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A stated choice model of sequential mode and destination choice behaviour for shopping trips

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Abstract. Stated preference and choice models currently used in urban planning are focused on predicting single choices. In this paper the intention is to extend these modelling approaches to the case of sequential choice behaviour. Design strategies and model specifications that allow one to predict sequential choice are discussed. The approach is illustrated in a study of sequential mode and destination choice behaviour for shopping trips. The research findings suggest that the proposed approach may be a valuable extension of currently available stated preference and choice methods to analyse more complex forms of decisionmaking.

1 Introduction

Choice models based on the revealed choices of individuals have traditionally received most attention in travel choice modelling in general and prediction of shopping trips in particular. There are numerous examples of research projects in which spatial interaction or multinomial logit models have been applied to observed spatial shopping patterns (for instance, see Barnard, 1987; Black et al, 1985; Fotheringham, 1988a; 1988b; Guy, 1987; McCarthy, 1980; Recker and Kostyniuk, 1978; Recker and Stevens, 1976; Richards and Ben-Akiva, 1974; Timmermans, 1981a; 1981b; 1984a; 1984b; 1984c; Weisbrod et al, 1984).

Recently, increasing attention has been given in the transportation and urban planning literature to deriving models from individuals' responses to hypothetical choice alternatives observed in (quasi-)laboratory experiments (Louviere, 1988). Individuals are typically presented with a series of hypothetical travel alternatives constructed according to the principles of the design of statistical experiments and are requested to express their strength of preference for each alternative. These overall preference measures are then decomposed into the part-worth utilities associated with the attribute levels used to describe the travel alternatives. This approach, which has been called 'conjoint analysis' (for example, Green and Srinivasan, 1978) or 'decompositional multiattribute preference modelling' (for example, Timmermans, 1984a), has become known in the transportation literature as 'stated preference analysis' (Kroes and Sheldon, 1988). Stated preference models have recently been applied in a variety of contexts, such as preference for bus services (Bradley et al, 1989; Timmermans and Overduin, 1981), competition between rail and coach services (Louviere et al, 1981), preferences for rail services (Anderson P B, et al, 1986; Dinwoodie, 1989), the effects of area licensing proposals (Hensher and Louviere, 1979), valuation of travel time (Hensher and Truong, 1985), route choice behaviour (Bovy and Bradley, 1985; Bradley and Bovy, 1984), and choice of car parking facilities (Axhausen and Polak, 1991).

Most of the stated preference methods applied in urban planning and transportation science that have appeared in the literature rely on the ranking or rating of data on hypothetical travel alternatives. Consequently, the models that are developed are preference models rather than choice models, the aim being to predict preferences

as opposed to choices. Because the aim of much applied research is to predict the likely consequences of transport policy decisions in terms of market shares and consumer choice behaviour, additional assumptions are required to relate the estimated preference function to subsequent choice behaviour. In early applications, almost invariably a deterministic choice rule was employed in which each individual was assumed to choose the travel option with the highest predicted preference or utility score.

Estimated market shares are predicted by aggregating the simulated choices. More recently, probabilistic choice rules have been applied in which choice probabilities are a function of (differences in) utility scale values (for example, see Green and Krieger, 1988; Timmermans and Van der Heijden, 1984). The best known of these probabilistic choice rules are the Bradley-Terry-Luce model (Bradley and Terry, 1952; Luce, 1959) and the logit model. Alternatively, the exploded logit model (Chapman and Staelin, 1982) may be used, which is based on the Luce and Suppes ranking choice theorem. Applications of this model can be found in, for instance, Moore (1988; 1989; 1990).

