CAPTURING INTERDEPENDENCIES IN TOUR MODE AND ACTIVITY CHOICE: A CO-EVOLUTIONARY LOGIT MODELLING APPROACH

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ABSTRACT

"Life is a Journey - not a Destination", **Author unknown.**

The paper aims to analyse the interdependencies in work-tour choice facets, specifically mode and activity choice. Activities may be inserted before, in-between and/or after the work activity resulting in the formation of complex work-tours. Traditional modelling approaches assume that tour-decisions are being made simultaneously or in some predefined order. Both these assumptions have inherent shortcomings such as defining a discrete set of choice alternatives or wrong estimation of parameters in the case of hierarchical estimation. To address the questions of interdependent tour-choice facets, the paper proposes the *co-evolutionary methodology*. The methodology holds implications for both the *estimation* and *prediction* phase of modelling. Separate utility models are *estimated* for each choice facet with the other choice facets used as independent variables. Estimated parameters thus represent the influence of the other choice facets. Prediction involves interactively updating predicted possibilities until a pre-defined convergence is reached (which solves the problem of circularity between linked decisions). Under the assumptions that individuals make least uncertain decisions first, the methodology provides for clarification on the order of decisions.

The empirical analysis uses detail, disaggregate travel-activity dairy collected in the Amsterdam region, The Netherlands, collected as part of a study into activity-travel patterns with public transport, undertaken for the Dutch Government. The results reveal that mode choice is significantly influenced by intermediate activities while intermediate activities are less influenced by mode choice. Also, before, in-between and after intermediate activities correlate with distinctly different transport, land use and socio-demographic characteristics. Considering the order of decisions, it was found that, in the majority of cases, intermediate activity choice rank higher up in the decision hierarchy while transport mode ranks rather low. The finding lends support to the hypothesis that intermediate activities might not be as discretionary as sometimes believed and that mode choice is determined, in most cases, by activity choice and not vice versa.

The findings of the research, while using data from the Netherlands, are potentially relevant to South Africa and hold implications for data collection, model specification and, ultimately, transport policy. South African travel surveys are mostly of the Origin-Destination which focuses on the separate trips with little activity or tour information collected. As a result, model specification does not incorporate activity or tour decisions. Given the importance of tours in structuring daily activity-travel behaviour, this might lead to unrealistic assumptions and invalid policies about travel behaviour, in specific mode choice and trip generation.

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1. INTRODUCTION

Activity-based models of travel behaviour recognise that travel is derived from the need to participate in spatially distributed activities (Jones et al., 1983; Ortúzar and Willumsen, 2002; Pas, 1995). These approaches use activities (as opposed trips) as the unit of analysis and an important modelling consequence from this decision is that the interdependencies between activities and travelling is explicitly recognised. That is, people are assumed to plan their daily activities (in order of importance) and arrange their 'derived' travel demand (mode choice, number of trips, route choice, etc.) around these planned activities. While all these decision are potentially very relevant to the urban transport planning process, this research will focus more on the last decision, i.e. the relationship between activity choice and mode choice.

Although the concept of activities as analysis unit is theoretically appealing, it does introduce considerable complexities in the modelling process and data collection. Among these complications, include, form example, how to derive trips from activities and secondly, how to model the interaction between activities and travel demand and the implications therefore for the urban transport planning process. Considering data collection, tour-based analysis requires a move from trip-based, origin-destination surveys to the development alternative (or in some instance complementary data-collection methods such as the activity-travel diary.

The relationship between activity choice and mode choice is particularly evident on the home-based work tour. Home-based tours are simply defined as a sequence of movements that begins and ends at the home location (Alves and Axhausen, 1994; Timmermans et al., 2003). Given the prominence of the work as a mandatory activity, the home-based work tour (or simply work-tour) is important in shaping daily activity and travel behaviour with the home and work location acting as pegs around which daily activity and travel behaviour are organised (Cullen and Godson, 1975; Forer and Kivell, 1981; McGuckin and Murakami, 1998). Many researchers have pointed to the secondary role of the work tour, i.e. providing an opportunity to link activities (Nishii et al., 1988). The possible linking of intermediate activities to the work tour clouds our understanding of the influence of policy and planning measures to entice users to shift from environmentally unsustainable transport modes, such as the car, to more sustainable public transport alternatives for their commute trip (Hensher and Reyes, 2000). Clearly, certain modes, such as the car, are more 'suited' to inserting activities on the work-tour by virtue of the mode's spatial and temporal flexibility.

The causal relationship, however, between additional activities on the work-tour and tour mode choice has not yet been well clarified and the implications for transport planning have not been quantified. Any relationship between activities and mode choice, might for example, result in problems when specifying models of decision chains such as the arbitrary choice of the sequence in which decisions are made. Any pre-defined order pre-supposes a decision structure that might not reflect actual circumstances and result in erroneous predictions. The alternative of assuming a discrete choice between all combinations of choices in the tour is also theoretically inadequate. The problem is aggravated in cases were intermediate activity and mode choice may be mutually interdependent. Identifying the decision structure underlying the insertion of intermediate activities (or trip chaining behaviour) may suggest a method for evaluating transport policies more effectively (Dueker et al., 1998; Nishii and Kondo, 1992).

