Published paper

Wardman, M.R. (1985) *An Analysis of Motorists' Route Choice Using Stated Preference Techniques.* Institute of Transport Studies, University of Leeds, Working Paper 212

Working Paper 212

September 1985

AN ANALYSIS OF MOTORISTS' ROUTE CHOICE USING STATED PREFERENCE TECHNIQUES

M WARDMAN

ABSTRACT

WARDMAN, M. (September 1985) An Analysis of Motorists' Route Choice Using Stated Preference Techniques. Working Paper 212, Institute for Transport Studies, University of Leeds.

This paper presents some results of an analysis of motorists' route choice based on stated preference responses. This is done for both an inter-urban and urban route choice context.

The nature of the study is exploratory, the analysis being based upon a pilot survey of some 79 motorists undertaken in March/April 1984. The quality and nature of the responses are assessed in terms of a 'rationality' test and also through a consideration of lexicographical forms of decision making.

The formal quantitative analysis examines the ranked preferences of motorists by means of an ordered multinomial logit model. Detailed results are presented for various formulations of the representative utility function to assess the influence of various relevant variables upon route choice and to identify the best explanation of motorists' stated route preferences in both route choice contexts. Values of time are derived for a variety of model specifications as part of this consideration of the usefullness of the ranking approach to an analysis of motorists route choice.

CONTENTS

ACKNOWLEDGEMENTS

Unpublished work quoted in this paper was produced as part of a research project into the value of time, undertaken for the Department of Transport by a joint team from the MVA Consultancy London, Leeds University Institute for Transport Studies and Oxford University Transport Studies Unit. The members of the team at the current phase of the project are:

Dr J J Bates	John Bates Services
Mr M Bradley	Oxford University
Dr A S Fowkes	Leeds University
Dr P B Goodwin	Oxford University
Mr H F Gunn	Cambridge Systematics Europe
Prof K M Gwilliam	Leeds University
Dr P M Jones	Oxford University
Mr R P Kilvington	Oxford University
Ms P Marks	Leeds University
Mr M Roberts	MVA Consultancy
Mr M Wardman	Leeds University

I would especially like to thank John Bates, Tony Fowkes and Phillipa Marks for their assistance, Professor Gwilliam for comments on a draft version of this paper and Dr Ian Johnson who collected the data. The views expressed in this paper do not necessarily reflect those of the Department of Transport or of other members of the study team.

1. Introduction

The findings from an analysis of motorists' route choice travel behaviour reported here are based upon a pilot survey of motorists undertaken in March/April 1984. The aims of this survey were twofold:-

a) The stated preference experiments undertaken in an earlier phase of this value of time project related only to rail and coach commuters in North Kent (Value of Time Study 1983). Hence problems specific to the analysis of motorists' travel behaviour have not received similar consideration. It is, therefore, necessary to investigate certain issues, such as the representation of the monetary costs associated with car use, and to assess certain factors which may be hypothesised to influence motorists' travel behaviour. The survey also provides some means of assessing how respondents perceived the stated preference exercise by noting, for example, their comments concerning the difficulty of the ranking task and also whether more information than that supplied was needed to realistically represent the route choice process.

b) The pilot survey was also undertaken in order to consider different survey methods in terms of their cost effectiveness in obtaining a given sample of motorists. This enabled recommendations to be made as to the best survey method to use in any further data collection exercise in comparable circumstances.

This paper concentrates on the former objective. The aim is to assess the performance of the ranking approach to value of time estimation in a motorists route choice context. This is done by means of both a qualitative and quantitative examination of the responses obtained from the ranking exercise. Considerations of the cost effectiveness of each survey method, along with details of the survey methods themselves, can be found elsewhere (Value of Time Study: 1984a, 1984b).

2. Data Collection Exercise

Respondents were required to rank travel options in order of preference where each option is characterised by certain travel attributes. Hence each respondents ordering yields a number of discrete statments of preference. Whilst the precise informational content of the responses depends upon the depth of ranking, fewer questions are required for a given level of information than is required by using, for example, a pairwise comparison approach, albeit at the cost of a more complex task being required of the respondent.

In the decade up to 1980, conjoint analysis; being a generic term for the analysis of ordinal statements of preference, had been employed in more than 300 commercial projects (Wittink and Cattin 1981). The ranking approach has also found numerous transport applications in a variety of contexts (Bates and Roberts 1983; Beggs, Cardell and Hausman 1981; Hensher and Louviere 1983; Steer, Davies and Gleave 1981; Value of Time Study 1983; Fowkes and Marks 1985; Bates 1985). The ranking approach used here was applied in two hypothetical circumstances:

a) Inter-Urban Route Choice

This experiment offered the respondent the choice of a 100 mile circuitous route which had no toll charge or a more direct 70 mile route where a toll was payable. This task involved the ranking of twelve travel options where eight of these options were tolled routes. The options offered the respondent the opportunity to trade-off between attributes across options such that estimates of the relative valuations placed upon various attributes could be obtained. The respondent was asked to imagine that the purpose of the journey was to visit friends for a weekend.

b) Urban Route Choice

This experiment follows along similar lines to the inter-urban, the respondent again being able to trade-off between attributes across options in the choice between a congested route of 9 miles and a longer but higher quality route of 12 miles where a toll was payable. The respondent was required to rank ten travel alternatives in order of preference where eight of the options were tolled routes. As with the inter-urban ranking, the journey purpose was to visit friends.

In each experiment, the motorist was given the distance, toll charge, average speed, travel time and petrol cost for each of the alternatives and a brief description of the hypothetical circumstances was also given.

The nature of the exercise is more hypothetical than was the case for the North Kent stated preference analysis and than is likely to be the case in future applications in this value of time study. This is because the exercise was not based upon routes or journeys with which the respondent would be familiar. This must be borne in mind when considering certain problems that may be encountered; the hypothetical nature of the exercise as it is undertaken here is not an inherent feature of this technique.

The findings from the analysis of the urban and inter-urban route choice data sets will be considered separately. Before the results of the formal analysis of the data are considered, the qualitative assessments of the responses which were undertaken will be outlined.

3. Qualitative Assessments of the Responses

A feature of the ranking task is the opportunity it provides to make some assessment of both the quality and nature of the responses supplied. The logit model to be used can handle error in the stated preference responses, to a certain extent, due to its stochastic component. However, we would be concerned if a high proportion of individuals supplied responses which appeared to be of poor quality given that this may increase the range in which the value of time estimate lies or indeed distort the estimate of the true value of time. Furthermore, responses which do not reflect trade-off behaviour may be misleading in the context of value of time estimation. It may, therefore, be preferable to omit from the formal analysis those orderings which can be identified as being of poor quality or which do not exhibit trade-off behaviour.

If the options had been formulated in a manner such that one option was clearly superior to all others (option j) whilst another option was clearly inferior to all others (option k), a rationality test might involve assessing whether options j and k are placed at the appropriate extremes of an individual's ordering. Such an assessment was possible for the ranking exercise completed by North Kent rail and coach commuters where it was found that approximately 10% of respondents did not place either one, or both, of these options at the appropriate extremes of their ranking (Value of Time Study 1983).

As no option in the set of route choice travel alternatives was totally dominant or dominated, such an assessment cannot be undertaken here. The options were, however, formulated in such a way that certain alternatives can be identified as being rationally preferred to certain others. It is assumed that the relevant monetary cost that influences choice is the straightforward unweighted sum of toll charge and petrol cost, that is a unit change in toll charge is regarded as being of an equal disbenefit to a unit change in petrol costs, and also that choice is influenced only by the level of time and total cost.

Given the travel time (T) and total cost (C) of two options i and j, rationality is defined such that if conditions 1 and 2 below are satisfied, for any pairwise comparison of travel alternatives, then option i dominates and is rationally preferred.

1. $Ci < Cj \quad Ti \leqslant Tj$ 2. $Ti < Tj \quad Ci \leqslant Cj$

A more rigourous test might introduce the variables speed and toll and compare options which are dominant in terms of petrol costs (PC), time (T), speed (S) and toll charge (TL); the four variables which characterise each option. Thus option i would be rationally preferred to option j if, for example:-

$$PCi < PCj \quad Ti \leqslant Tj \quad Si \geqslant Sj \quad TLi \leqslant TLj$$

However, this would restrict the number of comparisons that could be made whilst it is considered that useful insights into the quality of the responses can be obtained by assessing the data according to conditions 1 and 2 above.

The assessment requires that the respondent has expressed preferences for less disutility rather than more such that his stated preferences are consistent with what we hypothesise to be his actual preferences. The inter-urban and urban route choice experiments contained seventeen and nineteen of these dominated pairwise comparisons respectively out of a possible total number of pairwise comparisons of sixty six and forty five respectively.

