THE DYNAMICS OF THE PERSONAL TRAVEL SYSTEM

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ABSTRACT: *The paper presents a dynamic interaction model which takes an overview of total travel. This has been developed by Shell Australia in order to explore the effects of increasing affluence, government policy and other factors on future energy requirements for the transport of people. The model simulates future travel, year by year, allowing for feedback effects such as congestion, pollution and the marginal value of time. Estimates are made of personal mobility by considering the demand for travel and modal choice. The dominant role of the car is emphasised. The impact of income and government policy on the demand for travel and on modal choice is evaluated. The paper discusses the structure of the model and the relationships used therein. Preliminary conclusions from the use of the model are presented.*

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INTRODUCTION

Forty per cent of Australia's energy consumption is in the transport sector with seventy per cent of this being supplied by petrol. Projections of demand for petrol until the end of the century are necessary for the effective planning of investment of supply facilities in the 1970s. Recent instabilities of growth in petrol consumption, the impact of the energy crisis and inflation on costs and growing awareness of saturation effects and of public transport have rendered conventional forecasting techniques inadequate. Cars and stationwagons account for about three quarters of petrol consumption and it is this sector which is expected to be the source of any major changes in the overall growth rate. A suitable forecasting model must take into account the underlying forces and their interrelationships in estimating future vehicle miles of travel and hence fuel consumption.

The presently accepted method (Burke et al 1972) of forecasting annual vehicle miles of travel (VMT) is:-

VMI = (population) x (vehicles/capita) x (av. annual miles/veh)

This can be modified by the addition of a fuel usage term to give total annual fuel consumption (Dupont 1975).[1] Various economic models exist for estimating car ownership (e.g. Tulpule 1975b, Tanner 1974, IAC 1974) but the average annual mileage is usually taken as an extrapolation of past trends. These models are inadequate because they fail to consider important interactions and are unable to reflect differing economic, social and political scenario assumptions. Their simplistic structures result directly from the fact that transport research into personal travel has concentrated almost exclusively on urban weekday travel. Little research

(1) Shell also developed such a model in 1974.

has considered weekend and non-urban travel and coverage is far from complete. However, in terms of forecasting total travel and energy consumption, the discretionary element of personal travel, a major part of which is at weekends or outside the major cities, is extremely important.

The model described in this paper represents all the important interactions and feedbacks of personal travel and simulates the growth of travel year by year. The basic forces behind growth in travel are increasing affluence and a growing population. As an example of the other interactions which affect travel, consider the effects of congestion. Congestion will inhibit car usage directly. It will also discourage car ownership, limiting car travel further. But congestion may persuade the government to build more roads, which will encourage more car travel. In addition, in the face of growing congestion government policy may react by encouraging public transport, by increased investment and/or subsidies, which will tend to militate against travel by car. In a similar manner to congestion, a growing proportion of leisure time spent travelling will inhibit further travel by increasing the valuation of marginal time. These are all examples of 'feedback loops'[1] and it is these kinds of interactions which are fundamental to the structure of the model.

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(1) A feedback loop exists where one variable of a system directly or indirectly controls another variable which in turn causes changes in the original one. Amplification and attenuation effects arise from positive and negative feedbacks respectively.

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Our approach has been strongly influenced by Forrester (1961) who developed systems dynamics, a method of representing the time dependent or dynamic behaviour of complex systems in a simulation model.(1) This technique is designed to handle feedback loops. As only the general form of many of the interactions are known, it is not feasible to produce firm planning figures. Rather the model is designed to examine many possible futures and to produce information on the stability of the system and on the relative importance of the different variables and interactions.

In this paper an overview of the model and of the main interactions are introduced (Section 2). Next, the different sectors of the model are described (Section 2 to 9). Some preliminary results and conclusions presented (Section 10). Appendix I discusses some of the problems of modelling, data and calibration while a section of mathematical derivation is relegated to Appendix II.

OVERVIEW OF THE MODEL

The structure of the model is shown in Figure 1. As we are primarily interested in the total demand for travel and the modal split between personal transport (i.e. the car) and mass transport systems (hereafter referred to as 'public transport'), the key sector is the one which determines demand for travel and modal split. As one of the most important determinants of travel is car ownership, a sector modelling this is included. Car ownership is influenced by disposable income and motoring costs. The latter are partly determined exogenously and partly by motoring taxes (i.e. sales tax, excise duty and registration fees) which, in turn, are

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(1) The Club of Rome's Limits to Growth model (Meadows et al 1972) is perhaps the best known implementation of the technique.

determined by government policy.[1] Government policy reacts to pollution, congestion and oil supply by setting the levels of motoring taxes, by controlling capital expenditure on roads and expenditure on public transport. The provision of roads and public transport will further modify the demand for travel and modal split.

Another important determinant of travel is society's perceived valuation of money and time. The utility of money and time for marginal travel will be determined by how much time and money is already being spent on travel, the amount of leisure time available and disposable income. The consequences of travel sector calculates the results of each year's travel (including the amount of time and money spent on travel) and the national economy sector completes the system by modelling the interactions of transport expenditure and motoring taxes on disposable income and leisure time.

The system thus consists of seven sectors (or sub models) which are connected by the interacting variables. Each sub model acts on a set of input variables to determine the values of the relevant output variables. An output variable of one sector will act as an input variable to another. The model as a whole simulates the system year by year. The complete list of sectors and interactive variables are given in Table 1.

DEMAND FOR TRAVEL AND MODAL SPLIT SECTOR

The purpose of this sector is to determine the demand for travel, in terms of annual miles per capita, and the modal split between cars and public transport. The external

(1) The three levels of government, Federal, State and Local, each control different parts of policy. In the model the three levels are not differentiated.