The main objective of this paper is to address the nature of the causal relationship between the work-tour choice facets (i.e. activities and mode choice) using a proposed *co-evolutionary methodology*. The methodology holds implications for both the estimation and prediction phases. Separate utility models are estimated for each choice facet with the other choice facets used as independent variables. Estimated parameters thus represent the influence of the other choice facets. Prediction involves interactively updating predicted possibilities until a pre-defined convergence is reached (which solves the problem of circularity between linked decisions). Assuming that least uncertain decisions are made first, the lower the relative degree of uncertainty for a particular choice facet will determine the position of the decision in the hierarchy. The co-evolutionary modelling methodology has been previously introduced and applied by Arentze and Timmermans to predict linked decision rules of activity scheduling and profiling decisions (Arentze and Timmermans, 2001). This application differs in that logit models are used (as opposed to decision trees) and the technique is extended to also predict the order of decisions.

The paper is structured as follows: The following section briefly reviews the literature on the relationship between intermediate activities and mode choice as well as the specific methodologies applied to assess these intrinsic linked decisions. This is followed by a discussion of the co-evolutionary and nested logit modelling methodology applied in this paper. The data collection and choice sets for estimation are subsequently discussed. The results of the models are presented in the following section before the paper is concluded with a discussion of the implications for transport policy and land-use planning.

2. TOUR CHOICE FACETS IN THE LITERATURE

The importance of tours in explaining travel and activity behaviour has long been recognised by the transport modelling fraternity and significant conceptual, methodological and empirical advances have been made. In fact, tours currently represent the *cornerstone of activity-based modelling efforts* (Arentze and Timmermans, 2000b; Daly, 1997; Krizek, 2003). Only a brief overview of some of the major findings and approaches are provided.

Strathman and Dueker (1995) used the United States Nationwide Personal Transportation Survey data (NTPS, 1990) to derive a trip chain typology, which they related to various socio-demographic, metropolitan structure and transport characteristics (Strathman and Dueker, 1995). Using cross-tabulations and binomial logit models (with the dependent variable the probability of a complex commute), they found that changing household composition and structure, higher incomes and the entrance of women into the labour market resulted in more complex work chains. Support for their findings is provided by McGuckin and Murakami (1998) who also found that women are more likely to form complex work trip travel chains (McGuckin and Murakami, 1998). The changing social and economic role of women (especially their increasing participation in the labour force) over the past three decades has had equally significant changes on travel behaviour and particularly on trip chaining. The difference between men and women in this regard, however, seems to be amplified by the household composition and gender roles, in particular child-care responsibilities.

In a series of articles dealing with the specific impacts of spatial-temporal constraints on the propensity to chain activities to the work tour, Nishii, et al. (1988), Kondo and Kitamura (1987) and Nishii and Kondo (1992) showed that the likelihood of pursuing a non-work activity in a separate, home-based trip chain will increase with the speed of travel, i.e. faster modes. Furthermore, the propensity to chain activities to the work tour increases as the commuting distance (and thus the trip duration), the travel cost or the density of opportunities increases. This also applies to train users if the number of transfers increases (Kondo and Kitamura, 1987; Nishii et al., 1988; Nishii and Kondo, 1992).

In addressing the issue of interdependencies of tour decisions, Adler and Ben-Akiva (1979) treat tour choice facets as a single joint choice of a complete travel pattern (travel pattern being defined as a set of tours – and included in tours the number of stops, mode choice etc. – made by an individual within a fixed time period). Using the utility maximising framework, they related the optimum travel pattern (measured in terms of the number of tours travelled on a given day and the number of stops made on each tour) to transport expenditure. They found that disincentives on travel (e.g. increase in travel expenditure) cause an overall decrease in the average number of sojourns per tour. This was found to be caused by the general reduction in the number of sojourns per household, which results in fewer opportunities for a household to link trips together in multiple-sojourns (Adler and Ben-Akiva, 1979).

Wen and Koppelman (2000) address the issue of interdependencies of tour choice facets by adopting a linked model methodology (Wen and Koppelman, 2000). They use a two-stage logit modelling approach system to model short-term travel and activity decisions. The first stage includes (a) the generation of daily maintenance activities (stops), and (b) the allocation of stops/cars among household members. The second stage includes the individuals' choice of travel patterns, including the selection of the number of tours and the assignment of stops to the tour. The expected utility of the second-stage models (tour formation models) is used in the estimation of the first-stage models, while the second-stage model is conditional on the estimated number of stops (from the first-stage model). Using a two-day travel and activity diary from Portland, Oregon (1994) they found that the expected utility on the individuals' tour pattern has an influence on the generation of maintenance stops and on the allocation of maintenance stops and cars among household members.

Little, if any, tour-based (or activity) research has been undertaken in South Africa (or any other developing country with the exception of Chile and India) (see for an overview of activity-based research in South Africa Behrens, 2001). Reasons for this relate to the traditional transport policy and planning objectives in developing countries which was, and remains, oriented to providing (road) infrastructure to accommodate increased traffic and / or to evaluate alterative route alignment for different transport systems. Research objectives were more concerned at providing accurate flow predictions (typical by a strategic transport model) as opposed to exploring behavioural determinants underlying travel behaviour. Such predictions typically require only data between origins and destinations, hence the collection of origin-destination (O-D) sufficed. A few studies did consider the relationship between trip making and activity behaviour, mostly to explore and compare the travel behaviour requirements of the different population groups (Behrens, 2001; Cameron et al., 1984).