Given the rigorous and often limited assumptions underlying these probabilistic choice rules, Louviere and Woodworth (1983) suggested choice data be used directly. Their approach differs from that taken in stated preference methods in that the hypothetical travel options are placed into choice sets. Subjects are asked to choose an option rather than to rank or rate the travel options in terms of overall preferences. Consequently, a choice model rather than a preference function is estimated. Different design strategies may be used, but often orthogonal fractional factorial designs are constructed because these are the most efficient. The multinomial logit model typically is used to represent the observed choice data. If the number of travel options among which individuals will choose is constant (say, N), and each travel option has M attributes with L levels, choice designs that satisfy the multinomial logit model can be constructed by designing an L^{NM} main-effects, orthogonal fractional factorial experimental design to create joint combinations of attribute levels. Often a constant travel option is added to each choice set to fix the origin of the utility scale. Individuals are requested to select one travel option from each choice set or to allocate some fixed set of resources (for example, trips) to the available travel options. Applications of this approach in travel demand modelling include that by Louviere and Hensher (1982).

The stated choice approach, however, is not necessarily restricted to the multinomial logit model. More complicated models can be estimated by using the principles underlying this approach. Substitution models that avoid the property of independence from irrelevant alternatives (IIA) of the multinomial logit model can be estimated by introducing the attribute levels of competing travel options into the utility function of the travel option of interest. Violations of the IIA property are present if these cross-effects are statistically significant. Borgers, Van der Waerden, and I have illustrated this approach in a model of destination choice (see Timmermans et al, 1991). Likewise, the effects of varying choice set composition and size, and choice set constraints on travel choice behaviour, can be estimated by including availability effects in the specification of the utility function. Estimation of such models requires one to construct choice sets of varying size and composition, 2^N designs being a potential candidate (Anderson D A, et al, 1992).

Clearly, much progress has been made recently in developing stated preference and choice models of travel demand. Nevertheless, a shortcoming of all these models is that they predict single choice behaviour. That is to say, mode or single destination choice is predicted as a function of choice attributes. Existing approaches do

not allow one to predict sequential choice behaviour. Therefore, if stated choice models are to become an alternative to the nested logit model of revealed choice behaviour, existing modelling approaches must be extended.

My objective in this paper is to extend stated choice models to allow the estimation of sequential choice behaviour. I present a design strategy that allows the efficient estimation of models of sequential choice behaviour, and I illustrate the approach in the context of the choice of shopping centres, given the choice of transport mode. To accomplish this goal, the remainder of the paper is organised as follows. First, in section 2, the modelling approach that allows one to estimate models of sequential choice behaviour is outlined. Then, in section 3, the approach is illustrated by using sequential mode-shopping centre choice as an example. Finally, in section 4, the implications of the results for current and future research in travel choice modelling are discussed.

2 Modelling sequential choice behaviour

The theoretical assumptions underlying the suggested approach are similar to those underlying decompositional choice models. It is assumed that shopping centres and transport modes can be represented in terms of a set of attributes that describes their positions on these choice dimensions. Individuals are assumed to derive a utility from each attribute level and to integrate their part-worth utilities into an overall utility or preference according to some combination rule. Further, it is assumed that the combination rule that individuals apply in the integration process can be uncovered in quasi-laboratory situations by presenting participants with a series of hypothetical shopping centres or transport modes and observing their responses. These hypothetical choice alternatives should be constructed according to the principles of the design of statistical experiments. Appropriately designed experiments allow one to estimate the applied utility function. If individuals are presented with choice sets of varying size and composition, or with choice sets of fixed size and consisting of choice alternatives of different attribute levels, and are asked to choose the one alternative they like most, the resulting choice data may be used to estimate simultaneously the utility function and the choice model that they apparently used in generating their responses. Obviously, the choice design that is constructed should allow the estimation of the assumed choice model. Orthogonal, main-effects, fractional factorial designs allow the efficient estimation of the multinomial logit model.

How can this approach be extended to model sequential choice behaviour? One way to test for dependence in sequential choices is to include the attribute levels of the choice alternatives available in the previous choice step in the specification of the utility function of the choice alternatives at the present choice occasion. If these cross-effects are not statistically significant, the attribute levels of the choice alternative selected at the previous step of the sequential choice process will not influence the choice probabilities at the present step. Similarly, significant cross-effects indicate dependencies in the sequential choice process. This sequential model can be compared in terms of predictive ability with an independence model that can be constructed by developing separate models for each step of the sequential choice process and multiplying the resulting choice probabilities.

