A MODEL FOR TRIPS GENERATED
BY HOUSEHOLDS

By H. J. Wootton and G. W. Pick

The freedom offered by the motor car is counteracted by growing congestion, parking
deficiencies and rising numbers of accidents. Side effects are also evident: decreasing
patronage of public transport and a changing environment. The many traffic studies
of the past decade are evidence of an intense desire to understand the problems and
to appreciate future travel demands. Most of the studies have made estimates of
future travel from models that conform to a clearly defined pattern. Some of the
procedures used in the models, particularly gravity models and assignment methods,
have been extensively studied, developed and documented, while others have re-
ceived little attention. It is surprising that trip end estimation, the first step of most
models and the subject of this paper, falls into the latter category, for these estimates
of trip making are input to, and therefore influence, the distribution and assignment
models.

METHODS OF TRIP ESTIMATION

The most widely used technique for estimating levels of trip making has been re-
gression analysis. The number of journeys is generally a function, usually linear, of
a set of independent variables which are assumed or shown to be relevant. The
method works well and has the advantage of flexibility, as it can be applied to almost
any situation providing sufficient data is available upon which to base the regression
analysis. A disadvantage of the method is that, being empirical in nature, it cannot
provide a real insight into the mechanism of trip generation or establish causal rela-
tionships between the dependent and independent variables. To use the method for
projection involves the assumption that regression coefficients established at a given
time are relevant at some future time. This assumption is unsatisfactory because it
is not clear what, in terms of physical experience, is being assumed, i.e. the meaning
of a regression coefficient is not easily interpreted.

An alternative approach is to establish a hypothesis of trip making and to test this
against available data. This is the method we have chosen to explore, and our hypo-
thesis is a systematic account of trip making behaviour which we shall test here on
data from the London1 and West Midlands2 Transport Studies. The method was first
introduced in the course of the second phase of the London Traffic Survey and was
called Category Analysis. Since then the procedure has been formalised and con-
siderably extended in terms of generality.
A family is a closely knit but independent unit. It also happens that the majority of journeys begin or end at home, and that most journeys are dependent on the family's needs and leisure. It is convenient therefore to consider a household as the fundamental unit of the trip generation process and to assume the journeys it generates depend on the household's characteristics and its location relative to the facilities (workplace, shops, etc.) it demands. We shall measure trip generation as the average number of one-way journeys generated by a household per weekday, and shall further assume that households with one set of characteristics exhibit a different average from households with other characteristics.

The household characteristics that are readily isolated and appear to be responsible for a systematic variation in trip generation are disposable income, car ownership, family structure and size. Logically it would also seem that the location of the household relative to other transport facilities and the ease of reaching required destinations will influence trip generation. These locational qualities are not easy to measure, and though it has proved difficult to establish their importance they appear

![Bar charts showing influence of car ownership on trip generation.](image)

*West Midlands Transport Study*  
*London Traffic Survey*

*Figure 1. Influence of Car Ownership on Trip Generation*
to be secondary to the internal characteristics of the household. This point will be returned to later.

A variable of prime importance to trip generation is car ownership. Figure 1 shows how the total number of journeys per day generated by a household is influenced by the number of cars available to that household. It is not clear from Figure 1 whether the increase in the number of journeys generated by car-owning households is a result of the availability of the car (or cars) or is a result of the larger income normally associated with these households. A further breakdown of the data shows that both income and car ownership are independently important in determining trip generation. Figure 2 shows that the number of journeys generated increases both with increasing income and with increasing car ownership. Therefore, both these factors are important in determining the number of journeys generated, and the observed relationships are sensible in that they conform with intuitive notions of the reasons for (or causes of) trip making.

