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THE PERTH (TRANSPORT) 2000 FORECASTING MODEL - A SENSIBLE HYBRID

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ABSTRACT: *A set of forecasting tools is being developed in Perth for use, initially, at a strategic level. The paper concentrates on the main features of the model package. These include a market segmentation approach which allows integration of disaggregate car ownership and trip frequency models into an aggregate model framework. Trip makers are separated into "choice" and "captive" travellers which, together with a multi-level logit mode choice model, should reduce specification errors. During the development stages particular attention was placed on the model's predictive sensibility.*

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THE PERTH 2000 MODEL

INTRODUCTION

In urban transport planning in particular, emphasis in recent years has turned from the long-range "regional transport plans" of the 1960's and early 1970's to incremental transport improvements or actions of a short-term, low cost nature. The roles of short and long-range planning, however, are clearly different and complementary. Most short-term plans and actions have long-term impacts which need to be identified. Furthermore, short-term actions are generally reactive in that they tackle existing problems. Long range planning, on the other hand, allows for identification and avoidance of potential future problems.

With these and other considerations in mind, a further planning reorientation is now taking place - a long range planning approach which is more exploratory (and far-ranging) in nature and which addresses concerns of a more recent vintage such as increasing transport costs, declining public transport patronage, community values and uncertainties about future environments. To our knowledge, the Perth (Transport) 2000 study[1] is one of the first attempts in Australia to proceed along this path. The study was initiated with the aim of evaluating transport policy options for Metropolitan Perth as we move towards the year 2000 and beyond. The approach adopted is to test, on a strategic level initially, the likely consequences of alternative transport options under a range of possible future "environments".

With the change in planning emphasis the requirements of the forecasting models changed. The conventional, aggregate models performed adequately for macro applications and evaluations under assumed stable conditions. However, more sensitive models were required for microscopic estimates of the (short-term) effects of particular policy actions. The newer type "individual choice" models, if properly specified, are clearly better suited for that task. Yet on their own, neither of the two types of models could satisfy the needs of the Perth 2000 approach.

This paper describes the set of forecasting tools developed in Perth during 1980/81 which, it will be seen, is a compromise between the proven "old" and the promising "new". The following section briefly outlines the overall model structure. In the third section the market segmentation approach is introduced which provides the necessarv link for applying disaggregate models in an aggregate framework. The fourth section then describes the mode and destination choice models. An overview and initial results of the model's application to year 2001 scenarios are presented in the fifth section.

The main purpose of this paper is to describe the concept and main features introduced in the Perth model. For finer details, including mathematical derivations, the interested reader is referred to the appropriate Technical Papers of the Perth 2000 study.

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1 The study is carried out by the Office of the Director General of Transport and scheduled for completion towards the end of 1981.

Prior to elaborating on the rather specialised aspects of transport modelling, it seems appropriate here to briefly outline the background and considerations leading to the Perth (Transport) 2000 study and with it, the need to review the existing models.

Study Background and Considerations

For a number of reasons, including foresight probably unequalled by town planners elsewhere in Australia, the development of the Perth Region, so far, has continued in a relatively smooth and uncontroversial way. With the adoption of the Metropolitan Region Planning Scheme (the "Corridor Plan") in 1963 an extensive network of major highway rights-of-way has been set aside or gradually been acquired. In 1970, the "need" for the planned network was ratified by the Perth Region Transport Study (PERTS). The progess of network implementation is, with minor exceptions, simply dependent on the availability of urban road funds. Given a population growth which still exceeds 2% per annum and acknowledging the existence of a land use/transport interaction effect, planners' predictions of "needs" have, up to now at least, been rather self-fulfilling.

In contrast, planning and implementation of public transport policies and facilities has met with rather more hurdles. Proposals put forward by PERTS and again by the Perth Central City Railway Feasibility Study in 1974 (PCCRFS) met with vocal opposition by some community groups. The replacement of the Perth-Fremantle passenger rail services with bus services in 1979 resulted in one of the largest petitions ever presented to the State Government. Transport planners were accused of being oil company puppets, ignorant of the needs of the transport disadvantaged, underestimating environmental costs, oil shortages and public transport demand elasticities, etc. In the meantime, the cost of operating public transport outpaced revenues to such an extent that, by 1981, the operating deficit reached $40 million which represented an average subsidy per passenger of 62 cents. On the other hand, the actual patronage at present is at a level substantially below that predicted by PERTS and PCCRFS.

The Perth 2000 study approach is more exploratory than that previously used and is based on two critical realisations. Firstly, factors which are outside the direct area of influence of the transport decision maker but which nevertheless affect the likely result of future transport options cannot be assumed to be unchanging in a changing world. Neither can they be ignored. Given the level of uncertainty about these factors, Perth 2000 is to analyse a range of possible future "environments" made up of combinations of variables such as economic conditions, energy availability and price, urban development, social changes and telecommunication effects.

Secondly, a less conservative view on the part of the transport planning profession, probably coupled with some change in community attitude towards urban transport, has considerably increased the range of alternative transport options open for consideration. Perhaps the planning approach adopted so far in Perth has placed too much emphasis on the development and evaluation of transport plans which derive from the current strategy. Perth 2000 is to look at the effect of a wider range of alternative transport options including technological investment and system management options as well as organisational initiatives.

OVERALL MODEL STRUCTURE

Figure 1 depicts a summarised flow of the adopted model structure for the Perth 2000 study. Essentially, the conventional, sequential approach has been retained as, to our knowledge, there are no practical alternatives at this stage that can fulfil the study requirements.

For the estimation of mode and destination choice in particular, the Perth model places heavy emphasis on car availability of individual trip makers rather than overall household car ownership levels. As a consequence, the main features of the model structure include a market segmentation module which, within the first part, divides commuters into "choice" and "captive" travellers, that is those with a choice of driving a car to work and those without that choice. In the second part of the market segmentation module, the adopted sequence then allows the determination of choice and captive non-work trips taking into account the outcome of the mode choice decision by commuters.

For the determination of mode and destination choice three distinct models were required, namely mode choice, trip attraction and trip distribution models. Two types of attraction models were developed. For work and education trips, trip rates per type of employee and type of student respectively were derived. For other trip types, where various socio-economic and land use activities attract trips, standard multiple regression equations were developed at an aggregate zonal level.

As part of determining destination choice, the well proven "gravity" or interactance models were calibrated using composite utilities derived from the mode choice models as impedance factors. The calibration was done separately for choice and captive travellers and for each of the five trip types described in the next section. In addition, commuters were segregated into blue and white collar groups in an attempt to reduce the linking of trip-ends from mainly white collar residential areas with attractions for mainly blue collar workers and vice versa.