To estimate the model of sequential choice behaviour efficiently, all experimental designs constructed to develop a choice model for each choice and the design to estimate the cross-effects should be orthogonal. This can be accomplished by constructing a single orthogonal fractional factorial design. Suppose that at the first step of the choice sequence individuals have to choose between two transport modes,

each described by three two-level attributes. Suppose also that they have to choose between two shopping centre profiles at the second step of the choice sequence, each described in terms of three three-level attributes. Then, orthogonality within and between the successive steps of the choice sequence is preserved if a fraction of the $2^6 \times 3^6$ factorial design that allows the estimation of the assumed choice model is constructed. The six columns of the design representing two-level attributes can be used to estimate the submodel of mode choice. Likewise, the six columns representing three-level attributes can be used to estimate the submodel of shopping centre choice. All twelve columns are required to estimate the model of sequential choice behaviour.

Parameter estimation is not different from conventional stated choice models. Different estimation techniques such as maximum likelihood and generalised least squares analysis (for example, see Louviere and Timmermans, 1990) may be used. In the present study, parameter estimation was based on the reweighted least squares method (Jenrich and Moore, 1975; Woodworth and Louviere, 1985).

3 The study

3.1 Study area and sample

The field research was conducted in Eindhoven, a major city in the south of the Netherlands. Self-completion questionnaires were distributed to a random sample of respondents. Respondents were told about the objectives of the survey and requested to return their responses in a self-addressed envelope to Eindhoven University of Technology. The questionnaire consisted of two parts. In the first part, a set of questions concerning respondents' shopping choice behaviour and cognition of shopping centres was asked; the second part concerned an experimental task which was constructed to examine respondents' sequential choice of transport mode and shopping centre. The results reported in this paper are based upon the second part of the questionnaire. A total of 750 questionnaires were distributed, of which 167 were returned. This is a response rate of 22.3%.

3.2 The design and experimental task

In order to estimate the sequential choice model, the following steps are required. First, the attributes that are supposed to influence the choice behaviour of interest need to be identified. Then, in the second step, each of the selected attributes is defined in terms of attribute levels. These attribute levels are then combined according to the principles of the design of statistical experiments. Usually, a fractional factorial design which allows one to estimate all main effects is selected. This approach is used in most applications of stated preference methods in the transportation literature. However, if choices rather than preferences are examined, the attribute profiles constructed according to the selected statistical design need to be placed into choice sets. One possible approach is to construct choice sets that satisfy the multinomial logit model. As already described in section 1, if the number of choice alternatives among which individuals will choose is constant (say, N), and each choice alternative has M attributes with L levels, choice sets that satisfy the multinomial logit model can be constructed by designing an L^{NM} main-effects, orthogonal fractional factorial experimental design. Choice sets created in this way have a fixed number of (travel) alternatives, but the positions of these alternatives on the selected attributes vary from choice set to choice set (for example, see Louviere and Woodworth, 1983). The respondents' task then is to indicate which one choice alternative in each set they would be most likely to choose, or, alternatively, to allocate some fixed amount of resources (for example, trips) among

the choice alternatives. These choices are then aggregated across respondents to produce relative frequencies of choice. Iteratively reweighted least squares analysis or other appropriate techniques can then be used to estimate the parameters of the choice model.

In the present study, shopping centres were characterised in terms of four attributes: size, price, parking facilities, and distance. These attributes were chosen because they have proven to be major determinants of consumer spatial shopping behaviour (for example, see Timmermans, 1993). Size, price, and distance were varied in terms of three attribute levels. The attribute of parking facilities was dichotomised. Hence, a 2×3^3 full factorial design would describe all possible combinations of attribute levels. The attributes and their levels are listed in table 1.

Table 1. Attributes and their levels.

