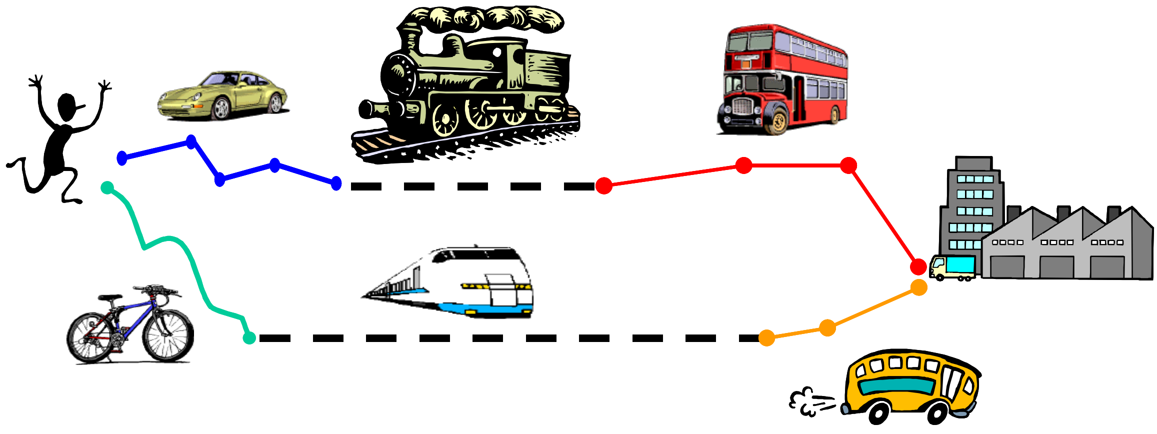

Choice set composition modelling in multi-modal travelling

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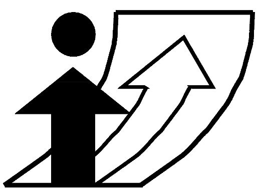

Moving through nets:
The physical and social dimensions of travel

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Choice set composition modelling in multi-modal travelling

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Abstract

Multi-modal trips are a common travel phenomenon and are expected to become more important in the future. However, multiple different types of choices, such as transport service types, travel modes, and transfer locations, are involved in a multi-modal trip and making it difficult to model multi-modal travelling. To analyse multi-modal travel behaviour a large-scale multi-modal travel survey has been carried out in The Netherlands.

The purpose of this paper is to present various types of multi-modal route sets collected from the survey, and two newly-developed methods for generating choice sets for estimation and forecasting purposes. A comparison between the generated and the reported choice sets is made to evaluate how well the estimated sets cover the reported sets.

The analysis of the results of the survey and the comparison of the different choice sets show that multi-modal travelling is indeed a complex topic. In general, many alternatives may be available to a traveller whereas only a limited subset of those alternatives is actually perceived. Even less alternatives are actually considered by trip makers. The analysis revealed some interesting characteristics with respect to travel behaviour. The algorithm presented to generate subjective choice sets provides good coverage for the separate trip components, while generating the complete alternative seems to be more difficult.

Keywords

Multi-modal, Choice sets, Survey, Public transport, Interlocal

Preferred citation

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1. Introduction

Over 20% of the inter-urban trips between the larger Dutch cities are multi-modal trips with usually train as the main transport mode (Van Nes, 2002). An increase in the market share of multi-modal transport may increase public transport occupancy rates and improve liveability of city centres. To improve the opportunities and conditions for inter-urban multi-modal transport, enlarged insight is required into the possibilities for multi-modal trip making with respect to the availability of travel modes (supply side) as well as the preferences of individual travellers (demand side).

The specific theoretical challenge with multi-modal trips is in the multi-dimensional character of these trips encompassing a multitude of choices with respect to travel modes, service types, routes, and access and egress points from the line haul mode, travel modes and routes for the access and egress trip parts to and from the line haul trip part, etc. Typical questions are how these choices are ordered, and which attribute preferences travellers have for the distinct trip and choice parts.

In order to analyse this complex topic we have adopted a route-based approach (e.g. Bovy and Stern, 1990, Fernandez *et al.*, 1994), i.e. we assume that a traveller has a set of possible route alternatives available for a specific trip (i.e. choice set) from which he or she chooses the alternative that is most suited. In this paper an alternative is defined as a sequence of modes and intermediate transfer nodes the traveller uses to make a trip from an origin to a destination. In this context a mode is defined as a transport service type in a vehicular or functional sense.

