MODELLING TRANSFERS IN MULTI-MODAL TRIPS: EXPLAINING CORRELATIONS

Sascha Hoogendoorn-Lanser
Transport & Planning, Technische Universiteit Delft
lanser@xs4all.nl

Bijdrage aan het Colloquium Vervoersplanologisch Speurwerk 2005,

24 en 25 november 2005, Antwerpen

Inhoudsopgave

Samenvatting

Modelleren van overstappen in multi-modale reizen: verklaring van correlaties

Een overstap is een essentieel onderdeel van een multi-modale reis. In dit artikel geven we een gedetailleerde beschrijving van het overstapproces en laten zien welke tijd, kosten en moeite met de verschillende stadia van het overstapproces gemoeid zijn. Omdat het opnemen van meerdere overstapattributen veelal tot hoge relaties tussen de geschatte parameters leidt, wordt in de meeste routekeuzemodellen slechts een klein aantal overstapattributen opgenomen. Als attributen sterk gecorreleerd zijn, is het moeilijk om de impact van de afzonderlijke attributen op het overstapproces vast te stellen. Door verschillende Path Size Logit modellen te schatten en te analyseren, hebben we bepaald welke combinatie van attributen het beste de rol van overstappen in het reiskeuzegedrag weergeeft. Voor de analyse is gebruik gemaakt van waargenomen multi-modale treinreizen in de Randstad. De modellen zijn vergeleken op loglikelihoodwaarde en op grootte van correlaties tussen overstapattributen. Het blijkt beter te zijn om het aantal keer overstappen niet als verklarende variabele in de nutsfunctie mee te nemen, omdat dit tot hoge correlaties met andere overstapattributen leidt. Deze correlaties kunnen verklaard worden uit de stadia van het overstapproces waarop de attributen betrekking hebben. Daarnaast blijkt het mogelijk te zijn om een combinatie van overstapattributen te kiezen, zodanig dat de overstap in detail wordt beschreven en tegelijkertijd de correlaties klein zijn. Het beste model bevalt vervoerwijze-indicatoren, stationsindicatoren, parkeerkosten, overstaplooptijd en overstapwachttijd.

Summary

Modelling transfers in multi-modal trips: explaining correlations

Transfers are essential parts of multi-modal trips. In this paper, we present a detailed description of the transfer process, and identify time, costs and effort related to the different stages of the transfer process. Since inclusion of multiple transfer attributes generally leads to high correlations between parameter estimates, in most travel choice models only a small number of transfer attributes have been distinguished. If attributes are highly correlated, it is difficult to establish their impact on the travel choice process (especially when using more advanced random utility models). By analysing Path Size Logit models that differ with respect to the way in which the transfer process is accounted for, we establish which combination of transfer attributes best reflects the role of transfers in the travel choice process. In the analysis, Revealed Preference data on multi-modal train trip making in The Netherlands is used. Apart from log-likelihood values, correlations between different classes of transfer attributes are used to evaluate the different models. We will show that it is better to exclude the number of transfers from the utility specification, because its inclusion results in high correlations with other transfer attributes. Correlations will be explained from the different stages in the transfer process to which transfer attributes relate. In addition, we will demonstrate that transfers can alternatively be accounted for by representing the transfer process in the travel choice models at a high detail level, thereby preventing high correlations. It turns out that the best model contains mode indicators, railway station indicators, parking costs, transfer-walking times and transfer-waiting times.

1 Introduction

Planning a multi-modal trip involves multiple choices with respect to modes, services, boarding nodes, transfer nodes and alighting nodes. Transfers are essential parts of multi-modal trips, because travellers that use different transport modes will have to transfer between them. Transfers involve time (e.g. transfer-waiting and transfer-walking times), monetary costs (e.g. car parking costs) and effort (e.g. boarding, alighting and walking), which all add to the inconvenience of travellers. This is why transfers are likely to play an important role in the multi-modal travel choice process and need to be properly accounted for in travel choice models.

Many stages of the transfer process can be identified, such as preparing to leave a vehicle, alighting / boarding a vehicle, parking and retrieving a vehicle, walking through a transfer point, waiting for a transport service and settling in a vehicle. Although each stage is likely to contribute significantly to the discomfort of a transfer, only a small number of transfer attributes is included in most travel choice models found in literature. This might be partly due to the fact that transfer attributes often correlate. For example, the number of transfers is positively correlated with total transfer-waiting time and total transfer-walking time. Another reason might be that properly accounting for transfers requires detailed data on the transfer process. On top of that, certain aspects of a transfer are difficult to quantify. The research questions to be answered in this paper are: 'Which are the different stages in the transfer process and which attributes can be distinguished for each of them?', 'Can correlations between parameter estimates be explained from the stages in the transfer process they relate to?' and 'Which combination of attributes best describes the transfer process?'.

The following approach has been used. First, a conceptual model of the transfer process is established. This conceptual model allows for the identification of the relevant stages in the transfer process and their transfer costs in terms of time, money and effort. The model is also used to recognize the correlations between the cost components in the different stages. To empirically underpin the significance of the cost components in transferring as well as to quantify the correlations, different PSL models are proposed and applied to Revealed Preference data. The PSL models describe traveller choice behaviour regarding the entire trip, i.e. including transfers. In this sense, the transfer processes are modelled in an integrated fashion.