Attribute	Level	Attribute	Level
Transport mode:		Shopping centre:	
Car		size	small; mainly groceries medium; most types of stores available large; a lot of choice many discount stores
parking costs (Fl h ⁻¹)	free	price	
	1		
	2		
travel time (min)	5	parking facilities	average price level expensive ample parking available parking spaces often occupied
	10		
	15		
Bus		distance (km)	< 1 1-3 3-5
return fare (Fl)	6		
	4		
	2		
travel time (min)	10		
	15		
	20		
frequency of service	every 15 min every 30 min		

Because I have assumed that transport mode choice influences the choice of shopping centre, the modes need also to be described in terms of attribute levels. Two modes were selected: car and bus. In this case, alternative specific utility functions were assumed. The car was described in terms of parking costs and travel time, whereas the bus was represented by three attributes: fare, travel time, and frequency. Parking costs, fare, and travel times were all three-level attributes; frequency was a two-level attribute. These attributes and their levels are also listed in table 1. Hence, a total of 2×3^4 (162) attribute combinations or profiles were possible.

The principle underlying the present approach is that both components of the sequential choice process (transport mode and shopping centres) under investigation should be estimated independently. A 2×3^4 subdesign describing the transport modes allows one to estimate the choice of transport mode. Similarly, a $2^2 \times 3^6$ design, consisting of two descriptions of hypothetical shopping centres in terms of generic attributes, allows the estimation of a model of shopping centre choice. These two subdesigns should be combined to estimate these two models independently. More specifically, a fraction of the resulting $2^3 \times 3^{10}$ full factorial design was

selected to estimate the sequential choice model. This fraction consisted of 36 treatments. Each treatment consisted of two transport mode options, varied in terms of two or three attributes, and two shopping centre options, each described in terms of four attributes. A constant base alternative described as 'none of these' was added to each choice set.

Respondents were asked first to choose between the two transport modes or 'none of these'. Then, they were requested to choose the hypothetical shopping centre they were most likely to patronise, given their choice of transport mode.

3.3 Results

The ultimate aim of the present research project was to estimate and test a stated choice model of sequential mode and shopping centre choice. It was assumed that the choice of shopping centre may be influenced by the choice of transport mode. To assess the performance of the model, its predictive success was compared with that of an alternative model in which it is assumed that these two types of choice behaviour are independent. Thus, three different choice models were estimated:

- (a) a model of mode choice behaviour, derived from the orthogonal fraction of the 2×3^4 subdesigns, which uses alternative specific utility functions;
- (b) a model of shopping centre choice, based upon an orthogonal fraction of the $2^2 \times 3^6$ subdesigns, which uses generic attributes;
- (c) a model of sequential choice behaviour derived from the orthogonal fraction of the $2^3 \times 3^{10}$ full factorial design, consisting of 36 choice sets.

The performance of model (c) was compared with the performance of a model of independence that resulted from multiplying model (a) with model (b). A multinomial logit model was assumed to represent the choice process in all three cases.

To estimate the choice models, the attribute levels need to be coded. Different coding schemes, such as dummy coding, effect coding, or orthogonal polynomial coding, may be used. The choice of coding scheme will not affect the goodness of fit of the choice model, but it will influence the parameter estimates and their interpretation, their standard errors, and the correlations, if any, in the design matrix. In the present study, effect coding was used. Consequently, the parameter estimates reflect differences from the mean utility. Effect coding implies that for any attribute with K levels, $K-1$ indicator variables are constructed. $K-1$ attribute levels are coded by a 1 on one of the indicator variables, and by zeros on the remaining indicator variables. The K th attribute level is coded by -1 on all $K-1$ indicator variables. The dependent variable of the model consists of the relative choice frequencies that are obtained by aggregating separately the responses across respondents for each choice alternative and choice set. Iteratively reweighted least squares analysis was used to find the parameters of the choice models.

The results of the parameters estimates that predict transport mode choice behaviour are presented in table 2. A number of interesting observations can be made with respect to these results. First, both alternative specific parameters are negative, suggesting that the propensity to choose car or bus for shopping is lower than the propensity to choose any other means of transportation. This finding reflects the fact that the majority of shopping trips in the Netherlands indeed are made on foot or by bicycle. The spatial distribution of retail facilities allows consumers to act in this way. Because of strong urban planning regulations, all neighbourhoods have at least one small shopping centre that provides all convenience goods; and walking distance to such centres rarely exceeds more than 500 m. As expected, the utility for the bus is in turn less than the utility for the car. Although the provision of public transport in Eindhoven is satisfactory, the bus is chosen less frequently for

probably because the time it would take to wait for the bus is more than the time it takes to walk to the shopping centre.