In addition to car ownership and income, one would suppose that the composition of the household is a further relevant independent variable. Figure 3 confirms this. It shows the effect of the number of employed residents upon trip generation by single-car-owning households. A similar variation is observed for households with no car and with more than one car. In addition to the number of employed residents, the total family size of the household is relevant, and we have found it convenient
to define the following six household structure types as being representative of those occurring in practice:

1. No employed residents and one non-employed adult
2. No employed residents and two or more non-employed adults
3. One employed resident and one or less non-employed adult
4. One employed resident and two or more non-employed adults
5. Two or more employed residents and one or less non-employed adult
6. Two or more employed residents and two or more non-employed adults

An alternative definition of family size and structure might have been a classification by sex and age, and significant results would still have been achieved. The distinction between employed and non-employed was made because it was felt that the majority of non-work trips are made by the non-employed or out of working hours. Analysis has proved this to be the case; work trips are wholly dependent on the number employed, while most non-work trips have one end at home, a much smaller number being made from places of work. Together with suitable definitions of journey purpose, this definition explains a considerable variation in trip making.

In addition to the six family structure classifications, we have used three car ownership levels and six discrete classes of income. The variation of income could have been treated in a continuous sense, but it is convenient from the point of view of both data collection and analysis to define the following income classes:
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1. Less than £500
2. £500 to £1,000
3. £1,000 to £1,500
4. £1,500 to £2,000
5. £2,000 to £2,500
6. £2,500 or more

In this way 108 household classes are defined, and associated with each is a trip rate. It is possible that these classifications may be further subdivided to include variations due to other household parameters; this has not been done because in the first place the quantity of available data is not sufficient to permit further sub-classification without sacrificing accuracy, and secondly, reason and experience do not suggest any other parameter as important as the three we have adopted.

MODES AND PURPOSES OF TRAVEL

The trips generated per day by a household of a given category include trips of several types.

In the present model the total number of trips is broken down by the mode of travel and purpose of the trip. Three modes and six purposes are isolated, as follows:

Modes –
1. Drivers of cars or motor cycles
2. Public transport passengers
3. Other passengers (mostly car passengers)

Purposes –
1. Work
2. Business
3. Education
4. Shopping
5. Social
6. Non-home based

(Purposes 1 to 5 have the origin or destination at home and are defined as home-based. This distinguishes them from purpose 6.)

Each of the 108 categories of household has associated with it a trip rate for each of the $6 \times 3 = 18$ mode and purpose combinations. The basic assumption is made that these trip rates are stable over time so long as factors external to the household remain the same as when the trip rates were measured. This is to assume that the trip-making activity of a household will not change unless it acquires another car, another member, or more income, and that when it does it will emulate the behaviour of those households already in the category it moves into.

Figure 4 shows trip generation rates by mode and purpose for a household with one employed resident in London and the West Midlands. It is encouraging to find families in the same category behave in a similar manner in both areas. Trends between categories are identical in the two studies and absolute differences are small. Indeed, differences cannot be readily proved statistically, and where they do exist they appear likely to be due to differences in the locational characteristics mentioned earlier.

The most important features of Figure 4 are the effect of income and car ownership on modal choice and total trip generation. In broad terms, increasing income creates a higher trip generation by all modes in both car-owning and non-car-owning households. Buying a car immediately increases the total trip generation of the household.
by approximately 2 trips per day, mostly non-work, and also causes a redistribution of the trips previously made. Thus, as car ownership increases, trips by car increase and trips by public transport show a significant decrease. One should note that the radically different public transport systems in London (underground, rail, bus) and West Midlands (essentially bus) cause only small differences in trip behaviour. The effect is chiefly on modal choice, slightly more public transport trips being made in London, particularly for work, at the expense of trips by private transport.
THE DISTRIBUTION OF HOUSEHOLDS

If the assumptions outlined previously are valid and the trip rates for each category are known, the number of trips generated in any given year can be found if the number of households in each category can be estimated for that year. This means that the distribution of households by car ownership, income and family structure must be estimated for the chosen year. The choice of these distributions is an important aspect of the simplicity of the model. There are large numbers of alternatives, but those we have chosen allocate households to the 108 categories from a minimum of planning information. It is significant that all the planning information required is available in the 1966 census of population, and earlier census data fulfils most requirements.