SECTORS
Demand for Travel and Modal Split
Car Ownership
Government Policy
National Economy
Roads and Public Transport
Value of Money and Time
Consequences of Travel

INTERACTIVE VARIABLES	
Congestion	Running Costs of Cars
Pollution	Public Transport Fares
Time Spend Travelling	Trips Speeds by Car
Money Spent on Travel	Trips Speeds by Public Transport
Car Ownership	Passenger Miles of Travel by Car
Expenditure on Roads	Passenger Miles of Travel by Public Transport
Expenditure & Subsidies for Public Transport	Leisure Time
Motoring Taxes	Utility of Money
Disposable Income	Value of Time

TABLE 1: THE SECTORS & VARIABLES OF THE SYSTEM

The major exogenous variables are gross domestic product (GDP), population and oil supply. The relative movement of different categories of costs are also defined externally.

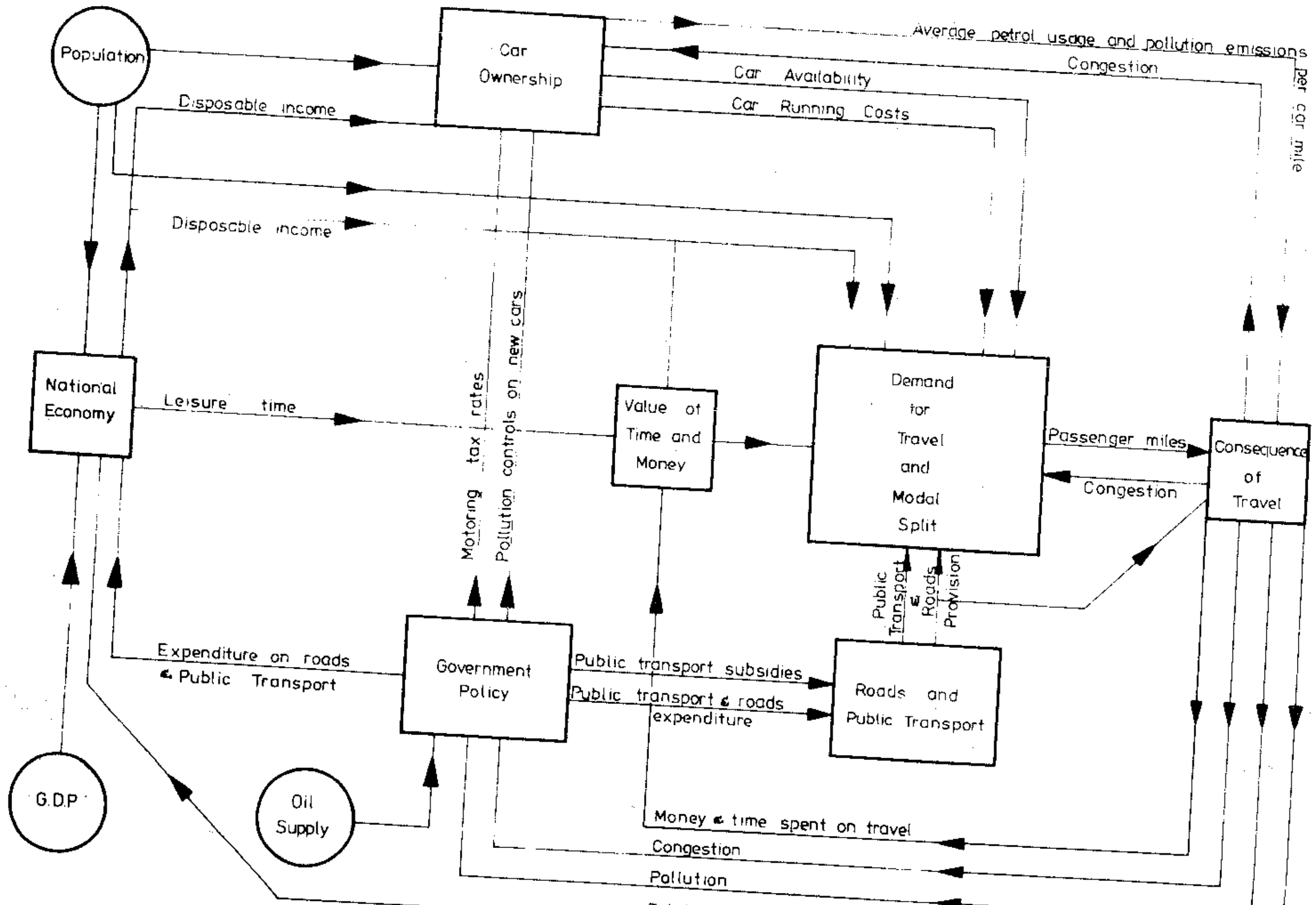

FIGURE 1. The Dynamics of the Personal Travel System

parameters of the sector are car ownership, the costs of running a car and of using public transport, disposable income, car and public transport trip speeds and the values of money and time.

Travel[1] is divided into four categories:

(i) Urban peak travel
(ii) Urban off-peak travel
(iii) Country travel
(iv) Business travel

Urban peak travel is considered to be non-discretionary and therefore its volume is inelastic. Categories (ii) and (iii) contain some essential travel but marginal travel in both cases is discretionary. Country travel is subdivided into two classes - travel by urban residents and that by country residents. Different modes of public transport are not considered explicitly.

Business Travel

Business travel is treated separately from the other three categories. Travel by car is estimated in terms of vehicle miles by a simple relationship of population and time. The latter variable is included to reflect technological progress (e.g. in telecommunications) and perhaps a continuing switch of business travel from car to air. As we are only interested in the energy consumed by cars, business travel by public transport is not forecast[2].

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(1) Journeys by bicycle and on foot are excluded and it is recognised there will be some travel generated by a switch to mechanically powered modes.

(2) As a high proportion of air travel is for business, the whole of air travel is excluded from the model.

Approach to Modal Split

For each travel category the relevant population is divided into two classes - those with a car available and those who are captive to public transport (Figure 2). The former may choose between using a car and public transport and thus public transport travellers are made up of both captives and choosers. This approach to modal split is at variance with that adopted by most workers in this field who ignore (probably for data reasons) the difference between public transport captives and those with a car available. (There are some exceptions, e.g. Davis 1974.) However, it is the author's belief that the approach used here is more realistic and emphasises, correctly, the dominant role of car availability with respect to modal split.

