WORLD BANK / INTERNATIONAL FINANCE CORPORATION

# OFFICE MEMORANDUM

TO: Mr. Harold B. Dunkerley

DATE: April 12, 1977

FROM: Gabriel J. Roth *GJR*

SUBJECT: The Plain Person's Guide to the UMOT (Unified Mechanism of Travel) Process

You asked me to prepare a note on Dr. Yacov Zahavi's UMOT process, indicating particularly its achievements to date and the problems still remaining. For the sake of those who have not followed Zahavi's work, I propose to respond by describing the process from first principles, in question and answer form.

## 1. What is the UMOT Process?

The UMOT Process is an urban transport/land-use model that simulates within one framework the travel behaviour of an urban population, the performance of its transport system and the distribution of its land uses. The process is made up of three separate elements:

(a) Basic principles, e.g. that people attempt to maximize their daily spatial opportunities by maximizing their travel distance within their constraints of time and money;

(b) A rigorous analysis and comparison of data obtained in the course of transport/land-use studies, and

(c) A series of relationships linking key parameters of urban structure and transport. Some of the relationships - such as "speed equals distance divided by time" - are merely definitional. Others - such as relationships between travel speeds and flows, and between travel speeds and travel costs - are observed performance indicators. Yet others - such as "stable travel time budgets" - are observed characteristics relating to particular cities or income groups.

## 2. What is the purpose of UMOT?

To establish a methodology that can be used to predict the effect on urban structure and travel of changes in key variables such as transport policies or road capacities. Therefore, the success of UMOT process stands or falls on its predictive powers.

## 3. How Can UMOT's Predictive Powers Be Tested?

One way is to compare, for a particular city, UMOT's predictions of parameters (such as daily household travel distance) against observed results. An example of how this has been done with the UMOT process is given in Annex 1. Another way is to observe travel conditions in a city at two different periods, and to use the UMOT process to "predict" changes from one past period to another. But

Dr. Zahavi has set UMOT an even more ambitious target: to predict travel conditions in one city (say Washington, D.C.) on the basis of relationships developed from information collected in another (say, Twin Cities), without the need to "calibrate" the model for each city separately. Zahavi argues that only if the model is developed to be transferable between different cities can he be sure that it will also be transferable between two time periods for the same city.

4. Why Did the Bank Commission the Development of UMOT?

Because the methodologies currently used by the engineering and planning professions have, despite the proliferation of costly and time-consuming studies, failed to produce operationally useful simulations of linkages between transport and land use. They are also unable to model the effects on trip generation of changes in transport policies, infrastructure or prices. Furthermore, the conventional modeling tools require costly and elaborate computing facilities, take years to construct, and yet cannot produce convincing forecasts.

5. How Is Travel Determined By the UMOT Process?

The starting points, and the key operational inputs, are the time and money "travel budgets" of different segments of the population; the size of households; the proportion of "travellers" in households at different income levels; and the costs and speeds of travel by different modes. These determine the average daily distance travelled by different income groups. The distributions of residences and employment (also key inputs) give the average trip-distances which, in conjunction with average daily travel distances, enable trip rates to be calculated as outputs. The link between the road network and travel speed is given by the "Alpha Relationship", which indicates the performance of the network in terms of the vehicle-miles it can "produce" at different speeds. The attached flow diagram illustrates some of the key elements of UMOT. Because of the interactions between these elements, the actual calculations involve a considerable amount of iteration.

6. Is UMOT A "Macro" or a "Micro" Tool?

The UMOT process is currently a "Macro" model: It simulates travel over a complete urban area during the whole of a typical week-day. It can, therefore, be used for "sketch-planning", e.g. to enable the analyst to assess the likely effect on urban travel of changes in policies, costs, etc. It can also predict travel generation by district, given a knowledge of incomes by district. But to simulate "micro" conditions on a road network (e.g. the effects on traffic using specific road links of an improvement to another specified link) a conventional road traffic distribution model is still necessary.

7. What is the Dynamic Mechanism of UMOT?

To describe the long-term relationship between travel and urban structure Zahavi uses a concept of "equilibrium" which may be described as follows: A population group is in travel "equilibrium" when its time and money budgets (i.e. the amounts of money and time that are expended by comparable groups on travel) are fully, and just fully, expended. If one or both of the budgets is not exhausted (e.g. if travel speeds are so low that some travellers run out of time before they run out of money), travellers will change travel modes, or change their places of residence or of work, in order to get into "equilibrium". A similar process would occur if one or both budgets are over-expended (e.g. if distances between residences and jobs make for abnormally long journeys, as in many LDC cities, and as in Washington, D.C., for travellers dependent on public transport (Annex 2)).