The Distribution of Households by Income

The average and standard deviation of income for the study area, traffic district or zone is assumed to be known, and the households are classified into income groups by assuming that the income distribution is represented by a continuous probability density function \( \varphi(x) \). The number of households having income \( x \) such that \( a < x \leq b \) is given by

\[
N \int_{a}^{b} \varphi(x) \, dx
\]

where \( N \) is the number of households in the zone. The function \( \varphi(x) \) is defined so that its mean and standard deviation are equal to the known values. We have used a Gamma distribution:

\[
\varphi(x) = \frac{x^{n-1}}{n!} \cdot e^{-x/n}
\]

\[
a = \bar{x}/\sigma^2
\]

\[
n = \alpha \bar{x} - 1
\]

because this fits the observed data well and is analytically convenient. Calibrated on information from the West Midlands Transport Study, the value of \( n \) was 1.636.

For forward projections of income distribution \( a \) was recalculated according to:

\[
a' = a/(1 + g)^y
\]

where \( g \) is the annual growth rate of income relative to the cost of living, \( a' \) is the recalculated value of \( a \) (i.e. \( a \) increases if \( g \) increases), and \( y \) is the number of years for which the projection is required. This process results in the average income increasing by a factor of \( (1 + g)^y \) during the projection period, while leaving the ratio of average to standard deviation unchanged.

The Distribution of Households by Car Ownership

To estimate car ownership it is assumed that there exists a conditional probability function \( P(n|x) \) of a household owning \( n \) cars if its income relative to the price of cars is \( x \). The proportion of households owning \( n \) cars is then given by:

\[
P(n) = \int_{0}^{\infty} P(n|x) \cdot \varphi(x) \cdot dx
\]

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The distribution \( \varphi(x) \) is the income distribution and is assumed to be a Gamma function as before. The functions \( P(n|x) \) were found to be of the form

\[
a_n \cdot x^{m_n} \cdot e^{-b_n x}
\]

where \( a_n, m_n, \) and \( b_n \) are constants.

Fitting this conditional probability function to West Midlands data gave values of the constants listed in Table 1.

**Table 1**

<table>
<thead>
<tr>
<th>Number of cars owned for given income</th>
<th>Constants</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 0 = P(0</td>
<td>x) )</td>
</tr>
<tr>
<td>( 1 = P(1</td>
<td>x) )</td>
</tr>
<tr>
<td></td>
<td>1.64</td>
</tr>
</tbody>
</table>

(These values only apply for income expressed in £1,000’s, e.g. income = £2,000, \( x = 2.0 \))

The number of households owning two or more cars was derived by subtraction of those with 0 or 1 from the total:

\[
P(n \geq 2) = 1 - P(0) - P(1)
\]

The curves established from the West Midlands data are plotted in Figure 5. Evidence has also been gained that these relationships remain remarkably stable from one area to another, even between countries. Figure 6 shows the curve for house-
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May 1967

A = Athens 1963
H = Helsinki 1966
L = London 1962
P = Puerto Rico 1965
USA = United States 1958
W = West Midlands 1964

Figure 6. Comparison of Car Ownership Habits in Different Cities

(Note: No compensation is made for the price of cars relative to income in plotting the points for the various cities. The points are located by a simple conversion of incomes at current exchange rates. See text. The upper and lower boundaries are extremes of conditional probabilities of not owning cars measured in WMTS and correspond to areas of high and low residential density.)
holds owning no car, and on it are plotted results from various cities throughout the world. The observations from these cities are positioned in Figure 6 by simple conversion of incomes at appropriate exchange rates. As the income scale implies the relative level of car prices in the West Midlands, compensation should be made for differences in the level of car prices in other cities. This is only possible in the case of London data, and if compensation is made the London results lie on the line $P(y|x)$ established in the West Midlands. The effect of lowering the price of cars relative to income is to increase the probability of owning a car. Thus the results in Figure 6 suggest an ordering of towns by car price levels, which is also suggested by other experience: e.g., car prices in Athens relative to incomes can be expected to be much higher than in the other cities.