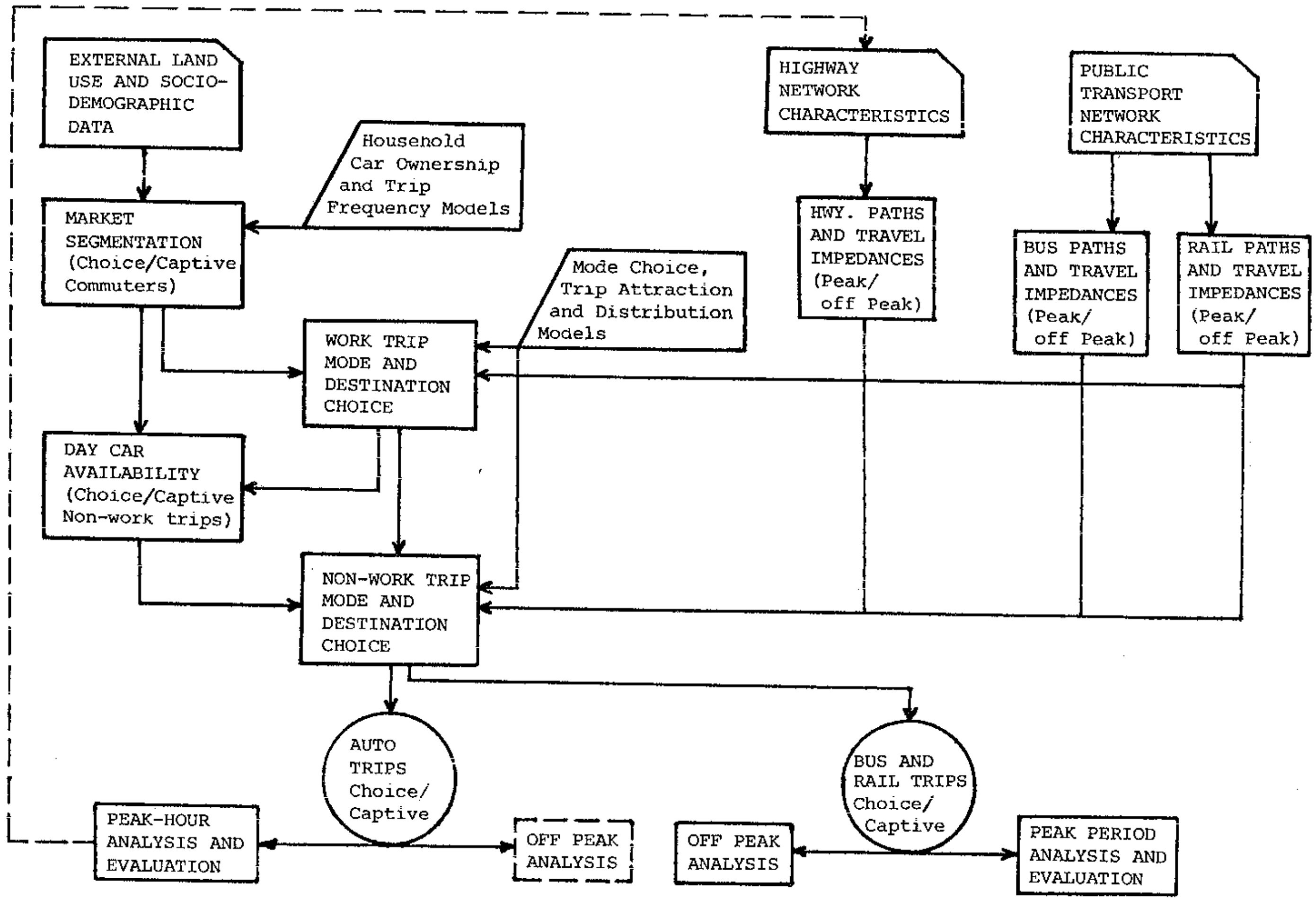


Figure 1 - MODEL FLOW

The distribution models are applied in a relaxed doubly-constrained form. While the attraction rates for work and education trips fully determine the relative zonal attractiveness, choice and captive travellers are let to compete to some extent. For other trip types, the constraint is further relaxed. There, a given surplus of total trip attractions is specified, say 20% above the control total determined by the trip frequency model, and the distribution model is allowed to freely operate within that margin. In this way a land use/transport interaction effect is introduced, an effect which was not explicitly considered at the land use allocation stage.

The application of mode and destination choice results in two forms of output. On the one hand, zone-to-zone trip matrices for the various trip types and travel modes are produced. On the other hand, the first set of evaluation measures are calculated, that is accessibility indices and indicators for the calculation of consumers' surplus.

The analysis of auto trip matrices includes a capacity restraint peak hour traffic assignment with an option to recalculate highway travel impedances for quasi-equilibrium model applications. An "environmental" evaluation is also carried out with regard to road accidents, vehicle emission and noise levels, etc. On the public transport side, interest for the strategic analysis centres mainly on peak period line-haul flows and the general levels of day-time and evening patronage.

MARKET SEGMENTATION

The advantages of "individual choice" models have long been recognised as being particularly beneficial for micro-estimates of short-term effects of given policy actions. For longer-term, strategic transport policy studies, however, practitioners have so far been rather reluctant to make use of such models. One of the reasons for this is the problem of applying disaggregate models in an aggregate modelling framework. In Perth, the aggregation problem has been tackled in two different ways; one approach is outlined here while the other is mentioned in the section on mode choice.

The household was adopted as the basic socio-economic and travel analysis unit. Hence, the first objective of the market segmentation approach was to disaggregate external (aggregate) demographic data, either census data or future projections, into household segments suitable as input to the trip generation models, that is car ownership and trip frequency models. Data requirements of these two models therefore constituted one of the main considerations in the selection of the segments. Other considerations centred around evaluation requirements. For example, the identification of pensioner households was seen as a useful grouping not only for the generation models but also for evaluations with regard to equity and other social issues. Table 1 shows the structure of the 16 chosen segments.

Table 1
SELECTED HOUSEHOLD SEGMENTS

SEGMENT	HOUSEHOLD SIZE	ADULTS	EMPLOYEES	CHILDREN	HOUSEHOLD TYPE
1	1	1	0	No	Pensioner households (no employees)
2	2+	1	0	Yes	
3	2+	2+	0	No/Yes	
4	1	1	1	No	Adult-only households (at least one employee)
5	2	2	1	No	
6	2	2	2	No	
7	3+	3+	1	No	
8	3+	3+	2	No	
9	3+	3+	3+	No	
10	2+	1	1	Yes	Families
11	3+	2	1	Yes	
12	3+	2	2	Yes	
13	4+	3+	1	Yes	
14	4+	3+	2	Yes	
15	4+	3+	3+	Yes	
16	-	-	-	-	Non-private households (Institutions, etc)

The household segmentation model was developed from 1976 census and survey data. The model uses simple factors and conditional probability distributions to assign zonal control totals such as the total population, the number of households, children and blue and white collar employees to the 15 private household segments. At this stage, non-private households are excluded from the model.