8. What Are the Time and Money Constraints on Travel?

The "travel budgets" described by Zahavi are the amounts of time and money that identifiable groups are found to spend on travel in the course of a typical week-day. The "travel time budgets" of groups of travellers tend to be stable in any society. In most US cities for example, they average 1.1 hours per traveller per day, door-to-door. "Travel money budgets" depend on household income, and in the U.S., for most income groups, they average 12-13 percent of total household expenditure for all travel, and about 10.5 percent for travel within urban areas. In the developing countries the proportions of time and money spent on travel appear to be higher than in the developed. The time and money constraints are key inputs to the UMOT process, and need to be experimentally determined as part of urban travel studies.

9. How Does the UMOT Process Differ From Conventional Urban Transport Planning Techniques?*

(a) Conventional models treat and forecast most travel components separately. For instance, motorization, trip distances, modal splits" (the proportions of trips by different modes) and trip rates, are all forecast separately. Even trip rates for different trip purposes (work, shopping, etc.) are forecast separately. But the UMOT process regards and treats all travel components, and the urban structure, as one system, within which almost all parts affect, and are affected by, the others.

(b) Conventional techniques use individual trips as the basis for modelling; UMOT focuses on travellers, and on the total distance travelled by them in a 24-hour period. For example, in the conventional methods, leisure and shopping travel are evaluated independently of work travel; in the UMOT process, an increase in the time spent on work travel is reflected in a decrease in travel for other purposes, because of the constraints on total travel. And conversely; if time is saved on a single trip, it is traded off for more trips, or longer trips, or a combination of both, on the same day.

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* Bank staff interested in the logic of "conventional" transportation/land-use models can consult the report we have just received on the Metro-Manila Land Use and Development Planning Project.

(c) Conventional techniques (or rather those of them that are sophisticated enough to use the concepts of economic demand) relate demand to "generalized cost" which is a composite of "money costs" and "time costs" perceived by travellers. These techniques rely on "money values of time" to put time and money on a common denominator. If, for example, time is valued at one dollar an hour, the conventional methodology will treat alike two travellers, one of whom saves one hour and four dollars and another who saves a dollar and four hours. The UMOT process, on the other hand, keeps time and money "budgets" as separate entities and, based on the observation that both tend to be stable, assumes that travellers desire to satisfy each budget separately.

(d) Conventional models use as principal inputs the "trip rates" of different population sections, from which a pattern of "generated" trips is predicted and used as a basis for travel forecasts that are virtually independent of the capacity of the transport system. The UMOT process uses the time and money constraints as inputs, and derives trip patterns as outputs that are directly related to the performance of the transport system and the urban structure.

(e) Conventional models concentrate on peak-period travel, the extent of which is arbitrarily determined as an input (e.g. peak periods of one, two, etc. hours are assumed for design year conditions). The UMOT process works on a 24-hour basis, and treats the extent of the peak-period as an output to be calculated.

(f) Conventional models use motorization levels, predicted separately, as inputs. The UMOT derives motorization levels, or at least car usage, as an output from travel money budgets and vehicle ownership and operating costs.

## 10. Does the UMOT Process Conflict With Conventional Methodologies?

It is in direct conflict with the "trip generation" element of currently used procedures, as described in (for example), the Transportation and Traffic Engineering Handbook of the Institute of Highway Engineers.* However, the UMOT process does not conflict with other elements of current procedures, such as the distribution of predicted traffic flows over road networks. Thus the UMOT concepts and procedures can be used in conjunction with many of the accepted procedures.

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* See Chapter 12, "Urban Transportation Planning" by D.K. Witheford (page 503, 1976 Edition): "Trip generation analysis is the key to obtaining future trip ends by zones. The basic procedure is first to relate survey-reported trip-making to household characteristics and the land-use types by zone through regression or factor analysis, using either single variable or multivariate approaches."

11. What are the Surveys Necessary to Obtain Inputs for UMOT?

For many cities no additional surveys need be made, as the raw data for conventional studies often contain all the data necessary for UMOT inputs. For example, travel time budgets can be obtained from the replies to household travel surveys, and travel money budgets from a knowledge of unit travel costs and information on trip lengths. Household income information is also often available from conventional surveys. For Bank purposes, the biggest informational gap will usually be data on non-motorized travel.

12. What Computer Facilities Does the UMOT Process Require?

An electronic pocket calculator with the capability of carrying out slide-rule type computations can suffice, but involves manual iterations. A fully programmable version, suitable for a high speed computer, could be developed.

