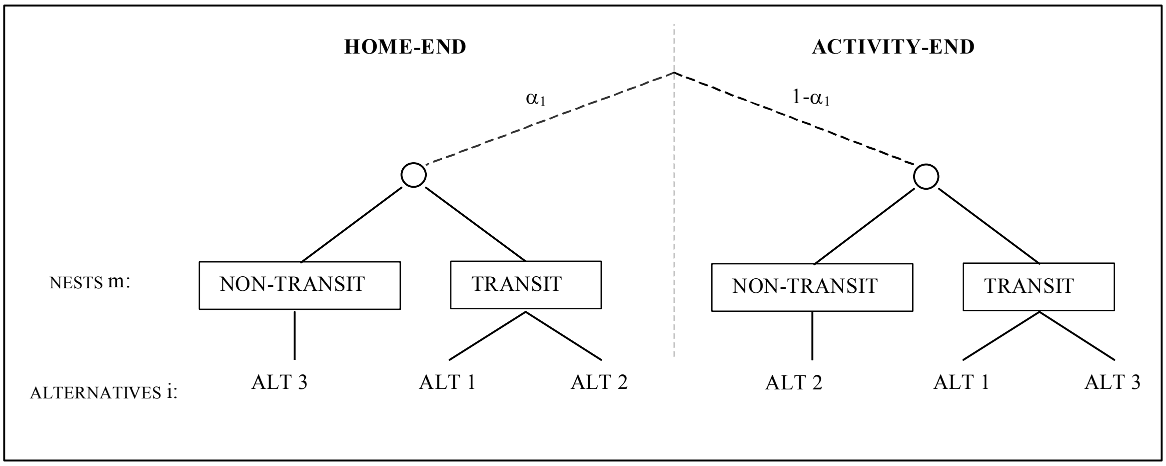


Modeling Route Choice Behavior in Multimodal Transport Networks

Piet H.L. Bovy, Rogier Uges, and Sascha Hoogendoorn-Lanser, Delft University of Technology

Conference paper
Session XXX

Moving through nets:
The physical and social dimensions of travel
10th International Conference on Travel Behaviour Research
Lucerne, 10-15. August 2003

Modeling Route Choice Behavior in Multimodal Transport Networks

Piet H.L. Bovy, Rogier Uges, Sascha Hoogendoorn-Lanser
Transportation and Planning Section,

Delft University of Technology, Delft, The Netherlands

Phone: 031-15 278 1681
Fax: 031-15 278 3179
eMail: bovy@ct.tudelft.nl

Abstract

The paper presents new findings on the influence of multi-modal trip attributes on the quality and competitiveness of regional multi-modal train alternatives. The analysis covers the entire trip from origin to destination, including access and egress legs to and from the train network. The focus is on preferences for different feeder modes, station types and train service types as well as on the relative influence of time elements and transfer penalties. Data from dedicated surveys are used including individual objective choice sets of 235 multi-modal homebound trips in which train is the main transport mode. The observed trips have origins and destinations within the Rotterdam-Dordrecht region in The Netherlands with an average total trip time of 50 minutes.

Hierarchical Nested Logit models are estimated to take account of unobserved similarities between alternatives at the home end and the activity end of the trip respectively, resulting in two-level nesting structures which differentiate between intercity (IC) and non-intercity railway station types at the upper level and between transit and private access modes at the lower level. In order to reflect the multidimensional structure of the data a more advanced so-called Multi-Nested GEV model according to the Principles of Differentiation has been estimated which significantly improves the explanatory power and stresses the importance of the home side of the multi-modal trip.

Keywords

Multimodal travel, choice sets, multidimensional choice modelling, train trips, Nested logit, Multi-nested GEV model

Preferred citation

P.H.L Bovy, R. Uges, S. Hoogendoorn-Lanser (2003) Modeling Route Choice Behavior in Multimodal Transport Networks, paper presented at the 10th International Conference on Travel Behaviour Research, Lucerne, August 2003.

1. Introduction

Competitive multi-modal rail alternatives ask for a well-functioning transportation system with seamless transfers between the different legs in the chain. Evaluation of proposals to improve the transportation system requires the use of forecasting and policy analysis tools, such as route choice models.

A recent study by Benjamins et al. (2002) explored the possibilities of modeling multi-modal route choice behavior. Thereby, Benjamins et al. primarily focused on the development of a tool for multi-modal trip assignment. The well-functioning of such trip assignment modeling is highly dependent on the availability of valid model specifications. Considering regional train journeys, the models should specifically reflect the route choice behavior of regional train users. The latter has received relatively little attention in the transportation literature (see e.g. Wardman (2001), Nuzzolo et al (2003), Nielsen (2000)).

The objective of this paper is to report findings from model estimations using original revealed choice data giving insight into regional multi-modal choice behavior of train users. In addition, the study aims to determine the influence of trip attributes on the quality and competitiveness of multi-modal alternatives. Thereby the analysis focuses on the influence of level-of-service attributes and preferences for different access modes.

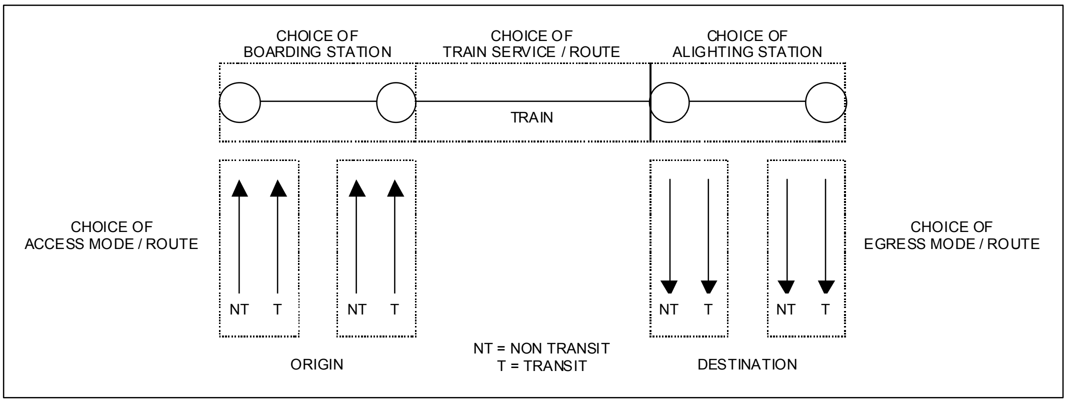
The paper first defines the basic elements of multi-modal trips and identifies the various choice dimensions and important trip attributes considered in the sequel. The expectations about the impacts of various trip attributes are given in section 3, while section 4 briefly summarizes the chosen modeling approach. It discusses the properties and functional form of the Multi-Nested GEV model of travel choice that is particularly suited for analyzing multi-modal trips. The data used in model estimation is introduced in section 5 giving insight into the format of alternatives and choice sets. The results of nested logit and Multi-Nested GEV model estimations are given and discussed in section 6.

2. Multi-modal train trips and hypotheses

A trip is considered multi-modal if a combination of different *vehicular* travel modes is used, consisting of either combinations of multiple public transport modes, or combinations of public transport and private modes (e.g. car, bike). 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 involved. In more than 50% of the cases train covers the longest distance of the multi-modal trip chain.

