Travel transferability between four cities

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INTRODUCTION

The essential purpose of travel models is prediction. We simulate the present in order to understand the future. But cities are liable to change over time, so we can never be confident that models that simulate the present are reliable guides to the future. If, however, a model based on observations in one city could be shown to have the ability to predict travel conditions in another city at the same point of time we would have more confidence of its ability to simulate conditions in the same city at a different point of time. This is the problem of model transferability.

Model transferability can be assured only by basing the model on travel characteristics which themselves are transferable. Therefore, this paper deals with travel characteristics which are transferable. The paper intercedes with the indication that a major travel characteristic which appears to be transferable between cities is that based on the regularities associated with the daily travel time expenditures per traveller. A model based on these regularities is therefore expected to be more transferable than one based on non-transferable characteristics such as trip rates.

The tests for the transferability of travel regularities between cities were part of the work under a contract with the U.S. Department of Transportation (DoT), requiring the examination of travel regularities in a U.S. city and their comparison with data from sources outside the U.S.¹. The purpose of the comparison was to verify basic relationships applicable in the UMT model.¹ The selected U.S. city was Baltimore and its travel data were compared with those of London and Reading in the U.K. Availability of data from Washington, DC allowed this city to be added as well, thus comparing two U.S. cities with two U.K. cities. Since this paper appears in a British magazine, the emphasis is put on the U.K. data, but detailed analyses are available for all four cities.

THE DATA

The London and Reading data were derived from the home interview surveys conducted in 1968 and 1977 as part of the Regional Highway Traffic Model (RHTM). The Washington and Baltimore data were derived from the home interview surveys conducted in these cities in 1968 and 1977, respectively. The basic tables for analysis, derived from the raw data, were prepared by Woodson, Jeffrey & Partners for London and Reading, and by the U.S. DoT for Washington and Baltimore.

The basic tables analysed in this report were not fully compatible with each other, partly because they were prepared in different formats and partly because the raw data classifications were different. The following principal differences are to be noted in the household samples: London—households that generated internal trips plus trips to external zones of a length less than 60 km (37 miles); Reading—households generating internal and all external trips; Baltimore—all households, but only their internal trips; Washington—analysed in this paper are households residing in a North corridor in the city, and only their internal trips were tabulated.²,³

Furthermore, the London, Washington and Baltimore tables include information on trips, while the Reading information is for total daily travel only. Moreover, the London, Reading and Baltimore travel distances, times and speeds are by mode, while in Washington travel is total, by all modes.

Lastly, travel distance in Baltimore is network distance. In Washington it is the X-Y co-ordinate distance (i.e. sum of the differences in the Xs and differences in the Ys), which was found to be about 0.95 times the network distance. In London and Reading, on the other hand, travel distance is airline distance. Hence, airline distances, in kilometres, is shown in the diagrams where only London/Reading relationships are included, while a transformation to network distance in miles, based on factors recommended by O/field, are shown in the diagrams where the U.S. cities are included.

Despite the above differences, a number of useful relationships emerged from the comparisons, as described below.

Table 1 summarises several principal characteristics of the four cities and their travel. (Washington 1968 data in Table I are total for the city, while the diagrams below show data for the North corridor only. The Washington 1955 data are added for comparison purposes.)

DATA STRATIFICATION

The raw data in each city were stratified by three principal dimensions: household annual income, household size and household car ownership level. Because of limitations imposed by the available sample size (shown in Table I), the number of income groups were: London—12 groups; Reading—6 groups; Baltimore—6 groups; and Washington—5 groups. Size was stratified into 5 groups in the first three cities (1, 2, 3, 4, 5+), and it was immediately available for 4 groups in Washington (1, 2, 3–4, 5+). Car ownership levels were 3 in London and Reading (0, 1, 2+), and 4 in Washington and Baltimore (0, 1, 2, 3+).
households or travellers that generated them. A traveller is defined as a person who made one or more trips by a motorised mode during the survey day.

The motorised modes are car, bus, rail, taxi and motorcycle in London and Reading, and car, bus, taxi and motorcycle in Baltimore. The travel characteristics, by household and by traveller, were daily travel time and distance, trips, trip distance and trip time. Additional tables were prepared for travel time and distance frequency distributions.

GENERAL COMMENTS

The rest of the paper is devoted to a graphical presentation of the relationships derived from the basic tables, with minimum text, in order to save space and following the saying that "a diagram is worth a thousand words." Five comments may be in order.

(1) Relationships analysed in depth are those basic to the UMO model, such as the daily travel time expenditures per
   person. A general analysis, based on aggregate data, was made of other relationships that emerged when examining the travel data of widely differing cities.