The segmentation process itself does not contain a level of sophistication worthy of further discussion here. Of interest is the concept which allows relatively unbiased application of disaggregate models. Critics of the approach might argue that the added accuracy gained at the car ownership and trip frequency stage may well be lost during the household segmentation process. While this cannot easily be disputed, it can be pointed out, however, that the details produced by the segmentation model allow explicit checks of data sensibility which otherwise would not be possible. Furthermore, the process allows for easy sensitivity testing of socio-demographic variables such as changes in retirement age, household size and population distribution.

Household Car Ownership

The adopted structure for modelling household car ownership is not unique. In fact a very similar approach has been used for at least three previous studies in Australia and is reported in more detail by Hutchinson(1979). The brief discussion here concentrates on some of the features incorporated in the Perth model, including a full integration into the model package, and on the level of stability when compared with the three other models mentioned.

A binary logit model was chosen of the, by now, familiar form:

$$P(\text{choice}) = \frac{e^u}{1+e^u}$$

where P(choice) is the probability of the upper level choice and u is a linear utility function. The model is then applied in the following sequence:

(i) car ownership/non-car ownership among all households

(ii) one car/multi-car ownership among households that
  (a) are car owning, and
  (b) have more than one adult;

(iii) two car/three+ car ownership among households that
  (a) are multi-car owning, and
  (b) have more than two adults.

The variables included in the model were:

- Number of adults in the household
- Whether or not the household contains children under driving age (used as a 0-1 variable)
- Number of adult employees
- Annual household income
- A measure of accessibility (initially defined as the distance from the household's residence to the Perth CBD in units of 50 km).

A number of estimation runs were carried out and the results of the adopted models are given in Table 2. The effect of the number of adults is effectively the same in all three choice situations but the effect of children and the number of employees diminishes with higher levels of car ownership. The income effect also diminishes but the relative impact of accessibility, or lack of it, increases steadily as the numbers of cars increases.

Table 2
HOUSEHOLD CAR OWNERSHIP MODELS - PERTH 1976

	COEFFICIENTS (STANDARD ERROR)		
	0/1+ CAR	1/2+ CAR	2/3+ CAR
Constant (Bias)	-1.81(0.23)	-3.37(0.08)	-4.27(0.17)
No. of Adults	0.68(0.20)	0.59(0.16)	0.73(0.27)
Children (0/1)	0.63(0.27)	0.41(0.15)	0.06(0.33)
No. of Employees	1.21(0.25)	0.30(0.12)	0.05(0.20)
Household Income(000)	0.164(0.042)	0.093(0.016)	0.062(0.024)
Accessibility (50 km)	0.93(0.77)	1.10(0.51)	1.40(1.27)
Observations	1149	889	171
Upper choice obs.	1001	464	78
Correctly classified	1038(90%)	605(68%)	115(67%)

Model Features The household segmentation approach outlined previously allowed a car ownership model to be specified that extended the set of independent variables normally found in such models. The results clearly indicate that the effect of household income on car ownership is not nearly as significant as more traditional models have tended to show. In fact, the significance of income for the initial choice decision (0/1+cars) might still be overstated because of the high correlation between low income and pensioner households. It is quite likely that the relatively low car ownership levels found among pensioner households is partly due to physical impairment.

Hutchinson rightly pointed out that the type of models described here have the potential for absurd application, particularly in predicting more cars than the number of adult household members. With the adopted household segmentation approach which, inter alia, classifies the households according to the number of adults, it was a simple matter to constrain the models such that one-adult households were excluded from multi-car ownership and two-adult households were excluded from three-or-more car ownership.

Because of the non-linearity of the logit model the well recognised problem of aggregation bias is introduced with a data set whose independent variables are normally available only in aggregate form for (future) application purposes. Again, the household segmentation structure has limited this problem to income, the only variable which in practice varies within each segment and for which an average value is used. Hence, during model calibration, in order to match the 1976 census data on car ownership levels, minor bias adjustments only were necessary.

The inclusion, at this stage, of a very crude measure of accessibility stems from purely practical considerations in that more appropriate indicators were not available at the time the models were developed. Now that mode and destination choice models are in hand, it is planned to replace the simple distance function with an accessibility measure as produced by the application of mode and destination choice.

Comparison with Other Studies - Similar car ownership models have been developed for Canberra, Adelaide and Brisbane. Because of specification differences a comparison, at this stage, must be limited to the important income coefficient. This comparison is shown in Table 3 and indicates both consistency in the diminishing effect of income and broad stability of the coefficient values. The results are encouraging and would appear to justify more detailed comparative analyses.

Table 3
COMPARISON OF INCOME COEFFICIENTS
IN CAR OWNERSHIP MODELS

City	Year	0/1+CAR	1/2+CAR	2/3+CAR
Adelaide	1977	0.270	0.048	0.044
Brisbane	1978	0.149	0.075	0.043
Canberra	1975	0.182	0.069	0.029
Perth	1976	0.164	0.093	0.062

Note: The coefficients relate to annual household income in $000. The Brisbane model was specified in terms of residual income, i.e. gross income less $3000.

Trip Frequencies

For the development of trip frequency models, two proven techniques are available - category or regression analysis. The former has been more widely used in recent years, possibly because it is a simpler and easier model to understand and eliminates some of the potential problems inherent in regression models (e.g. inter-correlation, heteroscedasticity). However, data requirements for meaningful category models are higher than for regression models, particularly where a more disaggregate approach is employed. The relatively small data base available in Perth, therefore, was a deciding factor in favour of regression models. These were developed from disaggregate data at the household level.

Dependent Variables Within the sequential flow of the model framework, the trip frequency equations are applied to the output of the car ownership model. This output consists of the number of households, for each zone, for 60 different household categories (i.e. 15 household segments x 4 car ownership levels). Hence, it was possible to estimate separate equations for different household category groupings. The three household types shown in Table 1 were selected a priori (i.e. pensioner households, adults-only households and families).

In addition, models were developed for five trip types as follows:

(i) Homebased Work trips for a typical 24-hour weekday
(ii) Homebased Education trips made during day time
(iii) Homebased Other trips made during day time (Shopping, Personal Business, Social or Recreation trips).
(iv) Non-Homebased trips made during day time.
(v) Evening non-work trips, i.e. trips starting after 6 p.m. and before 4 a.m.

The decision to separate day time from evening trips is rather unique and was based on two primary considerations. Firstly, observed characteristics are different for evening and day-time travel. To a large extent, the reason for this is that cars used for work trips are back home and available to all household members for evening trips. Secondly, with the study's interest on public transport policies, a more reliable estimate of evening travel, particularly public transport travel, was seen to be desirable.