A trip chain in which train is used as the main mode can be broken down into three components, namely a main train leg and two non-train legs. In our analyses, we make distinctions between the *non-train legs* in two different ways. First, we differentiate between access and egress legs where the access leg is defined as the trip from the origin to the boarding railway station while the egress leg is the trip from the alighting railway station to the destination. Second, the non-train legs can be segmented into home-end legs and activity-end legs. 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 (see Figure 1). Many choices are closely related and not independent. As an example, the attractiveness of the walk access alternative may be dependent on the choice of boarding station.

Figure 1 Choice dimensions in multi-modal train alternatives



Previous studies (e.g. Wardman (2001)) showed that different aspects of travel time are valued differently by travelers. In general, the walk and wait times are perceived as more onerous than in-vehicle times. Besides, the valuation of time is influenced by factors, such as trip distance, travel mode, trip purpose and socio-economic characteristics of the traveler. Accordingly, in our analyses total trip travel time will be broken down into the following elements:

- Access time, i.e. the travel time from the origin to the boarding railway station;
- Waiting time at the first transit stop or railway station;
- Main journey in-vehicle time;

- Transfer time, divided into walk time and wait time;
- Egress time, i.e. the travel time from alighting railway station to the destination.

Furthermore we distinguish:

- Home end travel time, i.e. the travel time at the home end leg of the trip;
- Activity end travel time, i.e. the travel time at the activity end leg of the trip.

In our analysis we focus on the supply side characteristics of the choice problem as opposed to personal characteristics. In other words, the study concentrates on the behavior of the average traveler in the sample. Below, behavioral hypotheses are formulated that will guide the analyses.

2.1 Railway station types

Observations show that travelers often prefer an Intercity (IC) station further away instead of a local station closer to the origin or destination. This preference for IC-stations may be a result of observed level-of-service variables such as travel times and service frequencies. However, unobserved attributes may have impact as well on travel disutility such as availability of facilities, personal customer service or safety feelings. This leads us to the hypothesis of a positive constant utility contribution of the trip attribute *IC-station.*

2.2 Differences between transit and private mode access time valuations

Station access/egress time can be segmented into private and transit mode access times where private mode access time includes both walk time, bicycle time and car in-vehicle time. Transit access modes include bus, tram and metro. It is expected that train travelers are more sensitive to private mode access time than to transit access in-vehicle time, based on the idea that transit travelers don't have to pay attention to traffic and are able to perform other activities like reading or working. The expected differences in travel time valuation lead to the hypothesis that transit access/egress times to/from train stations are perceived less onerous than private mode access time. This equally means that mode specific times will give better explanations than generic travel times.

2.3 Differences between travel time valuation at different parts of the trip

There is reason to believe that travelers perceive travel time differently at either end of the trip. E.g.. Van der Waard (1988) found that access time is valued more negatively than egress time presumably because of the relatively lower level of uncertainty at the egress side of the trip, where the traveler is able to make a much more precise and reliable prediction of the remaining time to his destination. To test whether this also holds for regional trips the following two hypotheses are formulated: Access time to train stations is perceived as more onerous than egress time, and home end travel time is perceived as more onerous than activity end travel time.

2.4 Transfers to high and low frequency services

The magnitude of the disutility of a transfer depends on various transfer characteristics, such as comfort, walk and wait times, mode types, and service frequencies. We focus on the latter. It seems reasonable to assume that travellers value transfers to high frequency services less negative since with higher frequencies, a failed connection has less severe consequences in terms of planned arrival times at the destination. The hypothesis to be tested then is that travellers attach lower disutility to transfers to high frequency services relative to transfers to low frequency services.

2.5 Train service types

It is assumed that train users have a preference for higher ranked train services, such as intercity or international train services not only because of shorter travel times but because of other unobserved factors as well such as image, vehicle type, or an aversion against intermediate train stops. The hypothesis then is that the usage of higher ranked train services has a positive impact on utility which is not explained by shorter travel times or other observed train service type attributes.

3. Adopted modelling methodology

Given the type of choice behavior in multi-modal trip making (multiple types of choices), the specific models used in this study are the Hierarchical Nested Logit (HNL) model (e.g. Cascetta (2001)) and the multi-nested GEV model (Bresnahan et al., (1997)). We postpone other candidate model types (CNL, PCL, Logit Kernel, Probit, etc) to a later stage in the research when larger samples are available.

3.1 The Hierarchical Nested Logit model (HNL)

Multi-modal trip alternatives consist of multiple components, such as the access leg, the train journey and the egress leg of which each component may be a source of correlation between alternatives. Nested logit models offer a means to account for these similarities by combining similar alternatives into nests. Multiple sources of correlation may lead to complex correlation patterns between the alternatives, as alternatives may exhibit correlation with different alternatives at different parts of the trip. An alternative A may be similar to alternative B at the access side, while being similar to alternative C at the egress side. In a HNL model, however, an alternative can only be allocated to one nest, reason why the model is not capable of exploring correlations along multiple dimensions symmetrically. The HNL model can only accommodate multiple dimensions by assigning each dimension to a specific tree level. The order of the nesting levels in the tree is a result of *a priori* assumptions about the relative importance or similarity of each dimension. This property is an important drawback of the HNL model, as it may result in poor representation of substitution patterns in our case. Because of this, the multi-nested GEV model will be explored for its ability to analyze multi-modal travel behavior more adequately by allowing cross-nesting.

3.2 The Multi-Nested GEV Model (MN-GEV)

In contrast to the HNL model, the MN-GEV model does allow differences in correlation along multiple choice dimensions. The model is capable of accommodating the distinct dimensions symmetrically, thus overcoming the strict hierarchical structure of the multilevel HNL models. The model is a weighted sum of multiple HNL models in which each HNL model represents a distinct choice dimension. To some extent the model can be considered as a simple form of a cross-nested logit model (Cascetta, (2001)). For a model with two dimensions the mixing distribution takes the following form:

$$P_i = \alpha_1 P_{i,d1} + \alpha_2 P_{i,d2} \qquad (0.1)$$

where:

P_i = probability of the alternative i being chosen.

$P_{i,dn}$ = probabilities of the alternative i being chosen along dimension n (takes the same form as the probability functions of HNL models).

α_d = weight for dimension d, which can be fixed, estimated or defined as a function of the logsum parameters. ($\sum \alpha_d = 1$ and $0 \leq \alpha_d \leq 1$).

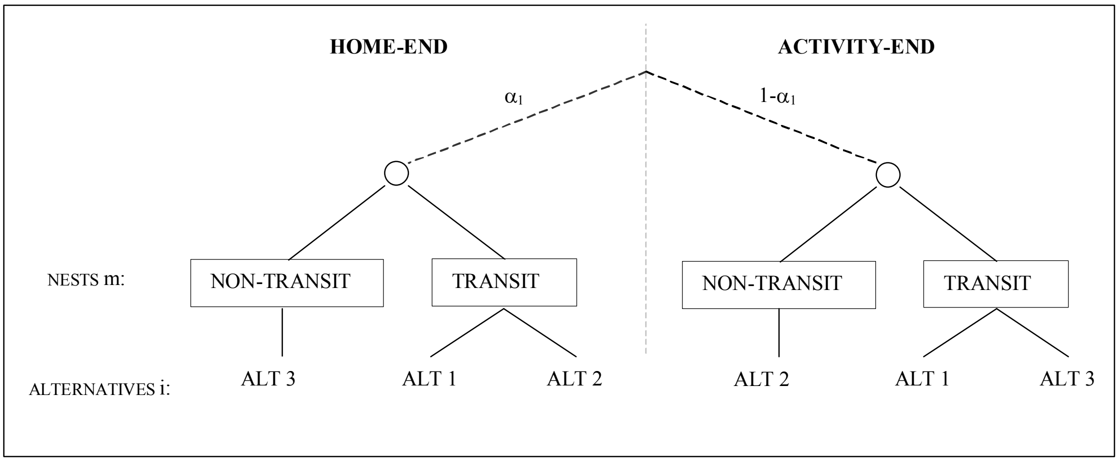
An example of a two-dimensional MN-GEV-structure is depicted in Figure 2. The model shown has a branch related to mode use at the home-end of the trip and a branch related to mode use at the activity end. Note that the clusters can be different at either branch. This example shows that alternatives 1 and 2 are combined at the home end, whereas alternatives 1 and 3 are nested at the activity end (both alternatives include transit).

