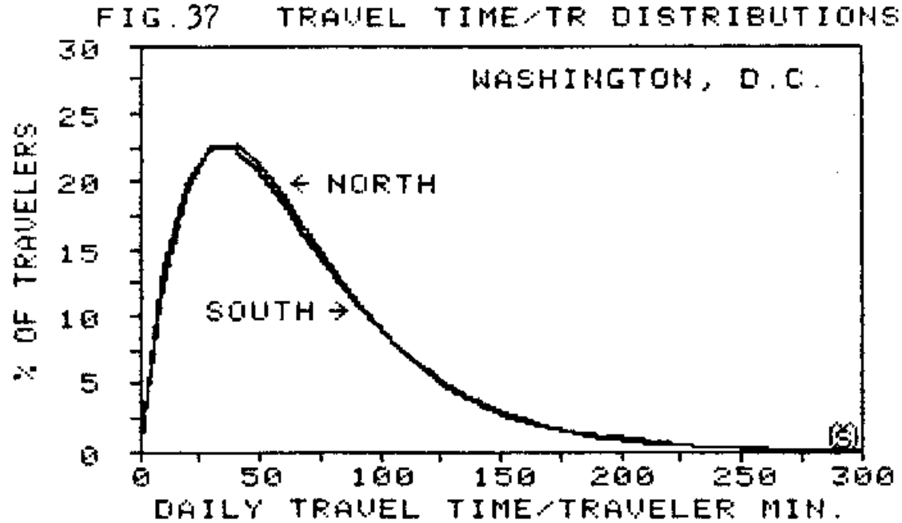


Table 4

WASHINGTON, D.C.: TEST FOR EQUIVALENCY

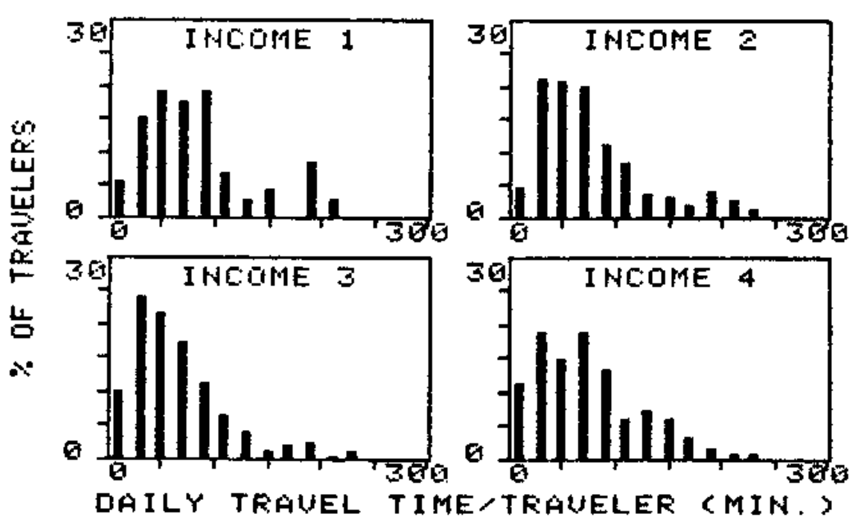
ALL TRAVELERS	TIME(MIN.) MAXIMUM	# OF TIME INTERVALS	DEGREES OF FREEDOM	OBSERVED CHI SQR.	CRITICAL VAL.(.05)
-NORTH-SOUTH	235	18	17	18.15	27.59

(2) London

Figures 38-40 (Appendix 6) show the travel time frequency distributions by income in London. These distributions were tested for equivalency, and the first test was carried out for all 12 income groups simultaneously. However, it resulted in a Chi square value well above the critical value. This result is explained by the markedly different spread of the tail-end of the distributions for the very low and very high income groups (see Appendix 6). Hence, the next test was carried out for pairs of adjacent income groups, as detailed in Table 5.

Fig. 38

LONDON DATA
DAILY TRAVEL TIME PER TRAVELER
MOBILITY SYSTEMS, INC.
NOVEMBER 81



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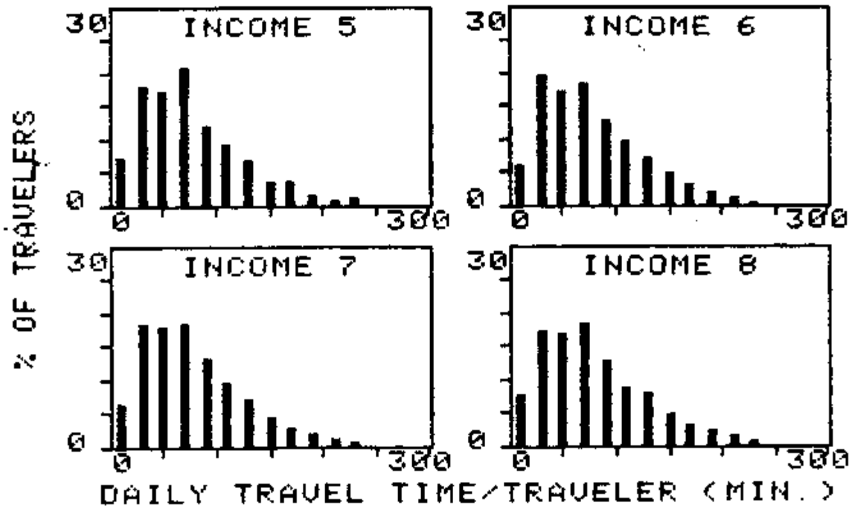


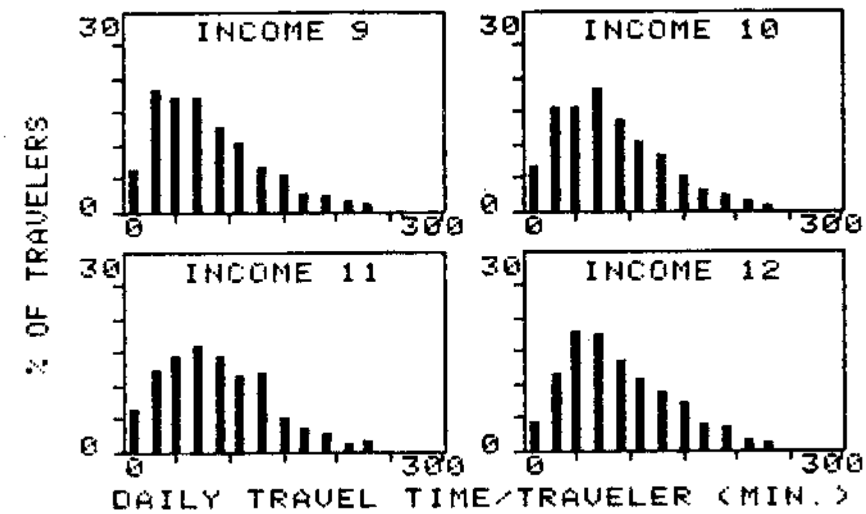
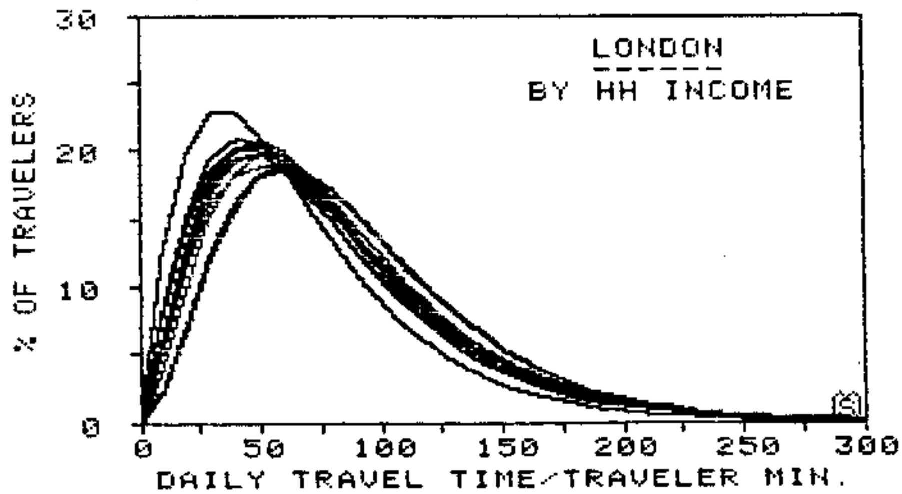


FIG. 39 TRAVEL TIME/TR DISTRIBUTIONS



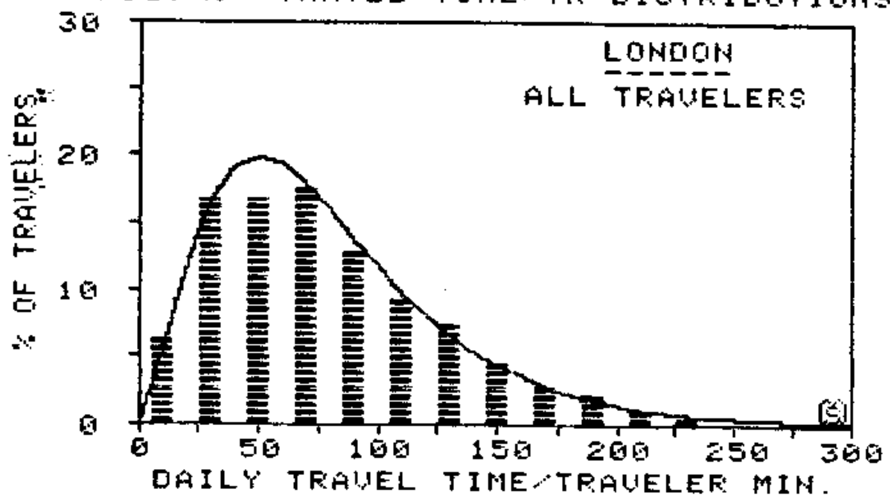


Table 5

LONDON: TEST FOR EQUIVALENCY, BY INCOME

INCOME GROUPS	TIME (MIN.) MAXIMUM	# OF TIME INTERVALS	DEGREES OF FREEDOM	OBSERVED CHI SQR.	CRITICAL VAL. (.05)
1 - 2	85	8	7	7.71	14.07
2 - 3	125	12	11	20.09	19.68
3 - 4	125	13	12	21.48	21.03
4 - 5	165	17	16	25.83	26.29
5 - 6	165	17	16	25.58	26.29
6 - 7	175	18	17	13.38	27.59
7 - 8	205	21	20	20.29	31.41
8 - 9	205	21	20	18.81	31.41
9 -10	205	21	20	20.91	31.41
10-11	165	17	16	26.95	26.29
11-12	165	17	16	20.34	26.29
5 -10	205	21	100	107.18	124.34

In almost all cases the null-hypothesis of equivalency is accepted. In the few remaining cases it is just beyond the threshold of acceptance. Table 5 also shows that the simultaneous analysis of the 6 middle income groups (5 to 10) results in acceptance of the null-hypothesis. It may, therefore, be concluded that while the time frequency distributions of travelers at the extreme-end income groups are different, the change is gradual, and travelers belonging to adjacent income groups behave similarly. Furthermore, travelers in the middle income groups 5 to 10 behave similarly.

In an effort to identify reasons for the above gradual shift between adjacent income groups, an additional test was carried out by stratifying the travelers by car ownership, as detailed in Appendix 7. The reason for this test can be found in Appendix 7, where the daily travel time per traveler (and C.o.V.) belonging to households owning 1 and 2+ cars is practically identical for samples excluding the 10 percent in the tail: 69.2 vs. 69.6 min. respectively (C.o.V. is .56 in both cases), while the daily travel time per traveler belonging to 0-car households is appreciably higher, namely 73.8 min. (C.o.V. is .48).

Indeed, the tests for equivalency between the three groups, as shown in Figures 41-42, suggest that the distributions of travelers belonging to households owning 1 and 2+ cars are similar, while the distribution of travelers belonging to 0-car households is significantly different from the other two groups, as detailed in Table 6.

Fig. 41

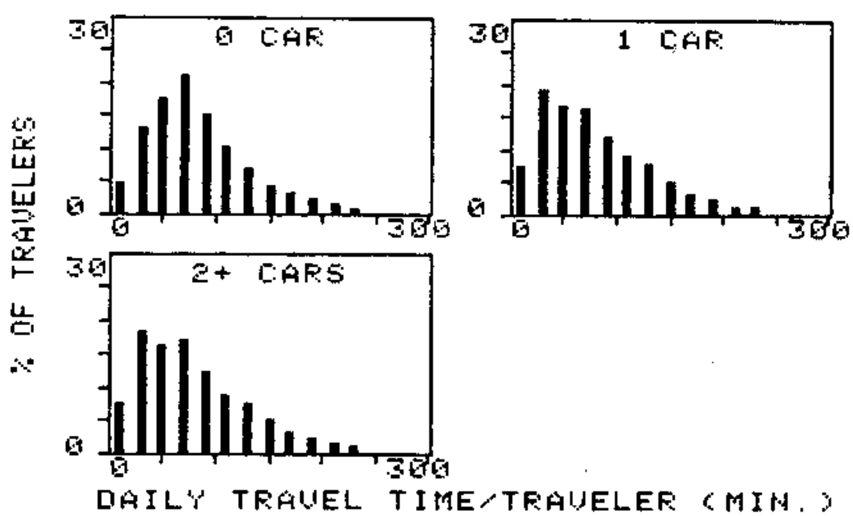


FIG. 42 TRAVEL TIME/TR DISTRIBUTIONS

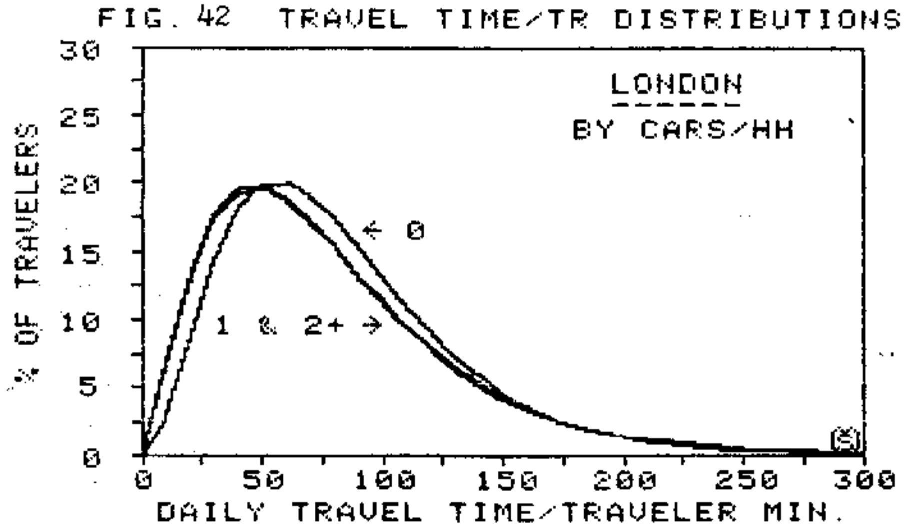


Table 6

LONDON: TEST FOR EQUIVALENCY, BY CAR OWNERSHIP

CAR GROUPS	TIME(MIN.) MAXIMUM	# OF TIME POINTS	DEGREES OF FREEDOM	OBSERVED CHI SQR.	CRITICAL VAL.(.05)
0-1-2	195	20	38	173.15	53.36
1-2	195	20	19	14.41	30.14

(3) Reading

Similar tests to the above were carried out for the 6 income groups in Reading (no stratification by car ownership level was available for Reading). Figures 43-45 (Appendix 8) show these distributions and Table 7 summarizes the results of the tests.