This paper focuses on the characteristics of multi-modal choice sets from two perspectives. The first is based on a survey of multi-modal trips in which also route alternatives are reported. In order to assess the quality of the reported alternative sets and to be able to estimate route choice models a method has been developed to generate an objective alternative set for each individual. The second perspective is based on a more traditional modelling approach in which realistic alternative sets for groups of travellers are generated. In both cases a comparison is made with the reported alternative sets.

The paper is structured as follows. In section 2 some theoretical concepts with respect to choice sets are discussed. Section 3 gives a short overview of the characteristics of the dataset of multi-modal trips, followed by the topic of the generation an individual choice sets. For the different alternative sets an analysis is made of the modal composition of the alternatives and travel time characteristics. In section 4 the aggregate generation approach is described and analysed. Finally, section 5 presents conclusions on reported and generated choice sets and recommendations for further research.

2. Notion and terminology of choice sets

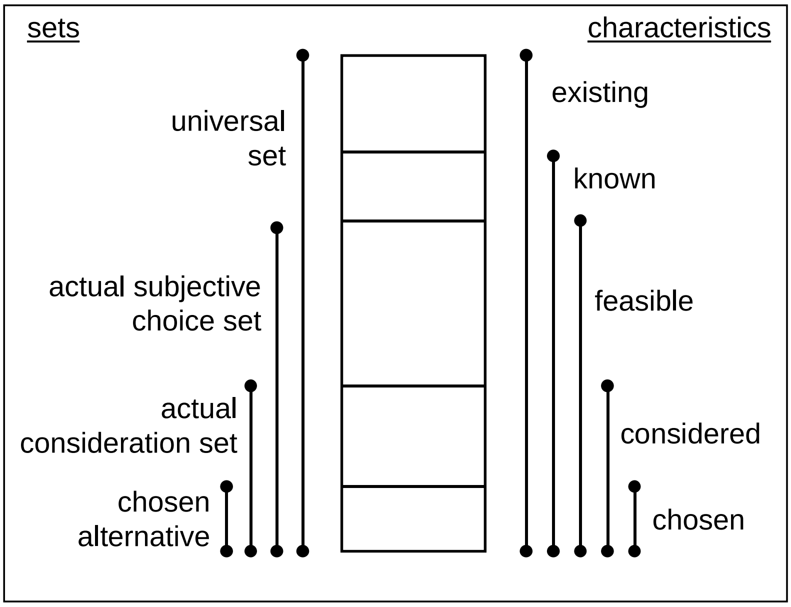
If an individual has decided to travel from an origin to a destination, i.e. the activities and the locations for these activities are decided upon, he or she has to make choices with respect to transport mode(s), route and departure time. We assume that the traveller chooses from a set of alternative routes which are defined as *uni-modal or multi-modal routes with corresponding departure times*. The number of alternatives for a specific Origin-Destination-(OD)-relation may be large, especially in urban road networks and multi-modal networks. At the same time the number of alternatives known to the traveller or considered by the traveller will be substantially smaller. To this end, the concepts of universal sets, master sets, objective choice sets, subjective choice sets and consideration sets are introduced and the relationships between these sets of alternatives are defined. Alternatives can be classified with respect to the fact whether or not they are *feasible to*, *known by* or *considered in the choice process by* the traveller. This classification can be made from a traveller's or a researcher's perspective and for an individual traveller or for a group of travellers.

2.1 Sets of alternatives from the individual's perspective

We take the position of an individual traveller, facing the transportation system, in which he or she is searching for a subjectively best way to satisfy a particular travel need. Ordering sets of alternatives from the perspective of an individual traveller starts with the alternatives that are *known by* that individual traveller, because the world is as large as what he or she knows. A subset of the known alternatives is *feasible* to the traveller. The word *feasible* refers to the availability of private transport modes and public transport services, time feasibility (time pressure at OD-addresses and time budget), monetary feasibility (monetary budget) and physical (dis-)ability. A subset of the feasible alternatives is *considered* during the actual choice process resulting in a chosen trip alternative.

The set of all existing routes is called the universal set. The actual subjective choice set consists of all trip alternatives that are both feasible to the individual and known during the decision process. The actual consideration set is defined as the set of all considered alternatives. Please note that the distinction between known and feasible is defined in terms of choice sets. Figure 1 shows the relationships among the characteristics and the corresponding sets of alternatives from the viewpoint of an individual traveller.

Figure 1 Relationships among existing, known, available, feasible and chosen trip alternatives from the perspective of the individual traveller



For groups of travellers a similar line of reasoning may be applied. However, individuals differ with respect to their knowledge of the transport network, availability of transport modes, travel needs and preferences. Although individuals may have more or less the same OD-relation, their chosen alternatives, consideration sets and subjective choice sets may differ considerably. In the case of groups of travellers unions of sets of alternatives are considered. The union of actual consideration sets and actual subjective choice sets are called actual consideration master sets and actual subjective master sets, respectively. The universal set is applicable to both the individual level and the group level.