The weight factor α reflects the dominance of one of the two branches. If α is equal to zero or one, the MN-GEV model devolves to a single HNL model. Bresnahan et al (1997) defined the weights as a function of the structural parameters, they can however also be fixed a priori or estimated separately.

Because of its flexibility, the MN-GEV model may give the best representation of choice behavior, relative to HNL models. The MN-GEV model not only takes account of unobserved similarities between alternatives but in addition it is more flexible than the HNL model since it allows correlation along different choice dimensions.

The model development process is done in a stepwise manner. Multinomial logit estimations are used to explore significance of attributes. On this basis, HNL-models are established to explore nesting structures that subsequently can be used for the branches of the MN-GEV-models.

Figure 2 Example of Multi-Nested GEV model nesting structure



4. Trip data used for analysis

The choice models are estimated using empirical data drawn from in-train and telephone surveys. This data includes observations of multi-modal trips in which the train is the main transportation mode. Information is available on both performed trips and corresponding individual choice sets. The survey includes a total of 1700 observations. For more detailed information about the survey, see Hoogendoorn-Lanser (2004).

Since we have a choice based sample (train users selected in the train) the choice models only describe the preferences and travel behavior of train travelers of whom we assume to have a relatively positive attitude toward public transportation modes, which may influence their assessment of transit access relative to private access modes. We have chosen to focus on trips within the corridor Rotterdam-Dordrecht in The Netherlands. The advantage of this region is the availability of sufficient multi-modal alternatives for most trips.

Figure 3 Railway stations in the Rotterdam – Dordrecht study area

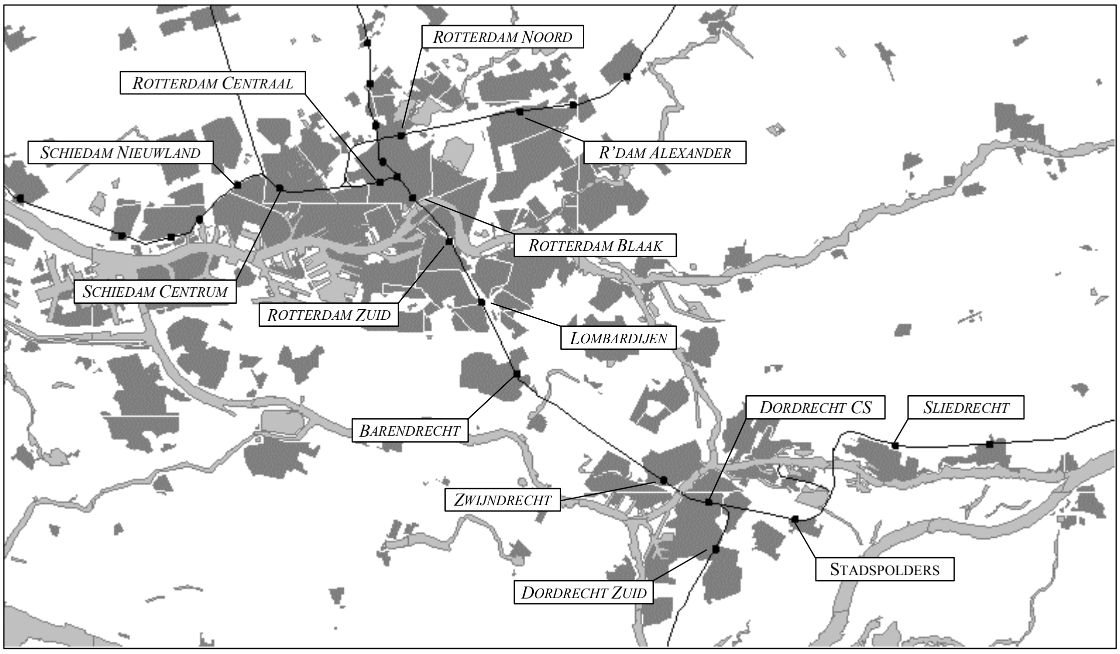


Figure 3 shows the locations and accessibility of the 14 railway stations in this region. In the Rotterdam metropolitan area, bus, tram and metro are available for the access and egress legs. Stations outside the center of Rotterdam all have P&R. On the other hand, the stations in Rotterdam city center (Rotterdam Centraal and Rotterdam Blaak) are poorly accessible by car and have no or few parking facilities.

4.1 Specification of multi-modal trip alternatives in the analysis

The multi-modal trips consist of three components, a main train part and two non-train parts, for each of which multiple alternatives are available (see figure 1).

Private mode access and egress alternatives are walk, bike and car. The latter represents both the drive-alone and shared ride alternatives. Only those private mode alternatives are included in the choice sets which are considered as reasonable for a specific trip. A mode is considered a reasonable alternative if the access distance lies between the 10th and 90th percentile values of mode specific access distances for train trips between 10km and 30 km (as reported by the Dutch National Travel Survey). Inclusion of private mode access alternatives depends on vehicle ownership and the part of the trip. Car and bike alternatives at the activity sides are excluded from the choice sets unless the survey data shows the contrary.

Transit access and egress alternatives are bus, tram and metro, mostly giving rise to two legs: walking to/from the transit stop and in-vehicle transit. Transfers between two access transit lines are possible although limited in number in the sample as well as in the network.

The train alternatives are generated using dedicated programming software (see Hoogendoorn-Lanser *et al.* (2004). As shown in Figure 1, we distinguish train in-vehicle legs (T1 / T2 / T3) and train to train transfers (TT). Train alternatives consist of up to three train in-vehicle legs.

The variables and attributes to be included in the utility functions mainly focus on the influence of alternative-specific attributes, as opposed to the influence of socio-economic attributes. The following constants and level-of–service (LOS) variables are considered:

- Access/egress mode-specific dummies;
- Train service specific dummies;
- Station type specific dummies;
- Mode-specific access travel times;
- Walk times at transfers.

- Wait times at transfers and at first stop;
- Transfer frequency;
- Parking costs.

Three types of transfers may be distinguished, namely within access or egress legs, between main leg and access/egress legs, and within the main leg. Separate variables for different transfer types are defined. First, the variables are segmented into distinct variables for transfers to high service frequencies and transfers to low service frequencies. Second, distinct transfer variables are defined for different mode types involved in the transfer (e.g. “train to train” transfers).

4.2 Choice set statistics

The dataset contains data of 235 individuals with a total of 3435 trip alternatives (on average 14 trip alternatives per respondent). Each alternative is a unique combination of boarding, alighting and transfer train stations, train services, access and egress modes which may be partly overlapping. The maximum number of alternatives found available for an individual in the sample equals 62, the minimum is one. The availability of a particular mode or modal combination for each of the three trip legs may be none, exactly one, or two or more times. To illustrate, in some cases, walking is not a feasible access mode (because of distance), in another case, multiple different ways of walking may be possible (e.g. to as many different railway stations). Alternatives with only scheduling differences are considered to be equal. These alternatives are included in the estimation dataset only once (perhaps later to be adjusted by a weight factor).