Second, it can be seen in table 2 that all estimated parameter values are in the anticipated directions. Utility for using the car for shopping increases monotonically with decreasing parking costs. The utility of the bus increases with decreasing fares at an increasing rate. Its utility also increases with a higher frequency of service. Utility for travel time decreases with increasing time for both car and bus. Respondents seem more sensitive to the travel time of the bus compared with the travel time of the car. It should be noted, however, that most parameter estimates are not statistically significant beyond conventional probability levels, with the exception of the alternative specific constants: the free parking attribute level and the F16 fare attribute level. This suggests that consumers apparently prefer walking or cycling, no matter what the actual attribute levels of the car and bus, to go shopping.

Table 2. Parameter estimates of the multinomial logit model of transport mode choice.

Attribute	Parameter	Standard error	t-value
Car:			
Constant	-0.237	0.04	-5.52
Parking costs (Fl h ⁻¹)			
free	0.200	0.06	3.36
1	-0.057	0.06	-0.95
2	(-0.143)		
Travel time (min)			
5	0.036	0.06	0.60
10	-0.004	0.06	-0.07
15	(-0.032)		
Bus:			
Constant	-2.574	0.11	-23.60
Return fare (Fl)			
6	-0.357	0.16	-2.17
4	-0.060	0.16	0.41
2	(0.297)		
Travel time (min)			
10	0.092	0.41	0.64
15	0.053	0.41	0.36
20	(-0.145)		
Frequency of service			
every 15 min	0.055	0.10	0.53
every 30 min	(-0.055)		

Note: The figures in parentheses are not estimated but are calculated so that the estimates sum to 0.

The simple multinomial logit model provided an 88% improvement over the null model. This improvement is significant beyond the 5% probability level. The correlation coefficient between predicted and observed choices was 0.914.

The model estimated to represent consumer choice of shopping centre was also a simple multinomial logit model. It contained four generic attributes: size, price, parking facilities, and distance. In table 3 I present the estimated parameter estimates, their standard errors, and associated t-values. It can be seen that all parameters are statistically significant beyond the 5% probability level and that all are in the

are in the anticipated directions. The utility of a shopping centre increases as its size increases. Utility also increases with decreasing prices and it decreases at an increasing rate with increasing distance. Respondents' choices are most influenced by price, followed by distance, and size, as indicated by the range in estimated parameters. It can also be seen from table 3 that utility for a shopping centre increases if ample parking is available.

Table 3. Parameter estimates of the multinomial logit model of shopping centre choice.

Attribute	Parameter estimate	Standard error	t-value
Constant	1.047	0.078	15.75
Size			
small	-0.502	0.06	-9.06
medium	0.193	0.06	3.70
large	0.409		
Price			
discount	0.750	0.06	13.48
average	0.555	0.06	10.00
expensive	-1.305		
Parking			
ample	0.353	0.04	9.50
often occupied	-0.353		
Distance (km)			
< 1	0.571	0.06	10.18
1-3	0.130	0.06	2.33
3-5	-0.701		

The goodness of fit of this choice model was satisfactory. The correlation between observed and predicted choices was 0.970; the improvement in log-likelihood over the null model was 89.431%.

The results of the model of sequential choice that predicts the probability of choosing a shopping centre as a function of shopping centre attributes and attributes of the transport mode chosen at the previous step of the choice process are presented in table 4. It can be seen that none of the transport mode attributes is statistically significant. Thus, it seems that the choice of transport mode does not influence shopping centre choice. Moreover, the parameters of the distance categories are not significant. This may suggest that the evaluation of distance categories differs considerably between respondents choosing different transport modes. All other parameter estimates run in the theoretically expected directions. This finding gives further support to the validity of the results. The correlation between predicted and observed choices is 0.98. The estimated sequential choice model exceeds the null model by 87.1% in terms of the likelihood ratio.