Independent Variables - Generally, independent variables which can be included in the trip frequency model are limited to those estimated by the market segmentation and car ownership models and those relating to service characteristics (accessibility). These variables are:

ACC - Accessibility, initially defined as the straight-line distance to the Perth GPO (in units of 0.5 km)
CAR - Total number of cars per household
ADLT - Number of adults per household
DCHD - Household without children (0) or with children (1) - relevant for pensioner households only
EMP - Number of employed persons per household
HINC - Household income ($000 per annum)

In addition, the somewhat unique Perth 2000 model framework made it feasible to include, for non-work trips, two further variables, viz:

WCAR - Number of cars per household used for work journeys
DCAR - Number of cars per household not used for journeys to work (i.e. cars available during day time)

This significant refinement was possible because the mode choice for work journeys is determined prior to the final estimation of trip productions for non-work trips. With this sequence, the number of employees driving to work can be estimated as well as the number of cars remaining "at home" during the day.

Model Equations and Calibration - Two sets of equations were estimated from survey data of 1147 households in relation to (i) person trips made by all modes of travel, including walk and bicycle, and (ii) trips by motorised modes only. Table 4 shows, as an example, the equation and associated statistics for homebased Other trips for motorised travel modes.

Table 4

FREQUENCIES FOR HOMEBASED OTHER TRIPS[(a)]
(excluding walk and bicycle)

	Pensioner Households	Adults-only Households	Families
Constant	0.340	0.196	1.890
ACC			0.019 (1.94)
ADLT	0.739(3.32)	0.746(4.36)	0.451(1.65)
CAR	0.859(4.31)		
DCAR		1.033(6.78)	0.995(5.29)
DCHD	0.572(1.58)		
EMP		-0.286(-1.53)	-0.552(-2.16)
Observations	267	377	503
Mean Trip Rate	2.13	2.11	3.34
Std. Deviation	2.24	2.36	3.28
R^2	0.15	0.22	0.08
F	15.2	34.5	10.6

(a) Homebased Other trips include shopping, personal business, social and recreational trips made during daytime.

Figures in brackets are t-statistics for the coefficients.

With disaggregate observations at the household level, the values of the dependent variable (trips per household) exhibit, in relative terms, a high variance which the models, given the limitations of the input data, cannot explain. As a consequence, goodness-of-fit indicators such as the coefficient of determination (R^2) are usually poor. Because of this problem, the model's base year performance was checked by way of comparisons between observed and estimated number of trips for selected population subgroups.

To a considerable extent, the observed high variance is a random occurence caused, for example, by the fact that the survey data was collected for a one-day period only and not all of the activities involving travel are undertaken daily. However, there is also an element of non-random variance which the limited independent variables are unable to explain. It is this latter element that is possibly more critical with regard to the model's forecasting ability. The inter-relationship between both the model parameters and the variables which cause the unexplained non-random variance are taken to remain fairly stable and constant over time.

Choice and Captive Commuters

Another feature of the Perth 2000 modelling approach is the segregation of the travel market into "choice" and "captive" travellers. This is in response to the more common practice of dividing the travel market on the basis of household car ownership levels which, quite clearly, has shortcomings in that it cannot explicitly identify car availability for individual household memebers and individual trips.

A captive commuter is defined here as a trip maker who has no access to a car, as driver, for the journey to work. Conversely, a choice traveller is defined as a person having all travel modes available for initial selection.(1) The number of captive and choice commuters are calculated on a household segment by segment basis, taking into account both driving licence availability and competing demands for car use by non-employees. The process is illustrated in Figure 2.

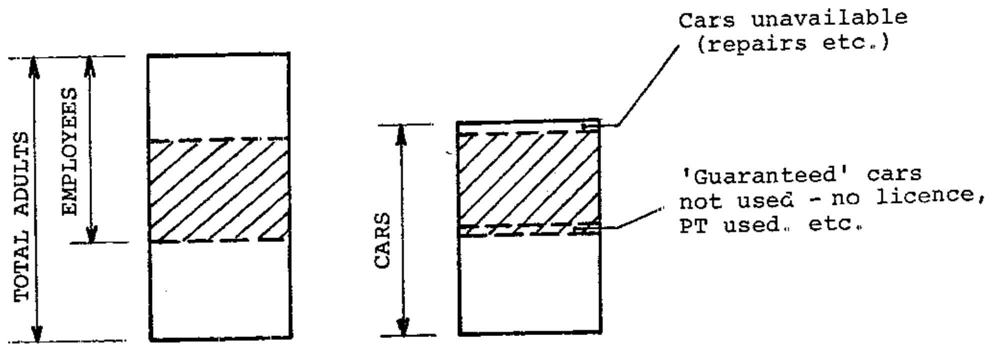


Figure 2 - CHOICE/CAPTIVE CALCULATION

1 As explained in the section on mode choice, the alternatives available to a certain sub-group of choice travellers, i.e. non-traders, are subsequently constrained.

The hatched area in the two columns represents the number of employees who are "guaranteed" a car for the work trip, that is they do not have to compete with non-employees for the use of a car. Survey data showed that, in 1976,93% of this group had driving licences and are thus choice travellers; the remaining 7% are captive travellers. Furthermore, approximately 5% of "guaranteed" commuters used public transport in preference to cars and there were thus a small number of "guaranteed" vehicles not used for work journeys. Also, some employees are not at work at any one day and a further correction factor of 0.85 was applied for absentees, leave takers, etc.

The proportion of the remaining choice commuters is given by the lesser of (i) the number of licensed employees and (ii) the number of cars available. For non-guaranteed employees, the proportions of those not holding a driver's licence were derived from survey data. The potential number of cars available to non-guaranteed commuters is calculated directly as the total number of cars less those used by "guaranteed" commuters. Non-guaranteed commuters, however, are competing with non-employees for the use of the car. The survey data showed several cases where potential choice travellers stated that a car was unavailable for their trip. It was estimated that some 12% of potential car trips to work were prevented because of competing demands for the vehicle.

The remaining commuters are regarded as captive passengers (car or public transport), thus enabling total captive and choice work trips to be calculated.

<u>Day Car Availability and Non-Work Trips</u>

The division of non-work trips into the captive and choice groups is again made individually for each of the 60 household categories. Compared with work trips, however, there are additional factors to be taken into account. Firstly, a proportion of non-work trips is made by children under driving age (captive). Secondly, the timing of non-work trips, particularly for shopping, social and recreational purposes, is less restricted than that of work trips. As a consequence, the majority of non-work trips can be scheduled in such a way that one available car is sufficient to satisfy the travel demands of more than one non-employed household member. Thirdly, a proportion of non-work trips during daytime is made by adults at work using, in most cases, the commuter car.

A model taking these factors into account can fairly readily be developed for base year applications. For application to a future planning year, however, a number of critical considerations are required in respect of:

- changes in the proportions of children within each appropriate household segment;
- changes in the proportions of unlicensed and licensed adults; and
- the distribution of increased household trip rates among the various person types in each segment.