The home end side of the trips shows the following sample modal split:

- Walk 27% - bike 29% - car 10% - transit 34%,

while the activity end side shows the following modal split:

- Walk 52 % - bike 3% - car 3% - transit 42%.

At the home-ends walk and bike are each available in at least 70% of the cases, while bus even in 81% of the cases. Tram and metro are much less frequently available at the home-end side since the locations of the respondents’ home addresses mainly (80%) are outside the Rotterdam Metropolitan area. The small sample sizes for these subclasses may result in some insignificant estimation values (e.g. modal constants).

At the activity-ends, walking and transit are the predominant means of transportation, since car and bike are usually only available at the home-end of the trip.

Table 1 Availability and usage of train service alternatives

	AVAILABLE				CHOSEN		
	1	2	3	4	5	6	7
	Number of trip alternatives	Number of train alternatives*	Number of Cases	fraction of sample (% of 235)	Frequency	% of available	Market Share
No transfers							
Intercity only	1017	140	124	52.8%	87	66.9%	37.0%
Express only	587	127	116	49.4%	44	35.2%	18.7%
Local only	1200	232	165	70.2%	87	48.9%	37.0%
Subtotal	*2804*	*499*			*218*		92.8%
One transfer							
Intercity-Intercity	16	4	4	1.7%	1	25.0%	0.4%
Intercity – Express	58	12	12	5.1%	0	0.0%	0.0%
Intercity – Local	357	75	59	25.1%	13	20.3%	5.5%
Express-Express	20	6	6	2.6%	2	33.3%	0.9%
Express – Local	120	29	28	11.9%	1	3.1%	0.4%
Local-Local	18	4	4	1.7%	0	0.0%	0.0%
Subtotal	*589*	*130*			*17*		7.2%
Two transfers							
Subtotal	*42*	*10*			*0*		0.0 %
Total	3435	*639*			235		100.0%

* *a train alternative represents a unique combination of train services and railway stations*

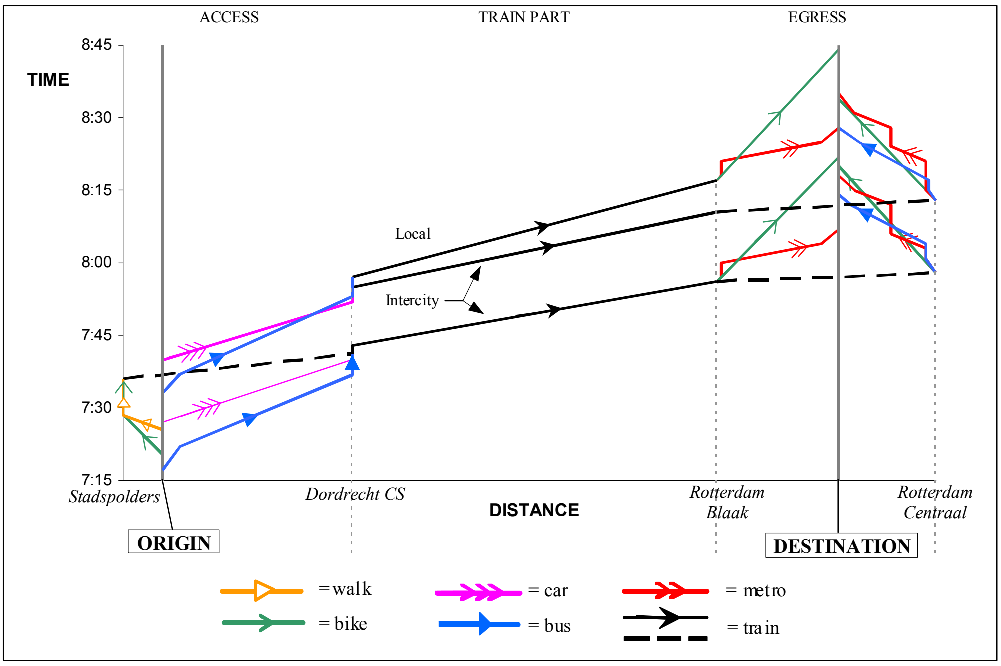
Legend:
Column 1 : Number of dataset trip records in which the indicated train service combination is included.
Column 2 : Total number of non-overlapping train alternatives in dataset.
Column 3 : Number of respondents with service combination available.
Column 4 : Fraction of sample with service combination available (based on column 3).
Column 5 : Number of times service combination is chosen.
Column 6 : Chosen, reported as fraction of the cases in which the service combination is available.
Column 7 : Market Shares is equal to the fraction of total chosen (235).

4.3 Train alternatives

Table 1 shows the availability and usage of the train service combinations. Because of the identical characteristics of intercity and international services, the combination of both is reported as *intercity service.* Market shares of Intercity and local service trains are equal although local services are more often available to individuals (70% relative to 53%). The majority of the available and chosen alternatives include direct train trips with no train-train-transfers. In only 17 of the 235 cases, an alternative with a transfer is chosen.

Figure 4 is a time-distance diagram showing the travel alternatives available to a specific respondent. At both ends of the trip there are two optional railway stations, namely Dordrecht Stadspolders and Dordrecht CS at the access end and Rotterdam CS and Rotterdam Blaak at the egress end.

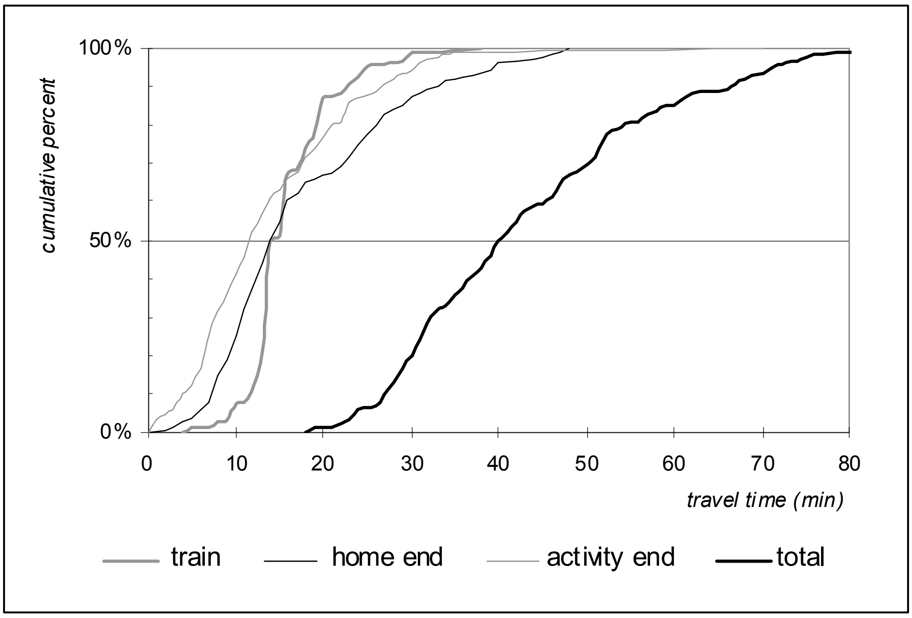
Figure 4 Time-distance diagram of 24 trip alternatives, available to a specific respondent



4.4 Statistics on travel times.

The average total trip time of the chosen alternatives is 48.5 minutes consisting of 18 minutes of travel time at the home ends, 14 minutes at the activity ends, and 16.5 minutes of train in-vehicle time. Figure 5 shows the travel time distributions for the train leg, the home-end leg, the activity-end leg and the total trip. The travel time distributions of the home and activity trip ends show a large spreading, compared to the train travel time distribution which is a consequence of a larger variety in travel speeds and distances at these parts of the trip. Total travel times of chosen trips vary from about 20 minutes to 80 minutes.