Fig. 43

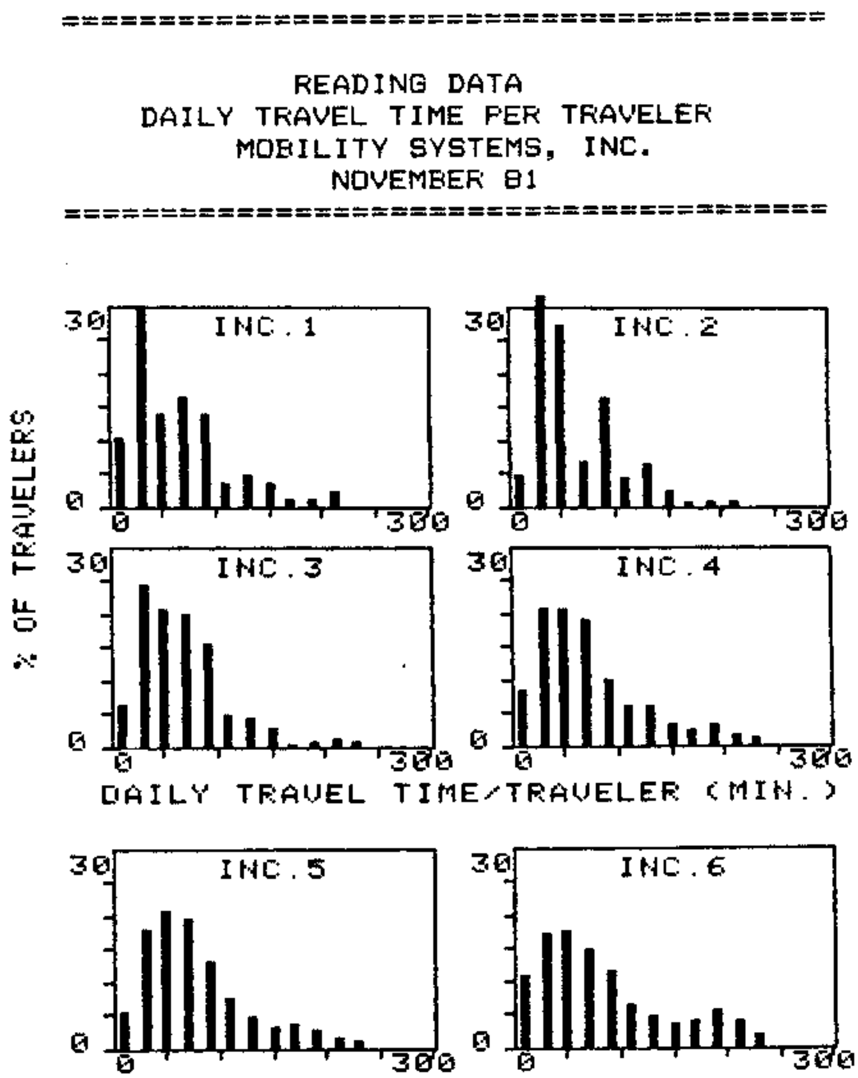


FIG. 44 TRAVEL TIME/TR DISTRIBUTIONS

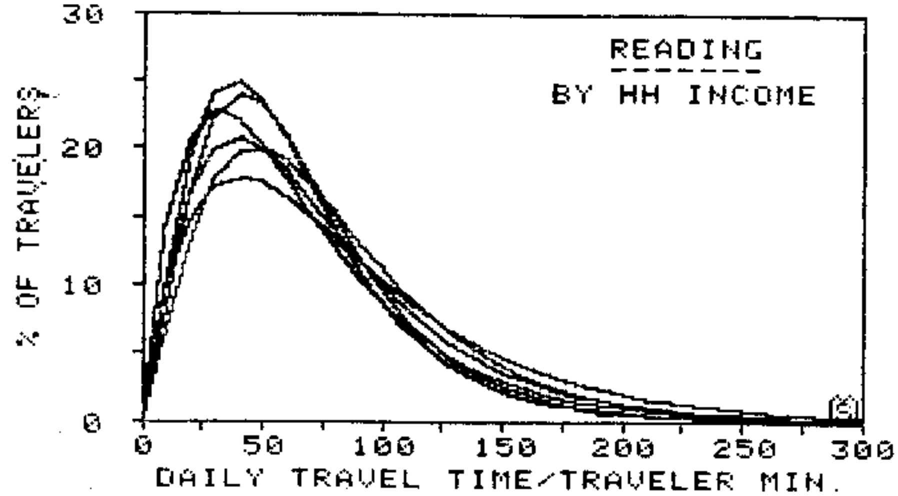


FIG. 45 TRAVEL TIME/TR DISTRIBUTIONS

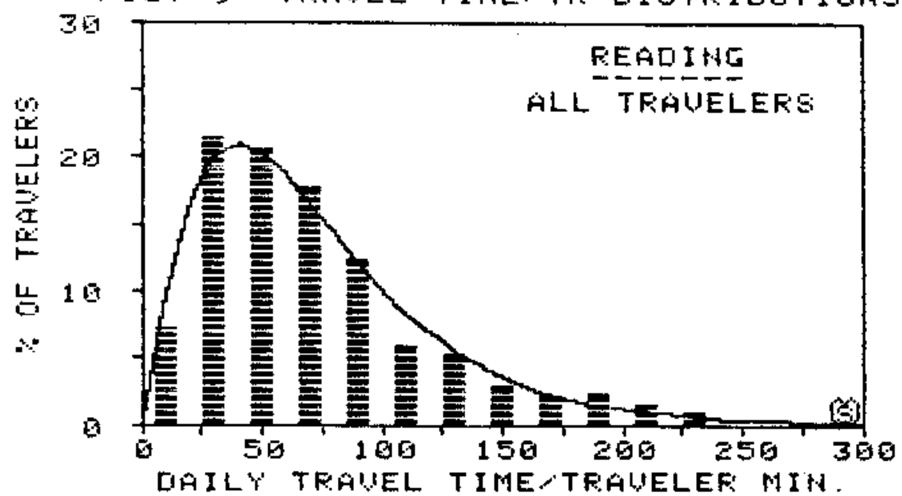


Table 7

READING: TEST FOR EQUIVALENCY, BY INCOME

INCOME GROUPS	TIME(MIN.) MAXIMUM	# OF TIME INTERVALS	DEGREES OF FREEDOM	OBSERVED CHI SQR.	CRITICAL VAL.(.05)
1 - 2	235	5	4	3.84	9.49
2 - 3	235	7	6	5.34	12.59
3 - 4	235	12	11	16.01	19.68
4 - 5	235	15	14	15.41	23.68
5 - 6	235	11	10	15.51	18.31

Following the London case, equivalency was accepted for adjacent income groups, thus suggesting a gradual shift in the distributions by income. Since the Reading data include also intercity travel, which increases with income, the spread of the distributions towards longer travel times increases with income, as shown in Figure 44.

(4) City Comparisons

The first test for equivalency of the travel time frequency distributions is between Baltimore and Washington, D.C. (North corridor), as detailed in Table 8. A test for equivalency of the two totals showed significant differences between the two cities. Therefore, additional tests were carried out by car ownership levels. As shown in Table 8, there were no significant differences between pairs of distributions by car ownership levels. Even when all car groups were grouped together (under 1+ cars) the null-hypothesis of equivalency still held. Put another way, 0-car travelers behave differently from car-owning travelers. It may, therefore, be concluded that different proportions of 0-car travelers in the two cities can affect significant differences between the two total time distributions, although separate car ownership groups do behave similarly (see, for instance, Figure 17). This result serves as an additional corroboration of the relationship shown in Figure 28a, where travelers traveling at (door-to-door) speeds below 10 mph (namely, mostly bus travelers) spend appreciably more travel time than travelers traveling at speeds above 10 mph.

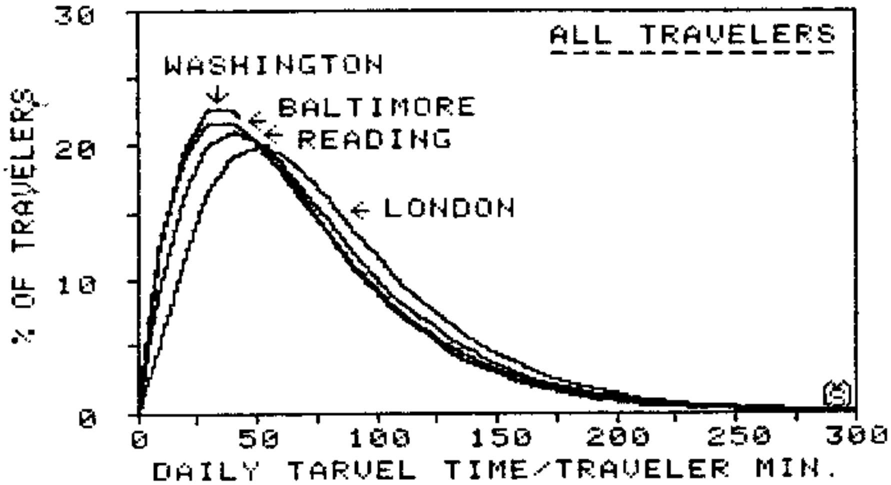
Table 8

CITIES: TEST FOR EQUIVALENCY, BY CAR OWNERSHIP

CITIES	CAR GROUPS	TIME(MIN.) MAXIMUM	# OF TIME INTERVALS	DEGREES OF FREEDOM	OBSERVED CHI SQR.	CRITICAL VAL.(.05)
BALTIMORE-WASHINGTON	0 - 0	235	7	6	10.88	12.59
BALTIMORE-WASHINGTON	1 - 1	235	7	6	5.81	12.59
BALTIMORE-WASHINGTON	1+ - 1+	235	7	6	10.33	12.59
BALTIMORE-WASHINGTON	2+ - 2+	235	7	6	8.75	12.59
BALTIMORE - LONDON	0 - 0	235	7	6	8.75	12.59
BALTIMORE - LONDON	2+ - 2+	235	7	6	9.26	12.59

An additional factor to consider while comparing different cities is the effect of regional/intercity travel on the frequency distributions. Figure 46 shows the total distributions for the four cities, where it becomes evident that the London and Reading distributions are more spread (i.e., higher daily travel time per traveler) than in Baltimore and Washington, D.C. Of particular interest is the additive effects of both regional travel and low travel speeds in London, which appear to have more adverse effects on its distribution than the counter effects of intercity travel at high speed in Reading.

FIG. 46 TRAVEL TIME/TR DISTRIBUTIONS



Tests for the equivalency of the total London vs. Reading distributions, and between them and the Baltimore and Washington distributions suggest that they are dissimilar. However, comparable groups appear to behave in similar ways; e.g., the travel time frequency distributions of 2+ car travelers in Baltimore and London are statistically equivalent ($X^2 = 6.79$; df = 6; $X^2_{\text{critical at .05}} = 12.59$).

In conclusion, the above tests indicate that the travel time frequency distributions display consistent regularities, which are a function of such factors as size of the urban area and prevailing speeds. Such relationships can be regarded as transferable between cities when the differences between the cities, and their travel (such as urban vs. intercity, as well as travel speeds), are recognized.

When only mean travel times are required for forecasting future travel behavior, then the fully transferable relationships shown in Figures 28 and 28a can be used for various groups of travelers in a city. If, however, the full range of each travel time frequency distribution is required, then it can be derived from the Gamma distribution where the mean is the above value and the coefficient of variation is about .65.

The point to emphasize is that the above analyses indicate that the relationships of the daily travel time per traveler display consistent regularities which are transferable between cities; it is not a constant daily travel time which is transferable, as some erroneously interpret it to be, but the <u>regularities</u> which are transferable.

The following sections present further comparisons of travel components in the four cities.

3.9 Trip Rate and Trip Distance vs. Daily Travel Distance

The product of daily trip rate per traveler and average trip distance equals, by definition, the daily travel distance per traveler. It was already shown in Figures 18-20 how trip rate and trip distance in Baltimore are traded off within the total daily travel distance per traveler. A comparison of the same relationships in three cities is shown in Figures 47-48.

FIG. 47 TRIP RATE VS. DISTANCE/TR.

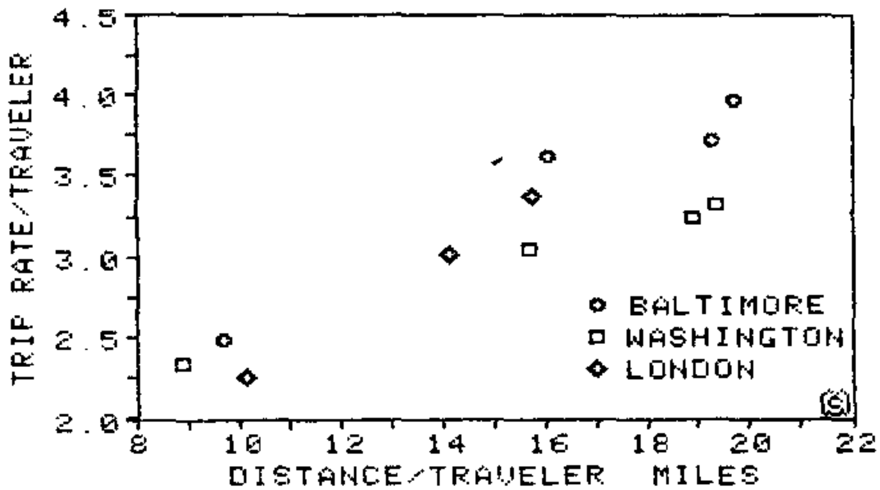
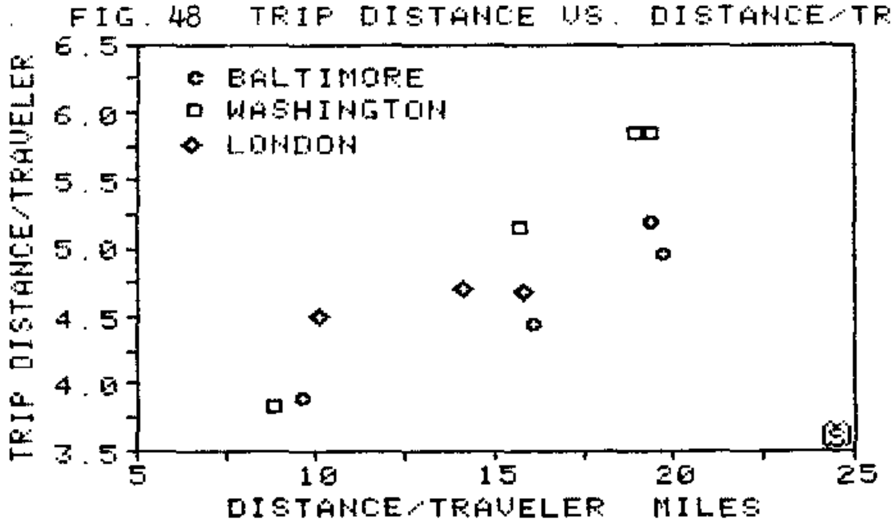


FIG. 48 TRIP DISTANCE VS. DISTANCE/TR

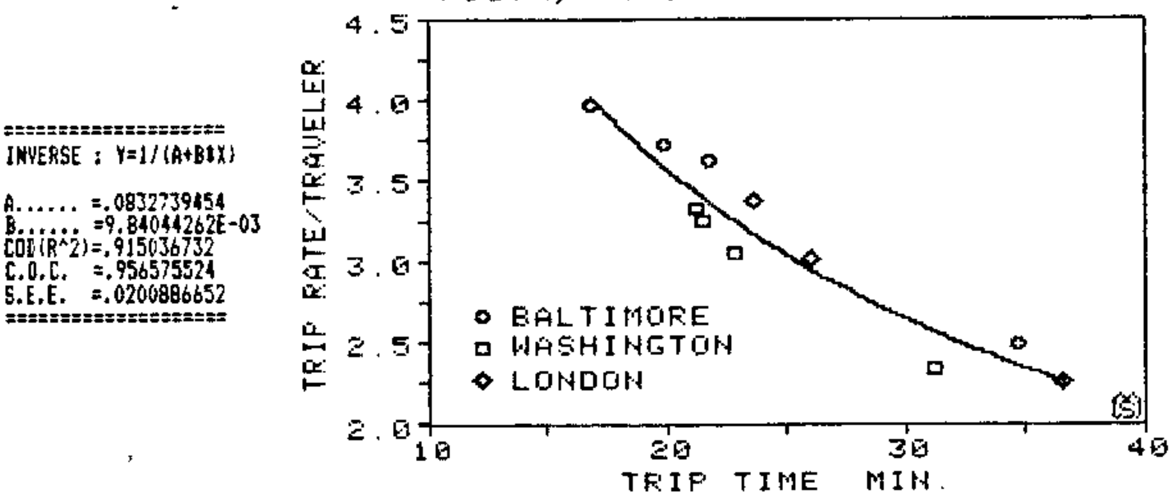


It is evident that numerical values of such relationships are not transferable between cities. One plausible reason for this result is that there is no one, universally accepted, definition of a trip and, therefore, trips are not the best travel component to be transfered between cities. Indeed, conventional trip generation models are found in most cases not to be transferable between cities, especially if they are also different in size and structure.

3.10 Trip Rate vs. Trip Time

Figure 49 shows the relationship between trip rate and trip time in three cities.

FIG. 49 TRIP RATE VS. TRIP TIME



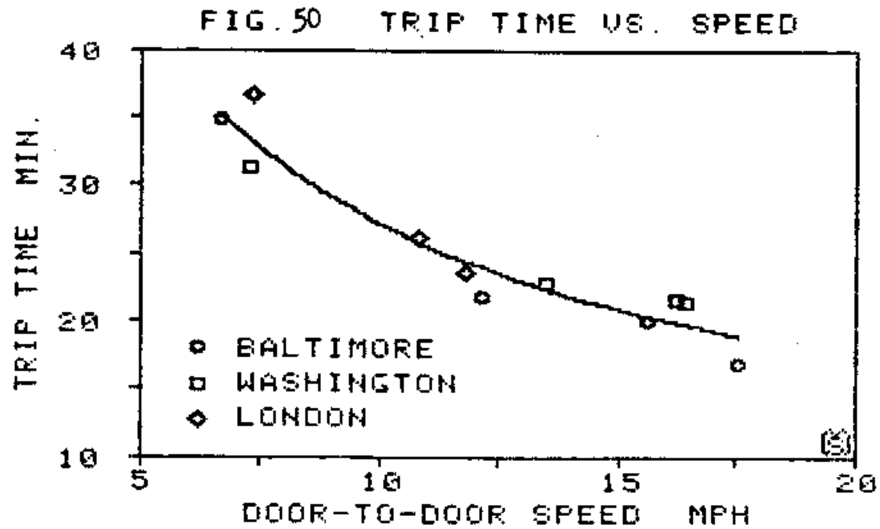
It can be inferred from this relationship that: (i) trip rate and trip time are inversely related, and (ii) although the relationship is similar for the three cities, it is not fully transferable. The last result is an expected one since the product of trip rate and trip time equals, by definition, the daily travel time per traveler, which can be different in different cities. Nonetheless, the consistent regularities observed in the daily travel time per traveler relationships enable one to derive the expected trip time from any given trip rate (by whatever definition) and thus relate the trip time frequency distributions to the daily travel time frequency distributions. Hence, Figure 49, although not fully transferable between cities, suggests a consistent similarity which can be useful for many purposes.