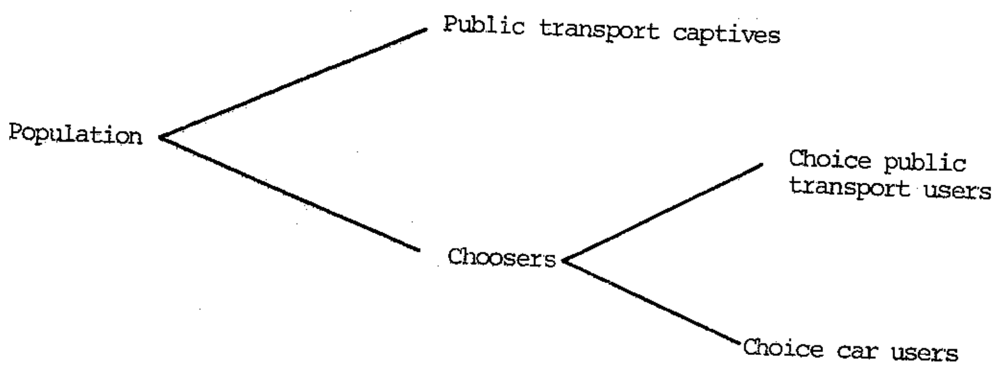

FIGURE 2: THE DIVISION OF POPULATION BY CAR AVAILABILITY AND MODAL CHOICE

Supply and Demand

The volume of travel is determined by the marginal utility of travel (i.e. a demand function) and the marginal cost of travel (Figure 3). A generalised marginal cost can be defined as the sum of money costs and time costs. Therefore, for car travel:-

$$\text{Generalised Cost} = \frac{(\text{Car marginal operating cost}) \times (\text{Marginal utility of money})}{\text{Car occupancy}} + \frac{\text{Value of time}}{\text{Car trip speed}}$$

The value of time is measured in cents per hour and thus both components are in terms of cents per passenger mile.

Similarly for public transport:-

$$\text{Generalised Cost} = (\text{Public transport fare}) \times (\text{Marginal utility of money}) + \frac{\text{Value of time}}{\text{Public transport trip speed}}$$

Because of the higher proportion of extra-vehicular time in public transport trips and their generally less comfortable and convenient nature, time is valued higher for public transport trips than for car trips (see Section 7).

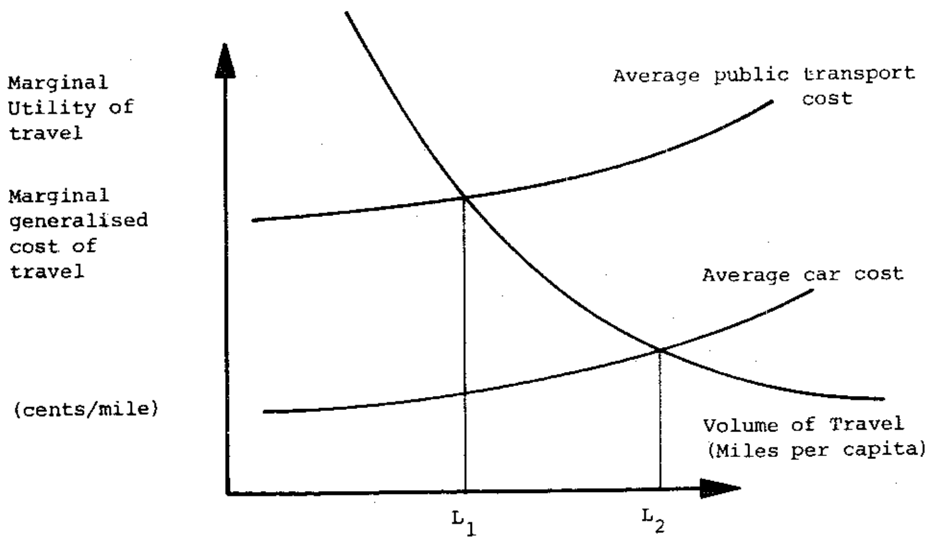

FIGURE 3: THE SUPPLY AND DEMAND CURVES

Once a demand curve is defined, the volume of travel can be determined. (As the length of individual urban trips will tend to increase with the size of cities, the volume of urban travel is modified by city size.) In general the marginal passenger cost for car travel will be lower than the public transport cost (as in Figure 3) and, as a result, more travel will be undertaken by those with a car available than by public transport captives.

Modal Choice

There is considerable variation in urban public transport trip speeds; the person living very near a railway station perceives a faster speed than one who lives further away. While there is less variation in car trip speeds, the uneven imposition of parking charges may cause a significant variation in the money cost of some car travel. Distribution of income will provide further variance about the mean costs in both cases. Therefore there will be distributions around the average generalised costs of Figure 3 as shown in Figure 4.

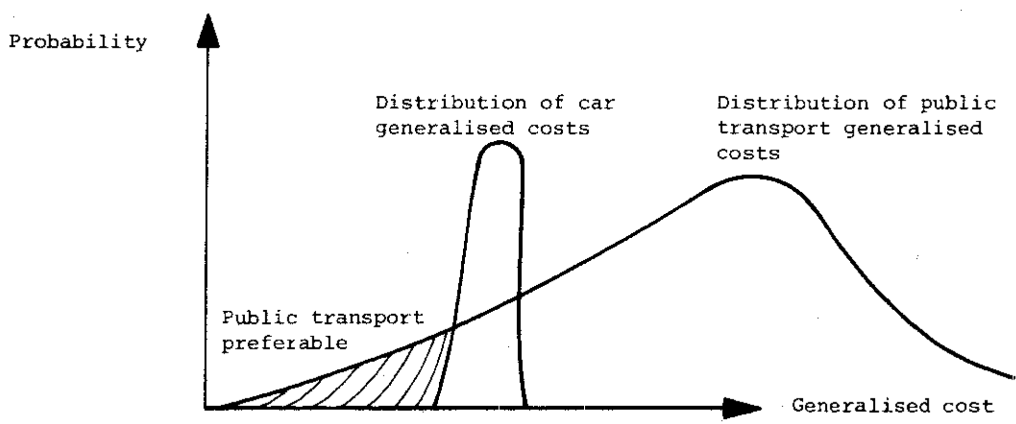

FIGURE 4: MODAL CHOICE

Thus for a minority of those with a car available, public transport is perceived as the better alternative, at least for some journeys. The public transport chooser will still undertake his marginal trips by car and so the average volume of travel by all those with a car available will be the same. But part of his travel will be by public transport and this volume is assumed to be equal to that travelled by public transport captives. (L1 in Figure 3).