The main contribution of this paper is that it explains correlations between transfer attributes from the stage(s) in the transfer process they relate to. For example, the number of transfers relates to the complete transfer process, while transfer-walking time only concerns a specific part of the transfer process. Furthermore, the best combination of transfer attributes is established by comparing various Path Size Logit (PSL) models - differing with respect to the combination of transfer attributes that is included in the utility specifications.

The paper is structured as follows. First, we define multi-modal trip making and present a conceptual model of the transfer process. Secondly, transfer attributes are distinguished accounting for one or multiple stage(s) in the transfer process and correlations between classes of transfer attributes are pinpointed. Then, the PSL modelling approach that is used in the analysis, is discussed. A short description is given of the multi-modal train trips data used to determine the significance of the different transfer attributes. Next, different PSL models will be applied to the multi-modal train trip data and modelling results are analysed. The paper concludes with summarizing the main findings.

2 Definition of a multi-modal trip

A *trip* is a sequence of transport modes and transfer nodes connecting a given OD-pair. A trip is *multi-modal* if it involves at least one transfer between - not necessarily different - mechanized modes. A multi-modal trip thus consists of either combinations of multiple public transport modes or combinations of public transport and private modes. For inter-urban trips to major cities, the market share of multi-modal alternatives amounts to more than 20%, where train is the most frequently used main mode. In nearly 60% of the cases, train covers the longest distance of multi-modal trips (*7*). Therefore, the empirical analysis focuses on inter-urban, multi-modal train trips. A trip, in which train is used as the main mode can be broken down into three components, namely a *train trip part* and two *non-train trip parts*. In our analyses, we differentiate between *access* and *egress*, where access is defined as the trip part from the origin to the boarding railway station, while egress is the trip part from the alighting railway station to the destination. Besides differences in access and egress modes, multi-modal trip alternatives differ in other attributes, such as boarding and alighting railway stations, train service types, transfer stations, and more. In adopting a multi-modal trip alternative, an individual faces multiple choices, each related to the above stated trip attributes.

3 Conceptual model of the transfer process

To answer the research questions formulated in the introduction, let us start by studying the different elements of the transfer process in more detail. By definition, the transfer process starts before the vehicle carrying the traveller enters a transfer point and finishes when the traveller is settled in the next vehicle. Each step in the transfer process involves certain *costs* (in terms of time, money and / or effort). The transfer process that can roughly be divided into the following stages:

1. park the vehicle (private modes only): Cyclists and car drivers provide their own transport services. Therefore, travellers first have to find free parking spaces and park their vehicles, before they can alight them. This always involves a certain time and effort, but not necessarily a parking fee. Time, effort and parking costs might differ considerably between vehicle types (bike / car), types of transfer points (railway station / urban public transport stop) and location of transfer points (city centre / suburb). Parking fees might be paid on arrival (parking meter) or on departure (guarded parking facilities).

2. prepare to leave the vehicle: Just before leaving a vehicle, travellers have to prepare. In public transport, preparation can start before the vehicle enters the transfer point. Travellers have to stop current activities (sleeping, reading, working or studying), collect their belongings and get up from their seats. Cyclists and car drivers first have to park their vehicles before they can prepare to leave.

3. alight the vehicle: When travellers are prepared to leave, they are able to alight the vehicles. Alighting a vehicle involves a certain time and effort, both depending on vehicle and traveller characteristics. In all cases, however, alighting - although inevitable to transferring - only takes a fraction of total travel time.

4. walk through the transfer point: Having left the vehicle, travellers might need some time to orient, that includes determine their current locations in relation to stairs, main hall, other platforms and so on), find out when and from which platform the next transport service will depart and establish their way to that platform. These aspects of transferring will play a more important role for occasional travellers, not being familiar with the layout of a transfer point and the timetable of a transport service. Walking from alighting to boarding platforms takes a certain amount of time and requires physical activity of travellers. Travellers' valuation of transfer-walking times might be influenced by type of

walking surroundings (sheltered / non-sheltered), type of transfer (cross-platform / non-cross-platform, combinations of modes) and height differences on walking routes (none / stairs / elevators / escalators).

5. wait for the next vehicle to arrive: Having reached the boarding location (platform or parking facility), travellers might have to wait for the next vehicle. Waiting times depend on transport service type (private mode / public transport). Bike and car have free time-accessibility - implying that bike and car use do not involve any waiting time - while public transport involves a certain transfer-waiting time (depending on timetables of consecutive transport modes in the multi-modal trip chain). Travellers' valuation of waiting times might be influenced by waiting surroundings (sheltered / non-sheltered, safety, and availability of seats, service personnel and shops).

6. retrieve the next vehicle (private modes only): Before cyclists and car drivers can board their vehicles, they have to find them and unlock them, taking both time and effort. Depending on the type of parking facility, a parking fee has to be paid (see also parking the vehicle).

7. board the next vehicle: When the next public transport vehicle has arrived at the platform or travellers have retrieved their bikes or cars, they have to board the vehicles. Boarding a vehicle involves a certain time and effort, both depending on vehicle and traveller characteristics. In all cases, however, boarding - although inevitable to transferring - only takes a fraction of total travel time.