Other qualitative assessments of the responses were undertaken as follows:

a) Some individuals may have a distinct aversity to paying tolls, for example, paying for the use of road space is opposed as a matter of principle. As such, motorists who are opposed to toll roads, and who believe that such toll roads are a possibility, may bias their responses in some attempt to reduce the likelihood that they perceive of tolls being more widely introduced or simply to register some protest against tolled roads. This response bias may take the form of untolled options being ranked as preferred. Analysis of the responses, in terms of whether untolled options are ranked as preferred, gives some indication as to the maximum number of respondents who have biased their responses in this way. Such an assessment has been undertaken with respect to the inter-urban rankings, where four routes are untolled, but not with respect to the urban rankings where only two routes are untolled. If it was found that a considerable number of respondents ranked the untolled options as preferred, it would be necessary to consider the data further to examine whether such ranking could be reconciled by reference to other criteria, such as, for example, the implied values of time from the ranking.

b) Certain respondents may possess non compensatory decision rules, for example, a lexicographic choice process. Whilst the latter is only one form of non-compensatory choice process, such decision making processes are often ignored in economic considerations of travel behaviour and in neo-classical economic theories of consumer behaviour in general.

Non compensatory choice processes involve an attribute by attribute consideration of alternatives where the disutilities associated with various attributes are not traded-off across options (Foerster 1979, 1980; Golob and Richardson 1980).

A lexicographic choice process identifies the most important attribute from those which characterise an option and choice is based upon that option which possesses this most important attribute at its highest utility (least disutility) yielding level. Once the most preferred option is identified, the process is repeated for the remaining options whereupon a complete ranking is eventually formed. An individual may rank the options on offer in terms of, for example, ascending levels of time.

If a respondent possesses a non-compensatory choice rule, the mode/route choice process is quite distinct from any benefit, in terms of reduced disutility, that is obtained from, for example, travel time savings. As such, the responses of individuals who possess non-compensatory choice rules might be omitted from the formal analysis undertaken for the purposes of inter-attribute valuation. Their choices are not consistent with utility maximising models of compensatory choice from which estimates of relative valuations are to be obtained.

The analysis undertaken here focuses upon the possible presence of lexicographic choice rules. This choice rule is the most amenable to assessment given the nature of the data. It is also perhaps that process which is most likely to be adopted if individuals are forced to consider the options, in a non trade-off manner in terms of one dimension, if they find the ranking task otherwise too demanding.

It is not clear what the implications for the ranking supplied would be if other forms of non compensatory choice rules applied, such as the elimination by aspects decision rule (Tversky 1972; Gunn 1982; Recker and Golob 1979). Choices based upon attributes achieving certain standards, particularly standards which are revised in the process of ranking options, can not be identified with the responses available here.

It is not possible, however, to uniquely distinguish lexicographic orderings although some progress can be made and insights obtained into the possible existence of such decision rules. There are a number of reasons why a ranking which appears to be based on a lexicographic choice rule may not in fact be so. Non trade-off behavoiur may be erroneously implied.

(i) If there are no apparent trade-offs in the ranking supplied, this may reflect a very high or very low value of time. The individual may be willing to trade-off time and money but the rate at which he can do so is not sufficiently attractive.

(ii) A ranking that exhibits no trade-offs between attributes may be obtained if certain included attributes are not relevant to travel choice. This is unlikely to be the case for the majority of respondents given the attributes that characterise each option in the experments undertaken here. However, if the respondent would not pay for the petrol used, or if petrol costs are not considered in route choice or are treated not as a variable cost but rather as, for example, a fixed weekly cost, the ranking supplied has an increased likelihood of exhibiting preferences which do not exhibit trade-offs.

(iii) Response bias, in an attempt to alter the perceived likelihood of some occurence, may lead to a ranking which appears lexicographic when a respondent's true decision process is of a compensatory nature. Thus, for example, a respondent may emphasise travel time savings, by ranking options according to time, to increase the chances of a time saving project being undertaken. Although such respondents do not possess non compensatory choice rules, omitting these respondents on the basis of apparently lexicographic choice rules would cause little concern as their responses are biased. However, if cost and time variations are perceived as equally likely, there is no incentive to bias responses as the individual would gain the greatest benefit by the introduction of that option which is most preferred. There is a lesser tendency for actual and stated preferences to diverge due to bias than is the case with, for example, transfer price.

(iv) Of some concern is the possibility that certain respondents are forced to supply one dimensional orderings due to difficulties in ranking the options according to a compensatory criterion. Whilst the respondent's ordering could here be correctly identified as being lexicogarphic, the problem rests with an ordering which is based on compensatory principles where possible, but where this proves too demanding, a lexicographic choice rule simplifies the remaining tasks required of the respondent in completing the ranking.

Given these limitations, it remains worth considering whether lexicographic choice processes are potentially present on a large scale. However, an upper bound to the number of respondents who possess lexicographic choice rules can be identified which will indicate whether there is any serious cause for concern. The findings from the rationality test which was undertaken are listed in Table 1.

TABLE 1: 'Irrational' Responses

Number of Irrationalities	0	1	2	3	4	5	6	7	8	9	10
Inter Urban	29	11	13	16	2	4	1	1	0	1	0
Urban	30	14	14	6	3	5	1	1	0	1	2

Notes:
Inter-urban contains 17 dominated comparisons from a possible 66.
Urban contains 19 dominated comparisons out of a possible 45.

The number of irrationalities, in pairwise comparisons of options based on travel time and total cost, follows a similar pattern in both experiments. The degree of inconsistency is relatively low, bearing in mind that an 'incorrect' ranking of one option may imply several irrational preferences of the type defined above in conditions 1 and 2. The findings do not give rise to serious concern about the quality of the responses supplied. Furthermore, few respondents supplied rankings which exhibited serious irrationalities in both the urban and inter-urban cases. If this rationality test had suggested that there were widespread irrationalities in the responses, the more rigourous but also more restricted examination of the responses, as outlined above, would have been undertaken.

Some assessment of the quality of the responses is necessary as the task required of respondents is not straightforward; involving the ranking of either twelve or ten options. As either the number of options to be ranked or the number of attributes per option increases, so the ranking task becomes more difficult. Research undertaken by Montgomery et al (1977) and Alpert et al (1978) raises questions concerning the use of rankings which include numerous attributes. They found that the two factor at a time approach performed better than the full profile approach where eight and nine attributes respectively characterised the options in the choice set. However, using three and five attributes respectively, Oppedijk van Veen and Beazley (1977) and Jain et al (1978) found a greater degree of consistency between the two factor at a time and full profile approaches.

The inclusion of too many options, or attributes per option, is likely to lead to information overload whereupon the respondent may ignore variations in variables of lesser importance or which exhibit little variation between options, or may resort to a one-dimensional consideration of the options to which we now turn.

To identify potential lexicographhich choice rules, rankings were constructed according to least travel time, total cost, petrol cost and toll charge. Where the relevant attribute has the same value between options, the individual is assumed to choose that option which dominates according to the remaining attributes. If such dominance does not exist for these remaining attributes, the appropriate options are interchangeable within the ordering.

In the inter-urban experiment, four of the 78 individuals supplied rankings which conformed to an ordering according to least travel time. One respondent supplied such a ranking based on ascending levels of total cost whilst one respondent supplied a ranking based on the level of toll charge.

In addition to those who supplied one-dimensional orderings, two respondents ranked the four untolled inter-urban options as preferred but did not supply a complete toll based ranking. Hence there is a limit of only two to the number of respondents who might have biased their responses against tolled roads, along with one person who supplied a complete toll based ranking.

In the urban route choice experiment, five respondents, from a total of 77, supplied time based rankings whilst the corresponding figures for such rankings based on total cost and petrol cost were five and one respectively. The rankings based on total cost and toll charge were quite similar, but not identical, in the urban case.

Approximately 8% of the inter-urban rankings and 14% of the urban rankings exhibited no apparent trade-offs. Moreover, there are several additional respondents whose ordering of the options is suspiciously approximate to a lexicographic form.

Four respondents supplied apparently lexicographic orderings in both route choice contexts; three of which were based upon travel time and one upon total cost. As nine respondents supplied such rankings in only one of the two route choice contexts, it might be inferred that these individuals do not have true lexicographic choice rules and that there is an upper limit of four to the number of respondents who possess such decision making processes. However, this finding suggests that these nine respondents either have varying decision rules, depending upon travel circumstances, or more likely that they possess compensatory choice functions but have found it too difficult to rank the options on this basis and have, therefore, resorted to a one-dimensional consideration of the options to simplify the task required of them. Simon (1955, 1978) has argued that the use of satisficing levels may be more appropriate, as a relatively simple basis of choice, when decisions are required in situations of numerous options and/or attributes. Such choice processes cannot, however, be considered with the data available here.

The maximum number of respondents who possibly possess true lexicographic choice processes is relatively low. Others may have resorted to such a choice rule, either in whole or in part, to simplify the task required of them. Moreover, there is little evidence of response bias in terms of favouring untolled options.