An equivalent speed Q is defined as that public transport speed which will cause the generalised costs of car and public transport travel to be equal i.e.

$$Q = \frac{\text{Value of Iime}}{\text{Car generalised cost - P.T. Fare x Utility of Money}}$$

A reference public transport speed T is defined as that speed which, if equal to Q will result in the modal choice being α. T is a measure of the variance of public transport average trip speeds (see Figure 5) and the modal choice M (the proportion of those with a car available choosing public transport) is given by:-

$$M = \alpha + \beta \quad \frac{I-Q}{T}$$

where α and β are positive constants.

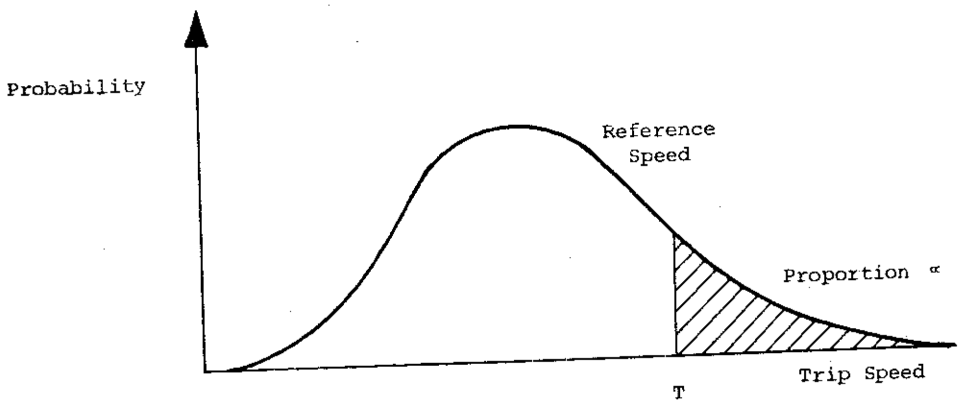

FIGURE 5: DISTRIBUTION OF PUBLIC TRANSPORT TRIP SPEEDS AND REFERENCE SPEED T

The Effect of Income

As income increases the demand curve will shift to the right. This effect is modelled by using an income independent demand curve and modifying the cost curve C:-

$$\text{Modified cost} = \frac{\text{Generalised Cost}}{\text{Income}^{z}}$$

The exponent z is a measure of the elasticity of travel to income. (Appendix II gives a fuller discussion and a mathematical derivation of Z.) Thus with rising affluence the modified cost will now decrease and travel will have a positive elasticity to income.

Car Availability

Car availability is defined as the proportion of persons to whom a car is available for a particular trip and it will be dependent on car ownership (cars per capita) and on travel category. For annual holidays and weekend trips in the country, car occupancy is high and it seems likely that most members of a car-owning household have a car available. Urban off-peak trips are less coordinated and car availability will be lower. For urban peak travel there will be some coordination between households (car pooling) and availability may be higher than in the off-peak. The increase in availability in a household will be much greater with the purchase of the first car than with the addition of second or third cars. After translating cars per capita figures into proportions of non car-owning, single-car and multi-car households on the basis of empirical data (differentiating between city and country) it is possible to estimate car availability as:-

$$\text{Car availability} = k_1 \times \text{Proportion of single-car households} + k_2 \times \text{Proportion of multi-car households}$$

K_2 will be greater than K_1 and both will have values specific to different travel categories.

CAR OWNERSHIP SECTOR

Disposable income, motoring costs, public transport availability and congestion are the factors assumed to affect the level of car ownership (cars per capita). The average rate of fuel consumption and of pollution emissions are determined by the relevant rates of both new and the existing stock of cars.

Car ownership can be expected to approach a saturation level asymptotically. Tulpule (1975b) describes four models which predict car ownership and also examines the estimates of the saturation level. Only one model uses a saturation effect and two acknowledge the effect of income and costs; none were considered adequate. The car ownership model used here is based on a logistic curve (Figure 6) similar to Tanner (1974) but modified by public transport availability and congestion functions.

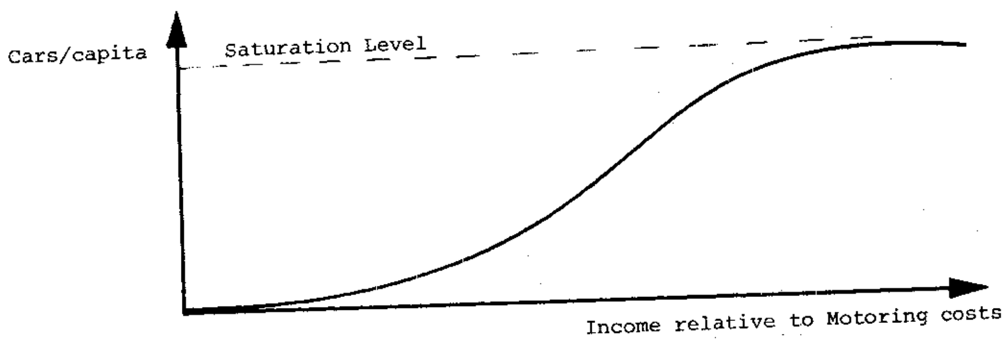

FIGURE 6: CAR OWNERSHIP AND INCOME RELATIVE TO MOTORING COSTS

$$Y = \frac{S}{1 + \frac{S-Yo}{Yo} \exp - a \left(\frac{X}{M} - \frac{Xo}{Mo} \right)} \times f(P) \times g(C)$$

where Y is the number of cars per capita
S is the saturation level
X is disposable income per capita
M is the motoring costs index
Yo, Xo, and Mo are values of Y, X and M in the base year
f(P) is the public transport availability modifier
g(C) is the congestion modifier
and a is a constant.