8. settle in the next vehicle: The transfer process ends when travellers have settled in the next vehicle. In public transport, that means finding free seats, sit down and start activities.

4 Identification of transfer attributes

The previous section provided a detailed description of the transfer process . Each step in the transfer process involves certain costs. To properly account these costs in travel choice models, we need to distinguish the relevant stage-specific attributes. For certain stages in the transfer process, attribute identification and estimation is straightforward, especially for transfer-waiting and transfer-walking. For others, this task is more involved. Some attributes relate to a single stage, while others account for multiple stages. Figure 1 shows the relationships between the different stages of the transfer process and the transfer attributes. Differences in travellers' preferences, albeit important, are outside the scope of this paper.

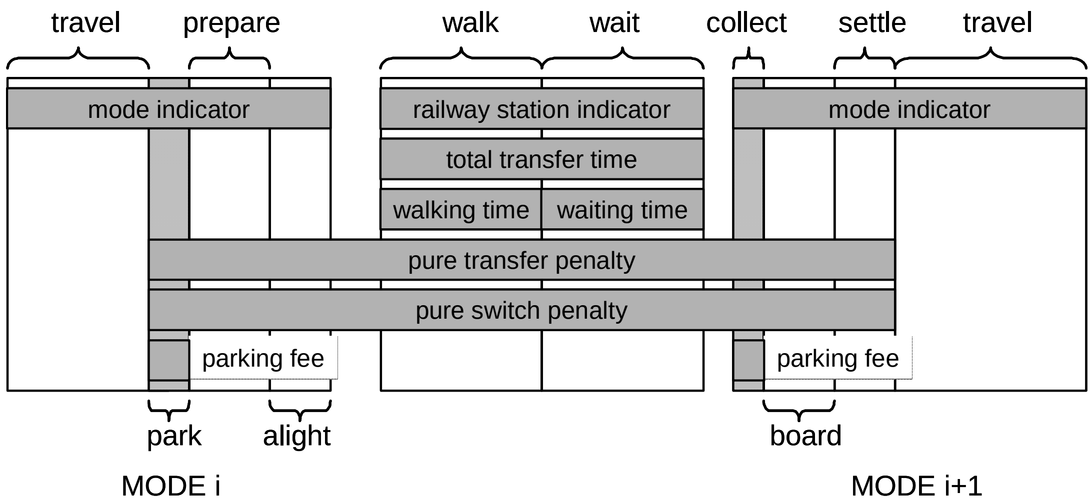

Figure 1 Overview of transfer process stages and the relationships between the transfer process stages and the transfer attributes.

4.1 Transfer-walking

For transfer-walking, transfer-walking times (or distances) are the most important attributes. To account for expected differences in travellers' valuation of different types of walking surroundings, we may 1) distinguish types of transfer-walking times or 2) include *transfer point indicators*. In the latter case, one transfer point indicator should be included for each transfer. However, note that transfer point indicators account for unobserved characteristics of a transfer point in general, such as safety, shelter, seating comfort, and availability of shops and service personnel.

4.2 Transfer-waiting

For transfer-waiting, transfer-waiting times are the most important attributes. Differences might be expected in travellers' valuation of different types of waiting surroundings. This can again be accounted for by inclusion of different types of transfer-waiting times or transfer point indicators.

4.3 Preparing and settling

For preparing and settling, time and effort can only be measured if travellers are accompanied by interviewers on their trips. However, such an approach is time and money consuming. Since preparing and settling are mainly dependent on mode type, inconvenience related to these stages might be captured by *mode indicators*. Similar to transfer point indicators, mode indicators should be included for each transport mode. Note however that mode indicators do not only account for mode-related transfer aspects, but for unobserved mode-related characteristics in general, like image, seating comfort and safety.

4.4 Boarding and alighting

Similar to preparing and settling, the time and effort involved in boarding and alighting can only be measured if travellers are accompanied by interviewers on their trips. Since boarding and alighting are mainly dependent on type of mode and transfer point (*8*), discomfort due to boarding and alighting might be captured by mode indicators and transfer point indicators.

4.5 Parking and retrieving

Like boarding, alighting, preparing and settling, actual parking and retrieving times are generally not observed. Also the effort involved in parking is difficult to measure. Average parking and retrieving times might be established taking into account type and location of transfer point and type of private mode. Since parking is inherent to private mode use and dependent on type of transfer point, these aspects may be captured by mode and transfer point indicators. Parking might involve parking fees, which might depend on parking durations and has to be paid on arrival or on departure.

4.6 Complete transfer process

The transfer process as a whole can also be accounted for by a single *pure transfer penalty*. In this way we can account for transfer stages, like ‘preparing’, ‘settling’, ‘boarding’ and ‘alighting’, that are difficult to quantify but inherent to transferring. This transfer penalty is expected to depend on the combination of transport services that travellers are transferring between. If no other trip attributes are included in the utility function, it is reasonable to assume that this transfer penalty is at least equal to the time needed for transferring. The number of transfers can be included to account for multiple transfers. The number of switches is closely related to the number of transfers. Earlier research by Hoogendoorn-Lanser (*3*) showed that travellers consider walking to railway stations to be a real part of a multi-modal train trip and as an alternative to for example cycling or urban public transport (UPT). Therefore, in computing the number of switches also the switch from walking to train (and vice versa) is counted. Walking to UPT stops, however, appears to be inevitable to UPT use, and therefore not counted.