An overview of current household travel surveys colleted recently in South Africa revealed significant differences in level of detail trip (and household) information collected. For the purpose of this paper, three datasets were considered, i.e. two Gauteng household travel surveys and one Cape Town O-D data set. Considering the former two, extensive morning peak period trip information was collected with some trips indicated as a linked trip (linked trip being defined as a trip with an intermediate stop). In the Cape Town O-D study, information was collected for the work commute only and no information was collected on whether trips are linked or not.

Based on some limited descriptive analysis of the Gauteng dataset, the data revealed very similar characteristics to the studies discussed above. That is, women undertake more linked trips and income and level of education is positively associated with link trips. Full-time employed people are also more likely to insert intermediate activities on the tour. Considering modes, linked trips are mainly a function of the car with less than 1% of public transport trips being linked. Cross-tabulation of population group (race) and linked-trip, revealed that while white, asian and coloured population groups revealed similar linked-trip characteristics, black travellers undertook significantly less linked trips. Although the Gauteng household travel surveys do provide much trip information, it only covers the morning peak period and the link-trip refers mainly to the serve-passenger/goods activity. As such, it was not possible to use these datasets in comprehensive tour-based analysis and it was decided to focus on the international surveys and studies.

In general, most studies agree that the forces behind the formation of complex work chains are related to household composition, urban form and spatial-temporal constraints. Considering the choice process, earlier studies have adopted a simultaneous choice model, i.e. the decision consists of a single choice of all choice facets (e.g., (Adler and Ben-Akiva, 1979; Strathman et al., 1994), a nested choice model, i.e. lower-level choices are nested within higher-level choices in some predefined hierarchy (e.g., (Wen and Koppelman, 2000) or a sequential choice model, i.e. decisions are made sequentially in some pre-defined order (e.g., (Borgers et al., 2002; Fujii et al., 1998). Notwithstanding their obviously valuable contribution, all of these approaches have shortcomings. Assuming a (subjectively) predefined order, as is done in nested and sequential approaches, presupposes a decision structure that might not reflect actual circumstances in all cases and hence results in erroneous or biased predictions. The alternative of assuming a simultaneous discrete choice between all combinations of choices in the tour is also troublesome as the number of choice alternatives increase tremendously with the number of choice facets and individuals may evaluate alternatives at the choice-facet level.

3. METHODOLOGICAL APPROACH AND DISAGGREGATED TRAVEL DATA

3.1 The Choice Problem

Faced with their daily activity programme (sets of activities to be included during the day) and available means of transport, individuals can organise their travel in individual trips and/or trip chains (or tours). This research is concerned with the scheduling of out-of-home activities (i.e. intermediate activities) on the work tour (work is assumed to be the primary subsistence activity and other daily activities are assumed to be scheduled around this). Activities available for insertion on the work tour include, in order of importance, *non-leisure activities* (church, medical and other planned personal and household non-leisure activities), *serving passengers or goods* (pick-up/drop-off of persons or goods), *maintenance activities* (shopping and services), *leisure* (social, recreational and cultural purposes) and *other* (i.e. remaining activities). Individuals can insert no additional activities on the work tour, in which case the work tour is referred to as a simple tour; or they can insert intermediate activities before, in between and/or after work, in which case the work-tour is referred to as a complex tour. Simple work tours refer to home-based tours on which no additional activity is inserted while during complex work tours, intermediate activities may be inserted before, during and after the main work activity. Figure 3 shows this distinction.