The functions of f(P) and g(C) are determined by estimating the maximum likely effects of each factor. The general form of the functions are shown in Figure 7[(1)].

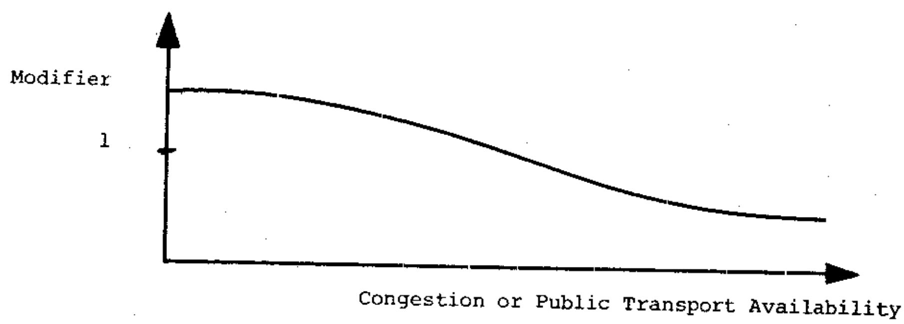

FIGURE 7: THE EFFECT OF CONGESTION/PUBLIC TRANSPORT AVAILABILITY ON CAR OWNERSHIP

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(1) Although other models have often included time as a variable, it is not included here and we consider only the causal variables, most of which have been highly correlated with time in the past but may not be in the future.

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The emissions and fuel consumption rates of new cars are determined by average weight and the severity of pollution controls. The number of new cars each year is estimated and recursive relationships are used to determine the average fuel consumption and emissions per vehicle mile[(1)].

GOVERNMENT POLICY SECTOR

Government policy controls:-

(i) Expenditure on urban and country roads.
(ii) Expenditure on urban and country public transport systems.
(iii) Subsidies and fare levels for public transport.
(iv) Emission controls on new cars.
(v) Excise duty on petrol.
(vi) Sales tax on new cars.
(vii) Registration fees for cars.

Under the hypothesis of rational government policy, high levels of pollution associated with car travel in the city will result in the introduction of regulations governing emission controls for new vehicles. These will make cars more expensive to buy and to run. Pollution may also have similar effects as congestion on government policy in that discouragement of car use in the urban peak may occur and urban public transport may be encouraged by higher levels of investment and subsidy. Increased expenditure on roads will also be a normal reaction to congestion. If Australia is expected to become increasingly dependent on overseas crude oil, total car travel may be discouraged by higher motoring taxes and by active support of public

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(1) Implicit in this model is the assumption that the person is the basic economic unit of ownership. However, there is evidence (Hollywood and Cameron 1976) that the household as the basic unit gives a better explanation of the available data. Ownership of the first and subsequent vehicles in the household can then be treated separately.

transport. Thus government policy is influenced by:-

(i) Pollution
(ii) Congestion
(iii) Oil Supply

While expenditure on urban roads and the introduction of emission controls each will be determined by one factor only, congestion and pollution respectively, the other government policy variables will be determined jointly by all three factors. The effect of each factor is unlikely to be additive. One model of government policy is to measure the importance of each of the inputs by means of a "severity" curve. An example is shown in Figure 8.

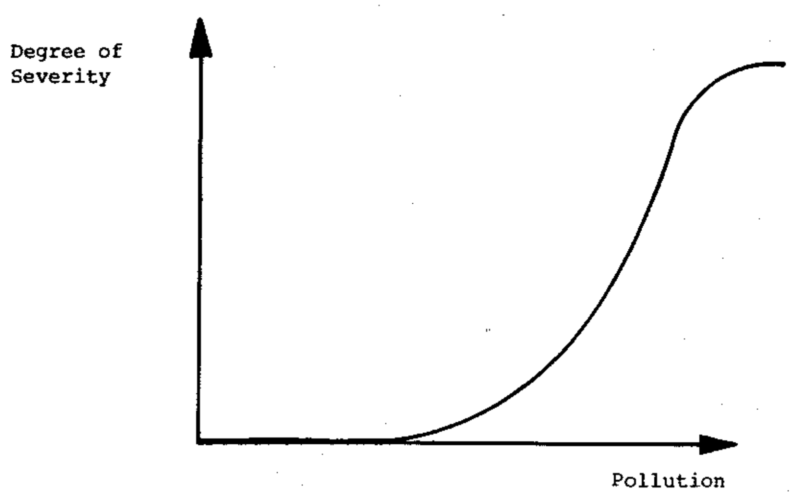

FIGURE 8: A GOVERNMENT POLICY SEVERITY CURVE

The input with the maximum level of severity is taken to be the determinant of the policy variables. Governments may be modelled as reacting by "doing a little of everything" or concentrating on one particular aspect (e.g. public transport) for a period of time before switching priority to another area. A high level of expenditure in one area will decrease the money available for other areas. The government's perception of congestion, pollution and oil supply may, of course, be lagged and/or distorted. It may react to their absolute level or to their rates of change (i.e. expectations).

It is clear that any model of government behaviour will be fairly arbitrary and, to date, no attempt has been made to construct such a model. Instead predetermined policy variables are input by the user. This method allows the effects of quantitive assumptions about government policy to be evaluated.

ROADS AND PUBLIC TRANSPORT SECTOR

The main purpose of this sector is to translate public capital expenditures on transport into measures of service, i.e. average trip speeds by each mode for each of the categories of non-business travel. In the case of both roads and public transport a notion of <u>capacity</u> is introduced. The effect of investment is first translated into terms of increments of capacity and thence into average trip speeds. Because capacity is determined by many factors (e.g. route mileage, number of lanes or tracks, intersection design, frequency of service, etc.) no attempt is made to relate capacity to any specific variable and a nominal scale is used.