5 Hypothesis on correlations due to structure of transfer process

Now we have identified attributes for each stage of the transfer process, we will focus on correlations between parameter estimates that might be induced by correlations between values of attributes. Correlations in this paper refer to correlations between parameter estimates and not between alternatives in the choice set (e.g. due to common trip parts). Two main types of correlations are considered in this paper. The first one is correlation between parameter estimates for which attributes values are correlated (type I). For example, transfer-waiting time is correlated with the number of transfers, meaning that if the number of transfers increases, on average also transfer-waiting time increases. The second one is correlation between parameter estimates for which attributes values are not related (type II). In this case, attributes account for similar unobserved characteristics. For example, values of tram and bus indicators are not correlated (indicate whether on not tram or bus has been used), but parameter estimates of tram and bus might be correlated because they both account for typical (unobserved) public transport related characteristics, like limited time availability (timetable), lack of privacy, (un-)reliability, fees and so on. This paper focuses on reducing types I and II correlation between transfer attributes by choosing a combination of transfer attributes that refer to different stages of the transfer process.

Table 1 shows relationships between stages of the transfer process and the aforementioned transfer attributes. Certain transfer attributes, like numbers of transfers or numbers of switches, account for the whole transfer process, while other transfer attributes, such as transfer-walking time or parking costs only account for part of the transfer process. We hypothesize that inclusion of transfer attributes that account for the same stages in the transfer process might lead to high correlations between parameter estimates. We also expect that the transfer process can be accounted for in a detailed manner in travel choice models, if the included transfer attributes relate to separate stages in the transfer process. To study this, we will first determine how transfers are accounted for in travel choice models found in literature. Secondly, we will estimate various Path Size Logit models differing with respect to the combination of transfer attributes that is included.

Table 1 Relationship between stages of the transfer process and transfer attributes.

stages → attributes ↓	parking	preparing	alighting	walking	waiting	retrieving	boarding	settling
Mode indicators	✓[1]	✓[1]	✓[1]			✓[2]	✓[2]	✓[2]
transfer point indicators	✓			✓	✓	✓		
number of transfers	✓	✓	✓	✓	✓	✓	✓	✓
number of switches	✓	✓	✓	✓	✓	✓	✓	✓
transfer times				✓	✓			
at transfer-waiting times				✓				
transfer-walking times					✓			
parking costs	✓					✓		

[1] Mode indicator of mode *i*. [2] Mode indicator of mode *i+1*.

6 Path size logit modelling approach

In multi-modal networks, travellers can choose from many different modes, services, boarding nodes, transfer nodes and alighting nodes. Consequently, multi-modal choice sets are often large and alternatives in a choice set are largely overlapping. Overlap should explicitly be accounted for in route choice modelling in order to prevent incorrect predictions (*1*, *2*). Different types of common route elements might be sources of correlation between routes (i.e. due to unobserved characteristics that are not included in the utility function). In (*5*) and (*6*), Hoogendoorn-Lanser et al. have shown that accounting for commonality of nodes, modes and services improves model performance considerably.

We adopt the *Path Size Logit* (*PSL*) *modelling approach* based on *legs* - where a leg is defined as a trip part between two nodes in which a single mode or service type is used - developed in (*4*) to account for overlap in a route choice context. The *path-size factor*, being an approximation of the amount of overlap of an alternative with all other alternatives in the choice set, is added to the utility function to increase an alternative's disutility in case of overlap. The *Exponential Path Size factor*, used in this paper, includes a size assignment parameter (*SAP*) to take the length of the overlapping routes into account. The value of this parameter is established during model estimation.

Another reason to consider PSL models is that more complex random utility models, like generalized nested logit models - distinguishing access and egress feeder mode nests - could not be estimated. For PSL models however of covariance matrix could be determined, thereby providing good insights into correlation patterns.

7 Data used to estimate effects of transfer attributes

This section briefly describes the Revealed Preference data that has been collected to estimate the choice models that are presented in the remainder of the paper. Which data, were to be collected during the survey, was determined directly from the identified state-specific attributes discussed in the previous sections of this paper.

To study the importance of transfers in travel choice modelling data has been used from a survey conducted among train travellers in an urbanized corridor in The Netherlands (*3*). The survey focused on the multi-modal trip itself (which modes were used, what were the transfer nodes, what were the boarding and alighting nodes) and on train-based trip alternatives known by the traveller. The survey data was extended with detailed data on all trip components, such as in-vehicle times per mode and costs, as well as with similar data for all other reasonable non-reported alternatives for the same trip. These reasonable alternatives were generated using a diachronic-graph representation of the multi-modal transport system (*3*). The data contains detailed information on transfers - gathered by means of dedicated measurements in railway stations, like transfer times, transfer-waiting times, transfer-walking times and distances, height differences and types of transfers, that enables us to study the transfer process in detail. To study the transfer process a sample containing 708 homebound trips is used. 70% and 30% of the trips are outbound-trips and return-trips, respectively.