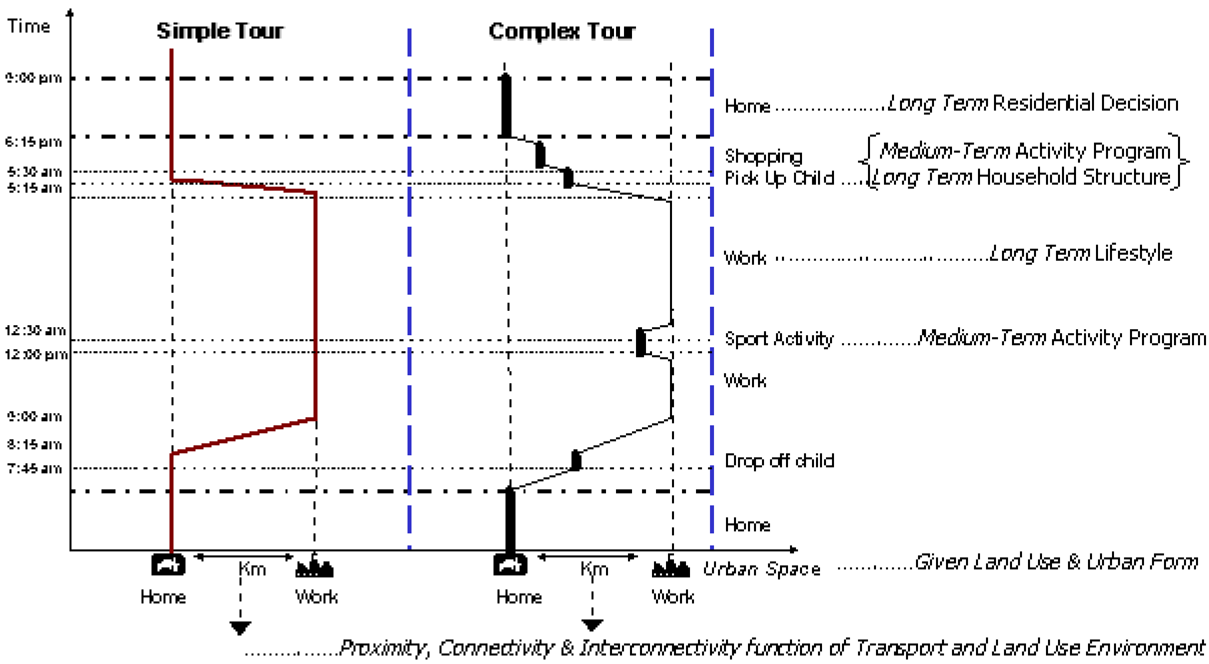

Figure 1. Simple and complex work tour formation.

The before, in-between and after intermediate activity are modelled as separate (discrete) choices as they do not refer to mutually exclusive categories. In the case of multiple intermediate activities on the same position (before, in-between, after) in the tour, the choice is defined based on the primary intermediate activity. The primary intermediate activity is selected on the basis on the hierarchy above, i.e.; Non-Leisure, Serve Passenger, Maintenance and Other in order of importance. The models thus refer to the *primary intermediate activity on the work-tour.*

An important property of the co-evolutionary approach is the assumption that the other choice facets are known for each decision. That is, for the mode choice decision, the observed intermediate activity choice is known while for the intermediate activity choice models, the mode choice and other intermediate activity choices are assumed to be known. This assumption implies that an activity is defined as available for insertion on the tour if two conditions are met. Firstly, an activity must occur on the day, i.e. it is included in the activity programme for that day. Secondly, after taking into consideration the other intermediate activities of the same type on the tour (i.e. before, in between and after), if any, there are still activities left for insertion for this particular choice. As such, the intermediate activity choice models (before, in between and after the main activity) refer to the choice of inserting an activity only when that activity is available for insertion on the tour. When no activity is available, either because it is not in the daily activity programme and/or this type of activity has been inserted on the tour in the other prisms, the option is excluded from the choice set.

Considering the main transport mode of a tour, the mode has been defined based on a hierarchy of modes: train, bus/tram/metro, car driver, car passenger, bicycle, walking and other, in hierarchical order. For example, any tour involving a train trip for any of the tour trips is defined as a train tour. Use of public transport modes as tour main mode does not preclude other modes from being used on the tour, for example slow modes can be used during the lunch hour. The model, however, predicts the main tour mode used. The choice set for the mode choice logit model is defined as car driver, car passenger, train, bus/tram/metro and slow (the latter includes both walking and the cycling). A nested structure is adopted with private, public and slow defined as the primary nests. Secondary nodes for private are car driver and car passenger. For public, the train and bus/tram/metro (B/T/M = one category) are the nodes. Slow was selected as the reference category. The car driver alternative was only available to people with a driver's licence. No other availability criteria were specified.

3.2 Co-Evolutionary Modelling Methodology

The co-evolutionary approach has implications for both the estimation and prediction phases. The process is initiated by estimating separate models for mode choice and intermediate activity choices (before, in between and after). These four models are individually estimated using the traditional multinomial/nested logit modelling framework (Ben-Akiva and Lerman, 1985; Lerman and Ben-Akiva, 1975; Richards and Ben-Akiva, 1975). The HieLow modelling software was used to estimate the parameters (Bierlaire, 1995). In each model, the choice outcomes of the other choice facets are included as independent variables. The estimated parameters for these choice facets thus indicate interactions between these choices. During the *prediction* phase, the co-evolutionary method involves an iterative procedure. Initially, the choice probabilities for the four decisions ($P_{ki}^{t=0}$ *where k = choice facet, i = alternative within choice facet and t = iteration*) are set as equal (*i.e.* $P_{k1}^{0} = P_{k2}^{0}$ *for each k*). The models are subsequently used to predict the probability distribution P_{k}^{t} assuming P_{j}^{t-1} for each decision $j \neq k$. The process is iterated until a convergence criterion is met, whereby convergence is measured as the *sum of absolute differences between updated probabilities and probabilities of the last iteration*. Once convergence is achieved, the choice facet with the lowest level of uncertainty is selected and a decision is made and fixed in the iterative process. Uncertainty is measured as the entropy of the choice probability distribution. A decision involves choosing the alternative that has the highest choice probability. Since a decision changes the choice probability, the same process is repeated until all decisions have been made.

The outcome of the above is a set of decisions for the choice of tour main mode, before intermediate activity, in between intermediate activity and after intermediate activity as well as the order of the decisions. In this procedure, the sequence of the decisions is predicted and case dependent rather than a-priory defined and constant across cases. Since the co-evolutionary approach assumes full information about the outcomes of related choices in the estimation stage, it may improve the predictive performance of the model as well. The main reason, however, for using this approach in the present study is that it allows the researcher to establish the nature of the interdependence between activity and (multi) tour mode choice. If the mode decision is made prior to the activity choice, there is evidence in the majority of cases that activity choice is conditional on mode choice rather than the other way round.