The capacities of the urban and country road networks and those of the urban and country public transport systems are treated separately. Capacity is calculated by:-

$$C_t = C_{t-1} + \frac{(E_t - C_{t-1} \times K_o)}{K_1}$$

where C_t is the capacity of the network/system in period t

E_t is the gross expenditure on the network/system coming to fruition in period t

K_o is the maintenance and necessary replacement cost per unit of capacity (a constant)

and K_1 is the capital cost per unit of marginal capacity (which varies with network size in urban areas)

In the city congestion is important and the road speed is set as a function of vehicle miles of travel per unit of capacity. Peak and off-peak travel are considered separately with different congestion functions. In the country where congestion is less important, road speeds are assumed to be a function of capacity per capita. Trip speed (door to door) is determined by road speed, trip length and access/terminal time.

The average trip speeds of the country public transport system are calculated in a similar way as for the country road system. Average trip speeds for the urban public transport system are calculated directly and are assumed to be related to the system capacity and to the urban population:-

$$S_t = \frac{aC_t + b}{P_t}$$

where St is the average trip speed in period t

P_t is the urban population in period t

and a and b are constants.

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In order to estimate modal choice a measure of variance of trip speeds is required. The reference speed T has been defined (Section 3) and T is determined by:-

$$I_t = S_t + p + q\frac{M_t}{C_t}$$

where M_t is the number of passenger miles carried by public transport in period t

and p and q are constants.

The inclusion of the last term for off-peak travel reflects the vicious circle of declining patronage resulting in a reduction of frequency of service and thus further reduction of patronage. It is omitted in the peak travel case (i.e. q = o).

Public transport trip speeds in cities depend critically on whether or not new routes are introduced. If no new routes are introduced an ever-declining proportion of the population will live close to public transport. New routes (especially for fixed track forms of transport) are more expensive to build but are more effective in decreasing average trip speeds. The capacities of the present network and of the new network are determined separately. Expenditure on a new network will only occur at a significant level if the total expenditure E_t is high[1].

It is also necessary to determine public transport fares given a level of subsidy or, if fares are specified, the amount of subsidy necessary. An operating cost per unit of capacity and the number of passenger miles defines a straight-forward relationship between subsidies and fares. The urban and country systems are treated independently.

(1) The political commitment to such a project will result in a high level of expenditure being allocated to it with effects on the amount of money available for other areas.

VALUE OF TIME AND MONEY

Over the past fifteen years the amount of money spent on travel has remained a remarkably stable proportion (12%) of household disposable income; there has, perhaps, been a slight upward trend. It would appear likely that the community as a whole has a strong predilection to maintaining this proportion. So while the cost of travel has risen less than that of other goods, and facilities have improved, this predilection has helped hold back an increase in the proportion of a household's budget which is spent on travel. Clark et al (1974) suggest that people spend a constant 500 hours per year travelling and increased mobility results from higher travel speeds as new modes of transport are developed.[1] There seems to be a predilection similar to that on expenditure and clearly people are unwilling to spend too much of their leisure time travelling.

We may model this mechanism on the money side by assigning a marginal value (or utility) to the nominal dollar. This utility will rise sharply if too great a proportion of the budget is spent on travel, and marginal travel will then be perceived as more expensive. If, therefore, household consumption on travel rose to 15% of disposable income, the utility of marginal expenditure may rise to, say, 1.5 and then the perceived cost of a gallon of petrol used for a marginal journey will be about one dollar. An exponential marginal utility curve can be defined (Figure 9).

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(1) As here we are only concerned with travel by mechanically powered modes an upward trend in the amount of time spent on such travel would be expected under this hypothesis because of the substitution of powered modes for journeys by bicycle and on foot.

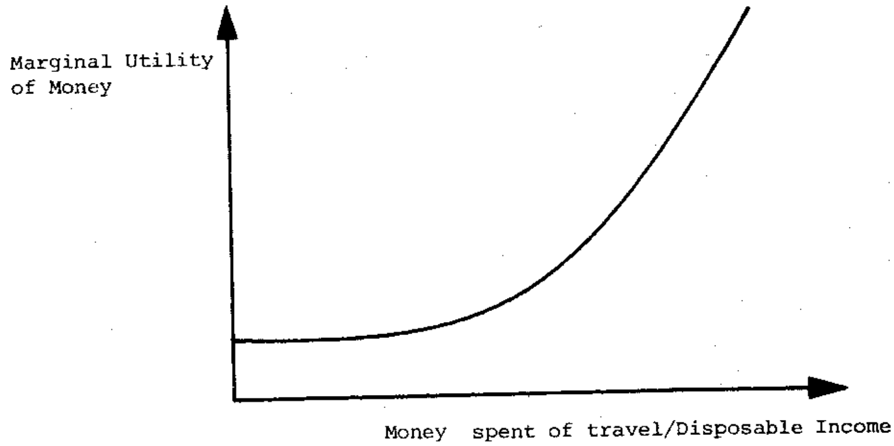

FIGURE 9: MARGINAL UTILITY OF MONEY

A similar curve can be defined for the marginal utility of time with the proportion of leisure time spent travelling as the determing variable. The base money value of time is taken as a fixed proportion of the average wage rate and thus the value of marginal time is given by its base value multiplied by the utility of time.

Valuations of in-vehicle, waiting and access time are commonly held to be different. Out-of-vehicle time, or excess time, is usually valued at between 1.75 and 2.0 times that of in-vehicle time (Davis 1974). In order to reflect the higher proportion of excess time associated with public transport travel, time spent travelling by this mode is valued at 25% higher than time for car travel.

NATIONAL ECONOMY SECTOR

The purpose of this sector is to translate the exogenous variables, GDP and population into measures of disposable income per capita and leisure time, taking into account the effect of public expenditure on roads and public transport, net of motoring taxes, on taxation rates and on the rate of capital formation. High public expenditure on transport together with low motoring taxes will lead to high taxation rates and low capital investment. The latter will result in a slowing of the rate of increase of productivity and thus of leisure time.

Households, companies and the government sectors are the three main elements of the economy. GDP is initially divided between these three and then transfers between them take place (e.g. the household sector receives dividends and net interest from the company sector and pays direct taxes to the government). Personal and company tax rates are determined in light of a government net income objective (exogenously defined). Capital formation is made up from total income less private and public consumption modified by net capital inflow from overseas. A productivity curve, relating GDP per worker hour to net capital stock per worker, allows the average hours worked per year and thus leisure time to be determined.