To properly determine the impact of transfers on the travel choice process, complete door-to-door trips should be considered because alternative feeder modes or train services almost always result in different transfer characteristics (and vice versa). This implies that transfer as well as non-transfer attributes need to be included in the utility specifications. The relevant non-transfer attributes that are included in the utility specifications are mode-specific in-vehicle times, UPT costs, walking times to UPT stops and headway of the first UPT service. In the previous sections, we have identified the most important attributes for the different stages of the transfer process. The interviews provided the necessary information to derive all of the listed transfer attributes, i.e. transfer times, transfer-walking times, transfer-waiting times, number of transfers, number of switches, parking costs, mode indicators and transfer point indicators. For a detailed description of the attributes included in the utility specifications, we refer to (*3*).

8 Estimation result using path size Logit models

To determine which combination of trip attributes best accounts for the inconvenience of a transfer, various Path Size Logit (PSL) models have been estimated. All models include the same set of non-transfer level-of-service (LOS) variables, like mode-specific vehicle times, UPT fees, walking times to UPT stops and headway of the first UPT service. The models differ with respect to the combination of transfer attributes, such as number of switches, number of transfers, transfer times, transfer-waiting times and transfer-walking times, parking costs, mode indicators (feeder mode and train) and railway station indicators. Although their characteristics might influence travellers' valuation of the transfer process, socio-economic were not included in the utility specifications.

Model PSL-1, not including any transfer attributes, is the base model in our analysis. To determine the impact of each class of transfer attributes separately, in step 1 (see block I in Table 2) only one type of transfer attributes is included in the utility function. Since the largest improvement in log-likelihood value is obtained if the number of transfers is included in the utility function, each of the models in step 2 (block II) incorporates the number of transfers and another type of transfer attributes. However, simultaneous inclusion of number of transfers and other types of transfer attributes in the utility function results in high correlations between parameter estimates. These correlations can be explained from the fact that the number of transfers account for the whole transfer, while at the same time certain stages of the transfer process are also accounted for by more detailed transfer-elated attributes. Therefore, in step 3 (block III) the number of transfers is excluded from the utility specification, and combinations of transfer attributes are selected that are mutually exclusive (do not relate to the same stages in the transfer process).

8.1 Inclusion of the single type of transfer attribute (block I)

In the first analysis step, only a single type of transfer attribute is included in the utility specification, being either mode indicators, railway station indicators, number of transfers, number of switches, transfer times, transfer-waiting time or transfer-walking time (resulting in models PSL-2 to PSL-9). Inclusion of a single class of transfer attributes might imply the inclusion of one attribute (number of transfers) or the inclusion of multiple attributes (mode specific indicator for each feeder mode). Column 9 in Table 2 shows the number of transfer attributes that is included in each model. A specific type of attribute may account for a single stage in the transfer process (transfer-walking time) or for multiple stages (number of transfers). The largest improvement in log likelihood value (13.6% compared to PSL-1) is obtained in by inclusion of just one single attribute, namely the number of transfers (PSL-5). This large improvement is probably due to the fact number of transfers accounts for all stages in the transfer process, while other attribute types only account for part of the transfer process. If only a limited amount of data can be collected on transfers, the number of transfers is the best way to account for transfers. It should be noted that inclusion of number of transfers results in additional correlation between number of transfers and mode specific in-vehicle times. Parameter estimates of PSL-5 are shown in Table 4.

Table 3 shows correlations between parameter estimates (both types I and II). The first row lists the main attributes classes for which parameter estimates turn out to be correlated in one or more PSL models, while the second row lists the type of correlation. In block I, only PS-2, including mode indicators, result in type I correlations (mode indicators and mode-specific in-vehicle times). It should be noted that, although separate transfer times have been included for train-train, UPT-UPT and train-UPT transfers in PSL-7 - all of them accounting for the same type of unobserved characteristics - they turn out not correlated with one another. The same holds for PSL-8 and PSL-9 including respectively transfer-walking times and transfer-waiting times. Inclusion of mode indicators results in correlation between UPT feeder mode indicators at the same trip end (e.g. access bus and access tram indicators) and not between corresponding UPT feeder mode indicators at access and egress (e.g. access bus and egress bus indicators). This correlation is likely to be caused by aspects specifically related to UPT use at access or at egress. At access travellers are uncertain about the remainder of the trip, while at egress travellers have almost reached their destinations. Preliminary results show that this type of correlation can only to a certain extent be removed using a Generalized Nested Logit structure.

8.2 Inclusion of combinations of transfer attributes (block II)

Since the largest improvement in log-likelihood value is obtained by including the number of transfers, PSL-5 is taking as a starting point in the second analysis. We study if, and if so, how much improvement in model performance can be obtained if transfers are accounted for in a more detailed way. To this end, PSL-10 to PSL-18 (Block II) all include the number of transfers as well as one or more other types of transfer attributes.

Table 2 Transfer attributes included in the different Path Size Logit models.