With the expected decrease in the overall household size from 3.11 persons in 1976 to about 2.8 persons by the year 2001, the proportion of children per household is decreasing. There are two broad alternatives for this decrease to affect individual household segments, viz:

(i) many or all of the appropriate segments, i.e. those with children, could experience a fall in the proportion of children; or

(ii) the proportion of children in each segment could remain fairly constant but the proportion of segments without children, or with fewer children, could increase vis-a-vis those with children.

The second alternative was taken as the more realistic.

The number of licensed adults has been increasing, relatively, and is expected to increase further. We take it that this increase is related to the increase in car ownership levels and assume, for future applications, that the number of licensed adults not at work is greater than or equal to the number of cars available for use during the day (DCAR). Under most future scenarios the level of car ownership will be higher than the present level and, therefore, the proportion of choice travellers will increase and so will the proportion of trips made by choice travellers. This creates two complications. Firstly, the proportions of captive and choice trips by adults at home will change and, secondly, this change will not be proportionate to the change in captive and choice travellers because of differential trip rates.

Survey data showed that "choice" adults make two to three times as many trips as do "captive" adults. The trip frequency models, based on household trip rates, to some extent take account of these differential person trip rates by way of separate equations for different household groups and by inclusion of the car ownership levels as significant variables. However, the frequency models, as such, do not explicitly distinguish between captive and choice trips, a distinction which is critical with regard to the mode choice decision.

In calculating the number of captive and choice non-work trips, the persons in each household category are determined first, that is children (captive) and captive and choice adults not at work. Captive and choice commuters have been derived earlier. The number of children is obtained by applying observed base year proportions, adjusted if necessary to ensure that zonal control totals are preserved. The number of "choice" adults not at work is derived by (NLIC|DCAR), where NLIC is the number of licensed adults not at work. DCAR is constrained to be not greater than all adults not at work (ANOT). The simple function 0.60 ANOT + 0.25 DCAR simulated the base year situation well. For future applications, however, 0.50 ANOT + 0.50 DCAR would be more appropriate under the assumption that NLIC will be at least equal to DCAR (note that the number of choice adults not at work = 0 if DCAR = 0).

Having estimated the number of persons by type, the corresponding observed trip rates are then applied. The summation of the resulting person trips over all person types will give SUMNT which can then be compared with the trips per household (MTRIP) as estimated from the trip frequency models.

For future applications, SUMNT is likely to be greater than MTRIP because of the relative increase in "choice" adults and the much higher trip rates for "choice" adults. The differential trip rates are clearly an indication of the higher mobility enjoyed by persons with a car available. However, there will be a limit as to the amount of travelling done by a household irrespective of the level of mobility. For example, weekly shopping trips are likely to be made by one person in the household irrespective of the level of mobility for a second household member.

The trip frequency models can be seen to reflect the overall travel demands of a household more accurately than the individual person trip rates. Therefore, MTRIP can be regarded as the household control total and the person trip rates must be adjusted, overall, by the factor (MTRIP/SUMNT).

If this factor is less than 1.0, which is to be expected, and the adjustment is made to all trip rates, a situation will arise where captive travellers will make fewer trips on average than in 1976, despite an increase in the socio-economic and mobility level of the household. For captive adults it can be argued that this is not necessarily unrealistic. The same, however, cannot be said for children. Surely, if a child is driven to school or sports, that trip will continue to be made if an additional car is acquired. Thus, the adjustments are made to trip rates for adults only.

The above procedure is carried out for all daytime trip types (i.e. education, other, non homebased). For evening trips, some necessary modifications are introduced. With most employees and cars used for the work journey back home after 6.00 p.m. no distinction is made for evening trips between adults at work and adults not at work. Also, DCAR is replaced with CAR, i.e. all cars available to a household. The number of "choice" adults is then determined by (ADLT|CAR) in a similar way to the function (NLIC|DCAR) used for daytime trip types.

MODE AND DESTINATION CHOICE

This section describes the specification, development and calibration of the mode choice models for Perth 2000. It also outlines how the mode choice models interact with the destination choice (distribution) models at the application stage.

Model Specification

The broad structure adopted for the mode choice models is a multi level logit model. This is an extension of the more common multinomial logit to allow a hierarchy of modes, although like all models in the logit family, it remains firmly based on the principle of consumer choice.

Choice Set Definition - When specifying a model it is of course important to first define what is known as the choice set, that is the set of alternative modes open to a particular traveller. Although there may only be a limited number of main modes, there are a large number of feeder mode/main mode combinations and these need to be reduced for practical application at a strategic level. With a framework of fairly large, strategic zones there is little to be gained by considering choices whose prime impact is intrazonal (e.g. walk and bicycle) and distinguishing between the various access modes for public transport. The market segmentation model, however, identifies "choice" and "captive" travellers separately and the choice set open to these two groups is given in Table 5 below.

Table 5
DEFINITION OF CHOICE SETS

Mode	Choice Travellers	Captive Travellers
Car Driver Alone	Yes	No
Shared Car - driver or passenger	Yes	No
Shared Car - passenger only	No	Yes
Bus passenger - walk or car access	Yes	Yes
Rail passenger - walk, car or bus access	Yes	Yes

Shared Car, as a mode, is only open to a limited number of travellers, that is those who know a driver/passenger travelling to their common destination. It is therefore a partial choice rather than a full choice. The model treats car sharing as potentially open to all but reflects the practical difficulties in its use by the use of a modal bias.

Allowing car as an access mode for "captive" travellers is a potential mis-specification. However, the outer area zones for which this is allowed have a very small percentage of non-car households. The non-availability of a car for a complete journey is, of course, a much stronger restriction than the non-availability of a car for a lift to a rail or bus station.

Within the choice and captive markets there are obviously subgroups with a more limited choice set than that specified in the above table. For example, the "choice" segment contains a number of captive drivers, that is non-traders. These may include business people who, for all practical purposes, need the car during or immediately after work. The extent to which the mode choice model recognises the existence of non-traders is mentioned later in this section.

Model Structure - Individual travel choice models, such as the logit model adopted for this study, are based on the assumption of utility maximisation. That is, each individual will make that choice which yields him the greatest perceived benefit. Suppose a mode k has various attributes with values X_{jk}, for example, cost, in-vehicle time, wait time etc. Then the utility U_k of the trip by that particular mode, for a particular individual, can be defined by:

$$U_k = \sum_j a_{jk} X_{jk} + \mathcal{E}k$$

where $\mathcal{E}$ is a random variable encompassing all the influence on the choice decision not included in the X_{jk}.