![Figure 7. Observed and Predicted Past Levels of Car Ownership - based on data for the West Midlands](image-url)
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( Note: Estimates 1953-1965 based on average incomes and car prices in those years. Forecasts for 1965-2010 based on an average change of income of 70% per annum relative to the price of cars. This is equivalent to the average growth rate in the period 1953-1964.)

Figure 8. Forecasts of Car Ownership - based on data for the West Midlands
For projection purposes it is assumed that the functions $P(n|x)$ are stable with respect to time and that the income distribution relative to the price of cars will change. Note that this change is not the same as is assumed for the distribution of households by income.

To test the validity of the technique we have estimated car ownership in the West Midlands over the last decade, using the historical variation in car prices. The functions $P(n|x)$ which have been used are those in Figure 5, and the results of the prediction are shown in Figure 7. It will be seen that good agreement with actual car ownership has been obtained. If the change in income relative to car prices observed over the last decade is maintained in the future we predict that car ownership will increase as shown in Figure 8.

**The Distribution of Households by Family Structure**

The family structure is obtained by combination of the distributions by family size and number of employed residents. These latter distributions are synthesised separately. At present a Poisson distribution is used for family size and a Binomial distribution for employed residents. These distributions fit the observed facts reasonably well, but the choice of distribution is open and others might have fitted equally. The only parameters needed for the synthesis of the family structure distribution are the average family size and average number of employed residents per household. These are readily calculated from planning data.

**AUTOMATING THE MODEL**

Without the computer the task of applying the model to make detailed forecasts of trip generation would be impossible. Consequently the computer program STEP$^3$ (Synthetic Trip End Prediction) has been written. The program is written in FORTRAN for the Control Data 3300 digital computer. It computes, from basic planning data for each traffic zone, the distribution of households by income, car ownership and family structure. The only data needed for each zone are the total population, households, employed residents and average income.

As an alternative to average income, the number of non-car-owning households (available from the 1966 census) may be input for the base year, in which case the program will use this information to estimate average income for that year and then project this average to the design year. This facility avoids the necessity of estimating incomes in each traffic zone from survey data or other sources.

When the three distributions referred to above have been estimated independently, the households are allocated to the 108 categories in such a way as to preserve the distributions. This is done by a combination of inverse probability relationships (car ownership and income) and iterative methods.

**TESTS OF THE MODEL**

On completion of the allocation of the households to the 108 categories, the trips generated by mode and purpose can be calculated by multiplying the number of households in each category by the appropriate trip rate and summing over all
categories. This process can be used as a simple test of the allocation model, for if trip rates are known from a given survey the trips that result from the model can be compared with the trips measured. Table 2 is such a test applied to the West Midlands data. Trip rates were determined from a household interview survey by grouping the households into the appropriate categories and calculating the rate from the observed number of trips and households in the category. The synthesised results of Table 2 are obtained by multiplying the observed trip rates by the number of households synthesised by the model for the category.

Table 2. Comparison of Observed and Synthesised Trip Generation – West Midlands Transport Study 1964

<table>
<thead>
<tr>
<th></th>
<th>Synthesised</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car and Motor Cycle Drivers</td>
<td>1,330,000</td>
<td>1,370,000</td>
</tr>
<tr>
<td>Public Transport Passengers</td>
<td>1,490,000</td>
<td>1,530,000</td>
</tr>
<tr>
<td>Other Passengers</td>
<td>530,000</td>
<td>540,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,350,000</strong></td>
<td><strong>3,440,000</strong></td>
</tr>
</tbody>
</table>

Confidence in the model can also be gained by making estimates of past levels of trip making and comparing these with historical data, just as the car ownership model was tested earlier in Figures 7 and 8. One source of historical data is the use of public transport in past years, but this raises the question whether trip rates based solely on household characteristics can be justified for use in circumstances where the external influence may be different. This particularly applies to public transport, and it is reasonable to suppose that changing levels of public transport service have effects on trip generation similar to those caused by the availability of a car. Some evidence of this was given earlier (see under Modes and Purposes of Travel, and Figure 4).