	Path Size Logit models	MSI	RSSI1	RSSI2	NOT	NOS	TT	TWtT	TWkT	NTA
	PSL-1									0
block I	PSL-2	✓								10
	PSL-3		✓							2
	PSL-4			✓						2
	PSL-5				✓					**1**
	PSL-6					✓				1
	PSL-7						✓			3
	PSL-8							✓		3
	PSL-9								✓	3
block II	PSL-10	✓			✓					11
	PSL-11		✓		✓					3
	PSL-12			✓	✓					3
	PSL-13	✓	✓		✓					**13**
	PSL-14	✓		✓	✓					13
	PSL-15				✓		✓			4
	PSL-16				✓			✓		4
	PSL-17				✓				✓	4
	PSL-18				✓			✓	✓	7
block III	PSL-19	✓	✓			✓				13
	PSL-20	✓	✓				✓			15
	PSL-21	✓	✓					✓		15
	PSL-22	✓	✓						✓	15
	PSL-23	✓	✓					✓	✓	**18**
	PSL-24	✓	✓					**t-t**	**t-t / u-u**	**15**

Abbreviation	*Description*	*Abbreviation*	*Description*
MSI	mode-specific indicator	TWkT	transfer-walking time
RSSI	railway station specific indicator	NTA	number of transfer attributes
NOT	number of transfers	IVT	in-vehicle time
NOS	number of switches	LL	log-likelihood
TT	transfer time	t-t	train-train transfer
TWtT	transfer-waiting time	u-u	UPT-UPT transfer
TRTA	time related transfer attributes		

The largest improvement in log-likelihood value (21.3%) results if mode indicators, railway station indicators and number of transfers are included in the utility specification (PSL-13). Although PSL-13 contains 12 additional parameters compared to PSL-5, this improvement is significant (nested hypothesis test). However, simultaneously inclusion of mode indicators, railway station indicators and number of transfers introduces an additional and substantial (0.7) correlation (type II) compared to PSL-2, namely correlation between number of transfers and mode indicators. This additional correlation might be explained from the fact that number of transfers account for the complete transfer process, while mode indicators account for transfer aspects that are influenced by mode characteristics, like preparation to leave&alighting or boarding&settling down. Lack of correlation between number of transfers and railway station indicators might indicate that railway station indicators do not account for walking and waiting surroundings in railway stations. Note further that 3 out of 8 feeder mode indicators are not significantly different from zero (see Table 4). Comparing models PSL-11 and PSL-12, differing with respect to the definition of railway station indicators, we can further conclude that accounting for (and differentiating between) access and egress railway stations is more important than accounting for all railway stations.

8.3 Best combination of time-related transfer attributes (block III)

Since number of transfers accounts for all stages of the transfer process, we exclude number of transfers from the utility specification in block III, and look for a combination of attributes where each attribute class relates to a different stage in the transfer process. Inclusion of number of switches (PSL-20) results in a smaller improvement in log-likelihood value (20.5%) than that of number of transfers (PSL-13). However, all mode indicators are significantly different from zero and no additional correlation is introduced. Model PSL-23, containing mode indicators and railway station indicators and separately including transfer-waiting time and transfer-walking time for train-train, train-UPT$^+$ and UPT-UPT transfers, results in better modelling performance than PSL-20. However, in PSL-23 3 out of 6 time-related transfer parameters are not significant at a 90%-confidence level. Therefore, parameters corresponding to train-UPT$^+$ transfer-walking time, train-UPT$^+$ transfer-waiting time and UPT-UPT transfer-waiting time are set to zero in PSL-24. The log-likelihood of PSL-24 (-1529.1) differs only slightly from the log-likelihood of PSL-23 (-1527.4), while the valuation of the remaining transfer-waiting time and transfer-walking time hardly differ between them. Inclusion of time-related transfer attributes, like transfer-walking time and transfer-waiting time, instead of number of transfers results in a slightly smaller log-likelihood value, but also in substantially smaller correlations (0.3 instead of 0.7). Therefore, PSL-24 gives the best representation of the transfer process.

8.4 Interpretation of parameter values in the overall best PSL model

Table 4 shows the parameter values for the overall best PSL model (PSL-24). In this section we focus on travellers’ valuation of transfer attributes. PSL-24 contains feeder mode indicators (separately for access and egress), railway station indicators (for boarding and alighting railway station), parking costs, train-train transfer-walking time, train-train transfer-waiting time and UPT-UPT transfer-waiting time. Note that all parameters values are highly significant and scaled with respect to train in-vehicle time.

Table 3 Overview of Path Size Logit modelling results, i.e. log-likelihood values and sizes of main correlation types.