The individual will choose that mode k for which U is a maximum. However, as $\mathcal{E}$ is a random variable, which is unknown for any particular individual, this choice can only be expressed as a probability. The actual probability in any particular instance clearly depends on the relative sizes of:

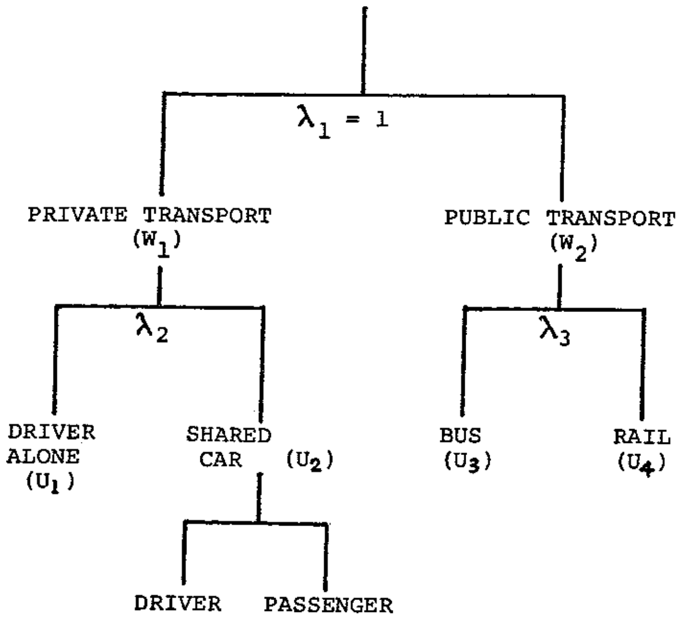
(i) the $\sum_j a_{jk} X_{jk}$; and

(ii) the $\mathcal{E}_k$

As $\mathcal{E}_k$ is a random variable, so is the difference of any two. If the difference is assumed to have a Weibull distribution, the choice probability can be expressed by the now familiar multinomial logit expression:

$$P \text{ (choosing k)} = \frac{e^{\lambda U_k}}{\sum_k e^{\lambda U_k}}$$

Where there are multiple choices, however, the above expression only holds if all the ε_k differences have the same variance, thus enabling a common value of λ to be used in the model. In the case of alternative transport modes certain pairs of choices such as bus/rail or auto driver/passenger are clearly characterised by a lower variance (and a higher value of λ) than the choice between car and public transport. With this in mind, a multi-level structure was adopted for Perth 2000; the hierarchical order of the available options is shown below:



There is a first level choice between private and public transport modes and a second level choice between driver alone and shared car on the one hand, and between bus and rail on the other hand. A further, third level choice is made between driver and passenger for travellers sharing a vehicle. Formally, the model is defined by;

Let $e^{\lambda_2 W_1} = e^{\lambda_2 U_1} + e^{\lambda_2 U_2}$

$e^{\lambda_3 W_2} = e^{\lambda_3 U_3} + e^{\lambda_3 U_4}$

Then P (car) = $e^{W_1} / (e^{W_1} + e^{W_2})$

P (PT) = $e^{W_2} / (e^{W_1} + e^{W_2})$

P (driver alone) = $(e^{\lambda_2 U_1} / e^{\lambda_2 W_1}) * p(\text{car})$

P (bus) = $(e^{\lambda_3 U_3} / e^{\lambda_3 W_2}) * p(PT)$

etc.

The theoretically most desirable method of estimating a multilevel logit model is by a single maximum likelihood calibration. This, however, requires an appropriate computer program and a data set containing observations for all relevant modes. Neither of the two was readily available and it was necessary, therefore, to estimate the model parameters in separate stages.

In the first stage the bus/rail model was estimated using a binary logit program and data from the 1976 public transport on-board survey. A similar approach was used for the second stage, the car/public transport model, but here 1976 Home Interview Survey data were used. Car driver/ passenger submodels were estimated at the stage where the models were calibrated for aggregate application purposes (see later in this section).

Estimation of Bus/Rail Choice Model

The model coefficients were estimated from 551 work trip records of "choice" travellers and 797 work trip records of "captive" travellers. As with most conventional travel surveys, little information was collected during the 1976 on-board survey in relation to travel impedances between origins and destinations. Variables such as access and egress time, waiting time and in-vehicle time had to be estimated from network data. Individual origins and destinations for the full sample of over 2600 records were plotted on a map and grouped in such a way as to minimise intra-group travel impedance variations. The selected records were then chosen from 22 origin areas and 4 destination areas. For each of the 88 trip interchange pairs network parameters were estimated for both public transport modes.

Table 6 documents the results of various model estimates. It should be noted that a common fare system exists in Perth for bus and rail travel. The effect of cost on mode choice therefore had to be determined solely from the car/public transport model. The following brief description of the steps taken towards the final model give an interesting account of a practitioner's approach in developing a sensible model, an approach a purist might reject out of hand.

The first estimates (Run A) resulted in coefficients which were consistent between the choice and captive data sets and had the correct signs. The model suggested that the choice between bus and rail is dominated by walk or bus egress in the central city. However, the obtained relativities between in-vehicle time, waiting time and bus egress time did not accord with prior experience.[1] In view of the

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1 During model development, attention was given to research work undertaken in 1976 to establish directly travel impedance values for commuters - Wildermuth (1976)

limited variability of the waiting time variable, caused by the inclusion of only a limited number of services and thus headways, the value of waiting time was constrained to twice the in-vehicle time for the next run. It was also decided to change the formulation for the access modes to allow separate values for in-vehicle time and vehicle to vehicle transfers. At the same time, the walk access and egress coefficients were constrained to the same value.

Table 6
BUS-RAIL MODE CHOICE ESTIMATES

	RUN A		RUN B		RUN C	RUN D
	Choice	Captive	Choice	Captive	Combined	Combined
Bus Bias	-1.46	-1.30	-0.97	-0.89	-0.49	0.18
PT In-vehicle time (IVT)	-0.080 (1.8)	-0.026 (0.7)				
Walk access time	-0.164 (2.3)	-0.164 (2.9)				
Car access time	-0.280 (4.2)	-0.312 (3.9)				
Waiting time (WAIT)	-0.042 (0.6)	-0.066 (1.0)				
Bus egress time	-0.398 (7.0)	-0.306 (6.8)				
Walk egress time	-0.167 (7.0)	-0.223 (8.7)				
PT IVT + 2 *WAIT			-0.127 (4.5)	-0.062 (3.7)		
Walk access/ egress time			-0.130 (5.0)	-0.169 (7.5)		
All vehicle - vehicle transfers			-2.06 (8.9)	-2.79 (6.5)		
Generalised time[(a)]					-0.079 (10.9)	-0.095 (15.5)
PT-PT transfers					-1.45 (6.1)	-0.95
Car - PT transfers					-2.28 (14.1)	-1.52
Number of observations	551	797	551	797	1348	1348
- Correctly classified	74%	76%	76%	77%	73%	69%

Notes: Figures in brackets are t-statistics for coefficients.
All times are in minutes

(a) Generalised time = Bus IVT + 0.75 Rail IVT + 2*WAIT + 2*Walk access/egress time + 0.80 car access time

The results of the second estimates (Run B) showed improved levels of significance. However, the relative transfer penalties were rather high. These penalties were acting to some extent as a mode-specific penalty, as no trips existed in the sample which required a transfer for the bus trip without also requiring one for the corresponding rail trip. For the next run in-vehicle time was therefore allowed to be mode-specific and thus reflect the possible advantages of rail over bus in terms of in-vehicle comfort. Typically, comfort and convenience factors could be expected to be around one third of the traditional "value of time". For Run C the rail in-vehicle time value was set to 75% of the corresponding bus value.