13. How Can the Bank Use the UMOT Process?

(a) To check the outputs of conventional transport studies.

(b) To obtain quick assessments of travel conditions in LDC cities for the appraisal of projects and for the identification of areas requiring more detailed study.

(c) To identify the transport policies and investments that could be used to guide the direction and form of urban development.

14. How Can the UMOT Process Help the Bank to Assess the Transport Needs of Low Income People?

Because it emphasizes the constraints on travel - the time and money budgets - the UMOT process is concerned with the travel habits of different income groups. By the very nature of the process, which studies travellers rather than trips, UMOT can identify the "travel disadvantaged" - those segments of the population that spend disproportionate amounts of time and/or money on travel. Annex 2 gives an example of how this was done for the Washington D.C. area, where it was found that those travellers who use only public transport spend more time, and travel less, than travellers who have access to private transport. Furthermore, the disadvantage of this group of travellers was found to have got worse from 1955 to 1968: They spent more time and made fewer trips at lower speeds, while other travellers spent the same time but travelled further at higher speeds. In the developing countries it will be necessary to apply the UMOT process to non-motorized, as well as to motorized, trips.

15. How Can the UMOT Process Identify Measures to Affect Urban Structure?

An improvement in transport (e.g. an increase in speed, or a reduction of costs) can generally be expected to lead to increased travel. But this increase can take a number of forms: If an urban area is allowed to expand, as in Washington, D.C., most of the increased travel will be used to lengthen trips, rather than to increase their number. Where expansion is difficult, as in London, transport improvements are more likely to result in an increase in the number of trips. The UMOT process can be used to assess the likely effect of transport improvements on urban structure, and thus to help planners select the measures most likely to lead to the results desired by our borrowers.

16. What is the Status of the Relationships Used in the UMOT Process?

It should be pointed out that many of the relationships used by UMOT are "indications" obtained by observation, and that the validity of the process does not require all the relationships to be constant for all time. Further study is needed to determine the "robustness" of the UMOT process in the face of changes in its underlying relationships. Many of the relationships are described in Staff Working Paper No. 230, "Travel Characteristics in Cities of Developing and Developed Countries" (SWP 230). The status of the most important is as follows:

(a) Travellers (or tripmakers) per household (SWP 230 pp 48-49)

The UMOT process relates travel to "travellers" (designated "tripmakers" in SWP230), who are defined as those who travel at least once on a typical week-day.* Any change in the number of travellers as a proportion of total urban population would have a corresponding effect on the mobility of that population. We have evidence that the proportion of travellers increases with car availability, (i.e. with income and household size), but do not know how it changes in relation to the availability of bicycles, motorized public transport; or other factors.

(b) Stability of Car Daily Travel Time (SWP 230, pp 46-47, 91)

The average daily time spent by cars moving on urban roads is relatively stable, both between cities and over time in the same city. Data collected by Zahavi indicate a range of 0.62 to 0.85 hours in the developed countries, and 1.10 to 1.40 hours in the developing ones. The stability of this factor can be considered to be established, but its value for individual urban areas should be obtained at every opportunity, certainly in cities in which Bank-supervised studies are carried out.

(c) Stability of daily person travel time (SWP 230 pp 50-51)

Data from US and UK cities suggest that daily travel time per person (as distinct from per car) has a high degree of stability. UK data include, and the US data exclude, walking time. The actual travel times cannot be compared as the UK data relate to persons and the US data to travellers ("tripmakers"). As mentioned in para 14 above, the US data also

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* i.e. If a population were to consist of 6,000 people each of whom travels on one day out of six, there would be 1,000 travellers.

identify a group of "disadvantaged" travellers - those who make all their motorized trips by public transport. Their daily travel time is abnormally long. We have no person-travel time data from the developing countries, and should give high priority to obtaining them as this factor seems to be of major importance in assessing the adequacy of urban travel opportunities and in predicting the effects of transport improvements

(d) Stability of travel money budgets (SWP 230 pp 36-37).

Evidence from Canada, the UK, West Germany, and the US indicate that expenditure on travel as a proportion of total household expenditure has a high degree of stability, both over time, and between income groups. A significant exception is provided by low-income people who make all other motirized trips by public transport. They spend a smaller proportion of their expenditures on transport than other income groups; in the developed countries this may represent inability to afford the use of private transport, and in the developed countries an inability to afford motorized transport of any kind. More data on household transport expenditures are clearly needed, but the formidable difficulties of obtaining this kind of information are well know. As a start, it would be desirable to look for information in published expenditure survey reports.