3.3 Data

As mentioned in the introduction, not much activity-based research is undertaken in South Africa. As a result, few data sources are available that comprehensively describes activity and travel patterns and, in specific, intermediate activities on a tour. Most surveys are of the conventional O-D type which generally does not collect information on intermediate activities. As a result, the data used in this study comes from an extensive 2-day travel and activity diary survey undertaken during April to September 2000 in the Utrecht-Almere-Amsterdam urban region, The Netherlands (Arentze et al., 2001). The research programme, for which the data were collected, is referred to by the acronym *AMADEUS*, which stands for "**A**ssessing the time-varying effects of **M**ultimodal transportation systems on **A**ctivity and **DE**stination choices in **U**rban **S**ystems". The research was commissioned by the Dutch government in an attempt to clarify multimodal travel and activity patterns (Arentze et al, 2001).

To summarise, a total of 1 966 households, representing 4 246 individuals, completed and returned usable diaries. Information on +/- 24 000 trips and 12 459 tours (i.e. an average of 2.1 trips per tour) were recorded. Of these, 1 331 (10.7%) tours involved a public transport mode while 11 164 (89.3%) tours involved private transport modes only. The survey data were combined with extensive data on the transport and land-use systems. For each tour, objective travel times were derived for slow, car and public transport modes using the national road and public transport network of The Netherlands (i.e. 'basisnetwerk'-file and 'Randstad Model'-file, 2000)(Adviesdienst Verkeer en Vervoer, 2003). Land-use data, which included accessibility measures, were derived for all 6-digit postal code areas (the chosen spatial unit) in the study area. The Netherlands counts a total of +/- 430 000 6-digit postal code areas (PCAs). Each 6-PCA contains +/- 17 persons and, given a 6-digit PCA location for a household, the location can be determined within 50 – 500 metres of accuracy depending on development density.

Work tours were selected (n = 3 980) and some additional selection criteria were applied which included selection of "closed tours" (tours that start and end at the home location on the same day), instances where travel times could be successfully derived (sometimes it was not possible to derive travel times as home and work locations where not coded correctly) and tours where the main mode was clearly identifiable. After all the selections, the dataset contained 2 757 home-based work tours. Table 1 shows the cross-tabulation of modes and intermediate activities for the dataset. The three columns (i.e. at least one intermediate activity before, in between and after work) refer to tours where *at least* one intermediate activity (IA) occurred and where intermediate activities are not mutually exclusive (thus they do not add up to the total for complex tours as shown in column 5).

Table 1. Tour mode choice and intermediate activity occurrence.

	1	2	3	4	5	6
Tour Mode	No Intermediate Activity *(%)* ***Simple Tours***	*At least* one IA before work *(%)*	*At least* one IA in-between work *(%)*	*At least* one IA after work *(%)*	***Complex tours*** *(%)*	Total
Car Driver	633 *(56)*	196 *(17)*	122 *(11)*	285 *(25)*	499 *(44)*	1132
Car Passenger	35 *(65)*	10 *(19)*	3 *(5)*	10 *(19)*	19 *(35)*	54
Train	346 *(72)*	30 *(6)*	33 *(7)*	86 *(18)*	133 *(28)*	479
Bus/Tram/Metro	121 *(68)*	12 *(6)*	8 *(5)*	45 *(25)*	58 *(32)*	179
Slow: walk & bike	529 *(58)*	146*(16)*	110 *(12)*	252 *(28)*	384 *(42)*	913
Total	**1664 *(60)***	**394 *(14)***	**285 *(10)***	**678 *(25)***	**1093 *(40)***	**2757**

The dataset contains, seemingly, more intermediate activities compared to other studies, which often found only +/-15% of all tours to be complex (Alves & Axhausen, 1994; Arentze and Timmermans, 2000a; Strathman et al., 1994; Strathman and Dueker, 1995). A possible explanation lies in the fact that for the AMADEUS dataset a relatively high percentage of drop off/pick up persons/goods activities (termed "serve passenger/goods in this study) were observed. The latter might be a result of the different diary format used in the study (Arentze et al. 2001a). Table 2 shows the type of intermediate activity inserted on the tour associated with the different transport modes.

Table 2. Tour mode and intermediate activity differentiated according to activity type.

Tour Mode	No Intermediate Activity (IA) (%)	At least one Non-Leisure	*At least one Serve Pass./Goods*	*At least* one Maintenance	*At least* one Leisure	At least one Other
Car Driver	633 *(56)*	31	*340*	82	67	14
Car Passenger	35 *(65)*	1	*13*	3	2	1
Train	346 *(72)*	4	*49*	57	28	3
Bus/Tram/Metro	121 *(68)*	2	*22*	22	11	3
Slow: walk & bike	529 *(58)*	27	*222*	107	64	6
Total	**1664 *(60)***	65	646	271	172	27

Table 3 shows the frequency distribution of intermediate activity type for the three intermediate choice models. There are relatively few cases for the activity categories maintenance, leisure and other in the before model. The low number of cases is probably due to the fact that most work tours commence in the morning and that (in the Netherlands at least) many shops and businesses do not open before 09:00 or 10:00am. Similarly, for the in between model there are fewer intermediate activity cases overall compared to the other two alternatives. Too few cases hamper the estimation of coefficients and it was decided to group some of the intermediate activity choices together. The results are shown in Table 4.

Table 3. Frequency distribution of choices for intermediate activity choices on work mode tours.