Figure 5 Travel time distributions of total trip and trip components



Transit access/egress modes have clearly higher in-vehicle times at the home ends than at the activity ends of the trips. This is consistent with observations that homes are located further away from the railway stations. In addition, the transit modes show much higher total access times than the private modes. This might also be explained by the distance dependent mode choice.

5. Hierarchical Logit model estimations

The model development process is done in a stepwise manner. Multinomial logit estimations are used to explore significance of attributes. On this basis, Hierarchical Nested Logit (HNL) models are established to explore nesting structures that subsequently will be used in the estimation of the MN-GEV-models. In each stage the attribute and nesting parameters are re-estimated.

5.1 Model variables and constants

The variables to be entered in the HNL utility function have been selected on the basis of MNL estimations. The MNL is known to be robust enough to justify its use as a first step in our analysis. Because of the small dataset, only the essential variables are selected for testing.

Most of these MNL outcomes are conform prior expectations. For deviating outcomes, plausible explanations can be given in terms of behavior typical for the sample at hand or in terms of insufficient data. A summary of the most notable findings is presented below (for final parameter estimates see appendix):

Train service type appeared to have no measurable added utility besides the included service attributes (train in-vehicle time). (also found by Nuzzolo et al (2003)). Maybe trips are too short to have an advantage from higher level service, or positive image aspects may be compensated by negative aspects such as more overcrowded or lower punctuality. Thus, no train service constants will be included.

Access travel time is segmented into distinct variables for transit modes and private modes based on expectations that train users are less reluctant to or prefer public transportation use. Moreover, the students in the sample, who have a student public transport card, may have an additional preference for transit because of the lower costs (in return they will accept higher travel times). Significantly different parameter estimates indeed were found for private and transit modes supporting the hypothesis that travelers value travel time differently in different modes. As a consequence we will use mode-specific travel times instead of generic times.

Transit *access in-vehicle time (IVT)* appeared not a significant factor. The choice for transit is apparently driven by other trip attributes, such as low costs (not included in the model). It seems plausible that transit in-vehicle time is less onerous than private modal travel time. However we would expect the transit IVT parameter to be at least negative. Maybe this is the result of omitting access cost variables in the analysis. To remedy this we imposed a restriction on the model by forcing the "*private mode IVT / transit IVT"* ratio to be smaller than a pre-determined value. In order to find more plausible and credible models we imposed the model forces the transit IVT parameter to be at least half travel time parameter for private modes. Consequently we can reject the hypothesis that travelers perceive transit access as equally onerous as private modal access.

The expectation that travelers perceive travel time differently at the access and egress parts of the trip did not appear the case. The results do not show significant differences in travel time valuation between both ends of the trip. Apparently it is more satisfactory (or sufficient) to capture the differences in access and egress mode specific constants. Equally, there appears to be no difference between valuations of home end travel time and activity end travel time.

Segmentation into high frequency and low frequency *transfers* gave better estimation results compared to segmentation into “train-train” transfers and non-“train-train” transfers in terms of significance of parameters and plausible relative weight values. This is most likely due to the lower co-linearity between *wait times at transfers* and *transfer penalty* parameters. As a result high-frequency – low-frequency segmentation is the preferred method for transfer specification. The penalty for transfers to low-frequency services is nearly double the penalty for transfers to high-frequency services (equivalent to 7 minutes of train in-vehicle time).

Contrary to expectation, there appears to be no significant preference for *intercity stations* explained by attributes other than travel time and frequency. Constants included for capturing this effect appear to be non-significant (stations at the home side). The low significance might indicate that IC stations have drawbacks as well (e.g. car accessibility, safety) such that the total sum of positive and negative aspects is relatively close to zero. At the activity end we find some indications of IC-station utility although the evidence is not convincing to draw definite conclusions. Station constants therefore are not included in nested models.

The inclusion of a *parking cost* variable resulted in a marginal but insignificant improvement of log likelihood value. The estimated parking costs parameter would imply a value of time (VOT) of more than 5 times the known values. The low significance and unrealistic VOT-value might be a result of the assumptions about parking (perceived costs, usage of facilities). Other explanations are the low level of variation in parking costs and a low number of chosen car access alternatives. Although we still believe parking costs to be an important variable, we decided not to use this factor in the HNL estimations.

5.2 Definition of nests and nested model structures

Alternatives that share common unobserved trip attributes are subject to correlated error terms in their utility functions. Many attributes may give rise to such correlations. This study focuses on three characteristics:

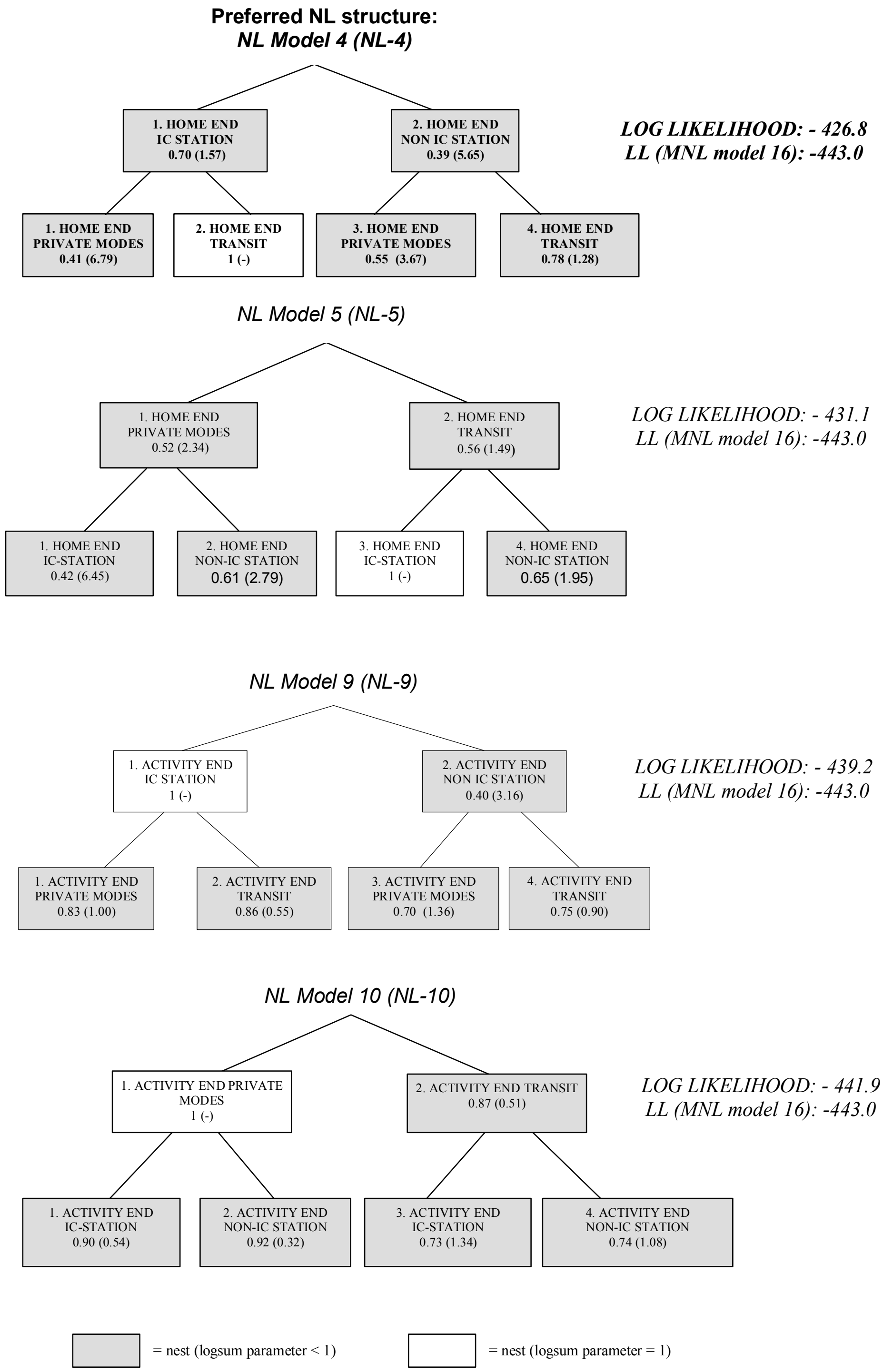
- Access and egress mode (or home end and activity end mode)
- Boarding and alighting railway station
- Train service type.