(2) An additional reason for relating aggregate data is to show how a trip by car are frequently different from those travelled by
   other modes. While a weekly travel diary would resolve part of the problem, the available one-day data make it difficult to isolate the sources of data variations. Furthermore, the small sample size in the Baltimore case (654 households representing more than 0.5m. households) and their stratification into 120 cells of socio-economic characteristics left many of the cells either empty or with too few households for deriving meaningful relationships.

(3) Most of the relationships derived for each separate city were based on three data sets, each stratified by one socio-
   economic characteristic (income, size and cars household). The closeness between the plotted three data sets indicated that the relationships are robust and consistent enough to emerge whichever way the data are stratified. (While the best-fits in the diagrams are based on least-squares regressions, this technique is used for presentation purposes only, and not for statistical tests.)

(4) No causal relationships are suggested in this paper since the UMO model is based on a multi-loop feedback process, where cause and effect may interchange, depending on the process step. Furthermore, the relationships are limited to one independent variable at a time not only because of the relatively small sample size, but also because of the high correlation between the socio-economic variables (see point (3) above).

(5) Most of the relationships for London and Reading are compared on the basis of household annual income. This is why only London and Reading are shown in the relationships which are based on income (e.g. Fig 2). When the relationships of the four cities are compared, the common denominator for comparison is car ownership level. Car ownership level is expressed by either average cars per household related to household income (say 0.5 cars per average household; e.g. Fig 1) or cars per household based on the availability of a car to a household, namely households owning 0, 1, 2+ cars in the two U.K.

6. Door-to-door speed

Figure 6 shows that door-to-door speeds (daily door-to-door travel time, including access and egress times) differ in the four cities. Once again, Reading is significantly different from the other cities. Speeds by mode are shown in Fig 7. Indicating that travel speeds by car and bus are lowest in London.

7. Travel time by mode

Figures 8 to 10 show the breakdown of the daily travel time per traveller in three cities by the available travel modes. An important result emerging from these figures is that although rail travel is conceptually regarded and treated as public transport, similarly rail travel, the time allocated to it follows that is, of car not of bus. Indeed, Fig 11 shows that the expected traditional shape of modal rates in London and Reading by travel distance, emerges only when the travel distance by bus is measured with respect to total travel distance. On the other hand, when bus and rail distance is measured with respect to total distance, the shape of the relationship is convex, indicating that more car ownership levels, namely contrary to the traditional shape. Thus, travel by rail has characteristics that resemble car travel much more than bus travel.

Two important indications may be inferred from the above results. First, a highspeed public transport system appears to be a partial substitute for cars; lower car ownership levels. In a large city having an urban 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 (the emphasis here is on the speed that the mode provides, and not on the mode's name).

The second implication, quite contradictory to conventional beliefs, is that high-income travellers appear to derive more benefits from a high-speed urban rail system than low-income travellers. One reason for this may be urban structure, since middle-

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8. Daily travel distance per traveller
Perhaps the most interesting relationship in this paper is shown in Fig. 12, depicting the daily travel distance per traveller versus speed.

This relationship based on car ownership, from 0-car at the lower-left corner to 2+ or 3+ cars at the upper-right corner can be regarded as transitive between all four cities. The same relationship emerges when the travel speeds are stratified by income and/or by household size. The only outlier in Fig. 12 is the group of travellers in Reading belonging to households owning 2+ cars, not only is their sample size small, but their share of inter-city travel is highest. This relationship can be regarded as one of the cornerstones for a transferable travel model, since passenger-miles of travel can then be estimated directly from travel speeds. Indeed, the same relationship was observed in such cities and regions as Munich, Nuremberg, Singapore and Tel-Aviv.

One conclusion inferred from this transferable relationship is that the daily travel time expenditures per average traveller are not regular regardless of how they are stratified (e.g., see Prendergast and Williams*). It is quite obvious, for example, that segmentation of travellers by such groups as housewives versus working husbands, or age 20-30 versus age 70-80, will result in significantly different daily travel time expenditures per average traveller. Again, the concept does not necessarily apply to the average of all persons, whether travellers or not (e.g., see Tanner*), because the proportions of travellers are found to change over time by such factors as household size (e.g., Fig. 3).

The question is whether the daily travel times of travellers are fixed—which, obviously, they are not—but whether regularities exist at a useful level of disaggregation that are transferable in space and time.

One such transferable regularity can be derived from Fig. 12. However, note that the values shown in this figure still permit great travel variations between individual travellers, as well as day-to-day variations of one traveller. The latter can far surpass variations between two travellers belonging to different socio-economic groups.

In order to test the regularities of travel time expenditures per traveller while accounting for socio-economic groups and variations within each group, the test was carried out on the frequency distributions of travel times by contingency table analysis, a stringent test. The results of this test are detailed below.