		LL	increase LL (%)	MSI - IVT[1]	MSI -MSI[2]	NOT / NOS - TRTA	NOT - MSI	TRTA – TRTA	IVT - IVT	IVT - NOT
	Main correlation type → PSL-models ↓			I	II	I	II	I & II	II	I
	PSL-1	-1931.8	-						0.5	
	PSL-2	-1722.6	10.8	-0.6	0.6				0.6	
	PSL-3	-1890.4	2.1						0.5	
	PSL-4	-1902.2	1.5						0.6	0.6
block I	**PSL-5**	**-1668.4**	**13.6**						**0.6**	
	PSL-6	-1794.5	7.1						0.5	
	PSL-7	-1784.0	7.7						0.5	
	PSL-8	-1797.6	6.9						0.6	
	PSL-9	-1834.4	5.0						0.6	
	PSL-10	-1550.7	19.7	-0.6	0.6		-0.7			
	PSL-11	-1621.3	16.1						0.6	0.6
	PSL-12	-1628.3	15.7						0.6	0.6
	PSL-13	**-1520.5**	**21.3**	**-0.7**	**0.7**		**-0.7**			
block II	PSL-14	-1534.3	20.6	-0.7	0.7		-0.7			
	PSL-15	-1643.1	14.9			-0.4			0.6	0.6
	PSL-16	-1642.5	15.0						0.6	0.6
	PSL-17	-1651.0	14.5			-0.4			0.7	0.5
	PSL-18	-1628.3	15.7			-0.3		-0.4	0.6	0.5
	PSL-19	-1532.5	20.7	-0.6	-0.6					
	PSL-20	-1536.7	20.5	-0.6	-0.6					
block III	PSL-21	-1543.6	20.1	-0.6	-0.6					
	PSL-22	-1598.7	17.2	-0.6	-0.6					
	PSL-23	**-1527.4**	**20.9**	**-0.6**	**0.6**			**-0.4**		
	PSL-24	**-1529.1**	**20.8**	**-0.6**	**0.6**			**-0.3**		

[1] Mode indicators at the same trip end
[2] Mode indicators and corresponding in-vehicle times

Train-train and UPT-UPT transfer-walking times appear not to be significantly different from one another. One minute of either type of transfer-walking time is equal to ± 11.4 minutes of train in-vehicle time. This implies that travellers strongly prefer cross-platform transfers (having minimal transfer-walking time) to non-cross-platform transfers. Train-train transfer-walking time is valued four times as onerous as train-train transfer-waiting time, meaning that travellers prefer waiting to walking in railway stations. UPT-UPT transfer-waiting time, however, does not influence the travel choice process (estimate is not to be significantly different from zero). The insignificance of UPT-UPT transfer-waiting time compared to train-train transfer-waiting time might be explained from the fact that:

- most UPT services in the study area are high-frequency services, while train services are mainly low-frequency services. Therefore, waiting times at UPT stops are relatively small, and travellers will be less inclined to actually plan transfers between high-frequent transport services;
- travellers' valuation of transfer-waiting time is nonlinear. Small transfer times are indeed preferred by travellers, but should not be too small to accommodate a smooth transfer.

Note that train-UPT$^+$ transfer-walking times and transfer-waiting times appear not to be significantly different from zero. This might be explained from:

- limited variation in train-UPT$^+$ walking times, resulting from similar layout of Dutch railway stations and their surrounding areas;
- structure of multi-modal trips, in which switching at railway stations is inherent to multi-modal trip making;
- inclusion of aggregate train-UPT$^+$ transfer-walking time and transfer-waiting time.

Parking costs refer to both car and bike. The contribution of bicycle parking costs to total trip utility will be small, since bicycle parking costs are ± 50 eurocents per day. The contribution of car parking costs to total trip utility will be considerably larger.

Travellers' preferences for private modes are similar for access and egress. However, travellers' valuation of UPT feeder modes is more onerous at egress than at access. Considering only mode indicators, the following ordering of feeder modes can be made: walk, metro, bike, tram, car and bus. From the railway station indicators it can be included that intercity and express railway stations are valued equally and are preferred to local railway stations. Furthermore, travellers' valuation of local railway stations is more onerous at egress than at access.

Table 4 Parameter estimates for the best overall model (PSL-24) and best models in block I (PSL-5), block II (PSL-13) and block III (PSL-24).

		PSL-5	**PSL-13**	**PSL-23**	**PSL-24**
		best I	**best II**	**best III**	**best overall**
access	*mode indicators*				
	walk	-	*0*	*0*	*0*
	bike[4]	-	6.37	-13.72	-13.68
	car	-	-5.27*	-26.28	-26.21
	bus	-	-7.73*	-28.60	-28.52
	tram	-	-0.62	-20.78	-20.80
	metro	-	13.71	-4.68*	-4.77*
	railway station indicators				
	intercity & express railway station[2,3]	-	*0*	*0*	*0*
	local railway station	-	-8.00	-7.79	-7.64
egress	*mode indicators*				
	walk	-	*0*	*0*	*0*
	bike[4]	-	6.37	-13.72	-13.68
	bus	-	-20.68	-44.34	-43.88
	tram	-	-10.37	-32.53	-32.35
	metro	-	-4.15*	-24.24	-24.24
	railway station indicators				
	intercity & express railway station[2,3]	-	*0*	*0*	*0*
	local railway station	-	-10.90	-10.81	-10.54
train	*mode indicators*				
	intercity[2]	-	*0*	*0*	*0*
	express	-	-5.31	-6.12	-6.03
	local	-	-6.31	-8.11	-8.04
UPT	access walking time to UPT stop	-1.84	-3.05	-3.40	-3.35
	egress walking time from UPT stop	-1.26	-1.46	-1.67	-1.61
	headway first stop	-0.23	-0.27	-0.40	-0.37
	UPT costs (€)	-2.94	-3.00	-3.45	-3.50
whole trip	*in-vehicle times (min)*				
	slow modes (access walk & bike)[5]	-1.50	-2.43	-2.64	-2.63
	slow modes (egress walk & bike)[5]	-0.86	-2.07	-2.22	-2.21
	car	-3.02	-3.84	-4.30	-4.29
	bus	-0.72	-0.61	-0.65	-0.65
	tram	-0.61	-1.01	-1.06	-1.06
	metro	0.21*	-0.56*	-1.08	-1.16
	train[1]	-1.00	-1.00	-1.00	-1.00
transfer	*time-related transfer attributes (min)*				
	waiting time train-train (passive)	-	-	-2.74	-2.76
	waiting time UPT-UPT (passive)	-	-	-0.73*	-
	waiting time train-UPT (passive)[7]	-	-	0.18*	-
	walking time train-train	-	-	-11.28	-11.45
	walking time UPT-UPT	-	-	-10.11	-11.37
	walking time train-UPT	-	-	-0.29*	-
	other transfer attributes				
	parking costs (€)	-4.23	-12.55	-14.71	-14.72
	total number of transfers	-11.23	-19.30	-	-
overlap	path-size (number of legs, *SAP*=18)[6]	14.90	31.50	28.65	27.37
statistics	final log-likelihood	-1668.44	-1520.49	-1527.41	-1529.09
	likelihood ratio test	1385.27	1681.17	1667.34	1663.98
	free parameters	14	26	31	28