At this stage it was also clear that little benefit would be gained by continuing to estimate separate models for captive and choice travellers; the respective coefficients were all within two standard errors of each other. In addition,PT to PT transfers were separated from the car access to PT transfers. Intermediate runs showed further that walk access could be taken as twice bus in-vehicle time without any significant model distortion.

The results of Run C suggested a PT-to-PT transfer value equivalent to 18 in-vehicle minutes. This was still high when compared with previous local findings. In view of the potential importance of transfers at the model application stage, the value was constrained to 10 in-vehicle minutes for the final estimate (Run D). The car to PT transfer value was also constrained to 16 in-vehicle minutes in line with the relativity between the two transfer types indicated in Run C. The results of Run D then defined a large part of the choice function for the car/public transport model.

Estimation of Car/Public Transport Choice

For this estimation only those travellers were considered with an unrestricted choice of all travel modes, i.e. traders. Because of the rigid selection only 21 observations of public transport commuters were obtained from the Home Interview Survey. An additional 52 observations of car commuters were included, leaving a data set of 73 home to work records for model estimation (trips back home from work were considered to be constrained by the choice decision made prior to the trip to work).(1) An estimate with limited data was considered to be far more desirable than a larger sample including travellers with a restricted choice set. The latter is a fairly common case of a mis-specified model leading to unrealistic model coefficients.

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1 While this paper refers to a mode choice model for work trips only, a similar model has been estimated for non work trips.

In order to calculate the full car/PT choice function, determined in part by the bus/rail estimation, the values of each of the independent variables were first established separately for each observation and for both the chosen mode and the alternative mode. Again, the lack of survey data relating to certain travel impedance values made it necessary to estimate parameters such as public transport access, egress and waiting time, egress time from the car park to the work place and perceived car running costs.

Preliminary car/PT model runs were carried out in order to estimate the model's sensitivity to different values of car in-vehicle time and car running costs. Indications from these runs were that a car in-vehicle time value equal to 80% of the bus in-vehicle time value and a perceived car running cost of around 2.5 - 3.0 cents/km (1976 prices) provided the best explanation of mode choice behaviour.

The results of the final work trip model runs are shown in Table 7. The utilities for these runs were calculated for three alternative modes, i.e. car driver, bus and rail. For shared vehicle trips the cost of car travel was halved. As the fare was the same for bus and rail travel, the composite PT utility could be calculated directly from the two generalised times.

Table 7
CAR-PUBLIC TRANSPORT WORK TRIP MODE CHOICE ESTIMATION

Run	Car Bias	COST	GENTIME	Correctly Classified	λ_2	Value of Bus IVT ($/hr)	Car Running Cost (c/km)
1	-0.37	-0.044 (3.2)	-0.887 (2.7)	74%	1.13	1.14	2.5
2	-0.19	-0.046 (4.0)	-0.814*	75%	1.23	1.00*	2.5
3	0.07	-0.045 (4.0)	-0.790*	81%	1.27	1.00*	3.0
4	0.41	-0.034*	-0.593*	75%	1.69	1.00*	3.0

Notes : Figures in brackets are the t-statistics
An asterisk indicates a constrained value

For Car : COST = perceived running cost + 0.5 parking cost
GENTIME = 0.076 IVT + 0.190 walking time

For Public Transport : COST = Fare

GENTIME = 0.095 bus IVT + 0.071 rail IVT + 0.190 waiting time + 0.190 walking time + 0.076 car access time + 0.95 PT-PT transfers + 1.52 Car-PT transfers.

The first, unconstrained run resulted in an implied value of bus in-vehicle time of $1.14 per hour which was within the expected range. However, the implied λ for the second level bus/rail split was greater than 1.0, as required by the model structure, but rather less than the prior expectation of around 2.[1] For the second run the value of bus IVT was constrained to $1 per hour, in line with previous research. The resulting value of λ_2 was still considered to be too low.

For the third estimation run, the cost of perceived car operation was increased to 3c/km and this resulted in the highest number of correctly classified observations. The value of λ_2 however did not increase sufficiently. As a consequence, it was decided to constrain the cost coefficient to one standard error below the estimated value. This increased λ_2 to a more acceptable value without significantly affecting the model's performance.

Model Calibration

A number of application issues had to be tackled during calibration (verification) of the mode and destination choice models against aggregate benchmark data. The sequence for model application is (i) the calculation of zone-to-zone mode probabilities and composite utilities for both, choice and captive travellers, (ii) trip distribution and (iii) mode split.

In an attempt to overcome the mode choice aggregation bias, the random component of the utility function was adjusted according to estimates of zone-specific variances of access/egress time differences between bus and rail and between car and public transport. As it turned out, these adjustments were not sufficient and further corrections to the bias term were necessary to match the benchmark data. The initial model also underestimated public transport trips to the Central City and a non-linear zonal attraction density function was added to the model.

For "choice" travellers a car driver alone/share car model was calibrated using a generalised cost for car sharers equal to 70% that for drivers alone. The model includes a trip density function (trips per unit of origin and destination area) to reflect the variations in the extent of difficulty of finding a driver/passenger travelling to the same destination. The third level choice, that is the choice between driving or riding in a shared car, is determined at the mode split stage using observed proportions.

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1 λ_2 is obtained, in this case, as the inverse of the generalised time coefficient.

Survey data indicated that approximately 20% of "choice" commuters are non-traders, that is captive car users. The observed proportion varied between 14% for central city-oriented trips to 22% for non-CBD trips, which is possibly a reflection of the larger number of blue collar employees (e.g. tradesmen) working outside the central city. At the mode split stage, therefore, the "choice" probabilities for public transport modes were applied to traders only. At the present time there are no available data sources indicating the extent of non-traders within the "captive" travel market.

As mentioned earlier, the distribution model is applied in a relaxed doubly-constrained form, allowing choice and captive travellers to compete for the available zonal trip attractions. During calibration the observed choice/captive distribution was simulated quite well. For future applications, however, the model's sensitivity in this regard needs to be watched.

STRATEGIC TESTS FOR THE YEAR 2001

At the time of writing this paper, a number of model applications to possible year 2001 environments have been carried out for work trips. Table 8 summarises the adopted test scenarios and transport strategies and gives some broad, initial test results.