(e) Trip distance in relation to the distribution of residences and jobs.

This is a key relationship, as it provides the link between the transport and land-use elements that make up the UMOT process. It suggest that average trip distance in an urban area equals the distance between the "weighted" centers of residences, and employment, respectively. The concept needs to be refined in various ways but, even in its present form successfully predicts average trip distances with an error of less than 10 percent.

(f) Dynamic Capacity of an urban road system (SWP 230 pp 30-33)

The UMOT process assumes that, given the total vehicle hours travelled on a road network, an increase in the "arterial" road length of $L$ percent would result in vehicle speeds increasing by $\sqrt{L}$ percent. This, too, is a key relationship; it is required for predicting the effects of infrastructure improvements on traffic speeds which, in their turn, affect travel distances, modal splits, etc. While the use of this relationship has enabled Zahavi to make acceptable predictions of traffic speeds, the definition of "arterial" road is ambiguous and more work is needed to establish a better measure of road network capacity.

17. In Sum, Does the UMOT Process have Potential For Development As A Tool For Operational Work?

It was suggested in paragraph 2 above that the usefulness of UMOT depends on its predictive powers. On this basis, it seems to score high marks for its predictions of the number and characteristics of motorized trips in Washington, D.C., Twin Cities, Bangkok and Kuala Lumpur. The process can give quick answers to basic questions within acceptable limits of error and without the need for elaborate computing facilities. So far as I am aware, no comparable tool exists. It seems to be particularly suited to identify the transport "deficiencies" of different income groups. However, the UMOT process needs much more empirical support before it can be accepted as valid in the developing countries, and it has not been tested at all for non-motorized trips.

18. Where Could We Go From Here?

The Bank now has the elements of a process which, even in its present stage of development, could enable its staff and its borrowers to make great advances in the understanding and prediction of urban transport and land-use phenomena. We could use it immediately in operational work while developing it further as follows:

(a) Data on travel characteristics from developing countries, particularly on travel time and money "budgets", should be collected to expand and refine the findings obtained already.

(b) The process should be applied to the travel modes of poor people: walking and cycling.

(c) The relationships between trip distance and the distributions of residences and jobs should be refined and extended by, for example, obtaining separate data for different income groups.

(d) The capacity measures for urban road networks should be improved.

(e) More information should be collected on two- and three - wheeled transport, commercial vehicles, buses, minibuses and taxis.

(f) A computer program should be developed to (i) store the relevant data in a systematic manner; (ii) produce key tabulations; and (iii) carry out the iterations needed to produce UMOT outputs.