4. The Modelling Process

As motorists are assumed to be constrained utility maximisers, such that a value to travel time is implied, the modelling process conforms to conventional disaggregate practice. The logit model is derived by assuming that individuals choose amongst alternatives according to greatest utility (least disutility) in a compensatory manner whilst the stochastic component, which allows for unobservable or omitted effects, is assumed to conform to a Weibull distribution.

The stochastic element is also called upon to represent the deviation of the i'th individual's tastes from the average with respect to each variable. Whilst the error term is no longer identically and independently distributed when inter-personal taste variation is present, work done by Horowitz (1980, 1981) and Fowkes and Wardman (1985) suggests that the coefficient estimates of the logit model remain reasonably robust in such circumstances.

The responses to a ranking exercise, for each individual, yield a number of discrete choices between travel options and conventional disaggregate models of travel behaviour can be applied with the advantage that, for a given sample size, there are more observations of choice than would be the case with a revealed preference approach.

The specific model used to explain individual's behaviour is a modification of the logit model, adapted to allow for the input of ranked data. If n options have been ranked in order of preference, a multinomial logit model can be calibrated for the most preferred option in relation to the remaining n-1 alternatives. This process is repeated for the preference of the second best alternative over the remaining n-2 options and continued until the ranking is exhausted. Hence for each individual, given a ranking of n options, we have n-1 observations of preference to be input to the multinomial logit model. This represents the maximum number of independent observations of choice that can be obtained from the ranking supplied.

The means of estimating the coefficients of the model is an iterative maximum likelihood process where the estimated parameters of a linear utility function are interpreted as scale transformations of the marginal utilities of the relevant attributes. As such, an estimate of a relative valuation is derived in the usual manner as a ratio of the appropriate coefficients. Various alternative algorithms are available for the estimation of relative preferences from ordered preference statements, for example, PREFMAP (Carroll 1972), MONANOVA (Kruskal 1965) and LINMAP (Srinivasen and Shocker 1973a, 1973b).

Whilst the pilot survey obtained only a limited sample of respondents (78 Inter Urban, 77 Urban), the ordered statements of preference allows the effective data set of discrete choices, which are input to the logit model, to be considerably expanded. Effective sample sizes of 858 and 693 at the maximum depth of ranking, for the inter-urban and urban cases respectively, allow worthwhile analysis to be undertaken.

The formal analysis of the responses assesses various representations of motorists' route choice and whilst value of time estimates are derived, this is not the sole purpose of the exercise. The findings of the models of inter-urban and urban route choice will be considered in turn.

5. Analysis of Inter-Urban Route Choice

Various models attempt to explain route choice by reference to relevant variables which are hypothesised to influence choice. The estimated coefficients of the logit model should have a negative sign if an increase in the level of an attribute leads to a reduction in utility (increase in disutility) and hence to a reduction in the probability of choosing that option as the most preferred in the choice set. The coefficients associated with each attribute are specified as generic, that is, for example, the same time coefficient is assumed to apply across all alternatives.

Alternative specific constants are not specified as there is no reason to suspect that any route is preferred to others for reasons other than those which are explained by the included relevant variables. For example, whether there is some tendency to favour untolled options, regardless of the level of the other relevant attributes, is analysed by use of a variable to reflect whether the route is tolled or not.

Table 2 lists the findings from an analysis of motorists' stated route preferences using the most straightforward forms of linear utility functions with 858 observations of discrete choice. Monetary costs are specified in pence, and travel time is expressed in minutes, which is the case throughout.

Model 2.1 is the most straightforward form of utility expression where the probability of choosing an option as preferred is explained simply as a function of total cost and travel time. Model 2.2 splits total cost into its constituent parts; petrol cost and toll charge, as is also the case with model 2.5, in an attempt to explore the hypothesis that a unit change in either petrol cost or toll charge have the same utility effect. Models 2.4 and 2.5 introduce a dummy variable to reflect whether a toll is payable; essentially specifying an alternative specific constant for tolled routes whilst 2.3 examines whether choice can be best explained with reference only to travel time and toll charge.

TABLE 2: Linear Models of Inter-Urban Route Choice

MODEL	2.1	2.2	2.3	2.4	2.5
PETROL COST		-.00380 (-7.24)			-.01036 (-5.86)
TOLL CHARGE		-.00521 (-16.45)	-.00398 (-15.75)		-.00523 (-16.40)
TOTAL COST	-.00513 (-16.49)			-.00523 (-16.43)	
TIME	-.03073 (-17.88)	-.03080 (-17.96)	-.02562 (-17.23)	-.03398 (-17.77)	-.04271 (-11.93)
TOLL DUMMY				-.41186 (-4.08)	-1.5342 (-3.90)
VOT(TC)1	5.99 (23.48)			6.50 (22.03)	
VOT(PC)2		8.11 (8.00)			4.12 (9.72)
VOT(T)3		5.91 (23.62)	6.44 (20.22)		8.16 (12.09)
LOG-LIKELIHOOD	-1347.27	-1342.41	-1368.89	-1339.08	-1334.64
RHO-BAR SQUARED	0.136	0.139	0.122	0.141	0.143

NOTES TO TABLE 2:
1. Value of time in terms of total cost (p/min).
2. Value of time in terms of petrol cost (p/min).
3. Value of time in terms of toll charge (p/min).
t statistics in brackets.

In all cases, the coefficients have the correct sign and are highly statistically significant although the Rho-Bar squared statistics are lower than is commonly achieved for similar sample sizes. The implied values of time, which vary somewhat according to the specification used, are also highly significant.

Model 2.1 yields a value of time which is relatively high at 5.99 pence per minute although this may be influenced by higher than average income respondents having a particularly high value of time. The value of time estimate has a relatively small standard error; a 95% confidence interval represents a range of plus or minus 8% of the central estimate.

Model 2.2 yields value of time estimates which vary according to whether a petrol cost or toll charge equivalent of the marginal utility of time is taken. The toll charge coefficient implies an effect upon utility somewhat greater than that for petrol cost. Both the petrol cost and toll charge coefficients are significant, as are the value of time estimates. The petrol cost and toll charge values of time have 95% confidence intervals which represent an approximate range of plus or minus 24% and 8% of the actual value of time estimates respectively. These relatively narrow ranges are encouraging with respect to the precision with which the value of time is being estimated.

The Oxford exploratory study of private travel (Value of Time Study 1983) found that motorists responded differently to petrol cost and 'out of pocket' cost variations. We might, therefore, expect motorists to react differently to toll charge and petrol cost variations. The findings of 2.2 suggests that motorists do in fact respond differently; a z statistic of 3.516 indicating that the difference in the coefficients is significant at the usual 95% level of confidence. Model 2.2 also represents a significant improvement upon 2.1 in terms of a likelihood ratio test. A chi squared of 9.72 exceeds the tabulated value of 3.84 at a 95% level of confidence for one degree of freedom reduction.

Model 2.3 explains route choice solely in terms of toll charge and travel time. Both coefficients are significant, implying a value of time in terms of toll charges which is not dissimilar to that of 2.2. However, as the petrol cost coefficient of the previous model is significant, it is not surprising that according to a likelihood ratio test, model 2.3 is not an improvement over 2.2. Indeed 2.3 performs considerably worse than 2.2 and it appears that motorists have based their choices upon petrol cost, toll charge and travel time considerations.

Models 2.4 and 2.5 introduce a dummy variable to represent an option where a toll is payable. It can be reasonably hypothesised that a change in toll charges directly influences utility but that the very existence of a toll has an impact upon utility quite apart from the precise level of the toll. This latter effect may stem from motorist's perceptions of delays and inconveniences at toll booths, which were not specified in the questionnaire, or from an aversity to tolls in principle. Hence the toll dummy variable is included as such effects are independent of the level of the toll charge. The toll coefficient in 2.2 includes both the variable and fixed influences of a toll upon utility.

In both 2.4 and 2.5, the toll dummy variables possess significant coefficients which are of the correct sign. Model 2.5, where total cost is split into its constituent parts, represents a significant improvement over 2.4 with a calculated chi squared of 8.88 for a reduction of one degree of freedom. Indeed, 2.5 represents the best fitting of these five linear formulations given the appropriate degrees of freedom adjustment.

The petrol cost and toll charge coefficients are, however, again significantly different, with a z statistic of 2.81, although the relationship between the two is reversed in comparison with 2.2; variations in petrol costs now having a larger effect upon utility than the toll charge. It is to be expected that the effect of the toll charge falls in relation to the impact of petrol cost changes given the introduction of the toll dummy variable. It is, however, somewhat surprising that once the toll effect that is invariant with respect to the toll level is accounted for, such a large discrepancy between the two coefficients remains.

The derived value of time in terms of petrol costs in 2.5 is more reasonable, at 4.12 pence per minute, although the toll based value of time is somewhat large at 8.16 pence per minute. The value of time for combined monetary costs in 2.4 is also rather large although in all cases, the range of the estimate at a 95% level of confidence is encouragingly small.

In some instances, the derived values of time are more significant, that is possess relatively lower standard errors, than the individual coefficients from which they are derived. This is also found to be the case for certain of the urban route choice results reported below.