External variables can be defined as those factors which have transport implications but over which the transport policy maker has little or no influence. Previous long-term transport studies, to a large extent, tended to ignore changes that are taking place in a number of these variables. In contrast, a pre-modelling stage of the Perth 2000 study placed considerable emphasis on identifying the potentially most significant external factors. At the same time, each selected variable needed to be specified in numeric terms for model input purposes. Given the level of uncertainty for a 20-year planning horizon, a subjective but qualified assessment was then made as to a realistic range of such values.

A transport strategy, on the other hand, comprises a set of policy elements directly determined by the transport policy executives. It is one of the prime objectives of the study to analyse the robustness and applicability of a given strategy under various operating environments (scenarios). More specifically, the two major issues in Perth are (i) the question of appropriate future transit technology for each of the five transport corridors and (ii) how best to retain our mastery over the automobile, particularly in sensitive areas such as the central city and the collar around the central city.

Table 8
BASIC ALTERNATIVE TESTS - YEAR 2001

	1976 BASE YEAR	EVALUATION BASE	FARE INCREASE	ALT. TRANSIT TECHNOLOGY	CENTRALISED LAND USE	FAVOURS P.T.	FAVOURS CAR
A. "EXTERNAL" VARIABLES							
Urban Core Population	570,000	648,000	as for EVALUATION BASE	as for EVALUATION BASE	746,000	746,000	648,000
Central City Employment	87,000	116,000			150,000	150,000	116,000
Working Pattern	5-day week	9-day f/night			9-day f/night	9-day f/night	4-day week
Growth in Real Income p.a.	base	1.5%			1.5%	Nil	2.5%
Telecommunication Effects	base	negligible			negligible	negligible	off-peak
Attitude to Public Transport	negative	neutral			neutral	positive	neutral
Fuel Price (1980/81 c/litre)	22	60			60	90	50
Car Fuel Consumption Index	100	75			75	75	75
B. TRANSPORT POLICY ELEMENTS							
P.T. Level of Service	base	improved	improved	improved	improved	improved	reduced
Main Transit Technology	Bus/HRT	Bus/LRT	Bus/LRT	Bus/Busway	Bus/LRT	Bus/LRT	Bus/HRT
Public Transport Fare Level	low	no change	+50%	+50%	+50%	no change	+80%
Highway Level of Service	high	high	high	high	reduced	reduced	high
CBD Parking Price/Quality	base	little change	little change	little change	little change	discourage	little change
C. INITIAL TEST RESULTS							
Cars per 1000 Adults	634	714	714	714	710	665	752
P.T. Commuter Trips/day	60,800	94,700	77,500	N.A.	96,800	195,600	54,200
Overall P.T. Usage-Commuters	11.0%	9.5%	7.8%	N.A.	9.7%	19.9%	5.7%
CBD P.T. Usage-Commuters	39.4%	46.6%	39.7%	N.A.	40.0%	71.5%	29.9%
Avg. Car Commuter Trip Length	10.1 km	11.2 km	11.2 km	11.2 km	N.A.	9.8 km	N.A.
Commuter Benefits ($ m. p.a.)	-	base	-10.2	N.A.	-6.0	+5.2	-6.2

N.A. - not available as yet

Application Issues

In applying the forecasting models to a future situation the practitioner is faced with a number of dilemmas to which he/she can find few discussions in technical papers. One of these issues is related to the applicability to a time-series framework of elasticities derived from cross-sectional analyses. General observations tend to indicate that cross-sectional models are somewhat over-sensitive in this regard.

In the case of the household car ownership model, however, the results of the year 2001 applications appear realistic. Expressed in a more common way than is shown in Table 8, the forecast number of cars ranges from 483 per 1000 persons (favours P.T. test) to 545 cars per 1000 persons (favours car test). The corresponding base year (1976) figure is 430, although this is not strictly compatible because of differences in household structure. The forecasts shown do however include some minor adjustments to the original model with regard to pensioner households. It was foreseen that older people of tomorrow, everything being equal, would have a somewhat higher car ownership level than today's pensioner because the former, specifically females, would be more confident to drive a car.

A further application issue arises at the mode choice stage with respect to the value of time savings (VOT). During model estimation great emphasis is being placed on various time related travel impedances (e.g. walk, wait, in-vehicle time). In a forecasting situation, just as critical of course are assumptions on the relative future values. It has previously been pointed out that VOT includes a substantial element of comfort and convenience and this part of VOT is treated in the Perth model as a variable under the heading Attitude to Public Transport. Depending on the test scenario, base year impedance coefficients, specifically transfer coefficients, were reduced to some extent. It was assumed that public transport marketing efforts would reduce the perceived comfort and convenience nuisance.

The "true" value of time is generally related to the wage rate or the household income level. This principle was adopted for the basic tests; alternative sensitivity tests are however proposed. In view of the predicted reduction in working hours and the corresponding increase in leisure time, it could be argued that travel time savings in the future, typically in the range of 1 to 10 minutes, may well be valued at a relatively lower rate than today.

Finally, a point worth noting with regard to the commuter benefits shown in Table 8: the positive value for the "Favours PT" test has little to do with increased public transport usage per se; it is simply caused by the lower VOT for the zero income growth scenario.

CONCLUDING REMARKS

From the outset, emphasis was placed on an incremental model development approach. Within an adopted sequential structure, individual models are firstly built to a level where they are fully operational and give sensible predictions. Thus, at this stage, the package consists of a hybrid of conventional aggregate and newer-type disaggregate models. The modular form of the package however readily allows for updating as data sources improve and resources permit.

The market segmentation model, as outlined, must be regarded as a successful way of integrating disaggregate car ownership and trip frequency models into an aggregate model framework. Furthermore, the separation of choice and captive (disadvantaged) travellers is useful not only in avoiding mode choice specification errors but also for social evaluations of alternative transport strategies.

The lack of a more comprehensive and cohesive set of survey data probably prevented the full merits of a multi-level mode choice model to be disclosed. There can be little doubt, however, about the desirability of the concept vis-a-vis the simple multinomial form.

In terms of further improvements to individual models within the package, the following are in the top part of our priority list:

- The replacement of the presently crude accessibility indicator in the car ownership and trip frequency models with more appropriate indices as produced by the destination choice model.
- The inclusion of a car ownership elasticity measure relating to car operating costs.
- A more formal car driver/passenger choice model.
- A more detailed review of the mode choice aggregation problem.
- The segregation of "traders" and "non-traders" to be extended to include captive passengers.
- The development of a more sophisticated peak period model which incorporates a temporal distribution of trips related to congestion levels.

REFERENCES

Hutchinson, M.J. (1979) - "Multi-variable models of car ownership", Traffic Engineering & Control, Vol. 20 pp. 399-403.

Wildermuth, H.K. (1976) - "Transport Policies for Central Perth - Review and Formulation", Director General of Transport, W.A., Chapter 9.