cc: Messrs. Jaycox, Churchill, Walters, McCulloch, D.D.Singh, Stone,
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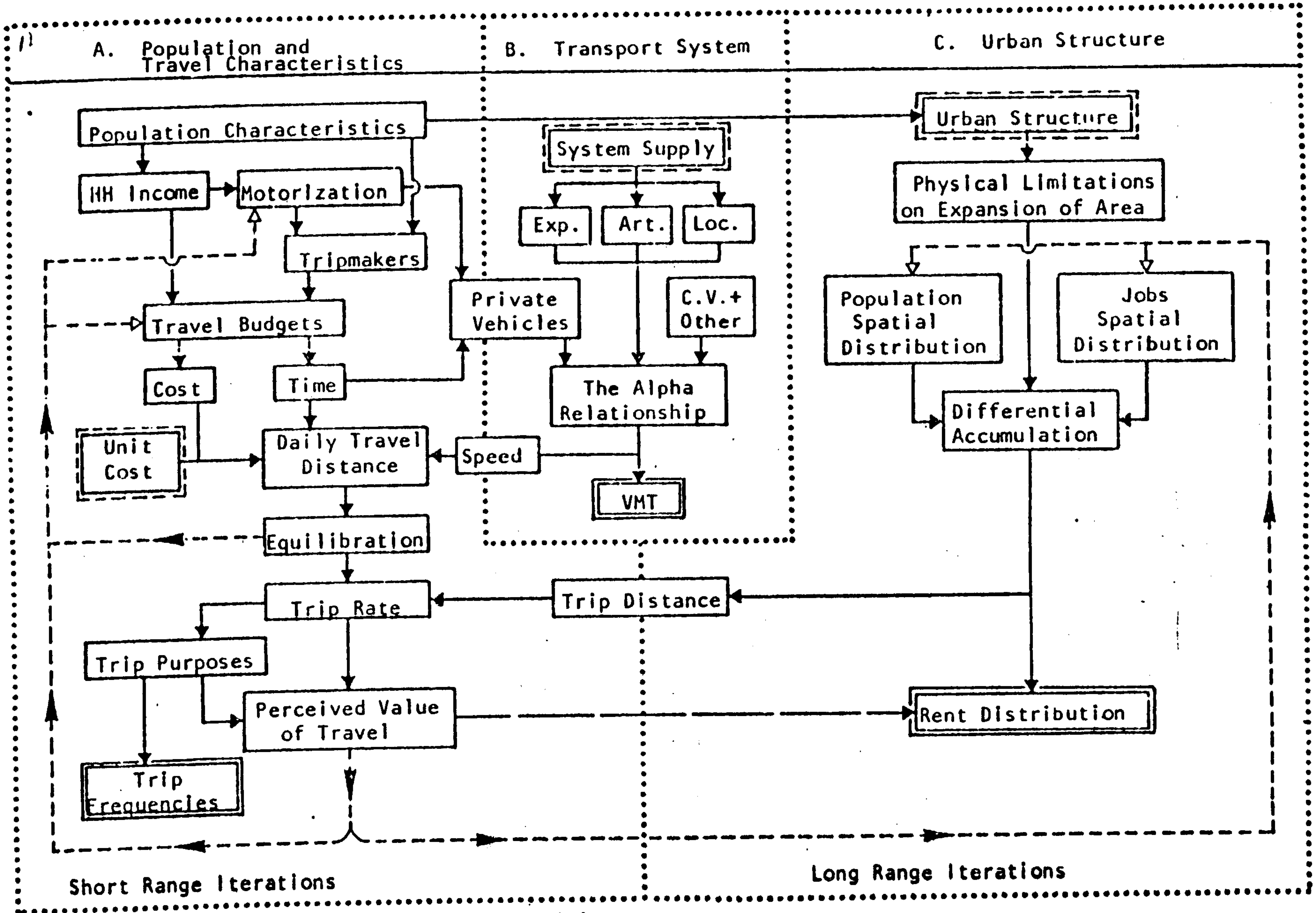
Schematic Flow Chart of the Unified Urban-Transport Model (UMOT)
(Private Transport)




=== Inputs senstive to alternative policies
Outputs

## Estimation of Household Travel Distance

Figure 1 shows the daily travel distance per household, by district, versus income for households who made all their travel by car. The relationship can be expressed by:

$$D/_{HH}, \text{ km.} = 1.8(10^{-6})\text{Inc.}^{1.869} \;;\quad (r^2 = 0.885); \quad (2)$$

(Data on a disaggregated basis result in even a better relationship, $r^2 = 0.943$).