CONSEQUENCES OF TRAVEL SECTOR

This accounting sector calculates petrol consumption, total motoring taxes, urban pollution density, congestion and total time and money spent on travel. Car occupancy has to be determined in order to translate car passenger miles to vehicle miles. Occupancy is assumed to decrease with rising car ownership and increase with greater congestion. A fuel economy function is also defined to reflect increased petrol usage in congested conditions.

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CONCLUSIONS

Analysis of model results gives a clear indication of the basic stability of the system. With growing income as a positive force and the value of time as the major restraining force, total demand for travel continues to rise. With rising affluence travel decisions will become increasingly dominated by considerations of time. The dominance of time has some important consequences:

(i) Conventional forms of public transport provide slower trips speeds than those for car travel, except in very congested conditions. As a result public transport usage will become increasingly concentrated in the urban peak. Unless substantial improvements can be made in overall trip speeds public transport must continue to decline in other sectors (i.e. areas of fast growing discretionary travel) in the face of rising car ownership.

(ii) The future of private individual transport (however powered) seems assured. The level of car ownership is seen as the dominant variable in the determination of future volumes of travel and modal split.

(iii) Government policy variables, which generally affect only the money component of travel costs, have only a secondary effect on future travel. If the government wishes to restrain car travel, encourage public transport, it can only (1) do this by making the ownership of the car more expensive rather than by changing the relative monetary costs of running a car and of using public transport. Once a car is available it is difficult to persuade the user onto

(1) Except by direct regulatory restraint.

public transport or to restrict his marginal journeys. The car buy/not-buy decision appears to be one of the few travel decisions dominated by monetary considerations.

It is interesting to note that the currently accepted assumptions of the relative future movement of motoring costs (BTE 1975), together with the effects of saturation and congestion, result in a forecast dramatic decrease in the rate of growth of car ownership. This has obvious consequences for Australia's oil industry.

Acknowledgements

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APPENDIX I

DYNAMICS OF THE PERSONAL TRAVEL SYSTEM

MODELLING, CALIBRATION AND DATA

Data for calibration is fairly sparse and the dominant criteria for estimating parameters and relationships was one of reasonableness, i.e. "does it appear to be a reasonable assumption/estimate?" and "does it give sensible results?". There are some areas where specific data collection would strengthen the calibration procedure considerably; in other areas, such as translating transport investment into trip speeds, there is no obvious method of improving estimates.

Calibration

Demand for Travel and Modal Split Sector.

The calibration of the main demand for travel and modal split sector is based on the two years, 1963 and 1971 when motor vehicle usage surveys were conducted (ABS 1965 and 1973c). Together with additional information from the Sydney and Melbourne transportation and ABS journey to work and school surveys and from other sources (ABS 1973a, Solomon 1974, Lee & Clark 1975) estimates were made of the amount of travel in each category and by each mode for these two years. After the estimation of the relevant positions on the utility of money and time curves and of trip speeds for each travel category, the generalised costs can be determined. Demand curves may be drawn up after assumptions are made on car availability. Calibration of so many variables on just two points has its dangers but, while theoreticians and others may be aghast, in the context of increasing the understanding of the whole system rather than producing "hard" forecasts, this method is not unreasonable.

National Economy and Car Ownership Sectors

The national economy and car ownership sectors can be calibrated with comparative precision. For the national economy sector the National Accounts (ABS 1973b and 1974) were used and over a period of twelve years relationships remained surprisingly constant giving greater confidence in the calibration. A motoring cost index, required to estimate car ownership, is formed by taking a weighting of new car price and operating cost indices. Both cost components are affected by the government policy variables. The implicit operating cost index in the National Accounts (Table 39 and 40 of ABS 1973b) is not totally satisfactory in its treatment of insurance and it was modified in this respect. It was also altered by putting less weight on petrol price and other mileage variable costs than is usual to reflect the more immediate and certain impact of the fixed cost components.

Government Policy Sector

No attempt has yet been made to formulate relationships in the government policy area.

Roads and Public Transport Sector

The roads and public transport sector is perhaps the most difficult to tackle. Expenditure data was obtained from the National Accounts and the Bank of NSW's Review (Bank of NSW 1974). The change in average trip speeds over the period 1963 to 1971 were based on a consensus of opinions of informed but non-specialist persons. The estimates of the capital and maintenance costs of roads per unit of capacity and of the relationships between average trip speed and capacity were made, fairly arbitrarily again using the criterion of reasonableness.

Value of Money and Time

Fouvy (1974) discusses the different money valuations of marginal travel time in the history of cost-benefit analysis. Widely differing estimates of between 9 and 155 per cent of the average hourly wage rate are presented. Empirically derived values tend to be in the lower range of up to 55 per cent. The Sydney and Melbourne Transportation Studies generally used 30 or 60 cents per hour (equivalent to about 20 to 55 per cent of average wage rate). Implicit in the assumption that the value of marginal travel time is related to wage rate is that rising incomes will lead to an increasing valuation of time. The assumptions used in the current version of the model are that the value of marginal travel time in 1970 was 25% of the average wage rate (20% in 1963) and that the utility of money in 1970 was 7½% higher than in 1963.

The Income Variable

At the present stage of the development of the model disposable income per capita has been used as the income variable, although this is not a totally appropriate measure of affluence especially with respect to discretionary expenditure. A better measure may be discretionary disposable income i.e. disposable income less essential consumption. One difficulty in defining essential consumption is that society's idea of what is essential will change over a period of time. The concept of permanent income is also useful in the explanation of household consumption behaviour. Permanent income reflects not only the instantaneous level of income, but expectations of future income and the real value of liquid assets.

Car Availability

Car availability (the proportion of people with a car available) is one of the most important factors in the determination of forecasting travel and modal split. In this inadequately researched area virtually no data exists. The proportion the population captive to public transport in 1970 is estimated to range from 15% for country travel by urban residents to 35% for off-peak urban travel (c.f. 27% of all urban households owned no car at this time). Davis (1974) derives much lower figures empirically.