3.11 Trip Time vs. Speed

The last relationship shown in this report is between trip time and door-to-door speed, as depicted in Figure 50. This relationship closes the circle of interactions between all principal travel components, where the daily travel time per traveler, and hence also the daily travel distance, are closely related to the available speed; trip rate and trip distance are traded off within the daily travel distance; trip rate and trip time are traded off within the daily travel time; and, hence, trip time is related to the available speed.

```
====================
GEOMETRIC(POWER) : Y=A*X^B

A...... =122.70822
B...... =-.65573108
COD(R^2)=.916718544
C.O.C.  =.9574542
S.E.E.  =.0735267878
====================
```



* * *

The next report will deal with the regularities of travel money expenditures, as derived from the observed regularities of daily travel distance by mode per household.

4. ACKNOWLEDGEMENTS

Special thanks are extended to Dr. Vernon Webster and his colleagues, of the TRRL, for their assistance in obtaining the London and Reading data; to Geoffrey Key and John Wootton, of Wootton, Jeffreys and Partners, for producing the London and Reading basic tables; and to James Ryan, of the U.S. DOT, UMTA, for producing the Baltimore basic tables. Appreciation is also extended to Eli Argon for programming and producing the diagrams.

APPENDIX 1

BALTIMORE DATA: URBAN TRAVEL

CLASSIFICATION BY HH INCOME.

GROUP NUMBER............:	1	2	3	4	5	6	TOT/AVG.
NO. HHS EXPANDED ('000)..:	44.21	84.80	68.63	134.21	95.34	108.40	535.59
HOUSEHOLD INCOME $('000)..:	3.00	6.00	10.00	15.50	22.00	28.00	15.95
% HHS TRAVELING..........:	71.80	80.20	93.90	98.80	100.00	100.00	93.50
HOUSEHOLD SIZE...........:	2.82	3.03	2.94	3.33	3.66	3.94	3.40
TRAVELERS PER HOUSEHOLD..:	1.40	1.74	1.66	2.02	2.30	2.87	2.14
CARS PER HOUSEHOLD.......:	0.36	0.70	0.88	1.55	1.80	2.32	1.49
DISTANCE/HOUSEHOLD.......:	16.55	22.85	22.74	33.69	46.15	55.16	36.74
DISTANCE/TRAVELER ....:	11.81	13.12	13.69	16.64	20.03	19.21	17.20
TRAVEL TIME/TR MIN......:	86.24	82.39	77.29	70.96	78.66	72.73	75.58
D-D SPEED MPH...........:	8.22	9.55	10.63	14.07	15.28	15.85	13.66
TRIP RATE/TR.............:	2.91	3.24	3.27	3.63	3.84	3.73	3.59
TRIP DISTANCE ....:	4.06	4.05	4.19	4.58	5.21	5.15	4.79
TRIP TIME MIN...........:	29.65	25.45	23.64	19.54	20.47	19.49	21.03

CLASSIFICATION BY CAR OWNERSHIP.

CARS PER HOUSEHOLD.......:	0	1	2	3 +
NO. HHS EXPANDED ('000)..:	116.19	183.91	159.61	75.88
% HHS TRAVELING..........:	74.40	97.90	99.10	100.00
HOUSEHOLD SIZE...........:	3.19	2.92	3.59	4.38
TRAVELERS PER HOUSEHOLD..:	1.57	1.80	2.28	3.30
DISTANCE/HOUSEHOLD.......:	15.22	28.90	44.12	64.51
DISTANCE/TRAVELER........:	9.68	16.07	19.32	19.70
TRAVEL TIME/TR MIN.......:	86.44	79.08	74.16	67.24
D-D SPEED MPH...........:	6.72	12.19	15.63	17.58
TRAVEL TIME/TR - CAR.....:	19.49	60.56	66.24	59.35
TRAVEL TIME/TR - BUS.....:	63.76	17.39	7.27	6.79
DISTANCE/TR - CAR........:	3.74	14.17	18.36	17.94
DISTANCE/TR - BUS........:	5.60	1.78	0.85	1.31
TRIP RATE/TR.............:	2.49	3.62	3.72	3.97
TRIP DISTANCE............:	3.88	4.44	5.19	4.96
TRIP TIME MIN...........:	34.68	21.84	19.93	16.92

CLASSIFICATION BY HH SIZE.

HOUSEHOLD SIZE ....:	1	2	3	4	5 +
NO. HHS EXPANDED ('000)..:	65.08	129.16	103.37	99.92	138.05
TRAVELERS/HH.............:	1.00	1.64	1.98	2.35	3.02
CARS PER HOUSEHOLD.......:	0.66	1.33	1.59	1.68	1.77
TRAVEL TIME/TR MIN.......:	76.44	72.72	73.67	80.18	75.16
TRAVEL DISTANCE/TR ......:	12.01	17.76	17.20	18.26	17.02
D-D SPEED MPH...........:	9.43	14.65	14.01	13.66	13.59
TRIP RATE/TR.............:	3.03	3.72	3.42	3.74	3.61
TRIP DISTANCE............:	3.97	4.78	5.03	4.89	4.71
TRIP TIME MIN...........:	25.23	19.56	21.54	21.46	20.81

(NOTE: DISTANCES ARE IN MILES)

BALTIMORE :TIME FREQUENCY DISTRIBUTION DATA (OBSERVED)

TRAVELERS CLASSIFIED BY HH INCOME AND CAR OWNERSHIP

#	GROUP MEAN TIME	INCOME GROUPS INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	CAR OWNERSHIP LEVEL 0 CAR	1 CAR	2 CARS	3+ CARS	# TOTAL
		TRAVELERS										
1	7.5	4	13	10	17	15	19	11	30	20	17	78
2	15	4	10	5	22	14	31	4	28	34	20	86
3	25	10	15	8	31	22	39	24	28	39	34	125
4	35	2	13	18	40	25	27	10	53	43	19	125
5	45	9	13	9	32	21	24	19	34	37	18	108
6	55	5	18	24	37	32	42	20	63	45	30	158
7	65	7	11	10	30	21	23	20	28	36	18	102
8	75	3	8	12	15	19	21	14	19	25	20	78
9	85	4	11	9	22	15	15	19	22	24	11	76
10	95	2	2	12	10	11	16	7	18	20	8	53
11	105	3	0	7	17	11	16	7	16	24	7	54
12	115	0	5	5	11	13	13	11	15	16	5	47
13	125	1	5	2	6	9	5	7	8	10	3	28
14	135	0	6	2	3	4	8	6	7	6	4	23
15	145	1	4	2	5	5	7	4	8	8	4	24
16	155	1	4	4	3	7	2	5	10	3	3	21
17	165	2	2	0	4	4	3	3	3	7	2	15
18	175	0	0	4	7	1	1	1	5	7	0	13
19	185	1	0	1	1	3	0	2	1	2	1	6
20	195	0	1	0	3	3	5	0	3	5	4	12
21	205	2	3	1	1	2	5	3	5	5	1	14
22	215	1	0	1	0	0	1	1	1	1	0	3
23	225	0	1	2	1	1	2	0	3	4	0	7
24	235	0	0	0	0	0	0	0	0	0	0	0
25	TOTAL	62	145	148	318	258	325	198	408	421	229	1256

BALTIMORE : TIME FREQUENCY DISTRIBUTION DATA (OBSERVED)

TRAVELERS CLASSIFIED BY HH INCOME AND CAR OWNERSHIP

#	MEAN TIME	INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	0 CAR	1 CAR	2 CARS	3+ CARS	TOTAL
	GROUP	INCOME GROUPS						CAR OWNERSHIP LEVEL				
		TRAVELERS										
1	11.25	8	23	15	39	29	50	15	58	54	37	164
2	30	12	28	26	71	47	66	34	81	82	53	250
3	50	14	31	33	69	53	66	39	97	82	48	266
4	70	10	19	22	45	40	44	34	47	61	38	180
5	90	6	13	21	32	26	31	26	40	44	19	129
6	110	3	5	12	28	24	29	18	31	40	12	101
7	130	1	11	4	9	13	13	13	15	16	7	51
8	150	2	8	6	8	12	9	9	18	11	7	45
9	170	2	2	4	11	5	4	4	8	14	2	28
10	190	1	1	1	4	6	5	2	4	7	5	18
11	210	3	3	2	1	2	6	4	6	6	1	17
12	230	0	1	2	1	1	2	0	3	4	0	7
13	TOTAL	62	145	148	318	258	325	198	408	421	229	1256

TIME FREQUENCY DISTRIBUTION STATISTICS : BALTIMORE

TRAVELERS CLASSIFIED BY HH INCOME AND CAR OWNERSHIP

GROUP	INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	0 CAR	1 CAR	2 CARS	3+ CARS	TOTAL
100% OF	**TRAVELERS**										
TR. OBSERVED	62	145	148	318	258	325	198	408	421	229	1256
MAX. TT (MIN)	230	230	230	230	230	230	210	230	230	210	230
AVG. TIME/TR.	69.52	67.03	71.07	64.68	70.92	65.52	74.64	66.06	69.88	59.2	67.44
S.D. OF TIME	52.67	49.87	47.5	44.25	47.09	47.86	45.53	47.78	49.3	42.58	47.24
S.E. OF TIME	6.69	4.14	3.9	2.48	2.93	2.65	3.24	2.37	2.4	2.81	1.33
COEFF. OF VAR	.76	.74	.67	.68	.66	.73	.61	.72	.71	.72	.7
ALPHA	1.74	1.81	2.24	2.14	2.27	1.87	2.69	1.91	2.01	1.93	2.04
BETA	.03	.03	.03	.03	.03	.03	.04	.03	.03	.03	.03
GAMMA	.92	.93	1.13	1.07	1.14	.95	1.53	.97	1	.97	1.02

APPENDIX 4

WASHINGTON, D.C. (NORTH): URBAN TRAVEL

CLASSIFICATION BY HH INCOME.

GROUP NUMBER............:	1	2	3	4	5	TOT/AVG.
NO. HHS EXPANDED ('000)..:	3.99	10.26	15.24	19.06	12.51	61.06
HOUSEHOLD INCOME $('000).:	3.00	6.00	10.00	16.00	25.00	13.82
TRAVELERS/HOUSEHOLD......:	1.29	1.30	1.80	2.27	2.69	2.05
CARS PER HOUSEHOLD.......:	0.52	0.71	1.22	1.62	1.83	1.34
DISTANCE/HOUSEHOLD.......:	5.42	20.08	29.43	41.64	47.87	34.53
DISTANCE/TRAVELER........:	11.94	13.09	16.37	18.38	17.80	16.85
TRAVEL TIME/TR MIN.......:	69.65	68.80	69.01	69.92	71.61	70.01
D-D SPEED MPH...........:	10.25	11.42	14.23	15.77	14.91	14.44
TRIP RATE/TRAVELER.......:	2.78	2.85	2.97	3.12	3.29	3.09
TRIP DISTANCE............:	4.30	4.59	5.51	5.88	5.41	5.46
TRIP TIME MIN............:	25.08	24.13	23.22	22.38	21.78	22.70

CLASSIFICATION BY CAR OWNERSHIP.

CARS PER HOUSEHOLD.......:	0	1	2	3 +
TRAVELERS/HOUSEHOLD......:	1.25	1.74	2.55	3.44
DISTANCE/HOUSEHOLD ......:	11.07	27.20	48.15	66.51
DISTANCE/TRAVELER........:	8.89	15.67	18.91	19.36
TRAVEL TIME/TR MIN.......:	72.86	69.47	69.79	70.59
D-D SPEED MPH............:	7.32	13.53	16.26	16.46
TRIP RATE/TR.............:	2.33	3.05	3.24	3.32
TRIP DISTANCE............:	3.82	5.13	5.84	5.83
TRIP TIME MIN............:	31.32	22.75	21.56	21.26

CLASSIFICATION BY HH SIZE.

HOUSEHOLD SIZE...........:	1	2	3-4	5 +
TRAVELERS/HOUSEHOLD......:	1.00	1.77	2.40	3.01

(NOTE: DISTANCES ARE IN MILES)

Cont.

APPENDIX 4

LONDON : URBAN TRAVEL

CLASSIFICATION BY CAR OWNERSHIP

CARS PER HOUSEHOLD.......:	0	1	2 +	AVG.
DISTANCE/HOUSEHOLD.......:	16.29	28.28	43.34	25.70
DISTANCE/TRAVELER........:	10.15	14.14	15.76	13.18
TRAVEL TIME/TR MIN.......:	82.78	78.49	79.76	80.02
D-D SPEED MPH...........:	7.36	10.81	11.85	9.88
TRIP RATE/TR.............:	2.26	3.01	3.37	2.85
TRIP DISTANCE............:	4.49	4.70	4.68	4.62
TRIP TIME MIN............:	36.62	26.10	23.63	28.12

(NOTE: DISTANCES ARE IN MILES)

READING : URBAN & INTERURBAN TRAVEL

CLASSIFICATION BY CAR OWNERSHIP

CARS PER HOUSEHOLD.......:	0	1	2 +	AVG.
DISTANCE/HOUSEHOLD.......:	25.12	40.71	65.81	40.59
DISTANCE/TRAVELER........:	17.64	21.33	26.89	21.83
TRAVEL TIME MIN..........:	78.70	74.25	86.76	77.68
D-D SPEED MPH...........:	13.45	17.22	18.59	16.86

(NOTE: DISTANCES ARE IN MILES)

DOOR-TO-DOOR SPEED BY MODE

CITY	BALTIMORE	WASHINGTON	LONDON	READING
CAR	15.94		12.12	18.81
BUS	6.36		5.30	7.87
RAIL	--	N/A	11.58	31.97
TAXI	5.84		8.00	--
MOTORCYCLE	15.14		14.31	16.91
AVERAGE	13.66	14.40	9.88	16.86

(NOTE: SPEEDS ARE IN MILES PER HOUR)

WASHINGTON D.C. :TIME FREQUENCY DISTRIBUTION DATA (OBSERVED)

TRAVELERS CLASSIFIED BY CAR OWNERSHIP

		NORTH CORRIDOR					SOUTH CORRIDOR					NORTH & SOUTH				#
	GROUP	0	1	2	3+	ALL	0	1	2	3+	ALL	0	1	2	3+	TOTAL
#	MEAN TIME	TRAVELERS														
1	7.5	7	62	78	16	163	9	50	65	15	139	16	112	143	31	302
2	15	10	108	162	27	307	17	115	147	32	311	27	223	309	59	618
3	25	29	200	260	55	544	24	149	169	46	388	53	349	429	101	932
4	35	17	133	182	47	379	17	79	111	26	233	34	212	293	73	612
5	45	27	119	173	23	342	20	78	111	29	238	47	197	284	52	580
6	55	50	163	226	68	507	14	136	172	50	372	64	299	398	118	879
7	65	10	97	111	25	243	9	55	82	15	161	19	152	193	40	404
8	75	19	90	138	34	281	13	68	92	29	202	32	158	230	63	483
9	85	21	93	131	31	276	11	84	107	19	221	32	177	238	50	497
10	95	14	52	89	20	175	7	47	51	13	118	21	99	140	33	293
11	105	10	62	89	25	186	8	65	62	19	154	18	127	151	44	340
12	115	11	49	77	13	150	5	50	60	16	131	16	99	137	29	281
13	125	3	39	46	8	96	2	15	29	7	53	5	54	75	15	149
14	135	6	30	44	11	91	1	33	32	7	73	7	63	76	18	164
15	145	5	20	34	9	68	2	27	28	6	63	7	47	62	15	131
16	155	1	21	22	6	50	1	5	22	6	34	2	26	44	12	84
17	165	5	15	17	8	45	1	12	23	15	51	6	27	40	23	96
18	175	4	15	16	4	39	1	8	15	4	28	5	23	31	8	67
19	185	0	5	12	5	22	0	4	15	0	19	0	9	27	5	41
20	195	1	9	8	1	19	0	6	8	1	15	1	15	16	2	34
21	205	1	4	5	2	12	0	5	6	5	16	1	9	11	7	28
22	215	1	5	6	0	12	0	2	4	0	6	1	7	10	0	18
23	225	0	4	6	0	10	0	1	5	0	6	0	5	11	0	16
24	235	0	3	1	0	4	0	1	1	0	2	0	4	2	0	6
25	TOTAL	252	1398	1933	438	4021	162	1095	1417	360	3034	414	2493	3350	798	7055

Cont.

APPENDIX 5

TIME FREQUENCY DISTRIBUTION STATISTICS : WASHINGTON D.C.