Model Nr.	**1**		**2**		**3**	
	Intermediate activity before work		Intermediate activity after work		Intermediate activity in-between work	
Choice Categories	**#**	**%**	**#**	**%**	**#**	**%**
No IM	2363	85.7	2079	75.4	2481	90.0
Non-leisure out	35	1.3	17	.6	16	.6
Bring Get	337	12.2	334	12.1	121	4.4
Maintenance	*9*	.3	195	7.1	80	2.9
Leisure	*6*	.2	123	4.5	46	1.7
Other	*7*	.3	9	.3	13	.5
Total	**2757**	**100**	**2757**	**100**	**2757**	**100**

Table 4. Frequency distribution of grouped choices for intermediate activity choice.

Model Nr.	1			2		3	
	Intermediate activity before work			Intermediate activity after work		Intermediate activity in-between work	
Choice Categories	**#**	**%**	**Choice Categories**	**#**	**%**	**#**	**%**
No IM	2363	85.7	No IM	2079	75.4	2481	90.0
Bring Get	337	12.2	Bring Get	334	12.1	121	4.4
Non-leisure out	35	1.3	Maintenance	195	7.1	80	2.9
			Leisure	123	4.5	46	1.7
Other	22	0.8	Other	26	.9	29	1.1
Total	2757	100	Total	2757	100	2757	2757

4. MODELLING RESULTS

Due to space constraints, the logit modelling results (i.e. mode choice, before, in-between and after intermediate activity) are not presented here but are available from the author on request. For the tour mode choice model, four categories of variables have been used, i.e. transport level-of-service, socio-demographic, intermediate activity and urban form variables. In as much as the data allowed, the same independent variables have been used in the three models of intermediate activity choice to facilitate comparison.

4.1 Mode Choice Model

In general, the results obtained for the mode choice models are in line with traditional mode choice models. Travel time, estimated as a generic coefficient, is appropriately signed and in order of magnitude of travel-time estimates in other models. Unfortunately, estimating mode-specific travel times proved unsuccessful. The train travel-time ratio is correctly signed (negative) implying that a larger differential between train and car travel time leads to a decrease in the utility of the train.

Considering the socio-demographic variables, the utility of public transport modes decreases with an increase in the number of cars per worker. An increasing household size leads to a decrease in the utility for all modes; however, the disutility is much smaller for car modes compared to public transport modes. For the reference category slow modes, the results imply that more household members will rely on slow modes when household size increases. Given that larger households generally contain more children, this finding is understandable. The male dummy variables reveal that the utility of public transport modes declines while it increases for car driver.

The insertion of before and after intermediate activities on the tour leads to a decrease in the utility of public transport modes. The coefficients are particularly strong for the before intermediate activity choice, which might reflect the especially rigid time regimes and schedules public transport travellers face on the trip to work in the morning time period. Fixed public transport schedules, fixed work start times, as well generally limited free time in the morning lead to an inability to undertake intermediate activities on the morning trip. In general, public transport travellers are not able to terminate their trip and deviate from the fixed public transport network.

On the other hand, none of the in between intermediate activity variables showed up as significant. As the model estimates the main mode used on the tour, the use of public transport does not exclude individuals from using slow modes (the reference category) in between work activities to insert intermediate activities on the tour. Public transport users may conduct in between intermediate activities by switching to walking (or cycling) if activity locations are within easy reach given their available time.

Two urban form variables were included, i.e. an origin and destination central business district (CBD) dummy indicating whether a person resides or works in a CBD location respectively. Whereas none of the origin CBD variables are significant, all the destination CBD variables are.

Individuals working in the CBD have a preference for public transport while the utility of the car is lower. The latter most likely relates to limited and/or expensive parking as well as congestion problems. Public transport networks are traditionally designed to converge on the CBD with good services running to and from the CBD.

4.2 Intermediate Activity Models

Only the main results are reported for the three (i.e. before, in-between and after) intermediate activity models. In general, the results show that for complex transport modes involving mode chaining and many transfers, such as public transport modes, the utility for insertion of intermediate activities on the tour decreases. Simple (i.e. single, unchained) private transport modes are more readily associated with intermediate activities on the tour. This supports the general notion that complex transport modes lead to simple activity chains while simple transport chains leads to complex activity chains. However, although this relationship holds in general, the relationship between intermediate activities and mode choice seems to be magnified or subdued by the location on the tour of the intermediate activity. The result showed that before and after intermediate activities are particularly negatively influenced by public transport modes while private transport modes are associated with an increase in the utility when inserting intermediate activities before or after. Inserting intermediate activities in-between the work activity, however, seems much less influenced by public transport. While factors such as density of opportunities and available time are obviously important, the results suggests that public transport users are not overly constrained by limited private mode availability (at the work location) and individuals may rely on slow modes for intermediate activities in-between the main activity.

Considering the socio-demographic, land use and urban form characteristics, the results of the empirical analysis reaffirms existing findings. In general, women remain responsible for most complex tours. Specifically, the serve passenger/goods activity predominantly remains a woman (wife's) responsibility. Furthermore, the same person assumes responsibility for both serve passenger activities during the day as opposed to sharing the activities between household members. Both these activities are also scheduled for the same tour as opposed to being inserted on separate tours. Work duration was also found to be positively associated with the serve passenger / goods activity before and after work. This result indicates that people, whom face much time pressure, compensate by inserting activities on the work tour. Finally, income was also positively associated with inserting intermediate activities on the work tour, indicating that as income increase, individuals and households are more likely to form complex tours.