9. Travel time budgets
The concept of a daily travel time budget has sometimes been misunderstood. It does not mean that each and every traveller must travel a fixed time per day each and every day, an interpretation which is quite absurd. Nor does it mean that time expenditures will

10. Travel time frequency distributions
Detailed analyses of the total daily travel time frequency distributions in each city were carried out for income and car ownership stratifications, by 10-minute intervals. Because of space restrictions, summarised examples are displayed graphically.

The first example is that of Baltimore. Figure 13 shows the frequency distributions for the 6 income groups (grouped by 20-minute intervals for clarity of presentation), while Fig. 14 shows Gamma functions fitted to the 6 income groups. Contingency table analysis indicated that the null-hypothesis of equivalence among the 6 distributions is accepted (at the 95% confidence level).

Figure 15 shows the Baltimore data stratified by car ownership levels. Of particular importance is the shift of the 0-car curve to the right, namely towards longer travel times. In this case equivalence was accepted for travellers of households owning 1, 2, 3+ cars, but it was rejected for 0-car travellers. That is, 0-car travellers spend significantly different (i.e., longer) daily travel times than car-owning travellers.

The total distributions of the North and South corridors in Washington were found to be equivalent, as well as for all car ownership levels within each corridor.

Figure 16 shows the Gamma functions fitted to the 12 income groups in London. In this case, however, the analysis of all 12 groups simultaneously indicated significant differences between them. An examination
of the travel time tables indicated markedly different spreads of the tail-end of the distributions for very low and very high income groups. The next test, therefore, was carried out for pairs of adjacent income groups, and in almost all cases equivalency was accepted, while in the few remaining cases the Chi-square value was just beyond the threshold of acceptance. Furthermore, even the simultaneous analysis of the middle 6 income groups (2000-8000 range) resulted in acceptance of equivalency. It may, therefore, be concluded that while the time distributions of travellers at the extreme-end income groups are different, the change is gradual, and travellers belonging to adjacent income groups behave similarly. Furthermore, travellers in the middle income groups 5-10, comprising 72 per cent of all travellers, behave similarly. Similar shifts by income were also noted in Reading, where equivalency was accepted for pairs of adjacent income groups.

Figure 17 shows the London data stratified by car ownership level. While equivalency between travellers owning 1 and 2+ cars was accepted, a significant difference was found between the 0-car and car-owning travellers. The 0-car curve is shifted towards longer travel times, in line with the trait noted in Fig 15. It may therefore be inferred that the gradual change in the proportions of 0-car versus car-owning travellers can be the reason behind the gradual shift of the distributions by income, as noted above. When referring back to Fig 12 it may further be inferred that it is the travel speeds which affect the shifts in daily travel times, and not the availability of a car, as such.

The effect of speed on travel can be seen best when comparing the time versus distance per traveller distributions. Figures 18 and 19 show the daily distance distributions in Baltimore and London respectively, by car ownership levels, which can be compared with their respective daily time distributions shown in Figs 15 and 17. (Note that travel distances in Baltimore are by 2-mile intervals, while in London they are by 10-km intervals.)

It may be concluded from this comparison that: (i) travel speeds increase with car ownership levels; and (ii) travellers at higher speed travel less daily travel time for more travel distance. It may also be concluded that part of the times saved by speed increases are traded off for more travel distance.

The above results suggest two interesting possibilities: (i) the generation of induced travel; and (ii) that the benefit derived from increased speed (namely the 'value' of saved time) is at least as much as the additional cost required to purchase the increase in both speed and travel distance.

A comparison between the total time distributions in each of the four cities is shown in Fig 20. It becomes evident that the regularities observed in the travel time distributions are transferable among the cities when accounting for such factors as speed.

Another useful characteristic of the time distributions is that their coefficient of variation (standard deviation over mean) is similar. For instance: London = 69; Washington (South) = 68; Baltimore = 64. Thus, once the daily mean travel time is known (or estimated from speed), the complete distribution can be constructed.

The analyses, samples of which are shown above, emphasize two conclusions. First, although individual travellers may spend different travel times during a one-day survey, the frequency distributions of
(2) In the search for transferable travel regularities between cities, the daily travel time per traveller, segmented by household's socio-economic principal characteristics, has been identified as a strong candidate. It is not a constant, but a function of door-to-door speed and other related factors.

(3) The transferable regularity of the daily travel time per traveller, and its derivative relationships such as travel distance by speed, can serve as one cornerstone for a feedback model of travel, where all principal travel components interact with each other, as well as with the transport system and urban structure. This approach ensures the internal consistency of a model in one city, as well as its transferability among cities.

The above points serve as the conceptual framework of the UMOT model.

Research is also being carried out on the transferable regularities observed in the travel money expenditures, and the results will be reported in a separate paper.

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