TRAVELERS CLASSIFIED BY CAR OWNERSHIP

GROUP	NORTH CORRIDOR 0	1	2	3+	ALL	SOUTH CORRIDOR 0	1	2	3+	ALL	NORTH & SOUTH 0	1	2	3+	TOTAL
100% OF TRAVELERS															
TR. OBSERVED	252	1398	1933	438	4021	162	1095	1417	360	3034	414	2493	3350	798	7055
MAX. TT (MIN)	235	235	235	235	235	175	235	235	205	235	215	235	235	205	235
AVG. TIME/TR.	68.24	64.71	64.55	67.17	65.12	55.14	64.53	66.66	68.22	65.46	63.12	64.63	65.44	67.64	65.27
S.D. OF TIME	41.25	44.88	43.64	43.22	43.89	36.29	44.03	46.81	46.97	45.4	39.86	44.5	45.02	44.92	44.54
S.E. OF TIME	2.6	1.2	.99	2.07	.69	2.85	1.33	1.24	2.48	.82	1.96	.89	.78	1.59	.53
COEFF. OF VAR	.6	.69	.68	.64	.67	.66	.68	.7	.69	.69	.63	.69	.69	.66	.68
ALPHA	2.74	2.08	2.19	2.42	2.2	2.31	2.15	2.03	2.11	2.08	2.51	2.11	2.11	2.27	2.15
BETA	.04	.03	.03	.04	.03	.04	.03	.03	.03	.03	.04	.03	.03	.03	.03
GAMMA	1.59	1.04	1.09	1.25	1.1	1.17	1.07	1.01	1.05	1.04	1.34	1.05	1.05	1.14	1.07
99% OF TRAVELERS															
TR. OBSERVED	250	1386	1915	435	3983	161	1086	1407	360	3004	411	2477	3327	791	6987
MAX. TT (MIN)	195	205	195	185	195	165	195	205	205	195	175	205	205	195	195
AVG. TIME/TR.	67.11	63.34	63.12	66.24	63.68	54.39	63.3	65.56	68.22	63.99	62.08	63.61	64.36	66.43	63.81
S.D. OF TIME	39.4	42.56	41.25	41.89	41.5	35.14	42.07	45.1	46.97	43.14	38.09	42.77	43.25	43.21	42.21
S.E. OF TIME	2.49	1.14	.94	2.01	.66	2.77	1.28	1.2	2.48	.79	1.88	.86	.75	1.54	.5
COEFF. OF VAR	.59	.67	.65	.63	.65	.65	.66	.69	.69	.67	.61	.67	.67	.65	.66
ALPHA	2.9	2.21	2.34	2.5	2.35	2.4	2.26	2.11	2.11	2.2	2.66	2.21	2.21	2.36	2.29
BETA	.04	.03	.04	.04	.04	.04	.04	.03	.03	.03	.04	.03	.03	.04	.04
GAMMA	1.83	1.11	1.2	1.33	1.21	1.24	1.14	1.05	1.05	1.1	1.49	1.11	1.11	1.21	1.16
95% OF TRAVELERS															
TR. OBSERVED	240	1338	1840	418	3858	154	1051	1363	350	2891	398	2394	3202	776	6749
MAX. TT (MIN)	155	155	145	155	155	115	145	165	165	155	145	155	155	165	155
AVG. TIME/TR.	62.74	59.18	58.74	61.89	60.03	50.41	59.64	61.66	64.68	59.65	58.64	59.58	59.88	64.21	59.87
S.D. OF TIME	33.68	37.03	35.69	36.58	36.75	30.23	37.51	40.14	42.56	37.82	33.51	37.45	37.45	40.54	37.21
S.E. OF TIME	2.17	1.01	.83	1.79	.59	2.44	1.16	1.09	2.28	.7	1.68	.77	.66	1.46	.45
COEFF. OF VAR	.54	.63	.61	.59	.61	.6	.63	.65	.66	.63	.57	.63	.63	.63	.62
ALPHA	3.47	2.55	2.71	2.86	2.67	2.78	2.53	2.36	2.31	2.49	3.06	2.53	2.56	2.51	2.59
BETA	.06	.04	.05	.05	.04	.06	.04	.04	.04	.04	.05	.04	.04	.04	.04
GAMMA	3.22	1.38	1.56	1.77	1.51	1.65	1.36	1.21	1.17	1.32	2.12	1.36	1.38	1.34	1.42
90% OF TRAVELERS															
TR. OBSERVED	228	1267	1762	403	3649	149	991	1290	329	2794	379	2258	3020	726	6370
MAX. TT (MIN)	125	125	125	135	125	105	125	135	145	135	115	125	125	135	125
AVG. TIME/TR.	58.63	54.44	55.17	58.65	55.28	48.24	54.8	56.42	58.46	56.57	54.76	54.6	54.86	57.85	54.93
S.D. OF TIME	29.2	31.95	32.07	33.06	31.74	28.27	32.87	34.43	35.77	34.57	29.32	32.35	32.23	33.5	32.08
S.E. OF TIME	1.93	.9	.76	1.65	.53	2.32	1.04	.96	1.97	.65	1.51	.68	.59	1.24	.4
COEFF. OF VAR	.5	.59	.58	.56	.57	.59	.6	.61	.61	.61	.54	.59	.59	.58	.58
ALPHA	4.03	2.9	2.96	3.15	3.03	2.91	2.78	2.69	2.67	2.68	3.49	2.85	2.9	2.98	2.93
BETA	.07	.05	.05	.05	.05	.06	.05	.05	.05	.05	.06	.05	.05	.05	.05
GAMMA	6.24	1.83	1.93	2.3	2.06	1.85	1.65	1.53	1.51	1.52	3.28	1.75	1.82	1.97	1.88

Cont.

WASHINGTON D.C. :TIME FREQUENCY DISTRIBUTION DATA (OBSERVED)

TRAVELERS CLASSIFIED BY CAR OWNERSHIP

#	MEAN TIME	NORTH CORRIDOR 0	1	2	3+	ALL	SOUTH CORRIDOR 0	1	2	3+	ALL	NORTH & SOUTH 0	1	2	3+	TOTAL
	TRAVELERS															
1	11.25	17	170	240	43	470	26	165	212	47	450	43	335	452	90	920
2	30	46	333	442	102	923	41	228	280	72	621	87	561	722	174	1544
3	50	77	282	399	91	849	34	214	283	79	610	111	496	682	170	1459
4	70	29	187	249	59	524	22	123	174	44	363	51	310	423	103	887
5	90	35	145	220	51	451	18	131	158	32	339	53	276	378	83	790
6	110	21	111	166	38	336	13	115	122	35	285	34	226	288	73	621
7	130	9	69	90	19	187	3	48	61	14	126	12	117	151	33	313
8	150	6	41	56	15	118	3	32	50	12	97	9	73	106	27	215
9	170	9	30	33	12	84	2	20	38	19	79	11	50	71	31	163
10	190	1	14	20	6	41	0	10	23	1	34	1	24	43	7	75
11	210	2	9	11	2	24	0	7	10	5	22	2	16	21	7	46
12	230	0	7	7	0	14	0	2	6	0	8	0	9	13	0	22
13	TOTAL	252	1398	1933	438	4021	162	1095	1417	360	3034	414	2493	3350	798	7055

TIME FREQUENCY DISTRIBUTION STATISTICS : WASHINGTON D.C.

TRAVELERS CLASSIFIED BY CAR OWNERSHIP

GROUP	NORTH CORRIDOR 0	1	2	3+	ALL	SOUTH CORRIDOR 0	1	2	3+	ALL	NORTH & SOUTH 0	1	2	3+	TOTAL
100% OF TRAVELERS															
TR. OBSERVED	252	1398	1933	438	4021	162	1095	1417	360	3034	414	2493	3350	798	7055
MAX. TT (MIN)	230	230	230	210	230	230	230	230	210	230	210	230	230	210	230
AVG. TIME/TR.	67.94	64.9	64.58	66.93	65.16	55.51	64.58	66.69	68.16	65.51	63.08	64.76	65.47	67.48	65.31
S.D. OF TIME	41.1	44.77	43.69	43.71	43.91	36.37	44.17	47.06	47.39	45.62	39.74	44.5	45.15	45.38	44.65
S.E. OF TIME	2.59	1.2	.99	2.09	.69	2.86	1.33	1.25	2.5	.83	1.95	.89	.78	1.61	.53
COEFF. OF VAR	.6	.69	.68	.65	.67	.66	.68	.71	.7	.7	.63	.69	.69	.67	.68
ALPHA	2.73	2.1	2.19	2.34	2.2	2.33	2.14	2.01	2.07	2.06	2.52	2.12	2.1	2.21	2.14
BETA	.04	.03	.03	.04	.03	.04	.03	.03	.03	.03	.04	.03	.03	.03	.03
GAMMA	1.59	1.05	1.09	1.2	1.1	1.19	1.07	1	1.03	1.03	1.35	1.06	1.05	1.11	1.07

APPENDIX 6

LONDON : TIME FREQUENCY DISTRIBUTION DATA (OBSERVED)

TRAVELERS CLASSIFIED BY HH INCOME

	GROUP	INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	INC.7	INC.8	INC.9	INC.10	INC.11	INC.12	TOTAL
	HHS UNEXPAN.	206	712	395	487	534	646	1105	953	730	656	441	294	7159
	HHS EXP.(00)	746	2557	1421	1747	1989	2375	4048	3487	2658	2408	1637	1094	26159
	EXP. FACTOR	362	359	360	359	372	368	366	366	364	367	371	372	365
#	MEAN TIME	TRAVELERS												
1	5	0	2	8	8	10	11	35	30	30	23	21	8	188
2	15	4	15	27	44	39	42	74	99	62	69	45	25	546
3	25	6	33	42	36	65	73	132	142	113	90	57	44	834
4	35	5	45	43	52	56	104	192	152	155	127	73	45	1049
5	45	7	44	26	36	59	81	167	143	119	107	77	64	934
6	55	7	33	51	32	58	73	149	141	134	107	72	76	937
7	65	7	47	44	48	67	94	173	180	134	151	93	74	1115
8	75	6	26	17	39	72	70	148	134	116	105	75	62	873
9	85	10	22	20	33	38	53	118	110	89	107	82	49	732
10	95	4	19	20	28	43	61	113	104	98	84	69	55	701
11	105	5	14	10	16	32	48	98	77	70	84	71	47	575
12	115	0	16	12	12	28	36	66	68	80	61	48	36	466
13	125	1	6	10	18	35	28	75	77	50	66	62	35	466
14	135	1	6	4	14	10	37	51	54	47	50	64	34	375
15	145	2	3	1	7	10	21	29	42	40	34	33	35	260
16	155	1	8	3	21	13	21	48	39	38	39	21	21	276
17	165	0	2	3	9	12	20	28	29	19	20	29	18	190
18	175	0	5	4	5	11	6	19	22	20	23	9	11	135
19	185	4	6	2	4	4	14	16	26	18	13	20	13	140
20	195	2	8	6	3	6	4	15	12	15	16	9	15	109
21	205	1	3	1	1	3	3	14	13	11	8	5	7	72
22	215	1	6	0	2	2	5	6	8	9	11	6	4	60
23	225	0	2	2	1	5	0	5	11	10	5	5	4	50
24	235	0	1	1	1	3	2	5	2	4	5	9	3	36
25	245	1	3	0	1	4	1	2	2	3	5	1	2	24
26	255	0	3	0	4	2	3	6	3	2	1	2	1	27
27	265	0	0	1	0	1	2	3	6	5	1	4	1	23
28	275	1	0	1	0	0	1	0	0	1	2	2	1	8
29	285	0	0	2	1	1	1	4	3	2	2	0	1	17
30	295	0	2	0	0	1	0	0	3	2	2	1	0	11
31	305	0	0	0	0	0	1	1	1	5	2	0	0	10
32	315	0	1	0	1	1	0	3	3	1	0	3	0	12
33	325	0	1	0	0	0	0	1	1	3	1	3	0	10
34	335	0	0	0	0	0	1	1	1	1	0	1	0	4
35	345	0	0	1	0	1	0	0	0	0	1	1	1	5
36	355	0	0	0	0	0	0	1	0	2	0	2	0	5
37	365	0	0	0	0	0	0	1	0	0	0	0	2	2
38	375	0	1	0	0	0	0	0	0	1	0	0	0	2
39	385	0	0	0	0	0	0	0	0	0	0	0	0	0
40	395	0	0	0	0	0	0	0	0	0	0	1	1	2
41	405	0	0	0	0	0	0	1	1	0	0	0	0	2
42	415	0	0	0	1	0	0	0	0	0	0	0	0	1
43	425	0	0	0	0	1	0	0	0	0	0	0	0	1
44	435	0	0	0	0	0	0	0	0	0	0	0	0	0
45	445	0	0	0	0	0	0	0	0	0	0	1	0	1
46	455	0	1	0	0	0	0	0	0	0	0	0	0	1
47	465	0	0	0	0	0	0	0	0	0	0	0	0	0
48	475	0	0	1	0	0	0	0	0	0	0	0	0	1
49	485	0	0	2	0	0	0	0	0	0	0	0	0	2
50	495	0	0	0	0	0	0	1	1	1	0	0	1	4
51	TOTAL	76	384	365	478	693	917	1801	1740	1510	1422	1077	796	11294

Cont.

APPENDIX 6

TIME FREQUENCY DISTRIBUTION STATISTICS : LONDON

TRAVELERS CLASSIFIED BY HH INCOME

GROUP	INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	INC.7	INC.8	INC.9	INC.10	INC.11	INC.12	TOTAL
100% OF TRAVELERS													
TR. OBSERVED	76	384	365	478	693	917	1801	1740	1510	1422	1077	796	11294
MAX. TT (MIN)	275	455	485	495	495	335	495	495	495	345	495	495	495
AVG. TIME/TR.	85.79	82.5	71.41	77.07	79.39	78.59	79.78	81.11	83.56	83.69	91.89	91.75	82.54
S.D. OF TIME	57.78	63.26	63.14	54.67	54.36	49.85	53.2	54.79	57.4	52.42	58.54	56.62	55.24
S.E. OF TIME	6.63	3.23	3.3	2.5	2.06	1.65	1.25	1.31	1.48	1.39	1.78	2.01	.52
COEFF. OF VAR	.67	.77	.88	.71	.68	.63	.67	.68	.69	.63	.64	.62	.67
ALPHA	2.2	1.7	1.28	1.99	2.13	2.49	2.25	2.19	2.12	2.55	2.46	2.63	2.23
BETA	.03	.02	.02	.03	.03	.03	.03	.03	.03	.03	.03	.03	.03
GAMMA	1.1	.91	.9	.99	1.06	1.32	1.13	1.1	1.06	1.38	1.3	1.46	1.12
99% OF TRAVELERS													
TR. OBSERVED	76	381	362	475	687	908	1784	1726	1496	1410	1068	789	11193
MAX. TT (MIN)	275	315	345	255	255	245	255	265	295	245	315	265	265
AVG. TIME/TR.	85.79	80.12	68.01	75.42	77.27	76.62	77.48	79.14	81.18	81.91	89.66	89.36	80.29
S.D. OF TIME	57.78	57.3	51.08	50.53	49.38	45.91	47.58	50.14	51.88	48.91	53.38	50.45	49.86
S.E. OF TIME	6.63	2.94	2.68	2.32	1.88	1.52	1.13	1.21	1.34	1.3	1.63	1.8	.47
COEFF. OF VAR	.67	.72	.75	.67	.64	.6	.61	.63	.64	.6	.6	.56	.62
ALPHA	2.2	1.96	1.77	2.23	2.45	2.78	2.65	2.49	2.45	2.81	2.82	3.14	2.59
BETA	.03	.02	.03	.03	.03	.04	.03	.03	.03	.03	.03	.04	.03
GAMMA	1.1	.98	.92	1.12	1.28	1.66	1.49	1.32	1.28	1.68	1.71	2.28	1.42
95% OF TRAVELERS													
TR. OBSERVED	73	369	347	458	662	873	1715	1669	1447	1360	1030	767	10792
MAX. TT (MIN)	205	215	185	175	185	165	175	185	195	185	195	195	185
AVG. TIME/TR.	79.25	74.35	60.82	70.17	71.83	71.87	72.22	74.34	76.06	77.1	84.08	85.52	75.17
S.D. OF TIME	48.5	48.02	37.2	43.01	41.23	39.92	40.25	43.43	44.27	42.59	45.19	45.61	42.76
S.E. OF TIME	5.68	2.5	2	2.01	1.6	1.35	.97	1.06	1.16	1.15	1.41	1.65	.41
COEFF. OF VAR	.61	.65	.61	.61	.57	.56	.56	.58	.58	.55	.54	.53	.57
ALPHA	2.67	2.4	2.67	2.66	3.03	3.24	3.22	2.93	2.95	3.28	3.46	3.52	3.09
BETA	.03	.03	.04	.04	.04	.05	.04	.04	.04	.04	.04	.04	.04
GAMMA	1.51	1.24	1.51	1.5	2.07	2.53	2.47	1.88	1.92	2.62	3.19	3.38	2.18
90% OF TRAVELERS													
TR. OBSERVED	70	346	330	444	635	832	1668	1592	1375	1304	992	728	10327
MAX. TT (MIN)	185	175	125	155	155	145	155	155	155	155	165	165	155
AVG. TIME/TR.	74.14	66.07	55.73	67.07	67.57	67.54	69.49	69.49	70.67	72.94	80.21	80.14	70.72
S.D. OF TIME	42.55	36.71	30.15	39.9	36.39	35.64	37.33	38.26	38.36	38.35	41.39	40.22	38.06
S.E. OF TIME	5.09	1.97	1.66	1.89	1.44	1.24	.91	.96	1.03	1.06	1.31	1.49	.37
COEFF. OF VAR	.57	.56	.54	.59	.54	.53	.54	.55	.54	.53	.52	.5	.54
ALPHA	3.04	3.24	3.42	2.83	3.45	3.59	3.47	3.3	3.39	3.62	3.76	3.97	3.45
BETA	.04	.05	.06	.04	.05	.05	.05	.05	.05	.05	.05	.05	.05
GAMMA	2.07	2.52	3.04	1.71	3.14	3.68	3.2	2.68	2.96	3.79	4.45	5.78	3.15

Cont.