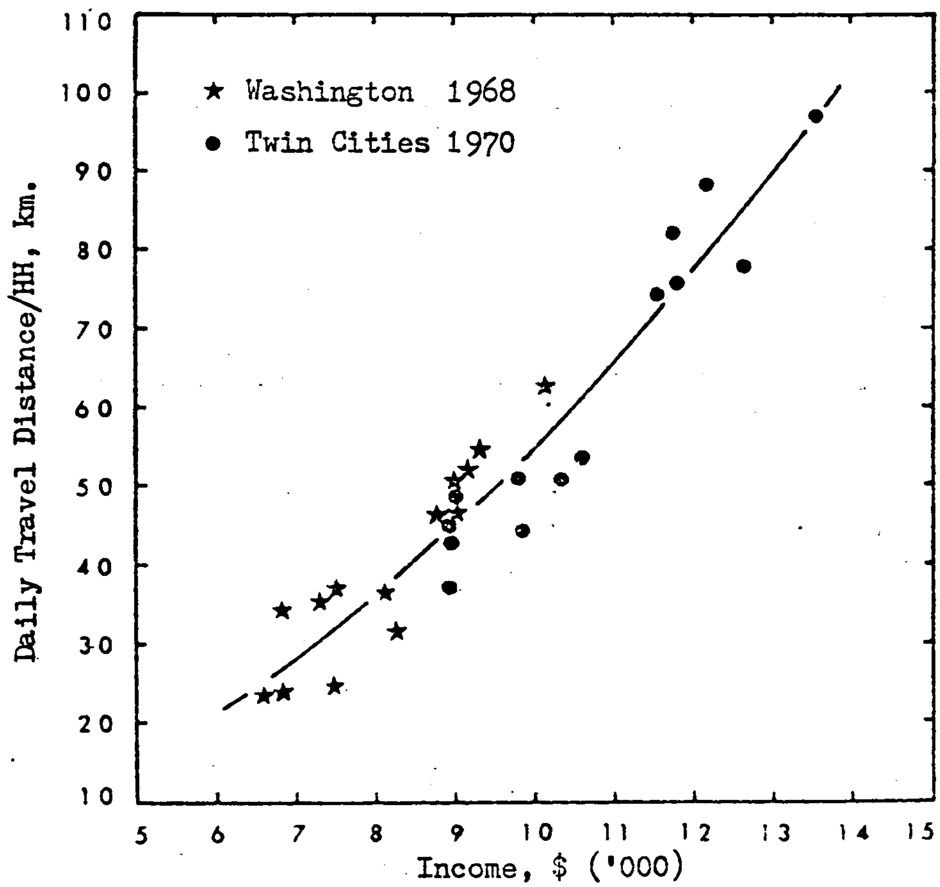



Fig. 1: Daily Travel Distance per Household vs. Annual Income (all travel by car only)

It can also be shown that the daily door-to-door travel speed of households is strongly related to the income level, and can be expressed for the above case by:

$$v, \text{ kph.} = -2.72 + 0.0029 \text{ Inc.} \quad (r^2 = 0.833); \qquad (3)$$

The car travel cost per unit distance depends on the speed of travel, as can be seen in Figure 2 for the travel conditions in the US in 1967-68 for a standard size car. This figure is based on the conventional operating costs by speed, while the standing costs are related to the car TT-budget, and within the range of speeds in urban areas it can be expressed by:

$$c = 1.494 \ v^{-0.75} \ ; \qquad (4)$$

where c is in US ¢ and the speed is in kph.

Fig. 2: The cost per mile vs. Speed for standard-size Car in the US, 1967-1968

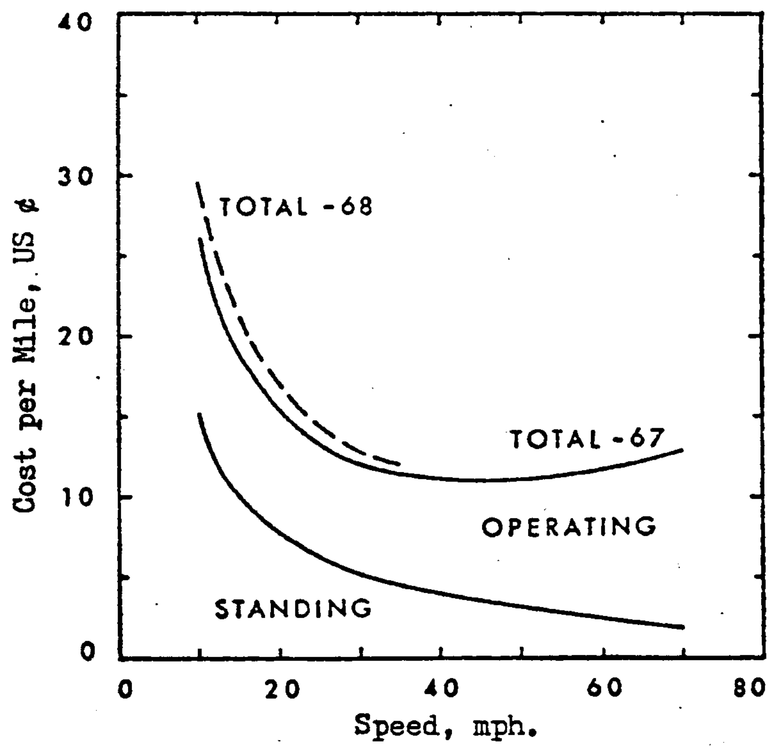



Table 1 summarizes the estimation of travel distance by income groups for households who made all their travel by car in Washington, D.C. 1968 and Twin Cities 1970, according to the following steps:

(1) Income group, by district;

(2) The road travel speed, derived from Eq.3 and multiplied by 1.58, the factor which transfers door-to-door speeds to network speeds;

(3) The cost per unit distance at the above speed, according to Eq.4;

(4) Income per weekday = Annual Income/312 days;

(5) The TM-budget per household, at 10.5 percent of the daily income;

(6) The daily travel distance per household, derived as the quotient of TM over c and multiplied by 1.5, the car average occupancy rate;

(7) The observed daily travel distance per household, as derived from Eq.2.