The relative small sample size does not allow to estimate complex structures with distinct logsum parameters for each available railway station or access mode type. Consequently we have chosen to differentiate between only two groups of access modes and railway stations. These groups are transit / private modes for access, and Intercity (IC) station[1] / non-intercity station (non-IC) for the railway stations. The alternatives that share transit modes are assumed to be correlated as a result of common characteristics such as comfort, image and privacy. The private modes may considered to be alike because of their flexibility. The similarities between alternatives that share specific station types are a result of common station characteristics such as the availability of shops, personal customer service, park and ride facilities, bicycle facilities, accessibility, location and safety.

We will present results of 8 of the tested model structures (table 2). Model structures which parameterize correlation at the home and activity ends show improved goodness-of-fit statistics (relative to MNL). On the other hand, the model which explores correlation at the train part of the trip devolved into the MNL model.

The tested model structures are illustrated in figure 6 (only bi-level cases are shown). NL models 1 through 5 parameterize mutual substitution at the home ends of the trip alternatives, models 6 through 11 at the activity ends.

Figure 6 Sample of best NL nesting structures and logsum parameters.



5.3 Estimation results

As shown in Table 2, two of the estimated *one level* nesting models have test statistics which are larger than the critical test values, implying a significant improvement relative to the best MNL estimate. These models are NL-1 (with nests for transit and private modes at the home ends of the trips) and NL-7 (with nests for IC-stations and non-IC stations at the activity ends of the trips). Multiple level nesting structures only lead to further model improvement when we consider substitution *at the home end of the trip*. A NL Model with *IC/non-IC station* nests at the higher level and *transit/private* modal nests at the lower level of the tree (NL-4) has the best goodness of fit. The log-likelihood value of this model is –426.8, (relative to -443.0 for the MNL structure). At a 95% confidence level, three out of six logsum parameter values are significantly smaller than one.

Table 2 Likelihood ratio tests for selected Nested Logit models

	Home–end nests				Activity-end nests			
	one-level		*two-level*		*One-level*		*two-level*	
	NL-1	NL-2	NL-4	NL-5	NL-6	NL-7	NL-9	NL-10
Log likelihood (LL_{NL})	- 436.6	- 441.6	-426.8	-431.1	-442.8	-440.6	-439.2	-441.9
Log likelihood MNL16 (LL_{MNL})	-443.0	-443.0	-443.0	-443.0	-443.0	-443.0	-443.0	-443.0
Likelihood Ratio Test Statistic*	12.8	2.8	32.4	23.8	0.4	4.8	7.6	2.2
Number of restrictions (R)	1	1	5	5	2	1	5	5
Critical test value [$= \chi_{(0.95,R)}$]	3.84	3.84	11.07	11.07	5.99	3.84	11.07	11.07

* = [-2 ($LL_{MNL} - LL_{NL}$)]

In NL-4, the logsum parameter of non-IC stations is 0.39 (see figure 6), indicating a high level of similarity between non-IC stations. Apparently, IC station alternatives are poor substitutes for non-Intercity stations. A reasonable explanation for this could be the availability of more competitive parking facilities at non-IC stations. The parking lots are less expensive and there is more parking space available. Correlation could also be a result of safety or service characteristics.

The logsum parameter values for private modes are estimated to be 0.41 and 0.55 respectively. These values indicate that there is a relative high rate of similarity between alternatives with private modal access at the home ends of the trips. On the other hand, the logsum parameters of transit nests are one or not significantly smaller than one. This is contrary to prior expectations that bus, tram and metro have common unobserved attributes. The low significance of the transit logsum parameter at the non-IC station branch might be a result of the low number of chosen alternatives in the nest.

Considering the log likelihood, NL-4 will be referred to as the preferred NL model (see figure 1)

6. Multi-Nested GEV model estimations

A multidimensional GEV model with multi-level NL structures for each dimension would lead to a model with a high number of structural parameters. However, too many degrees of freedom may lead to non-unique solutions and interpretation difficulties. Given the limited sample this leads us to test only MN-GEV models which take account of two choice dimensions. Further limitation of degrees of freedom is achieved by fixing or constraining some of the included parameters.

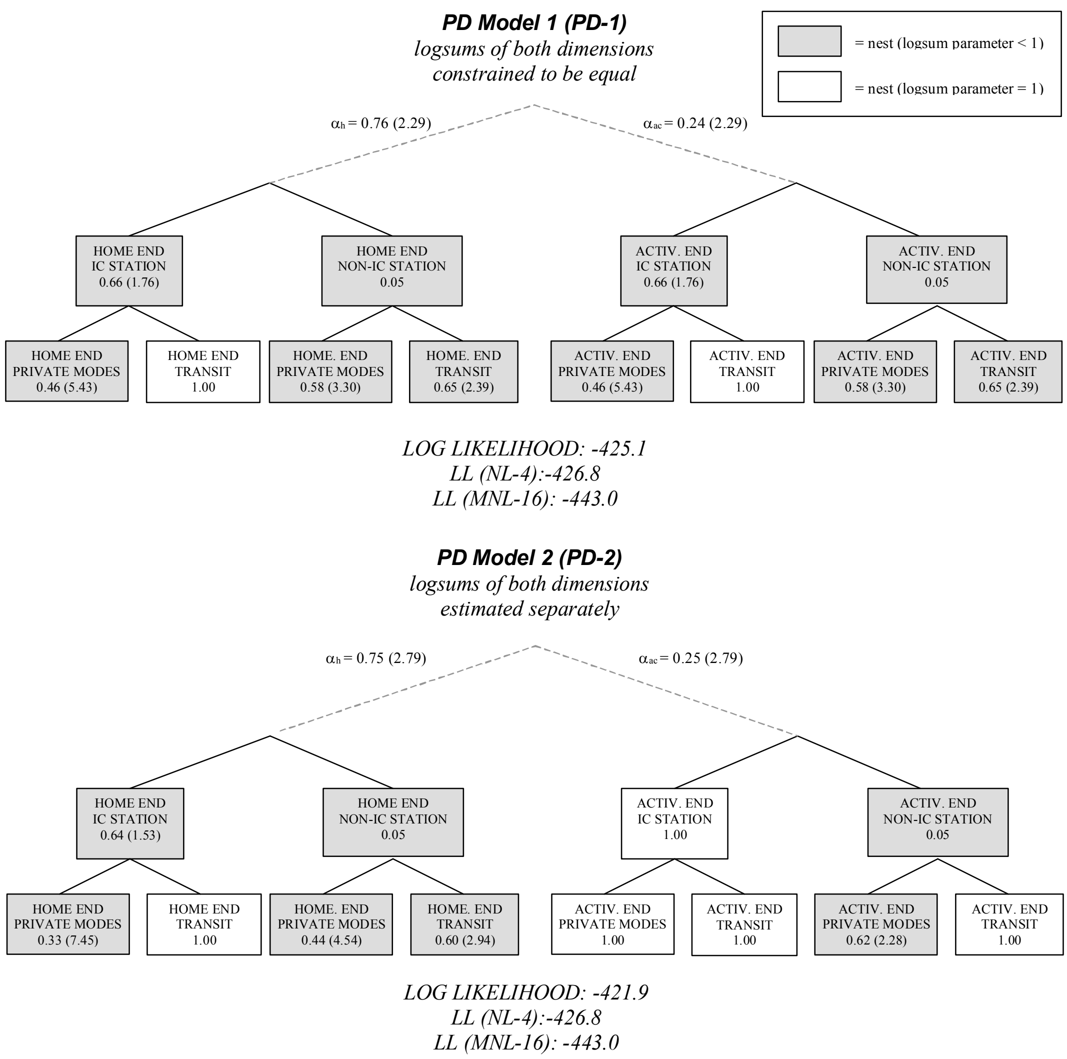
The estimated MN-GEV models include branches for both the home and activity end dimensions as suggested by the NL-analyses. Each branch contains the preferred NL model for the corresponding trip parts, which is NL-4 for the home end and NL-9 for the activity end. The corresponding MN-GEV tree structure is depicted in Fig. 7. As shown both branches include station type nests at the upper level and access mode type nests at the lower level. In our case, the weights of each dimension (α) are estimated using the model.