If the options were formulated on the basis of an orthogonal design, the variables would be distributed independently of each other and hence the off-diagonal terms of the variance-covariance matrix of estimated coefficients would be zero. The options do not, however, follow such an orthogonal design and the covariance between the time and cost coefficients is here positive. The formula for the variance of the ratio of two coefficients is:-

Var(t/c) = c**-4[c**2(Vart) + t**2(Varc) - 2ct(Covct)]

where c and t are the estimated cost and time coefficients, Varc and Vart their respective variances, Covct the covariance between the two and where ** denotes raised to the power of. The covariance between the estimated time and cost coefficients, which is here positive, has operated so as to reduce the variance of the ratio of the two coefficients. Thus in the results reported above, the value of time estimate is more significant than either one or both of the individual coefficient estimates from which it is derived.

Table 3 lists the results of further linear models of route choice which were examined, where dummy variables are widely used in an attempt to discern certain effects. A dummy variable allows the estimation of the impact of moving from some base level of variable x to some other level. If there are n levels of variable x, n-1 dummy variables are specified and the utility effect is measured in relation to the n'th. The inclusion of n dummy variables would lead to a singular matrix, and although some estimates may be obtained, they would not be meaningful.

Model 3.1 continues the analysis of the effects of toll charges. The dummy variables T1, T2, T3 and T4 represent the toll levels of £1, £2, £4 and £6 respectively and along with petrol cost and travel time are used to explain motorist's route choice. The toll dummies indicate the effect upon utility of introducing a toll and subsequently increasing it to a maximum of £6. Hence the signs of the toll coefficients should be negative as utility falls as we move away from the base toll level of zero. Moreover, the coefficients should also become larger negative numbers as the toll is increased to reflect the fall in utility. Both of these conditions are satisfied and the coefficient estimates are also highly significant.

The implied value of time in terms of petrol costs is quite plausible and highly significant. However, the most interesting findings stem from a consideration of the implied utility effects of variations in the toll charge.

It can be reasonably hypothesised that the introduction of a toll has a greater impact upon utility, for a given toll charge variation, than subsequent increases from a non zero base. This is because the introduction of a toll includes the utility effect attributable to any aversity to tolls, either in principle or due to perceptions concerning inconvenience and delay, in addition to the monetary outlay that is incurred. A movement from a £1 to £2 toll charge includes only the utility effect relating to the increased monetary outlay.

The implied utility effects are listed in table 3A. As expected, the introduction of a toll has a greater impact upon utility, per unit change in toll, than subsequent increases. Of further interest is the approximate constancy of the incremental utility effect when the toll is continually increased from the £1 toll level, which accords with the often made assumption that the marginal utility of income is constant when the implied income effect of a cost variation is not large. These findings are most encouraging in terms of the quality of the responses obtained from the ranking exercise and the means by which these responses are modelled.

TABLE 3: Linear Models to Examine Non-Linearities in Choice

3.1 $U = -0.0105PC - 0.043TIME - 2.060T1 - 2.642T2$
$(-5.88) \quad (-11.71) \quad (-5.22) \quad (-6.25)$

$- 3.679T3 - 4.695T4 \qquad VOT(PC) = 4.10$
$(-8.47) \quad (-4.69) \qquad (9.84)$

LOG LIKELIHOOD = -1334.53 RHO-BAR SQUARED = 0.143

3.2 $U = -0.0043TC + 1.133S1 + 2.375S2 + 2.879S3$
$(-14.75) \quad (8.30) \quad (15.99) \quad (16.68)$

LOG LIKELIHOOD = -1380.54 RHO-BAR SQUARED = 0.114

3.3 $U = -0.0023T + 0.895S1 + 1.766S2 + 1.861S3$
$(-11.58) \quad (6.73) \quad (13.07) \quad (13.17)$

LOG LIKELIHOOD = -1435.63 RHO-BAR SQUARED = 0.079

3.4 $U = -0.0056TC + 4.171TIME1 + 3.711TIME2 + 2.598TIME3$
$(-16.60) \quad (17.20) \quad (17.14) \quad (12.79)$

$+ 1.193TIME4$
(6.37)

LOG LIKELIHOOD = -1323.70 RHO-BAR SQUARED = 0.150

3.5 $U = -0.0053PC - 0.0056T + 4.166TIME1 + 3.712TIME2$
$(-9.07) \quad (-16.23) \quad (17.15) \quad (17.14)$

$+ 2.604TIME3 + 1.209TIME4$
$(12.80) \quad (6.40)$

LOG LIKELIHOOD = -1323.50 RHO-BAR SQUARED = 0.150

3.6 $U = -0.0119PC - 0.0057T - 1.226TD + 0.429SD + 4.953TIME1$
$(-1.66) \quad (-16.56) \quad (-0.99) \quad (0.60) \quad (7.60)$

$+ 4.426TIME2 + 3.088TIME3 + 1.482TIME4$
$(6.46) \quad (5.93) \quad (4.76)$

LOG LIKELIHOOD = -1322.57 RHO-BAR SQUARED = 0.151

NOTES TO TABLE 3:

PC, TC, T, TD, SD represent petrol cost, total cost, toll charge, toll dummy (= 1 if payable), and speed dummy (= 1 if 70 mph).
S1, S2, S3 - Speed Dummy Variables indicating 40, 50 and 70 mph.
TIME1, TIME2, TIME3, TIME4 - Time Dummy Variables denoting times of 60m, 85m, 105m and 120m (together), 140m and 150m (together).
T1, T2, T3, T4 - Toll Dummy Variables for £1, £2, £4, £6 tolls.

TABLE 3A: Impact of Toll Charge Variations (Model 3.1)

CHANGE IN LEVEL OF TOLL CHARGE	CHANGE IN UTILITY PER UNIT CHANGE IN TOLL
0 - 100p	-0.0206
100p - 200p	-0.0058
200p - 400p	-0.0052
400p - 600p	-0.0051

Model 3.2 uses dummy variables in a similar manner to examine whether motorists have a preference for driving at certain speeds and thus base their rankings, in part, upon the speeds associated with an option. The dummy variables S1, S2 and S3 represent speeds of 40, 50 and 70 mph respectively. As 30 mph is the base speed, from which the utility effects of the faster speeds are measured, the speed coefficients should have positive signs, and increase as speed increases, if faster speeds are preferred. 3.3 varies from 3.2 in that total cost is replaced by the toll charge. Petrol costs were not included separately as they are partly dependent upon speed.

In both 3.2 and 3.3, all the coefficients are significant and of the correct sign. However, the substitution of the total cost term by the toll charge leads to a marked worsening in the explanatory power of 3.3 in relation to 3.2. Model 3.2 does not itself perform as well as the linear models previously considered and as such, it is concluded that such a formulation, based largely upon speed, does not provide the best insight into route choice behaviour.

Models 3.4, 3.5 and 3.6 attempt to discern non-linearities in the utility function with respect to time. Whilst the marginal utility of income is unlikely to vary considerably in these circumstances, where the implied income effect is not substantial, constancy of the marginal utility of time might be seen as more of a special case. In the analysis of North Kent commuter's mode choice (Value of Time Study 1983), it was found that as times and costs increased, there was a tendency for respondents to increasingly prefer the faster mode. This suggests that the value of time is not invariant with respect to the amount of travel time incurred.

The so called law of diminishing marginal utility implies increasing marginal disutility as travel time increases, that is the utility to be gained from a given time saving falls as travel time is lower. As less travel is a good rather than a bad, this assumption states that the utility to be gained at the margin from time savings falls as more time is saved, that is as time itself is lower. However, theoretical reasoning may also support a value of time which falls as travel time increases, that is there is no reason why the marginal utility of time may not increase in the relevant range. In this case, theoretical reasoning is of little use in indicating what to expect, although a constant value of time across time remains a special case, and the issue requires empircal investigation. Indeed, for some individuals the value of time may be a positive function of time, for others the reverse may be the case whilst there may remain some for whom the value of time is approximately invariant with respect to the level of time. It may be that the overall effect, being an average of these individual effects, is not substantially different from a constant average value of time with respect to time.

The dummy variables in models 3.4, 3.5 and 3.6 represent the four time groupings of 60 minutes, 85 minutes, 105 and 120 minutes combined and 140 and 150 minutes combined. The omitted time is 200 minutes whereupon the time coefficients should be positive, a reduction in travel time being beneficial, and as travel time falls, so the coefficients should become larger. These conditions are satisfied for each of the models whilst in models 3.4 and 3.5 the remaining coefficients are of the correct sign and all coefficient estimates are significant.

Models 3.4 and 3.5 yield results which are somewhat at odds with those previously derived. The petrol cost and toll charge coefficients in 3.5 are not significantly different, a z statistic for the difference being 0.63, and they are similar to the total cost coefficient in 3.4. Given this finding, it is not surprising that with a calculated chi squared of 0.40, a likelihood ratio test suggests the lost degree of freedom is not compensated by a sufficient increase in the log likelihood such that 3.4 performs the better. Indeed, according to this criterion, 3.4 provides the best explanation of motorist's route choice in this inter-urban context.