LONDON : TIME FREQUENCY DISTRIBUTION DATA (OBSERVED)

TRAVELERS CLASSIFIED BY HH INCOME

#	GROUP	INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	INC.7	INC.8	INC.9	INC.10	INC.11	INC.12	TOTAL
	HHS UNEXPAN.	206	712	395	487	534	646	1105	953	730	656	441	294	7159
	HHS EXP.(00)	746	2557	1421	1747	1989	2375	4048	3487	2658	2408	1637	1094	26159
	EXP. FACTOR	362	359	360	359	372	368	366	366	364	367	371	372	365
#	MEAN TIME	TRAVELERS												
1	10	4	17	35	52	49	53	109	129	92	92	66	33	734
2	30	11	78	85	88	121	177	324	294	268	217	130	89	1883
3	50	14	77	77	68	117	154	316	284	253	214	149	140	1871
4	70	13	73	61	87	139	164	321	314	250	256	168	136	1988
5	90	14	41	40	61	81	114	231	214	187	191	151	104	1433
6	110	5	30	22	28	60	84	164	145	150	145	119	83	1041
7	130	2	12	14	32	45	65	126	131	97	116	126	69	841
8	150	3	11	4	28	23	42	77	81	78	73	54	56	536
9	170	0	7	7	14	23	26	47	51	39	43	38	29	325
10	190	6	14	8	7	10	18	31	38	33	29	29	28	249
11	210	2	9	1	3	5	8	20	21	20	19	11	11	132
12	230	0	3	3	2	8	2	10	13	14	10	14	7	86
13	TOTAL	74	372	357	470	681	907	1776	1715	1481	1405	1055	785	11119

TIME FREQUENCY DISTRIBUTION STATISTICS : LONDON

TRAVELERS CLASSIFIED BY HH INCOME

GROUP	INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	INC.7	INC.8	INC.9	INC.10	INC.11	INC.12	TOTAL
100% OF TRAVELERS													
TR. OBSERVED	74	372	357	470	681	907	1776	1715	1481	1405	1055	785	11119
MAX. TT (MIN)	210	230	230	230	230	230	230	230	230	230	230	230	230
AVG. TIME/TR.	81.89	75.54	64.62	73.15	75.76	76.35	76.7	78.12	79.05	81.37	87.61	88.6	79.13
S.D. OF TIME	51.38	49.48	44.07	47.65	47.1	45.9	46.41	48.58	48.76	48.12	49.66	49.42	48.17
S.E. OF TIME	5.97	2.57	2.33	2.2	1.8	1.52	1.1	1.17	1.27	1.28	1.53	1.76	.46
COEFF. OF VAR	.63	.65	.68	.65	.62	.6	.61	.62	.62	.59	.57	.56	.61
ALPHA	2.54	2.33	2.15	2.36	2.59	2.77	2.73	2.59	2.63	2.86	3.11	3.21	2.7
BETA	.03	.03	.03	.03	.03	.04	.04	.03	.03	.04	.04	.04	.03
GAMMA	1.37	1.19	1.07	1.21	1.42	1.63	1.58	1.41	1.46	1.76	2.22	2.46	1.54

APPENDIX 7

LONDON : TIME FREQUENCY DISTRIBUTION DATA (OBSERVED)

TRAVELERS CLASSIFIED BY CAR OWNERSHIP

GROUP	0 CAR	1 CAR	2+ CARS	TOTAL
HHS UNEXPAN.	3235	3201	803	7159
HHS EXP.(00)	11677	11809	2939	26159
EXP. FACTOR	361	369	366	365

#	MEAN TIME	TRAVELERS			
1	5	44	109	35	188
2	15	111	325	111	546
3	25	182	499	150	834
4	35	257	588	202	1049
5	45	268	501	163	934
6	55	330	460	146	937
7	65	403	531	180	1115
8	75	319	404	151	873
9	85	258	368	106	732
10	95	254	320	127	701
11	105	174	305	95	575
12	115	180	213	73	466
13	125	140	245	80	466
14	135	98	211	64	375
15	145	68	141	50	260
16	155	80	144	50	276
17	165	59	104	26	190
18	175	43	63	29	135
19	185	42	75	22	140
20	195	35	51	23	109
21	205	24	34	14	72
22	215	22	24	14	60
23	225	12	29	9	50
24	235	11	17	8	36
25	245	9	11	4	24
26	255	6	17	4	27
27	265	5	12	5	23
28	275	1	4	4	8
29	285	6	9	2	17
30	295	2	8	0	11
31	305	1	7	2	10
32	315	6	6	1	12
33	325	1	8	1	10
34	335	0	2	2	4
35	345	1	2	2	5
36	355	2	1	2	5
37	365	0	1	2	2
38	375	1	1	0	2
39	385	0	0	0	0
40	395	0	1	1	2
41	405	0	2	0	2
42	415	0	0	1	1
43	425	1	0	0	1
44	435	0	0	0	0
45	445	0	1	0	1
46	455	1	0	0	1
47	465	0	0	0	0
48	475	0	1	0	1
49	485	2	0	0	2
50	495	2	2	0	4
51	TOTAL	3461	5857	1961	11294

Cont.

APPENDIX 7

TIME FREQUENCY DISTRIBUTION STATISTICS : LONDON

TRAVELERS CLASSIFIED BY CAR OWNERSHIP

GROUP	0 CAR	1 CAR	2+ CARS	TOTAL
100% OF TRAVELERS				
TR. OBSERVED	3461	5857	1961	11294
MAX. TT (MIN)	495	495	415	495
AVG. TIME/TR.	85.23	80.98	82.46	82.54
S.D. OF TIME	53.04	55.97	57.07	55.24
S.E. OF TIME	.9	.73	1.29	.52
COEFF. OF VAR	.62	.69	.69	.67
ALPHA	2.58	2.09	2.09	2.23
BETA	.03	.03	.03	.03
GAMMA	1.41	1.04	1.04	1.12
99% OF TRAVELERS				
TR. OBSERVED	3429	5801	1945	11193
MAX. TT (MIN)	255	265	275	265
AVG. TIME/TR.	82.91	78.62	80.34	80.29
S.D. OF TIME	46.97	50.55	52.2	49.86
S.E. OF TIME	.8	.66	1.18	.47
COEFF. OF VAR	.57	.64	.65	.62
ALPHA	3.12	2.42	2.37	2.59
BETA	.04	.03	.03	.03
GAMMA	2.23	1.26	1.22	1.42
95% OF TRAVELERS				
TR. OBSERVED	3310	5606	1883	10792
MAX. TT (MIN)	185	185	195	185
AVG. TIME/TR.	78.19	73.72	75.44	75.17
S.D. OF TIME	40.39	43.72	45.22	42.76
S.E. OF TIME	.7	.58	1.04	.41
COEFF. OF VAR	.52	.59	.6	.57
ALPHA	3.75	2.84	2.78	3.09
BETA	.05	.04	.04	.04
GAMMA	4.41	1.74	1.65	2.18
90% OF TRAVELERS				
TR. OBSERVED	3166	5364	1783	10327
MAX. TT (MIN)	155	155	155	155
AVG. TIME/TR.	73.84	69.2	69.62	70.72
S.D. OF TIME	35.6	39.02	38.92	38.06
S.E. OF TIME	.63	.53	.92	.37
COEFF. OF VAR	.48	.56	.56	.54
ALPHA	4.3	3.15	3.2	3.45
BETA	.06	.05	.05	.05
GAMMA	8.89	2.3	2.42	3.15

Cont.

APPENDIX 7

LONDON : TIME FREQUENCY DISTRIBUTION DATA (OBSERVED)

TRAVELERS CLASSIFIED BY CAR OWNERSHIP

GROUP	0 CAR	1 CAR	2+ CARS	TOTAL
HHS UNEXPAN.	3235	3201	803	7159
HHS EXP.(00)	11677	11809	2939	26159
EXP. FACTOR	361	369	366	365

#	MEAN TIME	TRAVELERS			
1	10	155	434	146	734
2	30	439	1087	352	1883
3	50	598	961	309	1871
4	70	722	935	331	1988
5	90	512	688	233	1433
6	110	354	518	168	1041
7	130	238	456	144	841
8	150	148	285	100	536
9	170	102	167	55	325
10	190	77	126	45	249
11	210	46	58	28	132
12	230	23	46	17	86
13	TOTAL	3414	5761	1928	11119

TIME FREQUENCY DISTRIBUTION STATISTICS : LONDON

TRAVELERS CLASSIFIED BY CAR OWNERSHIP

GROUP	0 CAR	1 CAR	2+ CARS	TOTAL
100% OF TRAVELERS				
TR. OBSERVED	3414	5761	1928	11119
MAX. TT (MIN)	230	230	230	230
AVG. TIME/TR.	82.09	77.5	78.58	79.13
S.D. OF TIME	45.92	48.82	49.77	48.17
S.E. OF TIME	.79	.64	1.13	.46
COEFF. OF VAR	.56	.63	.63	.61
ALPHA	3.2	2.52	2.49	2.7
BETA	.04	.03	.03	.03
GAMMA	2.41	1.35	1.32	1.54

APPENDIX 8

READING :TIME FREQUENCY DISTRIBUTION DATA (OBSERVED)

TRAVELERS CLASSIFIED BY HH INCOME

GROUP	INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	TOTAL
HHS UNEXPAN.	169	169	248	404	243	100	1333
HHS EXP.(00)	7155	7580	10586	16975	10702	4028	57023
EXP. FACTOR	42.34	44.85	42.69	42.02	44.04	40.28	42.78

#	MEAN TIME	TRAVELERS						
1	5	1	1	6	13	3	3	26
2	15	8	6	14	43	24	19	113
3	25	12	20	31	64	41	21	188
4	35	14	27	45	78	44	15	223
5	45	7	21	37	85	50	24	224
6	55	5	19	28	56	49	13	171
7	65	11	6	45	81	60	17	218
8	75	3	4	18	49	34	14	122
9	85	5	16	19	39	34	12	126
10	95	7	8	30	28	29	12	113
11	105	1	5	6	23	15	5	56
12	115	2	1	8	16	21	8	56
13	125	2	4	7	25	11	9	57
14	135	2	5	6	16	12	1	43
15	145	3	3	6	9	3	1	25
16	155	0	0	2	11	12	6	31
17	165	1	1	1	6	5	3	16
18	175	0	0	0	8	11	5	25
19	185	1	0	1	11	6	8	25
20	195	0	1	1	9	6	3	19
21	205	2	0	0	2	3	4	11
22	215	0	1	3	7	4	4	17
23	225	0	0	1	6	2	4	13
24	235	0	0	1	1	3	0	5
25	245	0	0	2	2	2	1	6
26	255	1	0	0	5	0	1	7
27	265	0	0	0	0	2	1	3
28	275	0	3	0	2	2	3	10
29	285	0	0	0	2	1	0	4
30	295	0	1	0	1	0	0	2
31	305	0	0	0	0	1	5	6
32	315	0	0	1	1	0	0	2
33	325	0	0	0	0	0	0	0
34	335	0	0	0	1	0	0	1
35	345	0	0	0	1	0	1	2
36	355	0	1	0	3	0	0	4
37	365	0	0	0	0	1	2	2
38	375	0	0	0	0	0	1	1
39	385	0	0	0	0	0	0	0
40	395	0	0	0	0	0	0	0
41	405	0	0	0	0	0	0	0
42	415	0	0	0	0	0	0	0
43	425	0	0	0	1	0	0	1
44	435	0	0	0	1	0	0	1
45	445	0	0	0	0	0	0	0
46	455	0	0	0	0	0	0	0
47	465	0	0	0	0	0	0	0
48	475	0	0	0	0	0	0	0
49	485	0	0	0	1	0	0	1
50	495	1	2	4	3	0	0	10
51	TOTAL	89	156	323	710	491	226	1986

Cont.

APPENDIX 8

TIME FREQUENCY DISTRIBUTION STATISTICS : READING

TRAVELERS CLASSIFIED BY HH INCOME

GROUP	INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	TOTAL
100% OF TRAVELERS							
TR. OBSERVED	89	156	323	710	491	226	1986
MAX. TT (MIN)	495	495	495	495	365	495	495
AVG. TIME/TR.	71.18	74.55	72.4	80.51	80.34	96.55	79.78
S.D. OF TIME	66.68	73.71	64.8	69.52	55.45	79.98	66.97
S.E. OF TIME	7.07	5.9	3.61	2.61	2.5	5.32	1.5
COEFF. OF VAR	.94	.99	.9	.86	.69	.83	.84
ALPHA	1.14	1.02	1.25	1.34	2.1	1.46	1.42
BETA	.02	.01	.02	.02	.03	.02	.02
GAMMA	.94	.99	.91	.89	1.05	.89	.89
99% OF TRAVELERS							
TR. OBSERVED	89	156	323	704	488	225	1970
MAX. TT (MIN)	495	495	495	355	275	365	355
AVG. TIME/TR.	71.18	74.55	72.4	77.17	78.87	95.31	76.68
S.D. OF TIME	66.68	73.71	64.8	59.58	52.3	77.96	57.46
S.E. OF TIME	7.07	5.9	3.61	2.25	2.37	5.2	1.29
COEFF. OF VAR	.94	.99	.9	.77	.66	.82	.75
ALPHA	1.14	1.02	1.25	1.68	2.27	1.49	1.78
BETA	.02	.01	.02	.02	.03	.02	.02
GAMMA	.94	.99	.91	.9	1.15	.89	.93
95% OF TRAVELERS							
TR. OBSERVED	85	149	308	679	470	217	1888
MAX. TT (MIN)	185	215	155	215	195	275	205
AVG. TIME/TR.	60.88	61.51	61.53	69.96	72.96	86.84	68.78
S.D. OF TIME	39.8	38.15	33.07	46.27	43.23	65.19	43.3
S.E. OF TIME	4.32	3.13	1.88	1.78	1.99	4.43	1
COEFF. OF VAR	.65	.62	.54	.66	.59	.75	.63
ALPHA	2.34	2.6	3.46	2.29	2.85	1.77	2.52
BETA	.04	.04	.06	.03	.04	.02	.04
GAMMA	1.2	1.43	3.18	1.16	1.75	.92	1.35
90% OF TRAVELERS							
TR. OBSERVED	83	143	294	642	442	207	1792
MAX. TT (MIN)	145	135	125	165	155	215	155
AVG. TIME/TR.	58.13	57.03	57.69	62.93	66.2	79.01	62.65
S.D. OF TIME	35.99	31.34	28.61	36.66	34.82	55.64	35.01
S.E. OF TIME	3.95	2.62	1.67	1.45	1.66	3.87	.83
COEFF. OF VAR	.62	.55	.5	.58	.53	.7	.56
ALPHA	2.61	3.31	4.07	2.95	3.61	2.02	3.2
BETA	.04	.06	.07	.05	.05	.03	.05
GAMMA	1.44	2.71	6.53	1.91	3.78	1.01	2.43

Cont.

APPENDIX 8

TIME FREQUENCY DISTRIBUTION STATISTICS : READING

TRAVELERS CLASSIFIED BY HH INCOME

GROUP	INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	TOTAL
100% OF TRAVELERS							
TR. OBSERVED	87	149	316	686	482	211	1923
MAX. TT (MIN)	210	210	230	230	230	230	230
AVG. TIME/TR.	64.48	61.68	65.25	71.87	76.43	82.04	71.68
S.D. OF TIME	46.12	38.63	39.89	48.8	48.09	58.95	47.61
S.E. OF TIME	4.94	3.16	2.24	1.86	2.19	4.06	1.09
COEFF. OF VAR	.72	.63	.61	.68	.63	.72	.66
ALPHA	1.95	2.55	2.68	2.17	2.53	1.94	2.27
BETA	.03	.04	.04	.03	.03	.02	.03
GAMMA	.98	1.38	1.52	1.08	1.35	.97	1.14

READING :TIME FREQUENCY DISTRIBUTION DATA (OBSERVED)

TRAVELERS CLASSIFIED BY HH INCOME

GROUP		INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	TOTAL
HHS UNEXPAN.		169	169	248	404	243	100	1333
HHS EXP.(00)		7155	7580	10586	16975	10702	4028	57023
EXP. FACTOR		42.34	44.85	42.69	42.02	44.04	40.28	42.78
#	MEAN TIME	TRAVELERS						
1	10	9	7	20	56	27	22	139
2	30	26	47	76	142	85	36	411
3	50	12	40	65	141	99	37	395
4	70	14	10	63	130	94	31	340
5	90	12	24	49	67	63	24	239
6	110	3	6	14	39	36	13	112
7	130	4	9	13	41	23	10	100
8	150	3	3	8	20	15	7	56
9	170	1	1	1	14	16	8	41
10	190	1	1	2	20	12	11	44
11	210	2	1	3	9	7	8	28
12	230	0	0	2	7	5	4	18
13	TOTAL	87	149	316	686	482	211	1923

U.S. Department
of Transportation

**Research and
Special Programs
Administration**

400 Seventh Street, S.W.
Washington, D.C. 20590

March 24, 1982

Dear Colleague:

The enclosed report, "The Travel Money Budget", presents data on travel expenditures for the cities of Baltimore and London. It complements a report you received previously on the subject of the travel time budget. Together these reports constitute the latest data in support of the concept behind the UMOT model.

As further results on the UMOT model become available they will also be sent to you.

Sincerely,

Robert W. Crosby

Robert W. Crosby
Chief, Systems Analysis Division

MOBILITY SYSTEMS, INC.

=========================

THE TRAVEL MONEY BUDGET

=========================

MOBILITY SYSTEMS, INC.

7304 BROXBURN CT.
BETHESDA, MD. 20034

(301) 229-7762

February 5, 1982

TECHNICAL MEMORANDUM(*)

TO : Robert W. Crosby
Chief, Systems Analysis Division, U.S. DOT

FROM : Yacov Zahavi
Mobility Systems, Inc. Y.Z.