6.1 Estimation results

A detailed overview of two of the MN-GEV model estimation results is included in Table . The corresponding branching and nesting structures are shown in Fig. 7.

MN-GEV model 1 (MN-1) constrains the logsum parameters of the matching nests to be equal. In MN-GEV model 2 (MN-2) each logsum is estimated separately. Both models show a domination of the home end side. This is consistent with the NL-model findings which show clear correlation patterns at the home ends as well.

Figure 7 MN-GEV model nesting structures and logsum parameters.



In MN-2, almost all logsum parameters at the activity end branch are higher than the logsum parameters of similar nests at the home-end branch. At the activity end, 4 out of 6 logsum parameters turn out to be one. Thus, at this side the model collapses into a nesting structure with only two nests (for non-IC stations and private modes at non-IC stations). The full tree structure of MN-2 has 7 additional degrees of freedom compared to the preferred NL model. The collapsed modal, which drops the nests with logsum parameters equal to one, retains only 3 additional degrees of freedom.

From a statistical perspective only the collapsed MN-2 model shows significant improvement. Table 3 shows that the *collapsed* MN-2 model rejects NL-4 at a 95% confidence level. Both MN-1 and the *full* MN-2 models are not able to reject the preferred NL model. From these results MN-2 appears to be our preferred model.

6.2 Examination of the preferred model structure

Model MN-2 estimates the choice dimension weight to be 0.75, which indicates that train users predominantly look at the transport situation at the home end of the trip. Moreover, the nesting structure of the model allows the interpretation that the travelers first decide which station type to use, and then decide which mode type to use for station access. Finally they choose among the distinct modes available to them.

A striking feature of MN-2 is the logsum parameter of 0.05 for the non-IC station nests. The value of 0.05 implies an almost deterministic choice between transit and private modal access to non-IC stations. In other words the travelers always choose the alternative with the highest deterministic utility value. At first sight the value of 0.05 seems to be somewhat low. However, it can be shown that this is fully consistent with observations in the sample.

Table 3 Likelihood Ratio Tests for PD models

	MN-1	**MN-2 (full)**	**MN-2 (collapsed)**
Log likelihood MN	-425.1	-421.9	-421.9
Log likelihood NL-4	-426.8	-426.8	-426.8
Likelihood Ratio Test Statistic	3.4	9.8	9.8
Number of restrictions (R)	1	7	3
Critical test value [= $\chi_{(0.95, R)}$]	3.84	14.07	7.81

6.3 Examination of MN-GEV model parameter estimates

The Appendix shows the weights of the observed level-of-service variables of MN-2. Contrary to our earlier expectations, the MN-GEV model estimates the weights for private modal access and egress time to be equal at a value of 1.6 of train IVT (see table 4). The value is similar to Wardman's weight value for 10 minutes of walk access time, which is equal to 1.65. The weights for wait and walk times are all estimated to be larger than train IVT. The weight of first wait time is 2.2, which is relatively close to Wardman's weight value for 5 minutes of wait time (2.42).

We find one minute of access or egress walk time to be equivalent to 1.6 minutes of train IVT. Transit access in-vehicle time is perceived less onerous than train IVT. In making mode and route choice decisions, people seem to be more focused on the travel time of the main public transportation mode than on access and egress *transit* modes. The penalties for low and high frequency transfers are equivalent to 5 and 12 minutes of train in-vehicle time respectively. The latter value being fairly consistent with previous research, which found train transfers to be valued as ten minutes extra travel time (Van Goeverden et al. (1990). This extra penalty for transfers to lower frequency services may reflect the more severe consequences of a failed connection, in terms of additional waiting time and late arrivals at the destination.

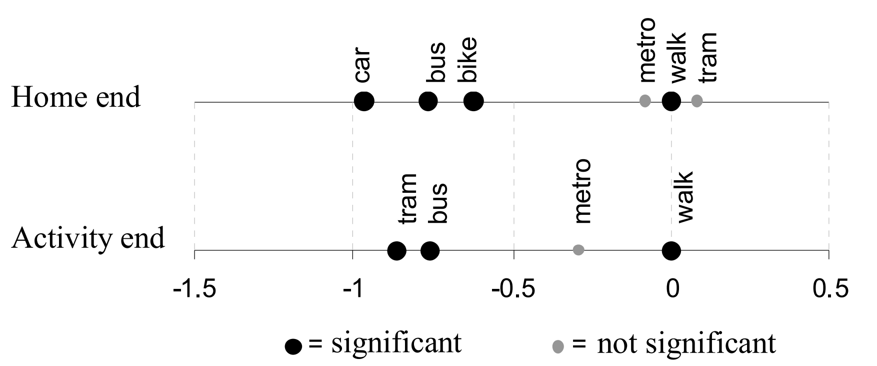
Table 4 Relative weights of mode specific travel time for MN-2 compared

	MN-2	NL-4	Wardman
Access IVT – private modes	1.6	1.6	1.37 - 1.65**
Access IVT – transit	0.8	0.8	
Train IVT	1.0	1.0	2.42
First wait time	2.2	2.2	- 2.69 **
Waiting time at transfers (train-train)	2.2	2.2	
Walking time at transfers	1.9	2.0	
Nr of high frequency transfers	5.1	5.7	
Nr of low frequency transfers	11.4	11.4	

** main mode in-vehicle time

The values of the access/egress mode constants are depicted in Figure 8. Only the bike, car (at home end) and tram (at activity side) modal constants are significantly different from zero, implying a non-zero average bias for these modes *relative to the walk access alternative.* Neglecting the observed variable levels of the modes, walk appears to be the preferred mode at both the home-end and activity end of the trip. This preference might be due to the flexible character of walking in combination with missing travel costs and parking difficulties. The estimated constants allow the interpretation that e.g. using the bike instead of walking at the home end is perceived as 9 minutes extra train in-vehicle time. Combining the home and activity ends one might suggest the following order or preference in the access modes: walk-metro-tram-bike-bus-car.