Plotting the time coefficients is somewhat inconclusive; there is no clear relationship apparent between the time coefficients and the level of travel time. Tables 3B and 3C list the implied changes in utility as travel time varies for 3.4 and 3.5 respectively; being the same in both cases. The derived values of time, in each instance, appear non linear although no discernable trend is apparent. However, further assessments based upon non linear utility functions were undertaken.

TABLE 3B: Impact of Time Variations - Total Cost Base (Model 3.4)

Change in Time	Utility Change per Unit Change in Time	Implied Value of Travel Time
200m - 145m	+ 0.022	3.93
145m - 112.5m	+ 0.043	7.68
112.5m - 85m	+ 0.040	7.14
85m - 60m	+ 0.018	3.21

TABLE 3C: Impact of Time Variations (Model 3.5)

Change in Time	Utility Change per Unit Change in Time	Implied Value of Time (Petrol)	(Toll)
200m - 145m	+ 0.022	4.15	3.93
145m - 112.5m	+ 0.043	8.11	7.68
112.5m - 85m	+ 0.040	7.55	7.14
85m - 60m	+ 0.018	3.40	3.21

Model 3.6 is the most general formulation considered. The speed dummy variable indicates whether the speed was 70 mph and is included on the assumption that it is this speed, if any, at which travel is specifically preferred. However, along with the petrol cost and toll dummy variable coefficients, it is not significantly different from zero. Moreover, 3.6 does not represent a significant improvement in performance over 3.4.

The results from various non linear utility functions which were calibrated are given in table 4. The quadratic form of 4.1 provides a plausible explanation of route choice. Each coefficient is significantly different from zero and in comparison with the linear model 2.5, which is the best of the straightforward linear models, it is a significant improvement.

However, the coefficient associated with the squared time term would imply a positive marginal utility of time, and hence a negative value of time, at sufficiently high levels of time. At a travel time of 434 minutes, which is over twice as large as the longest travel time involved, the value of time would become negative. Extrapolation over this range would, in any event, be risky; we have no observations of preference in this range. At the lowest time of 60 minutes, the implied values of time in terms of petrol costs and toll charges are 4.21 and 10.48 pence per minute whilst these fall to 2.64 and 6.56 pence per minute respectively at the largest travel time of 200 minutes.

The petrol cost and toll coefficients are again significantly different, with a z statistic of 3.70, which is reflected in the differential value of time estimates obtained at a given time level. The toll charge based value of time estimates do appear to be somewhat large. The model does not, however, perform as well as the best linear model of 3.4 as the latter achieves a greater log likelihood for the same number of explanatory variables.

Model 4.2 aims to capture non linearities with a utility expression which includes time in logarithmic form. The petrol cost and toll coefficients are significant, and of the correct sign, but they are again somewhat dissimilar. The implied values of time, based on petrol cost and toll charges are 6.00 and 15.33 pence per minute at 60 minutes ranging to 1.80 and 4.60 at 200 minutes. This model, however, provides a less satisfactory explanation of behaviour than the previous one.

Model 4.3 introduces the reciprocal of time, included along with petrol cost and toll charges. The inclusion of the toll dummy variable did not allow the iterative maximum likelihood procedure to converge. The coefficient associated with the time term is of the correct order to imply a negative marginal utility of time as required whilst it is also significant along with the cost terms.

TABLE 4: Non Linear Models of Inter-Urban Route Choice

4.1 $$U = \underset{(-5.92)}{-0.0137PC} - \underset{(-16.08)}{0.0055T} - \underset{(-4.43)}{2.21TD} - \underset{(-5.98)}{0.0669TIME} + \underset{(2.31)}{0.000077TIMESQ}$$

LOG LIKELIHOOD = -1332.00 RHO-BAR SQUARED = 0.145

4.2 $$U = \underset{(-6.08)}{-0.0143PC} - \underset{(-16.82)}{0.0056T} - \underset{(-4.38)}{2.202TD} - \underset{(-10.81)}{5.151LOGTIME}$$

LOG LIKELIHOOD = -1355.55 RHO-BAR SQUARED = 0.131

4.3 $$U = \underset{(-7.11)}{-0.0041PC} - \underset{(-14.47)}{0.0047T} + \underset{(16.38)}{267.77RECTIME}$$

LOG LIKELIHOOD = -1413.88 RHO-BAR SQUARED = 0.115

4.4 $$U = \underset{(-3.79)}{-0.0057PC} - \underset{(-15.54)}{0.0048T} - \underset{(-1.73)}{0.589TD} + \underset{(10.90)}{7.95LOG(360-TIME)}$$

LOG LIKELIHOOD = -1344.42 RHO-BAR SQUARED = 0.136

NOTES: Notation as for Table 3 except additionally: TIMESQ = Time Squared, LOGTIME = Log of Time, RECTIME = Reciprocal of Time.

The implied values of time in terms of petrol costs and toll charge vary from 18.14 and 15.83 pence per minute at 60 minutes travel time to 1.63 and 1.42 pence per minute at 200 minutes. This formulation does, however, give a rather poor explanation of choice in relation to other models whilst the value of time estimates seem somewhat implausible.

If it is considered that, for a non linear value of time with respect to time, the marginal value of time increases as travel time increases, which is consistent with the concept of diminishing marginal utility, models 4.2 and 4.3 would not be satisfactory. Given a positive coefficent associated with the time squared term, model 4.1 would also be unsatisfactory on these grounds. The stated preference analysis of North Kent commuters (Value of Time Study 1983) suggested that the value of time was an increasing function of travel time.

Model 4.4 represents the final version of a series of non linear calibrations. The time variable is some constant (TT) minus the travel time of the relevant option. Disutility increases more rapidly in the neighbourhood of the threshold TT; the utility function being asymptotic as travel time approaches TT. A value of TT must be selected before estimation can be undertaken, where TT must exceed the maximum travel time present in the choice set. As TT tends to infinity, the model returns to a linear form.

The selected values of TT for which estimation was undertaken commenced at 210 minutes and was increased in intervals of 30 minutes up to the 360 minutes of the final estimated model which is reported here. As the value of TT was successively increased, the log likelihood achieved also increased although the rate of increase diminished. The coefficients also became more significant as TT increased, although in the final calibration the toll dummy is not quite significant. The coefficient associated with the time term is of the correct sign to imply a negative marginal utility of time as required.

This formulation also allows the value of time to increase as travel time increases. The values of time, in terms of petrol costs and toll charges, range from 4.62 and 5.52 pence per minute at 60 minutes to 8.67 and 10.35 pence per minute at 200 minutes. With a log likelihood of -1344.42, the final version of this formulation did not produce an equivalent performance, given the degrees of freedom, to that acheived by the quadratic model or the better linear models.

It appears, therefore, that a non linear utility function may not be the best means of representing route choice. The dummy variable models 3.4 and 3.5 hinted at a non linear value of time but no clear trend emerges, partly due to the limited number of value of time estimates that are obtained from these models. Whilst it can be reasonably hypothesised that individual's values of time are some function of the level of time, the average value of time may be roughly constant if there is some offsetting effect between values of time which increase and decrease as travel time increases.

6. Segmentation According to Income Levels

As non linear utility expressions do not provide the best explanations of route choice, and for ease of interpreting the results and comparing them with results derived elsewhere, linear utility functions were used in the analysis of route choice according to various income groups. The North Kent results (Fowkes 1984; Value of Time Study 1983, 1984c) conflicted in that the values of time derived from the stated preference analysis were not related to income whilst those obtained from the revealed preference analysis showed a strong positive relationship between income and the value of main in vehicle time. Table 5 summarises the results derived from segmentation according to income.

Two model formulations were used: a straightforward linear expression including only total cost and travel time as explanatory variables, and the best simple linear model, based on 2.5 above, which includes travel time, petrol costs, toll charges and a toll dummy variable as explanatory variables.

The values of time, in terms of total cost, tend to increase as income increases. Assuming that the marginal utility of income falls as income increases given the large income difference between groups, and that the marginal utility of time is approximately constant across groups, the findings conform to what might be hypothesised to occur. The overall value of 5.99 pence per minute is heavily influenced by the large values of time associated with the two highest income groups considered. The results derived from this segmentation, using a straightforward linear model, are rather encouraging although the results based on model 2.5 are more ambiguous.

Model 2.5 was the best fitting of the linear models used where an invariant value of time is implied. However, there appears to be no clear relationship between either the petrol cost or toll charge based value of time estimates and the level of income. The petrol cost coefficient becomes insignificant upon consideration of income groups in excess of 11,000. This suggests that petrol costs are relatively unimportant for higher income motorists and choice appears to be based primarily upon toll charge and travel time considerations. The discrepancy between the utility effects attributable to petrol cost and toll charge variations, evident for the respondents as a whole, is also maintained across the various income groups.