SUBJECT: THE TRAVEL MONEY BUDGET

1. INTRODUCTION

1.1 The analysis of travel regularities in four cities, Washington, D.C. and Baltimore in the U.S., and London and Reading in the U.K., was reported in a previous technical memorandum, of December 15, 1981. It was shown that travel characteristics in a city are related through a system of close interactions. The report further showed that certain travel characteristics display regularities which are transferable among the four cities, principally the daily travel time per traveler. Due to its transferable regularities, the daily travel time per traveler is regarded in the UMOT travel model as a time budget allocated to travel, and applied as an explicit constraint in a process where accessibility to opportunities within an urban area is maximized.

The second explicit constraint in the maximization process of the UMOT model is the travel money budget. This report presents new evidence supporting the existence of transferable regularities associated with the travel money budget, thus adding further confirmation to the underlying principles of the UMOT model.

1.2 The money expenditures on travel can be derived from two principal sources. The first source is a direct one, where household members are either interviewed personally, or requested to fill out written questionairs, about their actual out-of-pocket money expenditures on travel. Periodic nationwide surveys, or infrequent urban travel home interview surveys, are examples of the first source.

The second source of information on travel money expenditures is an indirect one, where expenditure estimates are derived from the product of the reported travel distance by mode per household and the travel costs/fares per unit distance. Based on the available data, the latter procedure has been adapted in this report.

1.3 While nationwide statistics on travel money expenditures per average household are well known, not many reports are available on such expenditures by household socioeconomic characteristics within urban areas.

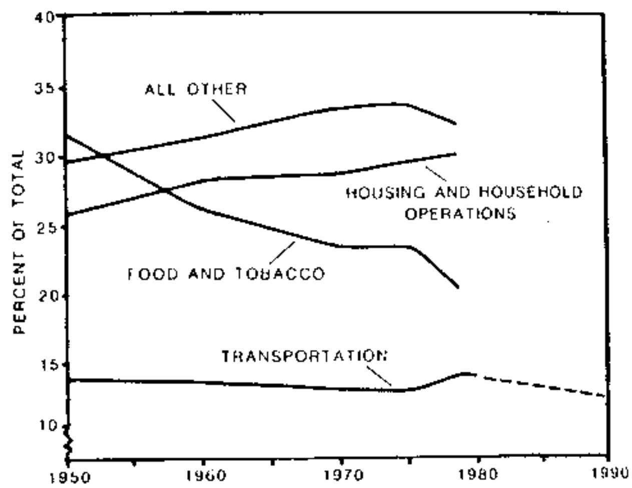
(*) An attachment to Progress Report No.10, The UMOT Travel Model-II.

The available information to this date can be summarized as follows:

Nationwide

(1) Yearly expenditures on transportation, as a percent of total personal consumption expenditure on goods and services, have been quite stable in the U.S. over the last 30 years, as shown in Figure 1 (1).

Figure 1. Transportation expenditures as a percentage of total personal consumption expenditures.



This stability is described in Ref.(1) as follows:

> "Between 1950 and 1970 the proportion of personal consumption expenditure devoted to transportation declined only slightly (from roughly 13 percent to 12 percent), even though the cost of travel in real terms fell substantially. A slight rise in the proportion of the budget devoted to transportation in 1974 was followed by a major increase from 1975 to 1977, when it reached a 20-year high of 14.3 percent.
>
> How transportation expenditure will change in the 1980s is unclear. The conjecture shown in Figure 1 suggests that household travel expenditure will decline slightly during the 1980s, and households will seek to reestablish the historical values of 12-13 percent." (Ref.(1), p.32).

(2) Similar trends and values were also noted in other countries. For instance: U.K. in 1972 - 11.7 percent (going up to nearly 15 percent in 1980); Germany, 1971-74 - 11.3 percent; Canada, 1963-74 - 13.1 percent (2).

Thus, although income levels and travel costs/fares can differ among developed countries, the percentage of the travel money budget in all available cases appears to be similar both spatially and temporally.

Within Cities

(Nationwide travel money expenditures include both urban and intercity travel, while urban travel money expenditures are those for urban travel only.)

(1) Washington, D.C., 1968 and Twin Cities, 1970, U.S. The daily travel money expenditures, averaged by zones, where: households traveling by car only - 11.0 and 10.1 percent, respectively; households traveling by bus only - 4.2 and 3.4 percent, respectively. The average value in each city was about 10 percent (3).

(2) The Nuremberg Region, 1975, Germany. The daily travel money expenditures were 11.8 percent for car-owning households, and 3.5 percent for non-car households, with an average value of about 10 percent (2).

(3) Two Residential Areas of Delhi, 1979, India. The daily travel money expenditures were 11 and 9 percent (4). Figure 2 shows the stability of the travel money budget across a wide range of incomes. (Only at extremely low incomes do the percentages increase.)

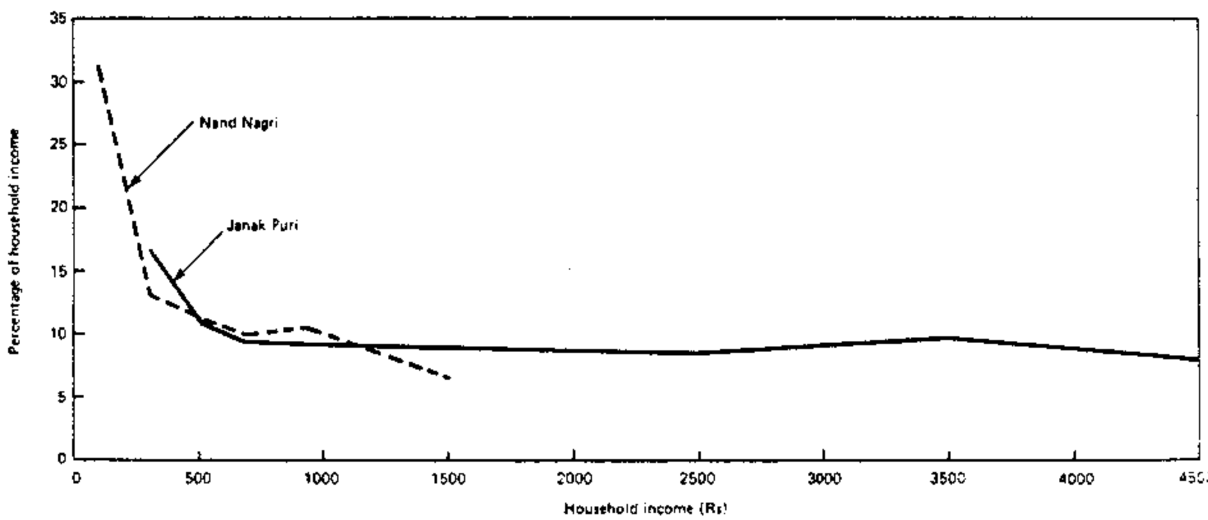


Fig. 2 Expenditure on transport as a proportion of household income

(4) Kuala Lumpur, 1978, Malaysia. The daily travel money expenditures were found to be within a narrow range: "All households, irrespective of income, spent some 8 percent to 11 percent of their total income on transport." (5)

Thus, there is an increasing amount of evidence to suggest that travel money expenditures per household, similar to travel time expenditures per traveler, display consistent regularities which appear to be transferable between cities of both developed and developing countries.

This report details the travel money expenditures per household in two additional cases, in Baltimore 1977 and London 1977. The results, once again, are about 10 percent of income in both cities.

2. THE TRAVEL MONEY BUDGET IN BALTIMORE AND LONDON

2.1 Introduction

When deriving estimates of travel money expenditures from the available data sets(*) - which are based on conventional home interview surveys - the following caveats should be noted:

(1) Daily travel costs were not reported. Therefore, they had to be estimated by indirect methods. (Even if they had been reported, the perceived costs, especially for car travel, would not necessarily be the actual costs.)

(2) Aggregation of households by income groups - 6 groups in Baltimore and 12 groups in London - results in estimates of travel money expenditures which are averaged over a range of different incomes.

(3) It is easier to transfer travel money between days than to transfer travel time. Consequently, wider variations should be expected in the travel money budget than in the travel time budget.

(4) While the daily travel time expenditures are related to the persons who actually reported them (i.e., travelers), the daily money expenditures are related to the households' income level. Hence, all households within a given income group, even those which did not generate travel on the survey day, have to be considered; the frequency of travel, namely the frequency at which the travel money is spent, has to be taken into account, especially when the available data are for only one survey day.

It is encouraging to note that in spite of the above possible variations, the results detailed in this report show consistent and transferable regularities in the two cities, similar to those observed in other cities.

2.2 Daily Travel Distance Frequency Distributions

It was shown in the previous technical memorandum that the daily travel time frequency distributions per traveler display consistent regularities, which can be correlated with travel speed. Similar frequency distributions have been derived for the daily travel distance per traveler in Baltimore, and are presented in Figures 3-4 for the six income groups, the four car ownership groups, and total (Appendix 1).

(*) The data sets were described in detail in the previous Technical Memorandum, dated December 15, 1981.

Fig. 3 Daily Travel Distance/TR Distributions, Baltimore

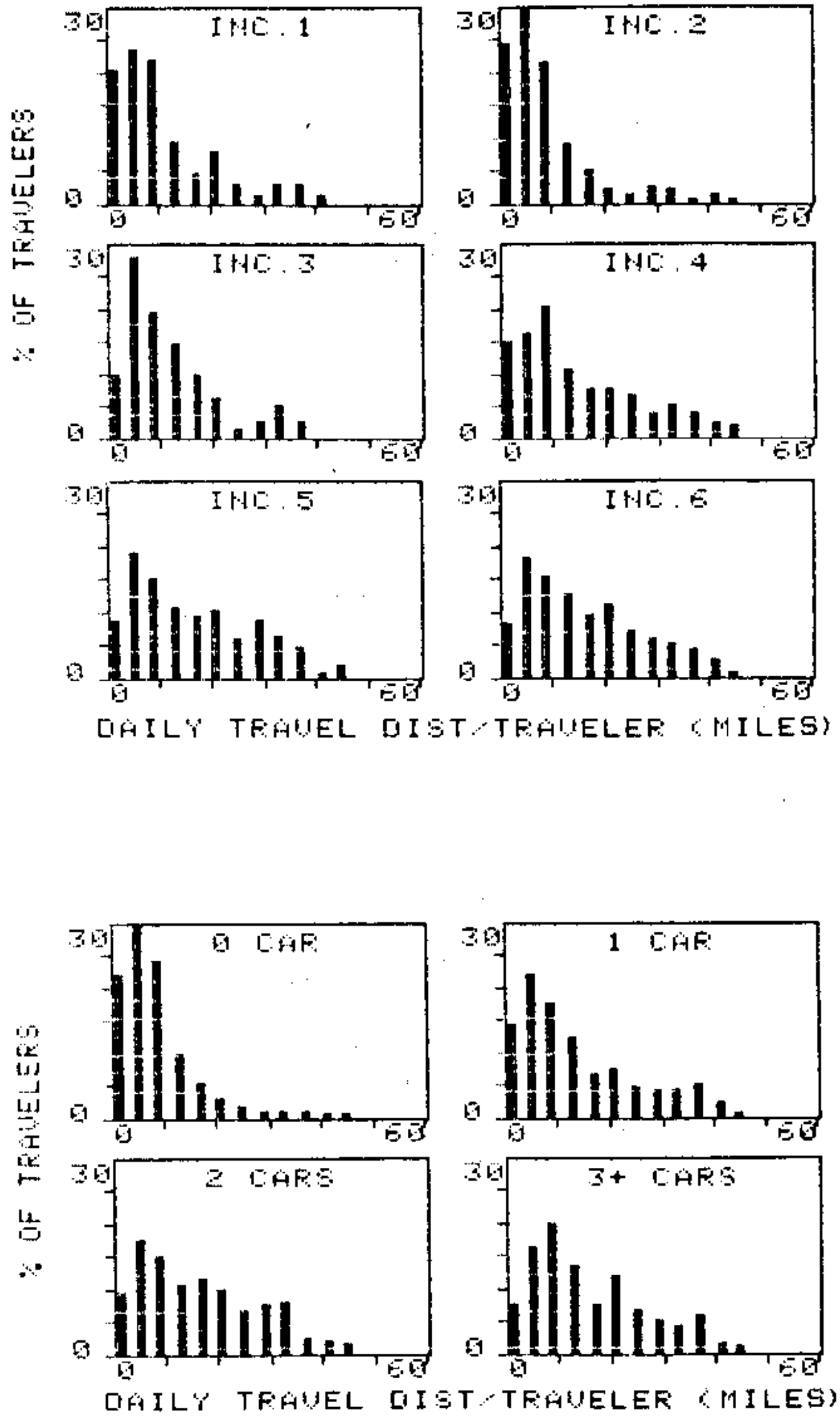
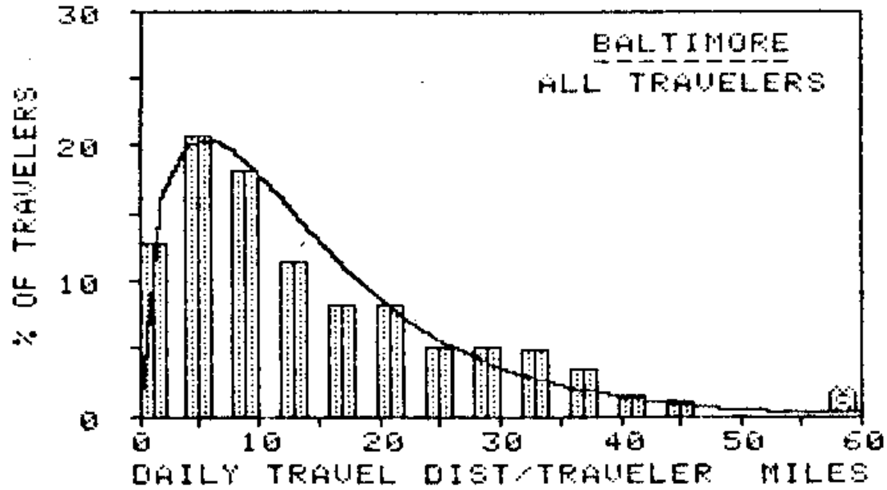


FIG. 4 TRAVEL DIST/TR DISTRIBUTIONS



A comparison between the time and distance distributions by household income in Baltimore is shown in Figures 5-6.

FIG. 5 TRAVEL TIME/TR DISTRIBUTIONS

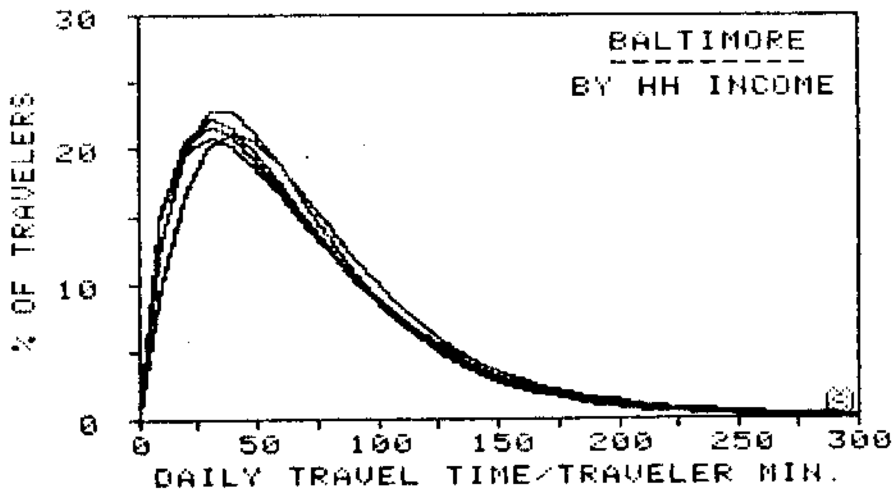
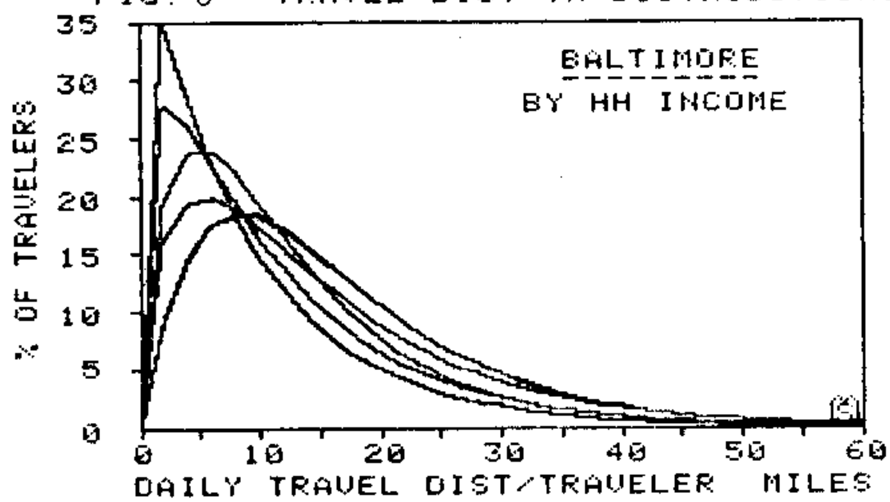


FIG. 6 TRAVEL DIST/TR DISTRIBUTIONS



It becomes evident from the above two figures that the distance distributions display appreciably more variation than the time distributions, and that the spread of the former distributions is highly correlated with income; travel distance per traveler increases with income.

A second comparison between the time and distance distributions is shown in Figures 7-8, this time for travelers in Baltimore segmented by car ownership levels.