Another way to assess the sequential choice model is to compare its predictive ability with the predictive success of an independence model that is obtained by multiplying the transport mode choice model with the shopping centre choice model. In table 5 I present a summary of some of the goodness-of-fit statistics that were calculated. Thus, these statistics indicate which of these two models predicts best the observed market shares for combinations of transport modes and shopping centres. Inspection of table 5 indicates that, regardless of the goodness-of-fit statistic, the proposed sequential model produces the best results. For example, Pearson's product-moment correlation coefficient between predicted and observed choice

Table 4. Parameter estimates for the model of sequential choice.

Attribute	Parameter estimate	Standard error	<i>t</i> -value
Constant	4.037	0.38	10.75
Shopping centre choice:			
Size			
small	-0.645	0.08	-7.39
medium	0.264	0.08	3.23
large	0.381		
Price			
discount	0.641	0.08	7.44
average	0.614	0.09	6.89
expensive	-1.255		
Parking			
ample	0.581	0.06	9.41
often occupied	-0.581		
Distance (km)			
< 1	0.007	0.09	0.08
1-3	1.692	0.09	1.83
3-5	-1.699		
Transport mode effect:			
Car:			
Parking costs (Fl h ⁻¹)			
free	0.133	0.57	0.23
1	-0.015	0.56	-0.03
2	-0.128		
Travel time (min)			
5	0.154	0.58	0.27
10	0.019	0.57	0.03
15	-0.173		
Bus:			
Return fare (Fl)			
6	-0.034	1.17	-0.02
4	-0.160	1.17	-0.09
2	0.194		
Travel time (min)			
10	-0.107	1.17	-0.06
15	0.318	1.17	0.18
20	-0.211		
Frequency			
every 15 min	0.236	1.12	0.193
every 30 min	-0.236		

Table 5. Goodness of fit of the choice models.

Statistic	Independence model	Sequential model
Correlation coefficient	0.715	0.977
Robinson's agreement	0.841	0.987
Theil's inequality coefficient	0.356	0.035
Mean absolute error	0.119	0.036
Minimum discrimination information index	9.843	1.497

frequencies of combinations of transport mode and shopping centre is 0.977, whereas its value is only 0.715 if these frequencies are predicted by multiplying transport mode probabilities with shopping centre probabilities under the assumption of independence. Thus, from a predictive viewpoint, the proposed sequential model provides satisfactory results.

4 Conclusions and discussion

In this paper I have explored the potential for estimating sequential choice models by using principles of stated choice methods. I have shown how discrete choice experiments may be used to derive models of transport mode and shopping centre choice and I have suggested design strategy that retains orthogonality properties within and between choice sets for elements of the choice sequence. It allows the efficient estimation of discrete choice models for each step in the choice sequence and for the sequential choice model.

The application of the suggested model of sequential choice behaviour was illustrated in the context of choice of shopping centre, given the choice of transport mode. I am not necessarily arguing that these choices are made in that order. This conceptualisation was required to develop the experimental task that was presented to the respondents. In fact, the suggested modelling approach allows one to test for the assumed structure in the choice sequence. The results of the present application suggested that choice of shopping centre is largely independent of choice of transport mode. Still, the predictive success of the sequential choice model exceeds the predictive success of a model of independence if one wishes to predict combinations of transport mode and shopping centre choice.

The results of the application and the ease of implementing the experiment leads me to conclude that this type of sequential choice model is easy to develop in cases of a moderate number of choices and attributes. Experimental designs that allow the estimation of the suggested type of model are readily available or can be easily constructed. It is also clear that these sequential models can be estimated from simple mail surveys and that the experimental task is easy to understand. Future research should test the limits to the suggested approach in terms of the number of attributes that can be included in the utility function and in terms of the extension of the suggested approach to problems of simultaneous choice. I hope to report on such developments in the near future.

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