While these general findings hold for the before and after work intermediate activities, the in-between intermediate activities show some distinct differences. For one, men are much more likely to insert intermediate activities in-between main activities (in specific leisure and maintenance activities). Longer trip durations (negative for before and after intermediate activities), increase the utility for in-between intermediate activities. In-between intermediate activities thus show some distinct different socio-demographic and transport properties compared to before and after.

4.3 Co-Evolutionary Model (CEM) Results

The co-evolutionary model converged in all of the 2 757 cases. On average 7.54 iterations with a standard deviation of 1.65 were needed to establish a decision on all four choice facets. If the choice facets were fully independent, then 1 + n iterations would suffice to reach n decisions. The higher number of iterations indicates that interdependencies played a role in the process. Table 5 shows the frequency distribution of the observed tour choice facets (column 1) and the predicted frequency distributions using the co-evolutionary model (column 2). As it appears, predicted frequencies closely match the observed frequencies. The only exception is that dominant choices are slightly over-predicted. This is what we would expect given the used decision rule, which selects the highest-probability alternative in every case. For the purpose of the present analysis, however, the decision outcomes are less relevant than the decision order, provided that biases at the level of outcomes are limited. Table 6 shows the order of the decisions in the CEM.

Table 5. Choice set predictions.

	Tour Choice Facet	Observed	CEM
Mode	Car Driver	0.41	0.54
	Car Pass.	0.02	0.02
	Train	0.17	0.09
	BTM	0.07	0.04
	Slow	0.33	0.30
Before	Non-Leisure	0.01	0.01
	Serve Passenger/goods	0.12	0.13
	Other	0.01	0.01
	No intermediate activity	0.85	0.85
In-Between	Other	0.01	0.01
	Leisure	0.02	0.02
	Maintenance	0.03	0.02
	Serve Passenger/good	0.04	0.06
	No intermediate activity	0.90	0.89
After	Other	0.01	0.01
	Leisure	0.05	0.04
	Maintenance	0.07	0.10
	Serve Passenger/good	0.12	0.14
	No intermediate activity	0.75	0.71

Table 6. Tour decision hierarchy.

	Choice Order	Frequency	%	Cum. %
Mode	First	94	3	3
	Second	228	8	12
	Third	250	9	21
	Fourth	2185	79	100
	Total	***2757***	***100***	
Before	First	1709	62	62
	Second	639	23.2	85
	Third	341	12.4	98
	Fourth	68	2.5	100
	Total	***2757***	***100***	
In-Between	First	843	31	31
	Second	1473	53	84
	Third	299	11	95
	Fourth	142	5	100
	Total	***2757***	***100***	
After	First	843	4	4
	Second	1473	15	19
	Third	299	68	87
	Fourth	142	13	100
	Total	***2757***	***100***	

As shown in Table 6, mode choice is nearly always chosen last, while intermediate activities rank much higher up. Before intermediate activity choice is in 62% of the cases the first tour decision made. In between intermediate activity choice is in 31% of the cases the first tour choice, but in 53% of the cases the second tour decision. After intermediate activity choice features lower down in the hierarchy, but is still ahead of mode choice; it is in 87% of the time the third or higher, most important decision, while mode choice is in 80% of the cases the last tour decision to be made. At the same time, it is important to note that considerable variation in decision order exists between cases. The latter finding supports the hypothesis that the assumption of a predefined and fixed decision order is in conflict with reality, at least in this case.

The estimation results of the logit models seem to support the co-evolutionary results. Firstly, whereas the tour mode choice (Appendix A) is very much influenced by intermediate activities (both in terms of the number of significant intermediate activity dummies and the strength of these dummies), the intermediate activity choice models show less relationship with the transport mode dummies. This might suggest that the decision to insert an intermediate activity is not so much a function of the mode but that the chosen mode is determined by the presence of intermediate activities on the tour.

5. DISCUSSION AND CONCLUSIONS

This paper addressed the issue of interaction in work tour choice facets (i.e. mode choice, before, in between and after intermediate activity choice) in an attempt to explore the role of transport mode on complex tour formation. The co-evolutionary methodology was proposed to clarify the nature of these possible *causal* relationships. As illustrated, the methodology combines well with the logit-modelling framework. It involves *estimating* separate choice models using full information about the outcomes of the related choices and then deriving *predictions* simultaneously based on an iterative procedure of updating choice probabilities. Assuming that least uncertain decisions are made first, a decision order can be derived from the model dependent on the utility distributions of the specific case.

The co-evolutionary model (CEM) successfully converged over the 2757 cases and provides for additional information not previously available with standard utility-based approaches. Furthermore, the CEM does not impose additional data needs and, as demonstrated, can be used successfully with the utility maximising framework.

An important benefit of the model is the information on the hierarchy of tour choice facets. The CEM showed that intermediate activity choices are made *before mode choice in most cases*. In these cases, the decision to insert an intermediate activity before work is *least uncertain* and therefore supposedly the first tour choice. Mode choice, on the contrary, is most uncertain and assumed to be the last tour decision. In conclusion, the co-evolutionary approach may not only improve the predictive performance of the model, but also allows one to establish the nature of the interdependencies between intermediate activity and tour mode choice if one is willing to make the required rationality assumption involved.