FIG. 7 TRAVEL TIME/TR DISTRIBUTIONS

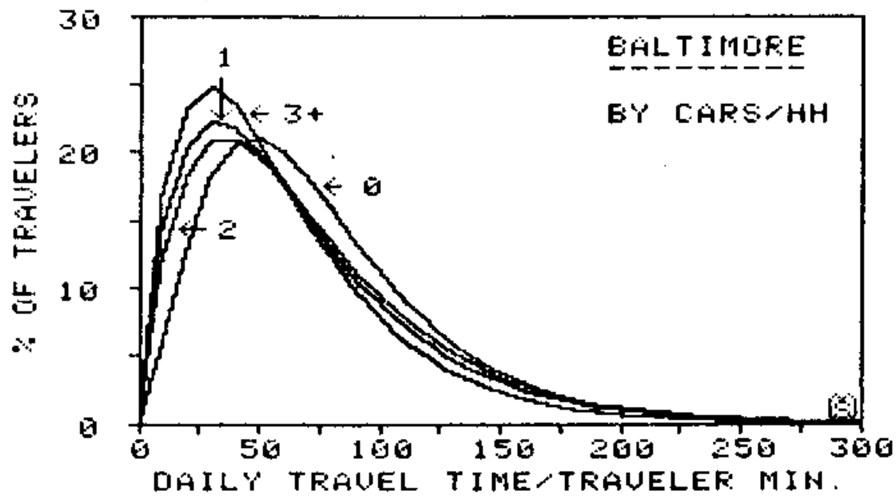
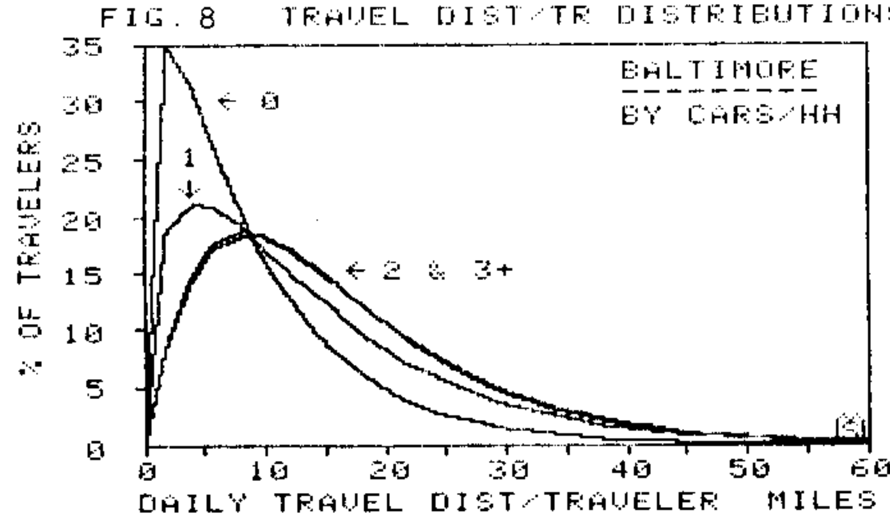


FIG. 8 TRAVEL DIST/TR DISTRIBUTIONS



It can be concluded that speed is a key factor in explaining travel behavior; non-car travelers spend more time for less travel distance, while travelers with greater car ownership levels spend consistently less travel time for consistently longer travel distance.

Similar results were also found for London. (It should, however, be noted at this stage that: (i) travel distances in London are shown in metric units, and (ii) while the distance intervals in Baltimore are by 2 miles, they are by 10 km in London. Hence, these differences should be noted when comparing the London diagrams with the Baltimore diagrams.)

Figures 9-10 show the daily distance per traveler frequency distributions in London, segmented by car ownership levels, and total (Appendix 2).

Fig. 9 Daily Travel Distance/TR Distributions, London

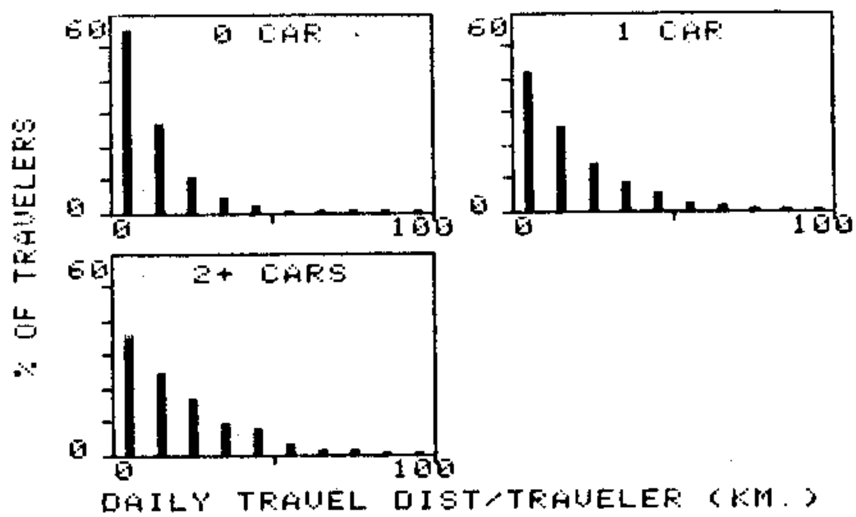
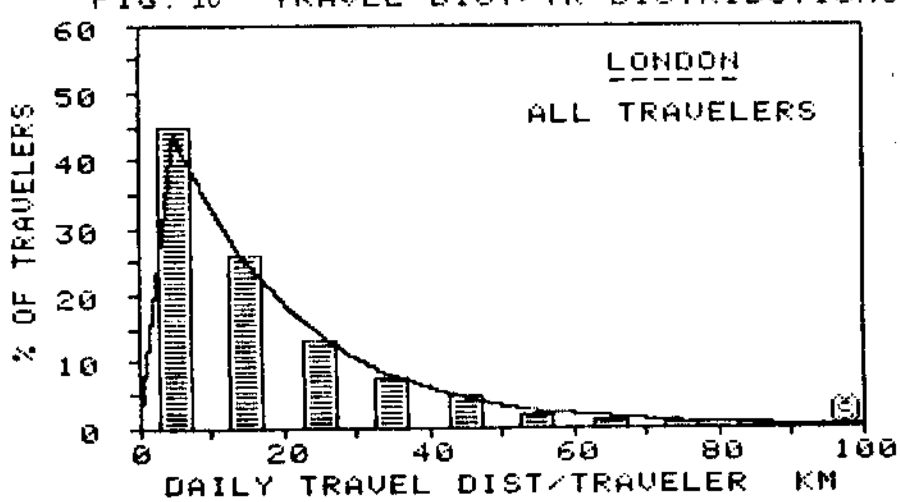


FIG. 10 TRAVEL DIST/TR DISTRIBUTIONS



A comparison between the time and distance distributions in London, by car ownership levels, is shown in Figures 11-12. As can be seen, the same consistent tendencies observed in Baltimore (Figures 7-8) are also evident in London; namely, less time is spent for more travel distance as car ownership levels increase.

FIG. 11 TRAVEL TIME/TR DISTRIBUTIONS

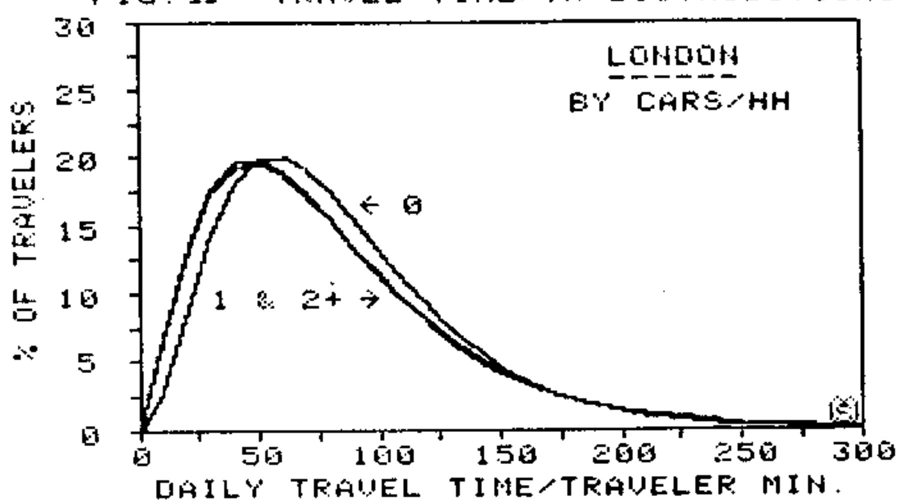
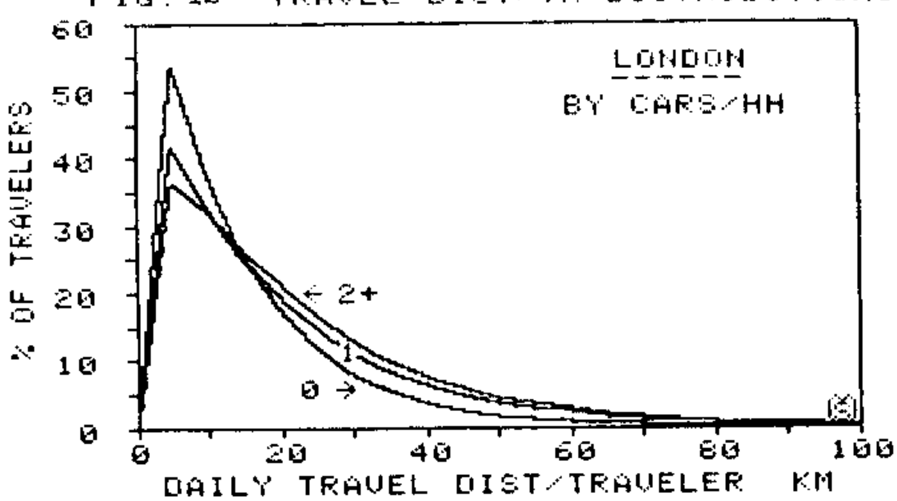


FIG. 12 TRAVEL DIST/TR DISTRIBUTIONS



The above results have been shown per traveler. The daily travel distance per household is dealt with in the next section.

2.3 Daily Travel Distance per Household, by Mode

Figures 13-14 show the daily travel distance per average household, by mode, versus household income in Baltimore and London. (Taxi and motorcycle distances are not shown since their values are very small.) (Appendix 3).

FIG. 13 DAILY DISTANCE/HH VS. INCOME

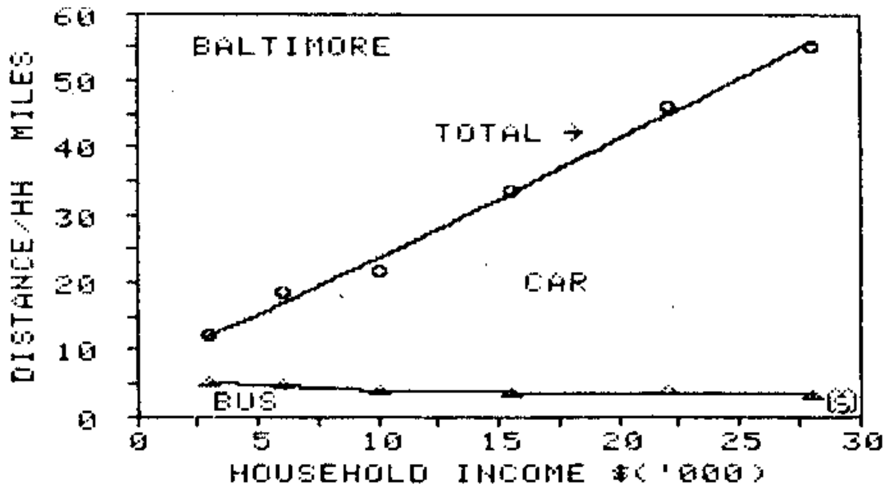
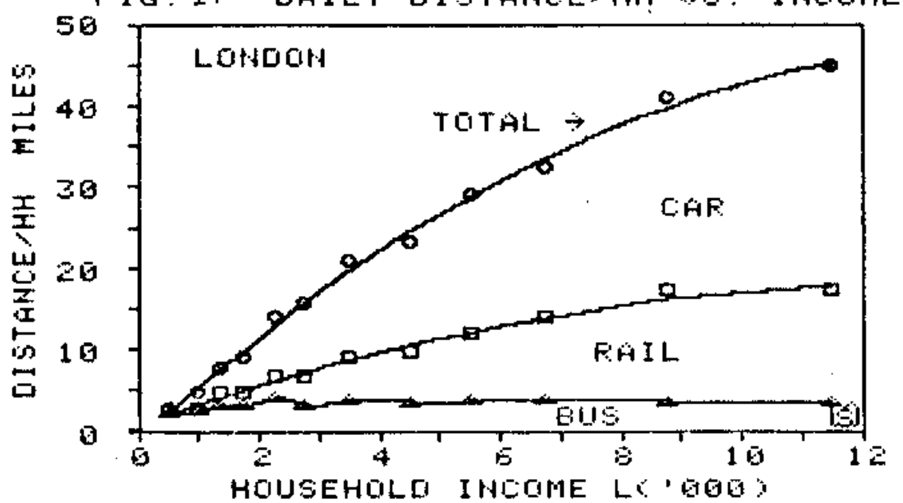


FIG. 14 DAILY DISTANCE/HH VS. INCOME



It becomes evident from Figures 13-14 that while the daily travel distance per average household can be different in different cities when stratified by household income (depending on such factors as household size and available modes/speeds), they increase consistently with income. Put another way, it can be concluded that the travel money expenditure per household increases with household income in a consistent way, as detailed below.

2.4 Travel Expenditures per Household

Travel expenditures per average household, stratified by 6 income groups in Baltimore and 12 income groups in London, were estimated as the product of daily travel distance per household by mode and their respective unit costs.

The unit costs of travel were as follows:

Baltimore, 1977: Bus fares were given by the Baltimore Regional Planning Council as 11 cents/mile. Taxi fares were estimated to be about 10 times bus fares, or 100 cents/mile. Car costs were derived from the U.S. DOT, FHWA publication "Cost of Owning and Operating Automobiles and Vans, 1979": in 1979 they were 24.6 cents/mile for a standard car, 21.7 cents/mile for a compact car, and 18.5 cents/mile for a subcompact car, all under suburban travel conditions. The values were interpolated for 1977, and an average value for the total urban travel was estimated to be 20 cents/mile. Motorcycle costs were estimated to be about one half car costs, or 10 cents/mile. Average passenger occupancies were estimated to be 1.5 for car and 1.2 for motorcycle.

London, 1977: D.T.P. recommended figures for 1976 were: bus fares - 4.90 p/mile, and underground rail fares - 5.07 p/mile. Since no data was available for taxi fares, they were estimated to be 10 times bus fares, or 49 p/mile. The available data for car operating costs were related to speed, and at a speed of 35 kph the operating cost was 2.6 p/km, or 4.18 p/mile. Hence, the full car travel cost, including depreciation, insurance and parking, was estimated to be 10 p/mile. Since no data was available on motorcycle costs, they were estimated to be 6 p/mile.

Two points should be noted at this stage. First, the daily travel distance by taxi and motorcycle per household were found to be very small in both cities and, therefore, any error in their estimated costs would not have any practical effect on the daily travel money expenditure per household. Second, the estimated car costs, 20 cents/mile in Baltimore and 10 p/mile in London, are first-cut bench-mark values, in the sense that they are gross average values; the actual values are expected to be significantly lower for low income households, operating mostly second-hand cars, while they are expected to be significantly higher for high income households, operating above-standard cars. Such differences in car costs are liable to surface when average values are used for all household classes. This, indeed, is the case, as shown below.

Appendix 3 details the estimated travel money expenditures per household in Baltimore and London. (The daily income per household for the purpose of estimating the proportions of travel money expenditures is taken as the household annual income over 320 active-days per year. Ref.2)

Figures 15-16 show the daily travel money expenditures vs. household income in Baltimore and London, where it becomes evident that the money expenditures increase consistently with household income.

FIG. 15 TRAVEL EXPENDITURE VS. INCOME

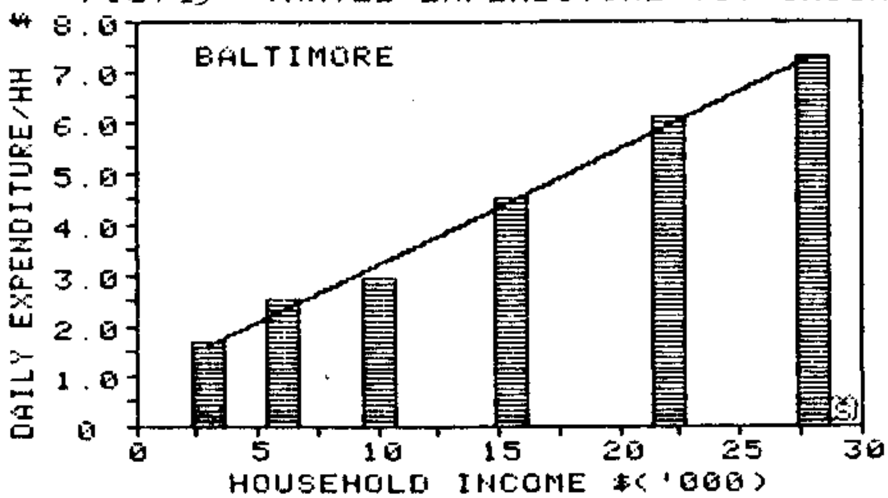
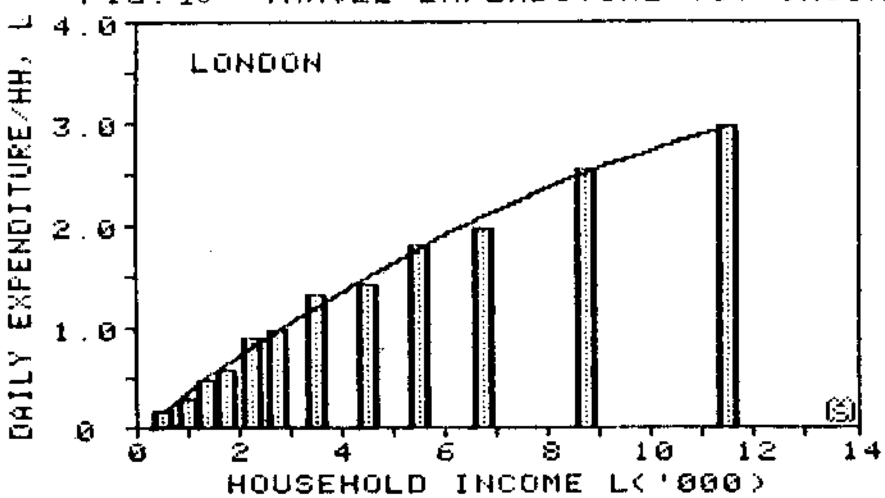


FIG. 16 TRAVEL EXPENDITURE VS. INCOME



A comparison between the above results and those observed in other cities (as detailed in Section 1.3) is shown in Figures 17-18. A line, expressing the observed 10 percent of income spent on travel in the other cities, is drawn in the two diagrams, which also show the estimated expenditures on travel.