There is also some evidence that disaggregating by income levels leads to the model of route choice performing better in terms of the rho-bar squared statistic. It may be that disaggregation according to income levels leads to more homogenous samples of individuals, and as such, the logit model is able to provide a better explanation of route choice.

TABLE 5: Value of Time and Income - Inter-Urban Route Choice

INCOME GROUP	N	UO	VOT(TC) (t)	RHO-BAR SQUARED	VOT(PC) (t)	VOT(T) (t)	RHO-BAR SQUARED
5000 OR LESS	11	121	3.65 (6.94)	0.107	2.32 (10.43)	8.69 (5.22)	0.138
5001-7000	13	143	4.03 (9.88)	0.132	2.94 (7.25)	6.86 (5.47)	0.150
7001-9000	10	110	5.91 (10.68)	0.182	4.23 (4.21)	8.09 (5.41)	0.200
9001-11000	14	154	5.97 (8.57)	0.100	3.61 (4.57)	8.90 (4.40)	0.106
11001 13000	8	88	5.84 (8.73)	0.176	*	6.89 (4.12)	0.188
13001-17000	7	77	10.69 (6.20)	0.225	*	11.86 (3.46)	0.229
17001-21000	8	88	11.95 (7.87)	0.316	*	10.95 (4.16)	0.324
WHOLE SAMPLE	78	858	5.99 (23.48)	0.136	4.12 (9.72)	8.16 (12.09)	0.143

NOTES TO TABLE 5:

N = Number of Individuals, UO = Usable Observations.
7 respondents did not state their income or had an income in excess of 21,000.
VOT(TC), VOT(PC), VOT(T) represent total cost based, petrol cost based and toll based values of time respectively.
* - petrol cost coefficient not significant at 95%.

7. Analysis of Urban Route Choice

The urban route choice experiment follows along similar lines to the inter-urban route choice experiment; the coefficients are again taken to be generic and alternative specific constants are not specified. Respondents were required to rank ten travel options in order of preference and a sample of 77 individuals yields 693 discrete choice observations to be input to the logit model after the full expansion of the orderings to rank nine. The results from the various calibrated models, of a straightforward linear form, are given in table 6.

Model 6.1 is the most straightforward form of utility expression. Each coefficient is highly significant, and of the correct sign, and the resulting value of time estimate, in terms of total cost, of 3.43 pence per minute is quite plausible. The value of time estimate is comparable with that derived in an analysis of North Kent rail and coach commuters by means of both revealed preference (Fowkes 1984) and stated preference (Bates 1984) techniques, although the journey purpose is here different to the North Kent study. The standard error associated with this value of time estimate is also relatively low; a 95% confidence interval having a range of plus or minus approximately 14% of the actual estimate.

Splitting total cost into its component parts, as is done in 6.2, suggests that motorists react differently to a given toll or petrol cost variation. The petrol cost coefficient is marginally insignificant whilst the value of time defined in terms of petrol costs is also insignificant. The toll based value of time appears quite reasonable and is highly siginificant. This model does not, however, constitute an improvement over 6.1 given a calculated chi-squared of 2.9 and a tabulated value of 3.84 for one degree of freedom reduction.

Model 6.3 assess whether choice is simply a function of travel time and toll charges, given that the petrol cost coefficient in 6.2 is insignificant. Both coefficients in 6.3 are significant, as is to be expected from the result of model 6.2. However, as models 6.1 and 6.3 include the same number of explanatory variables, it can be seen that 6.1 provides a marginally better explanation of route choice although the results are in any event comparable.

Model 6.4 splits total cost into its constituent parts whilst a toll dummy variable is also included in an attempt to discern the toll effect which is invariant with respect to the actual toll charge. The results are, however, somewhat confusing. Whilst the effect of a toll charge falls in relation to that of petrol cost, in comparison with 6.2, the toll dummy variable is of the wrong sign despite being significant. The former result is to be expected but the introduction of a toll should not, in itself, increase utility. However, only two of the ten options are untolled. This result contrasts with those derived in the inter-urban context where the toll dummy variable successfully discerned the hypothesised effect of the introduction of a toll in most of the cases in which it was applied. The log likelihood criterion also suggests a significant improvement over 6.1, with a chi-squared of 63.94, but theoretical considerations require that 6.1 is preferred as the toll dummy coefficient in 6.4 is of the wrong sign.

TABLE 6: Linear Models of Urban Route Choice

MODEL	6.1	6.2	6.3	6.4
PETROL COST		-0.0181 (-1.85)		-0.0678 (-5.76)
TOLL CHARGE		-0.0378 (-11.57)	-0.0406 (-13.78)	-0.0502 (-13.93)
TOTAL COST	-0.0342 (-14.01)			
TIME	-0.1174 (-13.05)	-0.1328 (-10.45)	-0.1472 (-14.64)	-0.1077 (-8.02)
TOLL DUMMY				1.3260 (7.64)
VOT(TC)	3.43 (14.19)			
VOT(PC)		7.34 (1.66)		1.59 (3.71)
VOT(T)		3.51 (15.69)	3.63 (17.96)	2.15 (9.35)
LOG LIKELIHOOD	-1025.78	-1024.33	-1026.03	-993.81
RHO-BAR SQUARED	0.118	0.118	0.117	0.144

Notes to Table 6: Notation as for Table 2 above.

Table 7 lists the results obtained by using dummy variable specifications to discern various effects, as was done in the inter-urban route choice experiment. Model 7.1 uses dummy variables to establish the effect of different toll charges upon utility. It appears that this model has not been successful, in discerning the effects we might hypothesise to exist, especially in relation to the same analysis undertaken in the inter-urban context. The variables T1, T2, T3 and T4 represent the toll charges of 10, 25, 40 and 60 pence respectively. As the base toll level from which the utility effects are measured is zero, the coefficients associated with these variables should have a negative sign.

The variables T1 and T2 both possess coefficients of the wrong sign, although that associated with T2 is insignificant. The introduction of the 10p and 25p toll charges may be associated with options which otherwise improve utility and hence such spurious relationships are implied. The results are comparable to that of 6.4 where the toll dummy variable also possessed a coefficent of the wrong sign.

Models 7.2 and 7.3 consider motorists' preferences for driving at certain speeds where the dummy variables S1, S2 and S3 represent speeds of 20, 30 and 40 mph respectively. It can be seen that the variables have the appropriate sign attached to their coefficients, given a base speed of 15 mph and that faster speeds are preferred, and are significant. The toll and total cost coefficents are also significant, of the correct sign, and are not dissimilar. Petrol costs are not included in 7.2 as they are a function of speed.

TABLE 7: Linear Models to Examine Non-Linearities in Choice

7.1 U = -0.0683PC - 0.1056TIME + 0.7968T1 + 0.0957T2
(-5.75) (-7.47) (4.68) (0.57)

- 0.5959T3 - 1.7090T4 VOT(PC) = 1.54
(-2.91) (-7.87) (3.59)

LOG LIKELIHOOD = -993.37 RHO-BAR SQUARED = 0.145

7.2 U = -0.0547T + 0.766S1 + 2.919S2 + 3.293S3
(-15.26) (4.79) (14.07) (13.17)

LOG LIKELIHOOD = -1005.84 RHO-BAR SQUARED = 0.134

7.3 U = - 0.0501TC + 0.894S1 + 2.522S2 + 3.068S3
(-16.07) (5.50) (13.07) (12.90)

LOG LIKELIHOOD = -993.34 RHO-BAR SQUARED = 0.145

7.4 U = - 0.0424TC - 0.416TIME1 - 1.752TIME2 - 2.278TIME3
(-13.40) (-3.26) (-7.13) (-12.30)

LOG LIKELIHOOD = -1005.37 RHO-BAR SQUARED = 0.135

7.5 U = 0.0426PC - 0.05086T - 0.0924TIME1 - 1.317TIME2 - 3.104TIME3
(2.39) (-13.91) (-0.63) (-4.97) (-12.19)

LOG LIKELIHOOD = -993.27 RHO-BAR SQUARED = 0.145

NOTES TO TABLE 7:

T1, T2, T3, T4 denote tolls 10, 25, 40 and 60 pence respectively.
S1, S2, S3 represent speeds of 20, 30 and 40 mph respectively.
TIME1, TIME2, TIME3 denote travel times of 24, 27 and a combined 35 and 36 minutes respectively.

As speed increases, so utility increases in both 7.2 and 7.3. However, there appears to be no real trend in the change in utility per unit change in speed as speed increases. It seems that motorists do not have a particularly strong preference for driving at certain speeds. However, model 7.3 which is an improvement in performance over 7.2, is the best model of all those considered in the urban example given the appropriate degree of freedom adjustments. It may be that the speed effect is reflecting a travel time effect although a model specified in terms of speed performs better than a time based formulation.