EXTERNAL INFLUENCES ON THE HOUSEHOLD

Two attempts have been made to determine how trip generation is modified by the level of public transport service provided. In the second phase of the London Traffic Survey the availability of bus and rail facilities was represented by accessibility indices which were defined for each zone and reflected the number and frequency of services. On analysis the rail accessibility index had no apparent influence on levels of trip making, probably because rail is used largely for the journey to work, for which people select specific services and a more generalised index is of little value. The bus accessibility index was of more value, and was defined as:

\[ \text{Bus accessibility index} = \sum_i \frac{\sqrt{N_{ij}}}{\sqrt{A_j}} \]

where \(N_{ij}\) = the off-peak frequency of buses on route \(i\) and passing through zone \(j\) and \(A_j\) = the area of zone \(j\) in square miles.

By the use of the square root this index places more emphasis on the number of different services in a zone than on the frequency of service. Division by the square root of the area is used to compensate for the unequal size of zones. As the number of routes tends to increase in proportion to the perimeter of the zones, the square
root provides the correct compensation. Values of the bus accessibility index ranged from 0 in the green belt around London to 60 in the centre.

Both bus and rail accessibility indices were included as locational variables in the category analysis for London. As noted earlier, no influence of the rail index was apparent, but where the bus index was high it caused trip generation rates to increase slightly, and there was also an apparent transfer of allegiance from rail to buses. The effect of transfer from car to bus is also evident, but probably less than from rail. In any event these indices suggest that the effects of changes in levels of public transport service are of less importance than the household characteristics.

The difficulty of representing availability of public transport facilities will have been noted from the foregoing. In most instances it is necessary to consider the particular application and choose an appropriate definition of availability. This was one of the reasons for trying a different representation of the effect of public transport services in the West Midlands Transport Study. The historical behaviour of the Birmingham City Transport Corporation was used to modify, by the level and cost of service provided, the number of passengers estimated from the model. Thus to make an estimate of usage of public transport for, say, 1957, changes of income, price of cars, population, etc., were noted, the STEP program was used to estimate trips generated in 1957 and the results were modified to account for the change in level and cost of service of public transport between 1957 and 1964. It was found that the level of service could be represented by vehicle miles, and cost by the average fare paid per passenger journey adjusted for the change in cost of living. Taking 1964 figures as 100%, the following formula, expressing all percentages relative to 1964, was established from Birmingham City Transport data.

\[
P_y = \frac{(V_y T_y)}{F_y}^4
\]

where

- \(P_y\) = public transport trips in year \(Y\) as % of 1964
- \(V_y\) = vehicle miles in year \(Y\) as % of 1964
- \(T_y\) = public transport trips estimated in year \(Y\) as % of 1964 before modification
- \(F_y\) = fares in year \(Y\) as % of 1964

This relationship was then used to estimate the past records of the other four transport authorities operating in the West Midlands and to estimate National and London Transport (bus) records. Some of these estimates, compared with actual behaviour, are shown in Figure 9. In each case the trip rates measured in the West Midlands Transport Study, and the same definition of level of service, were applied to the appropriate changes in household characteristics and fares, etc. The success of the method, particularly in re-creating London Transport and National histories, is most encouraging.

EXTENSIONS OF THE MODEL

Some questions may have arisen in the reader's mind that we have so far chosen to ignore. The following notes will clarify some of the problems concerning assumptions, application of the models or availability of data.