The order of the intermediate activity decisions also seems to correlate with the temporal and spatial constraints placed on individuals during the three prisms on the work tour. Clearly, engaging in activity participation on the way to work is subject to more temporal and spatial constraints than after work. The possibility of arriving late for work and opening hours, is arguably more severe in the morning prism than in the evening prism. Discretionary activities are thus much more likely to be scheduled for the evening prism while only mandatory activities will be inserted into the morning prism. The presence of mandatory activities in the morning prism will demand much spatial and temporal flexibility of the transport mode and, again, modes will be chosen based on the presence and nature of intermediate activities.

The above findings have significant implications transport and land-use planning, in developed as well as developing countries such as South Africa. Clearly, household structure and individual role within the household (both endogenous variables in transport and land-use policy) remain significant factors influencing the propensity to insert intermediate activities on the work tour. The increasing entry of women into the labour market and their continuing responsibility for traditional household tasks such as caring and chaperoning young children will clearly impact on their trip-chaining propensity. Furthermore, given that these tasks are often inserted during peak periods, their impact on congestion is to be expected. As household care tasks tend to be mandatory and, as demonstrated by the co-evolutionary methodology, the intermediate activity before work dominates the tour choice facets, it is likely that the transport mode will be chosen to suit the intermediate activity requirements of women and not the other way around. Women's requirement to combine household and facility responsibilities with the work tour makes it likely that they will increasingly rely on the *flexibility of private transport modes* to satisfy their trip-chaining needs. Transport policy should keep track of socio-demographic trends and target appropriate public transport market segments.

Furthermore, the effect of public transport policies aimed at decreasing public transport travel time between home and work will be muted if the specific market segments (e.g. high-income choice users) are faced with many intermediate activity requirements. The improvement in public transport travel time will be partly offset by the additional travel time required to travel to intermediate activity locations, which are often inadequately served by the inflexible public transport network and service schedule. Thus, integrating public transport and land use, for example by providing retail, service and even childcare facilities at public transport transfer facilities, will allow people to satisfy the complex mode chaining requirements in the constrained activity spaces allowed for by public transport, which ultimately should benefit public transport as a substitute for car travel.

The findings also hold implications for transport planning and modelling in South Africa, specifically data collection, model specification and, ultimately, transport policy.

Considering data collection, most travel surveys in South Africa collect mainly origin-destination information which contains (trip) information such as the main mode used, travel time, distance, time of departure, etc. Information on activities and linked trips (or intermediate activities), is generally not collected. Collecting tour information, however, does place significantly more demands on data collection methods. Conventional O-D surveys rely on relatively simple questionnaires about a trip (typical the commute), collected by interviewers during visits to the home or work location. Tour information requires *activity-travel diaries* covering a longer time period (1 – 7 days) to be completed by *respondents* during the day. Respondent burden and level of education are, therefore, key factors that influence quality of the completed diaries. Activity-travel diaries are also notoriously difficult and expensive to design and to derive sufficient and accurate information from. Testing of alternative activity-travel diaries in developing countries becomes a crucial activity in order to ensure adequate response and data quality.

Activity diaries provide a much richer specification of data from which to capture underlying causal relationships, specifically between *activity demands and mode choice, trip generation* and complex tour formation. Given that mode choice is influenced by (and indeed influences) activities on the work commute, these activities, and the characteristics associated with intermediate activities (i.e. household structure, urban form and land use and activity program variables), should be include in models of *mode choice and trip generation*.

Households which face many activity demands (such as households with school-going children, double income earners, etc.) will place more demands on the temporal and spatial flexibility of the transport mode. Furthermore, the spatially distributed land use environment of South Africa cities demands more spatial flexibility from transport modes. In order to satisfy all their activity requirements, individuals from such households will tend to form complex work tours and will be less inclined to shift to public transport modes.

Considering captive transport users, while they are, arguably, limited in their mode choice decision, these users may trade-off activity and travel decisions (such as foregoing activities due to long travel times and inflexible transport modes, leading to social-exclusion). Furthermore, the analysis showed that income, level of education and car ownership is positively associated with the propensity to link trips. Government's economic and social development objectives (such as NEPAD) will have a positive impact on these characteristics and hence the occurrence of linked trips. Captive transport users should therefore not be treated as future captive travellers. By allowing captive users to satisfy all their activity demands, policy makers will ensure that captive users become choice public transport users when their economic and social circumstances allow this.

As stated in the introduction, travel is a derived demand, derived from the need to participate in spatially distributed activities. This research showed that mode choice (at least in developed countries such as The Netherlands) is more often than not, a secondary choice to activity choice. By not taking into consideration the activity demands placed on transport modes and the derived nature of mode choice, policy makers run the risk of over-predicting the demand for public transport as a substitute to private car. This is even more the case when models are not adequately specified as a result of limited data. As Hensher and Button states, it is difficult to justify the *"…continued, grossly obese estimates of the predicted use of public transport and the equally anorexic cheapness found in their (…models…) construction" (Hensher and Button, 2000)*. While the authors of this paper do not necessarily agree with the harshness of the statement, it does emphasise the need to obtain good quality, disaggregated activity-travel data (covering longer time periods) that will allow the specification of complex models of activity-travel behaviour. Such models will obviously benefit model accuracy and improved decision-making.

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CAPTURING INTERDEPENDENCIES IN TOUR MODE AND ACTIVITY CHOICE: A CO-EVOLUTIONARY LOGIT MODELLING APPROACH

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