[1] Parameter estimates are scaled with respect to train in-vehicle times. [2] The IC train constant, the walk indicators and the IC railway station indicators were constrained to be zero (base parameters). [3] The express train station indicator appeared not to be significantly different from zero and was therefore constrained to be equal to zero. [4] Bike indicators at access and egress appear not to be significantly different from one another and were constrained to be equal. [5] Bike and walk times appeared not to be significantly different from each other for access as well as egress, and were constrained to be equal. [6] Parameter estimates are not significantly different if the original path size formulation is used instead of exponential one. [7] Aggregate transfer-waiting times and transfer-walking times were computed over train-UPT and UPT-train transfers. [*] Parameter estimate not significantly different from zero at a 90%-confidence level.

9 Conclusions

This paper showed how transfers can best be accounted for in travel choice models. In literature, the number of transfer attributes included in utility specifications is small. Reasons for this might be the limited availability of transfer data or correlations between transfer attributes. To get insight into causes of correlations among transfer attributes, first a detailed analysis of the transfer process has been made. Costs (in terms of time, money and / or effort) were identified for all relevant stages of the transfer process.

Using detailed empirical data and applying a Path Size Logit approach, we have shown that transfers can be accounted for in detail in travel choice models. The overall best model includes 13 transfer attributes, including transfer-waiting times, transfer-walking times, mode indicators, railway station indicators and parking costs (all being highly significant). From the analyses it can further be concluded that inclusion of the number of transfers in travel choice models is likely to result in correlations (type I) between the number of transfers and other transfer attributes, like transfer-waiting times, transfer-walking times or mode indicators, because the number of transfers refers to the complete transfer process, while most other transfer attributes referred to specific stages of the transfer process. These correlations are high (absolute value > 0.7), causing problems in estimating advanced random utility models (e.g. Generalized Nested Logit model) and in identifying the value (and thus role) of certain transfer attributes in the travel choice process. Inclusion of a combination of transfer attributes that are associated with different stages of the transfer process results in considerably smaller correlations.

References

1. Ben-Akiva M., M. Bierlaire (1999), Discrete choice methods and their applications to short-term travel decisions, In: Hall R.W. (ed.) Handbook of Transportation Science, Kluwer Academic Publishers, Boston.

2. Cascetta E., A. Nuzzolo, F. Russo & A. Vitetta (1996). A modified logit route choice model overcoming path overlapping problems: Specification and some calibration results for interurban networks, In: Lesort J.B. (ed.) *Transportation and Traffic Theory*, Proceedings of the 13th International Symposium on Transportation and Traffic Theory, Pergamon.
3. Hoogendoorn-Lanser S. (2005). *Modelling travel behaviour for multi-modal transport networks*, TRAIL Thesis Series T2005/4, TRAIL, The Netherlands.
4. Hoogendoorn-Lanser, S. & R. Van Nes (2004). Multi-modal choice set composition: Analysis of reported and generated choice sets, *Transportation Research Record* 1898, pp 79-86.
5. Hoogendoorn-Lanser, S., R. Van Nes & P.H.L. Bovy (2005a). Path-size modelling in multi-modal route choice analysis. In: *CD-ROM of 80th Annual Meeting of Transportation research Board*. Accepted for publication in Transportation Research Records.
6. Hoogendoorn-Lanser, S., R. van Nes, P.H.L. Bovy (2005b), Path size and overlap in multi-modal transport networks: a new interpretation. Paper submitted to 16th International Symposium on Transportation and Traffic Theory. University of Maryland, College Park, Maryland, USA, July 19 - 21, 2005
7. Van Nes, R. (2002). Design of multi-modal transport networks: A hierarchical approach. Trail Thesis Series T2002 / 5, DUP, Delft, The Netherlands.
8. Weidmann, U. (1992). Fahrgastwechsel bei autobussen, *Verkehr und Technik* 4, 138-144 (in German).