Relationships

Some relationships between variables are well defined, e.g. car vehicle miles as a function of car passenger miles and occupancy. Other relationships are less straightforward. Urban road capacity (measured in nominal units) reflects the combination of the quantity and quality of road surface, design of intersections and traffic management etc. As vehicle miles per unit of road capacity increases, road speeds will fall. While it is possible to calibrate such a congestion curve on a micro level (i.e. for a particular stretch of road) it is not possible to calibrate the macro curve at all precisely. The reaction of government policy to different stimuli is another relationship impossible to quantify with confidence. However it would be reasonable to expect that at low pollution levels governments will take no action but that after a certain level reaction, in terms of pollution controls and public transport expenditure, will increase exponentially with rising pollution until limited by other constraints such as economic policy.

Forrester and others generally use "multipliers" to estimate the cumulative direct effect of several variables on another. For example in the World model (Meadows et al 1972) the birth rate is determined by:

Number of Births	=	Population
	x	Overcrowding Multiplier
	x	Material standard of living multiplier
	x	Food per capita multiplier
	x	Pollution multiplier

Forrester (1961) believes only the general shape of the relationship is important to a system's behaviour. We have, in some areas, used more conventional economic models. Like others we have not let the absence or limitations of data and knowledge prevent us from making estimates in order to get results. However the model does provide a framework into which reasonable assumptions can be put, leading to increased understanding of the importance of and interactions between different factors.

The simulation model does not solve any simultaneous equations and some feedbacks, which in reality are instantaneous, are modelled as being lagged by one time period. Obviously if the length of a period is short enough there is no loss of accuracy although there is a danger of unstable oscillations. While special computer simulation languages, DYNAMO (Pugh 1961) and DYNSYS (Kneen 1974), have been developed for system dynamics models, the Fortran IV language has been used in this case because of the lack of easy availability of the specialist languages.

Future Developments

Future development of the model may include the consideration of air travel, as a second and distinct public transport mode, and a car industry sector. With the importance of the car ownership variable, the future of the car industry (and its interactions with government policy) is not without interest. The inclusion of such a sector may also allow car size and different power unit technologies to be considered.

APPENDIX II

DYNAMICS OF THE PERSONAL TRAVEL SYSTEM

THE EFFECT OF INCOME ON THE DEMAND FOR TRAVEL

If all factors in the generalised cost function are kept constant apart from income then we may write the generalised cost as:-

$$C = K_1 U_M + K_2 Y$$

where U_M is the marginal utility of money

Y is disposable income per capita

and K_1, K_2 are positive constants

Now

$$\frac{\delta C}{\delta Y} = K_1 \frac{\delta U_M}{\delta Y} + K_2$$

While $\frac{\delta U_M}{\delta Y}$ is negative it is also likely to be small and

certainly $K_2 > K_1 \frac{\delta U_M}{\delta Y}$ and so $\frac{\delta C}{\delta Y} > 0$.

We are faced with the apparent paradox that as income increases, so does the generalised cost and, under the assumption that the elasticity of the volume of travel with respect to generalised cost is negative (say $- E_O$), that the volume of travel will decrease as income increases. The resolution of this paradox is held in the fact that the marginal utility of travel curve (i.e. the demand curve) is not independent of income. With reference to Figure 10 an initial level of income Y is associated with a cost curve C, a demand curve D, and a volume of travel L. With an increased level of income, the rise of the cost curve to C* will apparently bring a reduction in travel from L to L*. But the increased level of income will also result in a shift of the demand curve to the right to D' with the resultant volume of travel L'. This situation may be modelled using an income-independent demand curve D if we modify the cost curve C with respect to income to obtain a cost curve C' and a volume of travel L'.

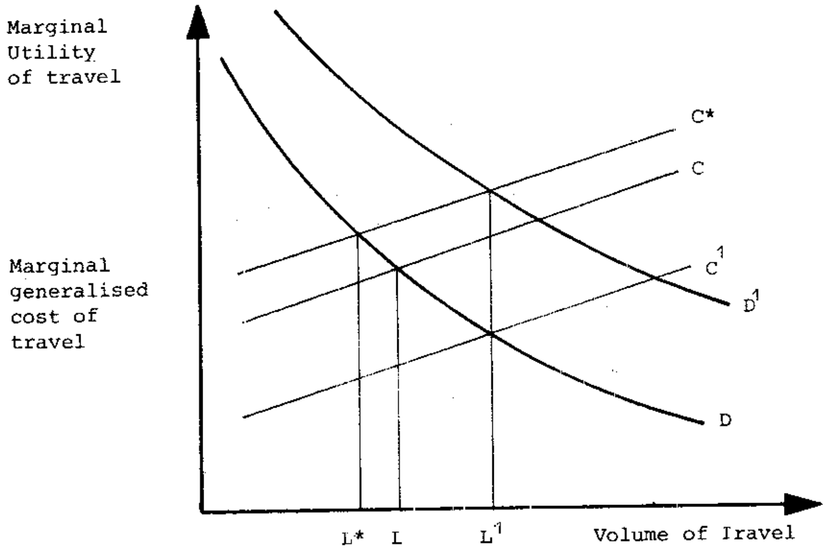

FIGURE 10: THE EFFECT OF INCOME ON THE DEMAND FOR TRAVEL

To reflect an income-independent demand curve, the generalised cost may be modified to:

$$C = \frac{K_1 U_M + K_2 Y}{Y^Z}$$

If we examine the elasticities of the volume of travel to income and to money cost, we may ascribe a meaning to the exponent Z. It can be shown (by simple calculus) that the ratio of these elasticities is:-

$$\frac{\beta - Z}{1 - \beta}$$

$$\text{where } \beta = \frac{K_2 Y}{K_1 U_M + K_2 Y}$$

The value of β ranges between 0.5 and 0.75 and estimates of income elasticity are between 2 and 5 (Tulpule 1975a) and of price elasticity between -0.3 and -2 (Tulpule 1975a, Bureau of Transport Economics 1975). A value of 2.5 is assumed for Z.

This method of estimating the effect of income is not intended to be an impregnable approach, but rather a not unreasonable one!