Table 1: Estimated vs. observed daily travel distance by car per household, by income, Washington, D.C. 1968 and Twin - Cities 1970

| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|
| Inc. | vx1.58 | c | Inc/day | TM | Dx1.5 | Dobs. |
| 7,000 | 27.78 | 0.123 | 22.44 | 2.36 | 28.7 | 28.15 |
| 8,000 | 32.36 | 0.110 | 25.64 | 2.69 | 36.7 | 36.13 |
| 9,000 | 36.94 | 0.100 | 28.85 | 3.03 | 45.4 | 45.02 |
| 10,000 | 41.52 | 0.091 | 32.05 | 3.37 | 55.5 | 54.82 |
| 11,000 | 46.10 | 0.084 | 35.26 | 3.70 | 66.1 | 65.51 |
| 12,000 | 50.69 | 0.079 | 38.46 | 4.04 | 76.7 | 77.08 |
| 13,000 | 55.27 | 0.074 | 41.67 | 4.38 | 88.7 | 89.52 |
| 14,000 | 59.85 | 0.069 | 44.87 | 4.71 | 102.4 | 102.82 |

The comparison between the estimated and the observed values is shown in Figure 3, where the curve represents the best-fit line of the observed values, as in Figure 1, while the dots represent the estimated values for each discrete income group.

It should be noted that the above exercise is based on average factors for the whole area, such as the TM-budget at 10.5 percent, and 1.58 and 1.5 mentioned in steps (2) and (6) respectively. Nonetheless, the match between the estimated and the observed values can be regarded as fully satisfactory.

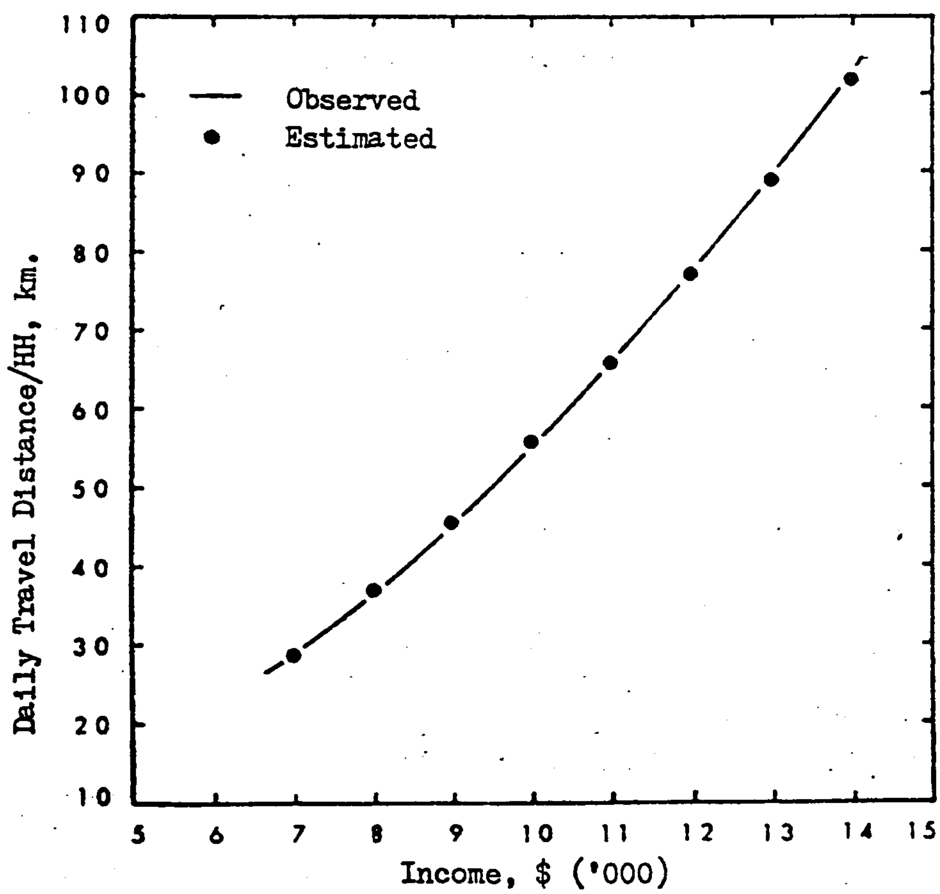



Fig. 3: Estimated vs. Observed Daily Travel Distance per Household vs. Household Annual Income, Washington, D.C. 1968 and Twin Cities 1970

Identification of "disadvantaged" travellers in Washington, D.C.

Recent analyses of four traffic studies in Washington, D.C. and Twin Cities showed that the average door-to-door travel time was about 1.1 hours for "car only" tripmakers over a 12-13 year period, as shown in Table 2. 1.10 hours was also the average daily travel time per car tripmaker for the whole U.S. in 1970.