Models 7.4 and 7.5 use dummy variables to represent travel times of 24, 27 and a combined 35 or 36 minutes respectively. The omitted travel time is 18 minutes whereupon the coefficients associated with these variables should have a negative sign and, as time increases, the coefficients should become progressively larger negative numbers. These conditions are satisfied in both cases. However, unlike the inter-urban experiment, this form of utility expression does not give the best explanation of route choice. Amending 7.4 and 7.5 by the inclusion of a toll dummy variable produces coefficient estimates associated with this variable which are of the wrong sign.

The coefficient associated with total cost in 7.4 is significant and of the correct sign, as is the toll coefficient in 7.5. The petrol cost coefficient in 7.5 is, however, of the wrong sign whilst the coefficient upon variable TIME1 is insignificant. The changes in utility per unit change in time in the more plausible model 7.4 are given in table 7A.

TABLE 7A: Impact of Time Variations - Total Cost Base (Model 7.4)

Change in Time	Change in Utility Per Unit Change in Time	VOT(TC)
18m-24m	-0.069	1.63
24m-27m	-0.445	10.50
27m-35.67m	-0.061	1.44

The implied values of time for the movements from 18 to 24 minutes and from 27 to 35.67 minutes are rather low. Moreover, the movement from 24 to 27 minutes implies an unreasonably large value of time. It may be that as a travel time of 27 minutes only enters the choice set once, preferences for this travel time cannot be discerned accurately.

Whilst 7.4 is inconclusive in indicating whether the value of time is constant across time levels, limited analysis was undertaken using non linear formulations. These findings are tabulated in table 8.

TABLE 8: Non Linear Models of Urban Route Choice

8.1 $U = -0.032TC + 0.049TIME - 0.0029TIMESQ$
$(-12.27) \quad (0.64) \quad (-2.18)$

LOG LIKELIHOOD = -1023.40 RHO-BAR SQUARED = 0.119

8.2 $U = -0.0379PC - 0.0346T - 2.984LOGTIME$
$(-4.26) \quad (-11.04) \quad (-9.78)$

LOG LIKELIHOOD = -1031.86 RHO-BAR SQUARED = 0.112

The quadratic form gave the best fit of the non linear models in the inter-urban analysis. Model 8.1 yields a significant coefficient upon the squared time term but the time coefficient itself is insignificant. However, the negative coefficient associated with the time squared term yields a value of time which increases as travel time increases. The implied values of time, ignoring the insignificant time term, are 3.26 pence per minute at the least travel time of 18 minutes ranging to 6.53 at the largest travel time of 36 minutes. This appears to be a reasonable range.

This model does not, however, perform as well as model 7.3 but does perform better than the straightforward linear models considered in table 6 where a chi squared statistic for the difference between 8.1 and 6.1 is 4.76 in comparison with a tabulated value of 3.84. This quadratic form was generalised by including a toll dummy variable and splitting total cost into petrol cost and toll charge. However, both the time and time squared variables were found to have an insignificant effect.

Model 8.2, where travel time is entered in logarithmic form, performs less well than the quadratic expression. The coefficients for the cost variables are both significant, of the correct sign and are not significantly different; a z statistic for the difference in the two coefficients being 0.40. The implied value of time in terms of petrol costs ranges from 4.37 at 18 minutes to 2.19 at 36 minutes which is a reasonable range although it might be preferred that the value of time increases as travel time increases. The inclusion of a toll dummy variable did not allow convergence in the estimation process.

Table 9 presents the results of analysis undertaken with respect to different income groups. A straightforward linear model was used, including total cost and travel time as relevant explanatory variables, as this model provided the best explanation of urban route choice from all the straightforward linear models considered where a readily interpretable value of time estimate can be derived.

There appears to be some form of the income effect we expect to exist, with a tendency for the value of time to rise as income increases. The overall average value of time is heavily influenced by the large values of time for those of the two highest income levels. The value of time estimates are all highly significant.

The findings are also similar to those obtained for the same model in the inter-urban context in terms of the rho-bar squared statistics obtained for the various calibrations. The rho-bar squared statistic achieved for these income groupings often exceeds that obtained for the whole sample. This again suggests that there is some merit in disaggregating according to income, to achieve a more homogenous sample of travellers, in addition to analysing whether income effects are present.

TABLE 9: Value of Time and Income - Urban Route Choice

INCOME GROUP	N	UO	VOT (t)	RHO-BAR SQUARED
5000 OR LESS	11	99	2.01 (3.14)	0.066
5001- 7000	13	117	2.50 (4.29)	0.074
7001- 9000	10	90	2.49 (6.03)	0.192
9001- 11000	14	126	3.95 (6.53)	0.129
11001- 13000	8	72	4.24 (5.28)	0.170
13001- 17000	7	63	10.17 (4.60)	0.325
17001- 21000	7	63	8.40 (4.80)	0.287
WHOLE SAMPLE	77	693	3.43 (14.19)	0.118

NOTES TO TABLE 9: 7 respondents did not state their income or had an income in excess of 21000.
N = Number of individuals, UO = Usable Observations.

8. Respondent's Comments

Two questions were included in the questionnaire which yield responses which may give some insight into how respondents perceived the tasks required of them and which may lead to suggestions as to possible improvements in survey design. The two questions were:

What other information (if any) would you have liked to have been given to assist you in making your choices?

We would be pleased to have any comments about the study, e.g. How difficult did you find the ranking questions?

Numerous respondents expressed concern over possible delays and inconvenience at toll booths whilst others expressed a dislike of having to pay for the use of road space. This aversity to toll charges and potential delays was found to be a significant effect in the inter-urban experiment (see models 2.5 and 3.1).

Of those who commented upon how difficult they found the ranking exercise, nineteen commented that the task was not difficult, or that it was even easy, whilst thirteen expressed some sort of difficulty undertaking the task. However, doubts must be cast upon anyone finding the tasks involved here to be easy given that respondents attempt to trade-off between attributes across numerous options.

Numerous respondents stated that they required further information to assist in their choice of routes, such as details concerning the quality of the roads, delays at toll booths, scenery, departure time and traffic conditions. It is not possible, however, to represent every aspect that may influence choice. Revealed preference analysis of travel behaviour has difficulties in assessing those influences which have a lesser bearing upon choice. Moreover, in less hypothetical circumstances, such as a stated preference experiment based on route choice in Tyneside, it is reasonable to assume that the degree of imperfect information surrounding options will be somewhat reduced. However, in less hypothetical circumstances there may be a greater invitation to bias responses in an attempt to influence policy making.

9. Conclusions

The analysis of the responses obtained from the pilot survey of motorists' route choice has been quite successful. Several of the findings are encouraging with respect to the application of this technique to motorists' route choice, particularly in less hypothetical circumstances.

i) In terms of the rationality test undertaken, it appears that the responses supplied by the majority of respondents are sensible and may well be an accurate representation of true preferences. This is encouraging given that a ranking task, involving either ten or twelve options, is not a straightforward exercise. Whilst the analysis indicates an aversity to tolls regardless of the level of toll charge, there is no evidence of widespread bias in terms of ranking the untolled options as preferred.

ii) It appears that most individuals are trading-off across attributes as required although a small minority of respondents may possess lexicographic choice processes. However, where a one-dimensional ordering is supplied it is in most cases only done so in one route choice context. Moreover, there are several rankings which approximate closely to the lexicographic form. This leads to the conclusion that the difficulty of undertaking the ranking exercise is a greater incentive to lexicographical orderings than the existence of actual lexicographic choice process. The incentive to resort to such one-dimensional rankings to simplify the task would be reduced if more straightforward forms of stated preference techniques were applied.

iii) The conclusion that we have for the greater part obtained responses of a satisfactory quality, which exhibit the required trade-offs between attributes, is further strengthened by reference to the results of the calibrated models. In the majority of instances, for both the urban and inter-urban route choice experiments, variables which can reasonably be hypothesised to have a strong influence upon choice have been found to have a significant effect of the correct sign. A toll effect was found to exist which was consistent with what might be hypothesised, the results of 3.1 being of particular interest. A reasonable income effect of the expected form was also apparent using the most straightforward form of utility expression. Whilst the derived value of time estimates depend to some extent on the model used, they are not in general unreasonable.

iv) There is conflicting evidence as to whether motorists react in a similar manner to given variations in toll charge and petrol costs. The petrol cost coefficient may be less than the toll coefficient if some individuals, for whatever reason, do not consider petrol costs in route choice. As the coefficient estimates are averages across individuals in the presence of inter-personal taste variation, the existance of a zero petrol cost coefficient for some respondents will tend to reduce the petrol cost coefficient in relation to that of the toll. In practice, petrol costs may be considered as difficult to calculate by the motorist but their presentation here in a 'taxi-meter' form may lead to some motorists considering petrol costs when they would not do so in practice.