Figure 8 Access/egress mode constants relative to walking.



6.4 Summary of MN-GEV model findings

Adoption of MN-GEV model specifications leads to improved model performance relative to the NL models.

- The similarity parameter estimates of the preferred MN-GEV model (MN-2) differ from the estimated parameter values of the NL models. In general the PD model estimates are closer to zero, which implies a higher level of similarity between alternatives in the nest.
- The estimated choice dimension weight of 0.75 indicates that train users predominantly look at the transport situation at the home end of the trip.

7. Conclusions and recommendations

A model has been developed for analysis of regional multi-modal choice behavior of train users, focussing on the relative influence of trip attributes on the quality and competitiveness of multi-modal travel alternatives.

The model developed can be characterized as a Principles of Differentiation (PD) Generalized Extreme Value (GEV) model. This model is particularly interesting for multi-modal travel analysis because it takes account of existing correlation of error terms along *multiple* choice dimensions. The home-end and activity end parts of the trip are distinct dimensions which are adequately considered in this model. The home-end situation appears to dominate the decision. Similarities between railway stations and access modes appear to be important sources of correlation. Our proposed model includes nests for Intercity stations and non-Intercity stations at the upper nesting level and nests for transit modal access and private modal access at the lower level . This finding can be interpreted as follows: the traveler first decides on the type of station to access the train network, and then decides on which mode type to use for station access. Finally, he chooses among the distinct modes available to him.

The model gives the following variables to be relevant for multimodal route choice decisions:

- Preference constants for different access modes;
- In-vehicle time variables, segmented into variables for train, transit access and private modal access;
- Walk time variables, segmented into variables for access walk time and walk time at transfers;
- Wait time variables, segmented into variables for first wait time and wait time at transfers;
- Number of transfers variables, segmented into variables for transfers to low frequency services and transfers to high frequency services.

The findings clearly show that the average traveler attaches different weights to the observable trip resistance attributes.

Theoretically and statistically the proposed PD-model leads to a better representation of choice behavior than MNL and NL models. In spite of the small dataset, we have been able to develop a plausible model with realistic parameter weights. The model is capable of measuring the impacts of changes in the most relevant trip attributes. Because the model includes several variables that may be changed through future policy decisions (travel times, frequencies, wait times), the model may be considered a useful tool to predict the effects of future policy actions.

8. References

Benjamins, M., Ch. Linveld & R. Van Nes (2002), *Multimodal travel choice modelling: a supernetwork approach*, In Preprints TRB Annual Meeting (CD-ROM).

Bresnahan, T.F., S Stern, and M.Trajtenberg (1997), *Market segmentation and the sources of rents from innovation: personal computers in the late 1980s*, Rand Journal of Economics, Vol. 28 (1997), Special Issue, pp. S17-S44.

Cascetta,E. (2001) *Transportation systems engineering: theory and methods.* Kluwer Academic Publishers

Hoogendoorn-Lanser, S. (2004). *Multi-modal inter-urban travel behaviour: Description of the inter-urban train survey*, report to be published February 2004, Delft University of Technology

Hoogendoorn-Lanser, S., M. Poelman, and P.H.L. Bovy (2004). *New approach to the generation of objective choice sets in multi-modal networks*, report to be published February 2004, Delft University of Technology.

Nielsen , O.A. (2000) *A stochastic transit assignment modelconsidering differences in passengers utility functions.* Transportation research 34B,pp.377-402

Nuzzolo,A., F. Russo & U. Crisalli (2003) *Transit network modelling: the schedule-based dynamic approach.* Collana Trasporti.

Van der Waard, J., *The relative importance of public transport trip-time attributes in route-choice*, Proceedings PTRC, 1988.

Van Goeverden, C.D., F.H. Behr, T.J.H. Schoemaker, and P.B.L.Wiggenraad, *Onderzoek overstapweerstand binnen het spoorwegsysteem*, Report VK 5302.308, Delft: Delft University of Technology, 1990 (in Dutch).

Wardman, M. *Public Transport Values of Time*. University of Leeds, 2001

Acknowledgement.

The authors are indebted to Frank S. Koppelman for his intellectual support and for bringing the Multi-Nested GEV model to their attention.

Appendix Estimation results Multi-Nested GEV Models

		PD-1		PD-2	
		estimate	t_stat	estimate	t_stat
CONSTANTS	Walk – home (base)	0	-	0	-
	Bike – home	-0.594	*-3.00*	-0.619	*-3.33*
	Car – home	-0.962	*-3.25*	-0.963	*-3.43*
	Bus – home	-0.565	*-1.52*	-0.762	*-2.02*
	Tram – home	0.084	*0.24*	-0.079	*-0.23*
	Metro – home	-0.120	*-0.30*	-0.190	*-0.52*
	Walk – activity (base)	0	-	0	-
	Bus – activity	-0.858	*-2.07*	-0.757	*-2.07*
	Tram – activity	-1.021	*-2.79*	-0.863	*-2.54*
	Metro – activity	-0.387	*-1.01*	-0.289	*-0.8*
TRAVEL		***Ratio <***	***= 1:2***	***ratio <***	***= 1:2***
TIMES	Private modes	-0.134	*-6.71*	-0.130	*-6.36*
	Transit modes	-0.067	*-6.71*	-0.065	*-6.36*
	Train	-0.084	*-3.95*	-0.082	*-4.24*
TRANSFER	**WAITING TIME**				
TIMES	First waiting time	-0.190	*-2.98*	-0.179	*-2.88*
	Non "train-train"				
	Train-train	-0.198	*-2.09*	-0.182	*-2.15*
	WALKING TIME				
	Non "train-train"				
	Train-train				
	All transfer types	-0.180	*-2.05*	-0.154	*-1.86*
NR OF	High frequency (> 6x / hr)	-0.462	*-1.53*	-0.420	*-1.44*
TRANSFERS	Low frequency (<= 6x / hr)	-0.942	*-2.90*	-0.935	*-2.93*

		PD-1				PD-2			
LOGSUM	**Upper level**	*HOME END*		*ACTIVITY END*		*HOME END*		*ACTIVITY END*	
PARAMETERS	NEST 1 (IC – station)	0.66	*1.76*	0.66	*1.76*	0.64	-	1.00	-
	NEST2 (non-IC - station)	0.05	-	0.05	-	0.05	-	0.05	-
	Lower level								
	NEST1 (private mode / IC)	0.46	*5.43*	0.46	*5.43*	0.33	*7.45*	1.00	-
	NEST2 (transit mode / IC)	1.00	-	1.00	-	1.00	-	1.00	-
	NEST3 (pr.mode/ Non-IC)	0.58	*3.30*	0.58	*3.30*	0.44	*4.54*	0.62	*2.28*
	NEST4 (trs.mode/Non-IC)	0.65	*2.39*	0.65	*2.39*	0.60	*2.94*	1.00	-
DIMENSION	WEIGHT		0.76	*2.29*			0.75	*2.79*	
STATS	Log Likelihood		-425.1				-421.9		
	LL (at zero)		-566.9				-566.9		