Several important assumptions and implications of the model that have been described concern trip rates. In general the trip rates are obtained from home inter-
Figure 9. Comparison of Observed and Predicted Public Transport Usage (buses only)
view surveys, but as an alternative a standard set of trip rates developed from past surveys may be used. If the latter course is adopted there is of course no guarantee that the mode-purpose breakdown of the standard total trip rates is appropriate to the situation being considered, and a small survey is necessary to establish the proper controls.

If a home interview survey is made to establish the trip rates the method has implications on the method of selecting samples, to ensure adequate representation of each category. To determine an appropriate sample for each category it would appear necessary to apply the model first to census data, thereby estimating the number of households in each category. A typology might also be constructed so that geographical areas can be selected where interviewing should take place.

The trip rates by car drivers measured today are in general appropriate to the free use of cars in the future. They are likely to become smaller if restrictions are placed upon this freedom. There is, at the present, insufficient data to examine what the change would be, but a possible hypothesis is as follows. Suppose a one-car-owning household makes a certain number of trips per day by car for a given purpose, and a restriction then comes into force which prevents the use of the car for that purpose. The hypothesis is that the household will in the extreme behave as a similar non-car-owning household with respect to trips for the given purpose. This would lead to a somewhat reduced number of trips being made by that household, and these would be transferred to public transport. In general terms this amounts to a reallocation of households in the model, which increases the effective number of non-car-owners to the extent that the restriction limits car usage.

Consideration should also be given at a fundamental level to improving the trip generation model. Though we have no immediate suggestions, it seems reasonable that parameters such as availability of modes and network conditions can be brought more directly into the model and might result in a direct estimate of trips with their origin, destination, mode and purpose stated. Such models will only arise from testing philosophical arguments and hypotheses, since the small amount of data available makes any empirical approach impossible.

Every trip has two ends, but so far we have only stated how many trips a household generates per day and have apparently not located the two ends. It is convenient to think in terms of a generating zone and an attracting zone rather than of origins and destinations. The generating zone is the home end of a home-based trip and the origin of a non-home-based trip, and the attracting zone is the other end of the trip. As five of the purposes mentioned earlier are home-based and account for some 85% of all trips, the model locates the generating zone of these trips A model to locate the attracting zone has been developed in which land use activity has been defined in eight classes. The classes are aggregations of standard industrial classifications and the intensity of activity is measured by number of employees, by school attendance or by number of houses. As all trips collected in the West Midlands Transport Study recorded the land use activity at the attracting end, attraction trip rates per unit of activity were calculated by mode and purpose and used to distribute the trips controlled in total by the trip generation model. The same land use classifications were used to develop models for estimating the generating and attracting zones of non-home-based trips, which were also controlled in total by the trip generation model.
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CONCLUSIONS

The few tests we have been able to make of the trip generation model are encouraging. In the future more tests will be made, and no doubt improvements will result. Nonetheless we believe that the model as outlined has a much wider application than that described here, and can only lead to more creative thinking on the trip generation process.

At the present stage of development, and with the encouragement of finding considerable similarities in travel habits between areas of a superficially dissimilar nature, we hope the method will lead to a rationalisation of traffic survey methods. In the extreme the model suggests that census information is a sufficient base from which to estimate travel patterns. With the aid of a few simple surveys, synthetic estimates of travel patterns are an immediate reality.

Acknowledgements

We wish to acknowledge the contributions made by Mr. J. E. Burrell and Mr. B. Jones, both of Freeman, Fox, Wilbur Smith and Associates. Mr. Burrell stimulated the original concept of category analysis and undertook much of the detailed work on the London results. Mr. Jones has implemented many of the new concepts and made them a practical tool on the computer.

References

2. West Midlands Transport Study, Volumes 1 and 2.
3. STEP is a computer program and forms part of a complete set of Transport Analysis Programs. The programs have been written by Freeman, Fox, Wilbur Smith and Associates, and are available on the CDC 3300 computer.

Freeman, Fox, Wilbur Smith and Associates,
London