It is hypothesised that the probability that the motorist considers petrol costs falls as petrol cost differences between routes fall; that is there is a greater likelihood that petrol costs are considered for inter-urban route choice and thus there will be a larger discrepancy between the two coefficients in the case of urban route choice. Whilst no clear evidence emerges from the findings, it does appear that there is some tendency for the petrol cost coefficient to fall short of the toll coefficient in urban route choice where the petrol cost difference between routes is relatively small. For inter-urban route choice, petrol cost is not a significant factor for higher income groups but there are several instances where petrol cost variations have a larger impact upon choice than an equivalent toll charge variation.

v) The values of time that are derived are, in the majority of cases, significant and are associated with relatively low standard errors. This is due, in part, to the experimental design which allows discrete statements of preferences to yield more information than might otherwise be the case (Gunn and Wardman 1985). The high standard errors often associated with value of time estimates have been a cause for concern. The main in-vehicle value of time estimate derived from the North Kent revealed preference analysis, where the estimate is considered precise in comparison with other studies, possessed a 95% confidence interval which represented around 33% of the actual value of time estimate with a larger number of observations than is available here of 873 (Value of Time Study 1984c).

Equivalent figures from other studies are plus or minus 62% of the central estimate (Quarmby 1967), plus or minus 85% (LGORU 1975), plus or minus 123% (Ortuzar 1980). Daly and Zachary (1977) obtained estimates for private and public transport in-vehicle time with ranges of plus or minus 70% and 56% of the central estimate respectively. The West Yorkshire study found ranges of plus or minus 56% and 66% for the revealed preference and transfer price analyses respectively (Value of Time Study 1984c).

The equivalent figures are generally much lower here. The advantage of stated preference techniques in this respect is also reflected in the range of plus or minus 6% of the central estimate derived from an analysis of North Kent commuters (Value of Time Study 1984c).

vi) The value of time might be expected to vary as time itself varies, constancy being a special case. In the range of travel times advanced, it was not apparent that the utility function was strongly non-linear in terms of time. It could be that there is some offsetting effect between those whose value of time is an increasing function of travel time and those whose value of time falls as travel time increases.

vii) It appears that petrol costs are an adequate representation of the monetary costs which influence route choice. Few respondents stated that they required more information on car costs to assist in their choice of route whilst the petrol cost coefficient is invariably significant and of the correct sign. Formulations which include only the toll charge to reflect monetary costs do not perform as well as those where petrol costs are also included. However, as noted above, there is conflicting evidence surrounding the relationship between the toll and petrol coefficients.

viii) Numerous respondents did, however, comment upon delays at toll booths and the inconvenience involved. As such, it may be worthwhile including in further such studies a variable which represents delays. This would then allow the analysis of a specific form of travel time incurred by motorists. As waiting time exists only in the form of traffic delays when car is the chosen mode, and walking time is the same for each route given the same parking space, an additional time dimension can be introduced in a realistic manner. This would then make explicit a variable which, in this study, is perceived by the motorist but otherwise unknown. Furthermore, for evaluation purposes, it is important that the correct value of time is entered into the calculations. It seems inappropriate to use the same time valuation to evaluate schemes which will reduce the amount of time spent in traffic delays or which aim to increase free flow speeds.

References

Alpert, M.I., Betak, J.F. and Golden, L.L. (1978) "Data gathering issues in conjoint measurement". Working Paper, Graduate Business School, The University of Texas at Austin.

Bates, J.J. (1984) "Values of time from stated preference data". PTRC Annual Summer Conference, Brighton.

Bates, J.J. (1985) "Sensitivity to level of service: Evidence from stated preference work". Paper presented at the 1985 Internatinal Conference on Travel Behaviour, Noordwijk.

Bates, J.J. and Roberts, M. (1983) "Recent experience with models fitted to stated preference data." PTRC Annual Summer Conference, Brighton.

Beggs, S., Cardell, N.S. and Hausman, J. (1981) "Assessing the potential demand for electric cars". Journal of Econometrics 16.

Carroll, J.D. (1972) "Individual differences and multidimensional scaling", in Mutlidimensional Scaling: Theory and Applications in Behavioural Sciences. Vol. 1, R.N. Shephard et al (eds), Seminar Press.

Daly, A.J. and Zachar, S. (1977) "The effect of free public transport on the journey to work". TRRL Supplementary Report 338.

Foerster, J.F. (1979) "Mode choice decision process models: a comparison of compensatory and non-compensatory structures". Transportation Research 13A.

Foerster, J.F. (1980) "Nonlinear and noncompensatory perceptual functions of evaluation and choice", in New Horizons in Travel-Behaviour Research, ed. Stopher, Meyburg and Brog, Lexington Books, Lexington, Mass. C17.

Fowkes, A.S. (1984) "The UK Department of Transport value of time project: results for North Kent commuters using Revealed Preference methods." Unpublished working paper.

Fowkes, A.S. and Marks, P. (1985) "An analysis of stated preference data for two samples of long distance business trravellers". Forthcoming Institute for Transport Studies Working Paper.

Fowkes, A.S. and Wardman, M. (1985) "The logit model and the consequences of inter-personal taste variations", UTSG Annual Conference, Birmingham. Unpublished.

Golob, T.F. and Richardson, A.J. (1980) "Noncompensatory and discontinous constructs in travel-behaviour models", in New Horizons in Travel-Behaviour Research, ed. Stopher, Meyburg and Brog, Lexington Books, Lexington, Mass. C19.

Gunn, H. F. (1982) "Introduction to individual choice models." PTRC Autumn Conference - New Methods for Analysing Travel Demand, Leeds.

Gunn, H.F. and Wardman, M. (1985) "Practical possibilities for enriching VOT data sets." Unpublished Value of Time Study Working Paper.

Hensher, D.A. and Louviere, J.J. (1983) "Individual preferences for international air fares." Journal of Transport Economics and Policy, 17.

Horowitz, J. (1980) "The accuracy of the multinomial logit model as an approximation to the multinational probit model of travel demand", Transportation Research 14B.

Horowitz, J. (1981) in Hensher, D.A. and Johnson, L.W., "Applied Discrete Choice Modelling". Croom Helm, London.

Jain, A.K., Acito, F., Malhotra, N. and Mahajan, V. (1978) "A comparison of predictive validity of alternative methods for estimating parameters in preference models". Working Paper, School of Management, State Universityof New York, Buffalo.

Kruskal, J. (1965) "Analysis of factorial experiments by estimating monotone transformations of the data." Journal of the Royal Statisitical Society, 25.

LGORU (1975) "Commuters' values of time". Report No. T55.

Montgomery, D.B., Wittink, D.R. and Glaze, T. (1977) "A predictive test of individual level concept evaluation and trade-off analysis." Research Paper 415, Graduate School of Business, Stanford University.

Oppedijk van Veen, W.M. and Beazley, D. (1977) "An investigation of alternative methods of applying the trafe-off model". Journal of the Market Research Society, 19.

Ortuzar, J.D. (1980) "Modal choice modelling with correlated alternatives". PhD Thesis (Unpublished), University of Leeds.

Quarmby, D.A. (1967) "Choice of travel mode for the journey to work", Journal of Transport Economics and Policy, Vol. 1.

Recker, W.W. and Golob, T.F. (1979) "A non-compensatory model of transportation behaviour based on sequential consideration of attributes". Transportation Research, 13B.

Simon, H.A. (1955) "A behavioural model of rational choice". Quarterly Journal of Economics, 69.

Simon, H.A. (1978) "On how to decide what to do". Bell Journal of Economics.

Srinivasen, V. and Shocker, A.D. (1973a) "Linear programming techniques for multidimensional analysis of preferences". Psychometrika, 38.

Srinivasen, V. and Shocker, A.D. (1973b) "Estimating the weights for multiple attributes in a composite criterion using pair-wise judgements". Psychometrika, 38.

Steer, Davies and Gleave Ltd, in association with Ted Hudson and partners (1981) "Final report on research into elasticity of demand in respect of service frequency and through trains". Report for British Railways Board.

Tversky, A. (1972) "Choice by elimination". Journal of Mathematical Psychology, 9.

Value of Time Study (1983) "Value of Time - Phase 2. Progress report for meeting on 22 November 1983". Prepared by: The MVA Consultancy, ITS University of Leeds, TSU University of Oxford. Unpublished.

Value of Time Study (1984a) "VOT Phase II. Car Driver Pilot Study". Prepared by: The MVA Consultancy, ITS University of Leeds, TSU University of Oxford. Unpublished.

Value of Time Study (1984b) "Phase II Final Report - Part 2". Prepared by: The MVA Consultancy, ITS University of Leeds, TSU University of Oxford. Report to the Department of Transport. Unpublished. See especially chapter 2.

Value of Time Study (1984c) "Phase 2 Reconciliation Report". Prepared by: The MVA Consultancy, ITS University of Leeds, TSU University of Oxford. Report to the Department of Transport. Unpublished.

Wittink, D.R. and Cattin, P. (1981) "Alternative estimation methods for conjoint analysis: a Monte Carlo study". Journal of Marketing Research, 18.

DOC/MW (11)
MW/plh/gmh
19.9.85