FIG. 17 TRAVEL EXPENDITURE VS. INCOME

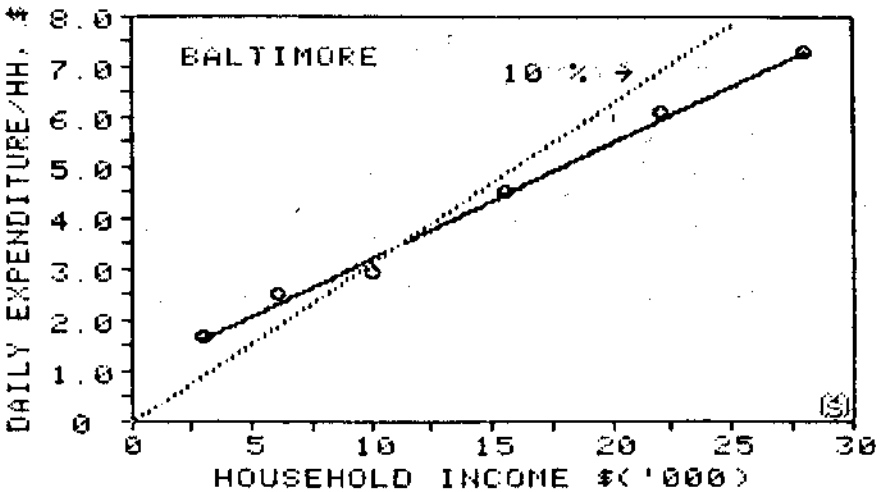
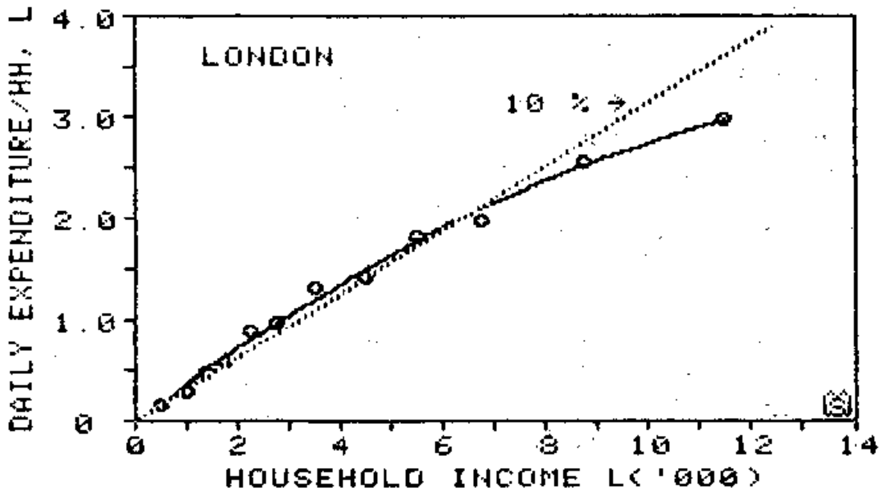


FIG. 18 TRAVEL EXPENDITURE VS. INCOME



The following conclusions can be inferred from the above comparisons:

(1) The average unit costs applied in Baltimore and London, which result in average expenditures of 9.2 and 10.0 percent, respectively, are similar in magnitude to those observed in other cities.

(2) Applying an average value for car travel cost to all income groups appears to be unsatisfactory; it results in overestimation of the travel expenditures at low income levels, and underestimation of the travel expenditures at high income levels. In other words, the unit costs would be lower than the average value for low income households (operating mostly below-standard cars), and they would be higher than the average value for high income households (operating mostly above-standard cars). [Assuming that the 10 percent line holds for all income levels, the unit costs of car travel by income group can then be derived.]

In summarizing the results of this memorandum, it should be noted that daily travel money expenditures per household can display very wide variations at the disaggregate level within each income group, partly due to differences in socioeconomic characteristics not accounted for in the above analyses (e.g., household size) and partly due to daily variations in travel generation. It is encouraging to note, therefore, that the stratification of households by income alone is sufficient to bring up consistent and transferable regularities not only in the daily travel time expenditures per traveler, as shown in the previous report, but also in the daily travel money expenditures per household.

The above results have far reaching implications for travel modeling since (i) only few household socioeconomic characteristics have to be predicted for a target year in order to estimate future travel, and (ii) the interactions between the time and money budgets per household can be used to operate the model; given the time and money budgets per household, the unit costs of the various available (or planned) modes, and an objective function (such as the maximization of accessibility), the model can predict the total daily travel distance per household, by mode, as well as all other travel components, without laborious calibrations. This is the conceptual - and operational - basis of the UMOT travel model.

The results of this report add further support to the underlying principles of the UMOT model. They also suggest a method for testing additional cases for consistent and transferable regularities associated with the travel money expenditures.

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2. Zahavi, Y. (1979). The UMOT Project. Report DOT-RSPA-DPB-20-79-3, U.S. DOT, Washington, D.C.

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5. Eastman, C.R. and Pickering, D. (1981). Transport Problems of the Urban Poor in Kuala Lumpur. TRRL Supplementary Report 683, Transportat and Road Research Laboratory, U.K.

APPENDIX 1

BALTIMORE :DISTANCE FREQUENCY DISTRIBUTION DATA (OBSERVED)

TRAVELERS CLASSIFIED BY HH INCOME & CAR OWNERSHIP

#	GROUP	INCOME GROUPS INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	CAR OWNERSHIP LEVEL 0 CAR	1 CAR	2 CARS	3+ CARS	# TOTAL
#	MEAN DIST.	TRAVELERS										
1	.5	2	9	5	10	6	8	9	19	10	2	40
2	2	11	26	9	36	15	17	35	38	27	14	114
3	4	10	22	19	32	19	29	40	36	34	21	131
4	6	5	21	21	18	27	27	20	51	35	13	119
5	8	8	19	17	27	18	24	32	33	28	20	113
6	10	6	12	11	36	19	23	17	36	32	22	107
7	12	4	6	16	19	15	24	9	34	26	15	84
8	14	2	7	5	14	11	15	11	14	16	13	54
9	16	2	4	6	12	11	14	5	14	22	8	49
10	18	1	3	8	11	12	15	6	13	23	8	50
11	20	3	2	5	13	14	23	2	16	25	17	60
12	22	2	1	4	10	11	11	4	13	14	8	39
13	24	1	1	1	13	9	16	2	12	18	9	41
14	26	1	1	1	7	5	6	2	6	8	5	21
15	28	1	2	2	9	11	12	2	10	19	6	37
16	30	0	2	2	3	10	6	0	7	11	5	23
17	32	0	1	4	11	8	7	0	9	17	5	31
18	34	2	2	3	5	7	8	2	7	14	4	27
19	36	2	0	2	9	5	7	1	11	5	8	25
20	38	0	1	2	3	6	6	1	9	4	4	18
21	40	0	1	0	3	0	4	0	5	2	1	8
22	42	1	1	0	4	1	4	1	3	5	2	11
23	44	0	1	0	3	1	0	1	1	2	1	5
24	46	0	0	0	2	3	2	0	2	4	1	7
25	TOTAL	64	145	143	310	244	308	202	399	401	212	1214

DISTANCE FREQUENCY DISTRIBUTION STATISTICS : BALTIMORE

TRAVELERS CLASSIFIED BY HH INCOME & CAR OWNERSHIP

GROUP	INCOME GROUPS INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	CAR OWNERSHIP LEVEL 0 CAR	1 CAR	2 CARS	3+ CARS	# TOTAL
100% OF TRAVELERS											
TR. OBSERVED	64	145	143	310	244	308	202	399	401	212	1214
MAX.DIST.(KM)	42	46	38	46	46	46	44	46	46	46	46
AVG. DIST/TR.	11.05	9.12	11.91	14.49	16.12	15.86	8.63	13.75	16.15	15.73	14.04
S.D. OF DIST.	10.05	9.05	9.2	11.47	11.22	11	7.87	11.22	11.17	10.83	10.95
S.E. OF DIST.	1.26	.75	.77	.65	.72	.63	.55	.56	.56	.74	.31
COEFF. OF VAR	.91	.99	.77	.79	.7	.69	.91	.82	.69	.69	.78
ALPHA	1.21	1.02	1.67	1.6	2.06	2.08	1.2	1.5	2.09	2.11	1.64
BETA	.11	.11	.14	.11	.13	.13	.14	.11	.13	.13	.12
GAMMA	.92	.99	.9	.89	1.03	1.03	.92	.89	1.04	1.05	.9

APPENDIX 1 (Cont.)

BALTIMORE :DISTANCE FREQUENCY DISTRIBUTION DATA (OBSERVED)

TRAVELERS CLASSIFIED BY HH INCOME & CAR OWNERSHIP

#	GROUP	INCOME GROUPS INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	CAR OWNERSHIP LEVEL 0 CAR	1 CAR	2 CARS	3+ CARS	# TOTAL
#	MEAN DIST.	TRAVELERS										
1	1.25	13	35	14	46	21	25	44	57	37	16	154
2	5	15	43	40	50	46	56	60	87	69	34	250
3	9	14	31	28	63	37	47	49	69	60	42	220
4	13	6	13	21	33	26	39	20	48	42	28	138
5	17	3	7	14	23	23	29	11	27	45	16	99
6	21	5	3	9	23	25	34	6	29	39	25	99
7	25	2	2	2	20	14	22	4	18	26	14	62
8	29	1	4	4	12	21	18	2	17	30	11	60
9	33	2	3	7	16	15	15	2	16	31	9	58
10	37	2	1	4	12	11	13	2	20	9	12	43
11	41	1	2	0	7	1	8	1	8	7	3	19
12	45	0	1	0	5	4	2	1	3	6	2	12
13	TOTAL	64	145	143	310	244	308	202	399	401	212	1214

DISTANCE FREQUENCY DISTRIBUTION STATISTICS : BALTIMORE

TRAVELERS CLASSIFIED BY HH INCOME & CAR OWNERSHIP

GROUP	INCOME GROUPS INC.1	INC.2	INC.3	INC.4	INC.5	INC.6	CAR OWNERSHIP LEVEL 0 CAR	1 CAR	2 CARS	3+ CARS	# TOTAL
100% OF	**TRAVELERS**										
TR. OBSERVED	64	145	143	310	244	308	202	399	401	212	1214
MAX.DIST.(MI)	41	45	45	45	45	45	45	45	45	45	45
AVG. DIST/TR.	11.11	9.09	11.99	14.55	16.09	15.96	8.68	13.77	16.2	15.81	14.08
S.D. OF DIST.	10.08	9.07	9.2	11.59	11.24	11.03	7.83	11.3	11.21	10.88	11
S.E. OF DIST.	1.26	.75	.77	.66	.72	.63	.55	.57	.56	.75	.32
COEFF. OF VAR	.91	1	.77	.8	.7	.69	.9	.82	.69	.69	.78
ALPHA	1.22	1	1.7	1.57	2.05	2.09	1.23	1.48	2.09	2.11	1.64
BETA	.11	.11	.14	.11	.13	.13	.14	.11	.13	.13	.12
GAMMA	.91	1	.91	.89	1.02	1.04	.91	.89	1.04	1.05	.9

APPENDIX 2

LONDON : DISTANCE FREQUENCY DISTRIBUTION DATA (EXPANDED)

TRAVELERS CLASSIFIED BY CAR OWNERSHIP

#	GROUP MEAN DIST.	CAR OWNERSHIP LEVEL 0 CAR	1 CAR	2+ CARS	TOTAL
		TRAVELERS			
1	5	6797	9093	2547	18436
2	15	3320	5500	1776	10594
3	25	1360	2976	1171	5507
4	35	553	1753	665	2971
5	45	261	1090	530	1882
6	55	80	468	218	767
7	65	53	252	85	390
8	75	13	140	66	219
9	85	3	136	42	181
10	95	23	58	30	111
11	105	11	40	16	67
12	115	11	35	14	59
13	125	3	29	8	40
14	135	0	11	0	11
15	TOTAL	12488	21581	7168	41235

DISTANCE FREQUENCY DISTRIBUTION STATISTICS : LONDON

TRAVELERS CLASSIFIED BY CAR OWNERSHIP

GROUP	CAR OWNERSHIP LEVEL 0 CAR	1 CAR	2+ CARS	TOTAL
100% OF TRAVELERS				
TR. OBSERVED	12488	21581	7168	41235
MAX.DIST.(KM)	125	135	125	135
AVG. DIST/TR.	13.05	18.34	20.78	17.16
S.D. OF DIST.	12.43	17.69	18.45	16.66
S.E. OF DIST.	.11	.12	.22	.08
COEFF. OF VAR	.95	.96	.89	.97
ALPHA	1.1	1.08	1.27	1.06
BETA	.08	.06	.06	.06
GAMMA	.95	.96	.9	.97

APPENDIX 3

TRAVEL MONEY EXPENDITURE : BALTIMORE

CLASSIFICATION BY HH INCOME

INCOME GROUP............:	1	2	3	4	5	6	AVG.
HH INCOME $('000).......:	3.00	6.00	10.00	15.50	22.00	28.00	15.95
INCOME/DAY $............:	9.38	18.75	31.25	48.40	68.75	87.50	49.84
CARS PER HOUSEHOLD......:	0.26	0.61	0.85	1.54	1.80	2.34	1.41
DISTANCE/HH : CAR.......:	6.66	13.74	17.21	29.18	42.27	51.62	30.22
DISTANCE/HH : BUS.......:	5.01	4.39	3.64	3.36	3.70	3.03	3.69
DISTANCE/HH : TAXI......:	0.21	0.17	0.17	0.16	0.03	0.00	0.11
DISTANCE/HH : M/C.......:	0.00	0.03	0.34	0.61	0.15	0.51	0.33
DISTANCE/HH : TOTAL.....:	11.88	18.33	21.36	33.31	46.15	55.16	34.35
MONEY EXPENDITURE, $....:	1.65	2.49	2.90	4.48	6.09	7.27	4.57
MONEY EXPENDITURE, %....:	17.60	13.30	9.30	9.30	8.90	8.30	9.17

(NOTE: DISTANCES ARE IN MILES)

TRAVEL MONEY EXPENDITURE : LONDON

CLASSIFICATION BY HH INCOME

INCOME GROUP............:	1	2	3	4	5	6	7	8	9	10	11	12	AVG.
HH INCOME L('000).......:	0.50	1.00	1.38	1.75	2.25	2.75	3.50	4.50	5.50	6.75	8.75	11.50	4.09
INCOME/DAY, L...........:	1.56	3.13	4.31	5.47	7.03	8.59	10.94	14.06	17.19	21.09	27.34	35.94	12.78
CARS PER HOUSEHOLD......:	0.07	0.11	0.24	0.33	0.45	0.56	0.72	0.85	0.96	1.08	1.27	1.52	0.70
DISTANCE/HH : CAR.......:	0.52	1.76	3.06	3.99	6.78	8.23	11.38	12.84	16.31	17.84	22.07	26.14	11.13
DISTANCE/HH : BUS.......:	1.99	2.36	3.15	3.10	4.01	3.26	3.68	3.58	3.94	3.77	3.59	3.54	3.43
DISTANCE/HH : RAIL......:	0.41	0.60	1.51	1.71	2.86	3.60	5.25	6.10	8.11	10.14	13.76	13.78	5.63
DISTANCE/HH : TAXI......:	0.00	0.01	0.05	0.07	0.16	0.11	0.09	0.09	0.15	0.07	0.26	0.58	0.12
DISTANCE/HH : M/C.......:	0.00	0.06	0.12	0.33	0.16	0.41	0.63	0.55	0.65	0.57	1.11	1.01	0.48
DISTANCE/HH : TOTAL.....:	2.92	4.79	7.89	9.20	13.97	15.61	21.03	23.16	29.16	32.39	40.79	45.05	20.79
MONEY EXPENDITURE, L....:	0.15	0.27	0.47	0.56	0.88	0.97	1.29	1.42	1.81	1.96	2.54	2.96	1.28
MONEY EXPENDITURE, %....:	9.60	8.70	10.80	10.20	12.50	11.30	11.80	10.10	10.60	9.30	9.30	8.20	10.04

(NOTE: DISTANCES ARE IN MILES)

The UMOT model