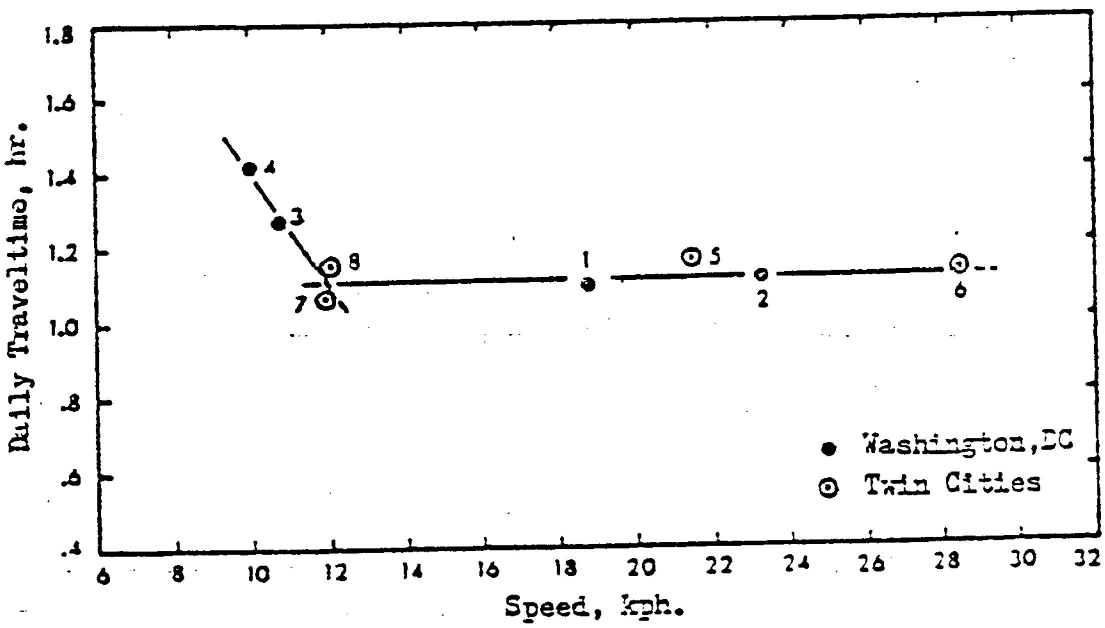
TABLE 2 - DAILY TRAVEL TIME PER TRIPMAKER VS. DOOR-TO-DOOR SPEED WASHINGTON, D.C. AND TWIN CITIES

| City | Year | Car | | | Transit | | |
|---|---|---|---|---|---|---|---|
| | | Travel Time Hours | Speed mph | Speed kph | Travel Time Hours | Speed mph | Speed kph |
| Washington, D.C. | 1955 | 1.09 (1) | 11.7 | 18.8 | 1.27 (3) | 6.6 | 10.7 |
| | 1968 | 1.11 (2) | 14.5 | 23.3 | 1.42 (4) | 6.2 | 10.0 |
| Twin Cities | 1958 | 1.14 (5) | 13.4 | 21.5 | 1.05 (7) | 7.4 | 11.9 |
| | 1970 | 1.13 (6) | 17.7 | 28.5 | 1.15 (8) | 7.5 | 12.1 |
| All USA | 1970 | 1.10 | | | | | |

Table 2 also shows the travel time of tripmakers who used only transit in Washington, D.C. and Twin Cities. This shows the significant result that while in Twin Cities the "transit-only" tripmakers had the same travel-time budget as the "car-only" tripmakers, namely about 1.1 hours per day, the travel time of "transit-only" tripmakers in Washington, D.C., in 1955 was at 1.27 hours per day, significantly higher than the travel-time budget of "car-only" tripmakers, and by 1968 the travel time of "transit-only" tripmakers in Washington, D.C. increased even more, to 1.42 hours, while the travel time of "car-only" tripmakers remained virtually the same.

The daily travel times of "car-only" and "transit-only" tripmakers shown in Table 2 are plotted in Figure 4 against average door-to-door travel speed, and it will be seen that the daily travel time rises when travel speeds fall below about 7.5 mph. (11 kph)

FIGURE 4. Daily Travel Time Per Tripmaker vs. Door-to-Door Speed Washington, D.C. and Twin Cities




It should be noted that while the trip rates of "car-only" tripmakers in Washington increased from 3.07 to 3.16 between 1955 and 1968, the trip rate of the "transit-only" tripmakers decreased from 2.31 to 2.12, and came close to the minimum trip rate of 2.0 per day.* The increase in the travel time of this group was therefore not accompanied by an increase in trip rate.

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* 2.0 trips per tripmaker is the minimum rate because virtually all urban trips involve outward and return journeys on the same day.