2.2 Sets of alternatives from a researcher's perspective

On the other hand we may take the position of an external observer or researcher, who tries to *define*, *specify* and *analyse* the trip alternatives of an individual traveller. To this end, the researcher *observes* current travel behaviour, i.e. observes traveller's choice sets, and *generates choice sets* for *analysing* travel behaviour or for *predicting* future travel behaviour.

2.2.1 Observed choice sets

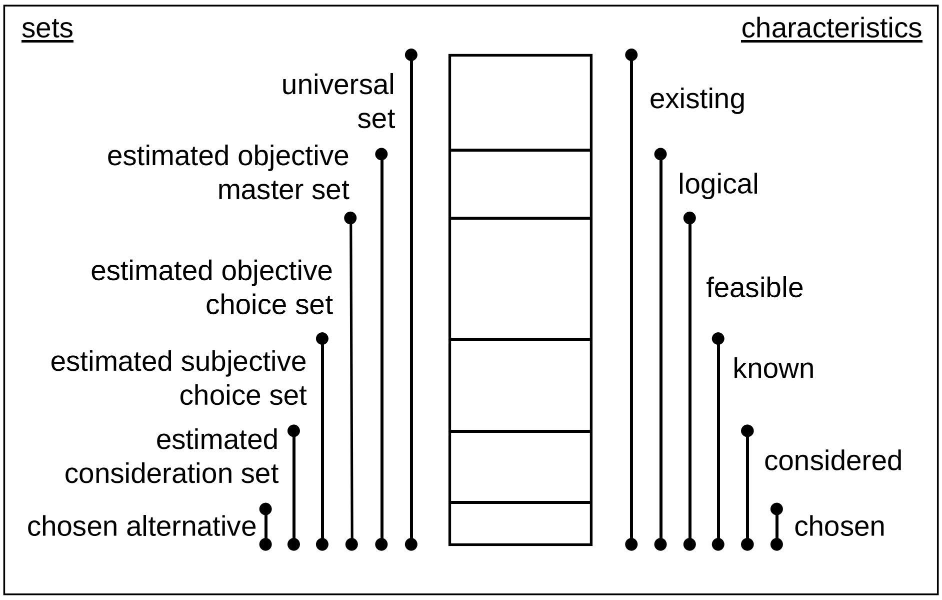
Using appropriate survey techniques the researcher may try to determine the chosen trip alternative and to obtain as much information as possible about the traveller's actual consideration set and actual subjective choice set. The collected sets of alternatives are called the observed consideration set and the observed subjective choice set. These sets of alternatives naturally stem from reports given by the traveller rather than being observed independently. During the interview the traveller may forget to mention an alternative (highly dependent on the used interviewing technique), does not share some information with the researcher (considers it to be not relevant), makes errors in describing the alternatives or has incomplete information about the alternatives. Besides that, the researcher makes errors interpreting the reports. Therefore, the observed consideration set and the observed subjective choice set both are considered as random samples that only partially cover the actual consideration set and the actual subjective choice set.

2.2.2 Generated choice sets

For modelling purposes the researcher generates or estimates choice sets, either to analyse travel behaviour or to make forecast for a future situation. choice set generation methods, such as simulation methods and route enumeration methods can be used to approach as closely as possible individuals' choice sets, resulting in estimated objective choice sets, estimated subjective choice sets and estimated consideration sets. This is a complex task, since 1) individuals and researchers often have different information about the transport network and 2) researchers do not precisely know the traveller's preferences nor the additional considerations taken into account in the choice process. Figure 2 shows the relationships among the characteristics and the corresponding sets of alternatives from the viewpoint of a researcher estimating choice sets.

Ordering sets of alternatives from the perspective of the researcher mostly starts with all *existing alternatives* called the universal set. In estimating the choice sets of an individual traveller or of a group of travellers, the researcher first excludes alternatives based on *objective criteria*, i.e. not require any information about the knowledge and considerations of a specific traveller. To this end, first all *illogical* alternatives are removed. The word *illogical* refers to alternatives including *loops*, and alternatives that are not *temporally suitable*, e.g. having impossible transfers. This step results in the estimated objective master set and contains all logical alternatives irrespective of traveller characteristics. Secondly, based on traveller and trip characteristics (availability of transport modes, time and monetary resources), the researcher specifies which subset of the objective master set is *feasible* for a specific traveller, resulting in the estimated objective choice set.

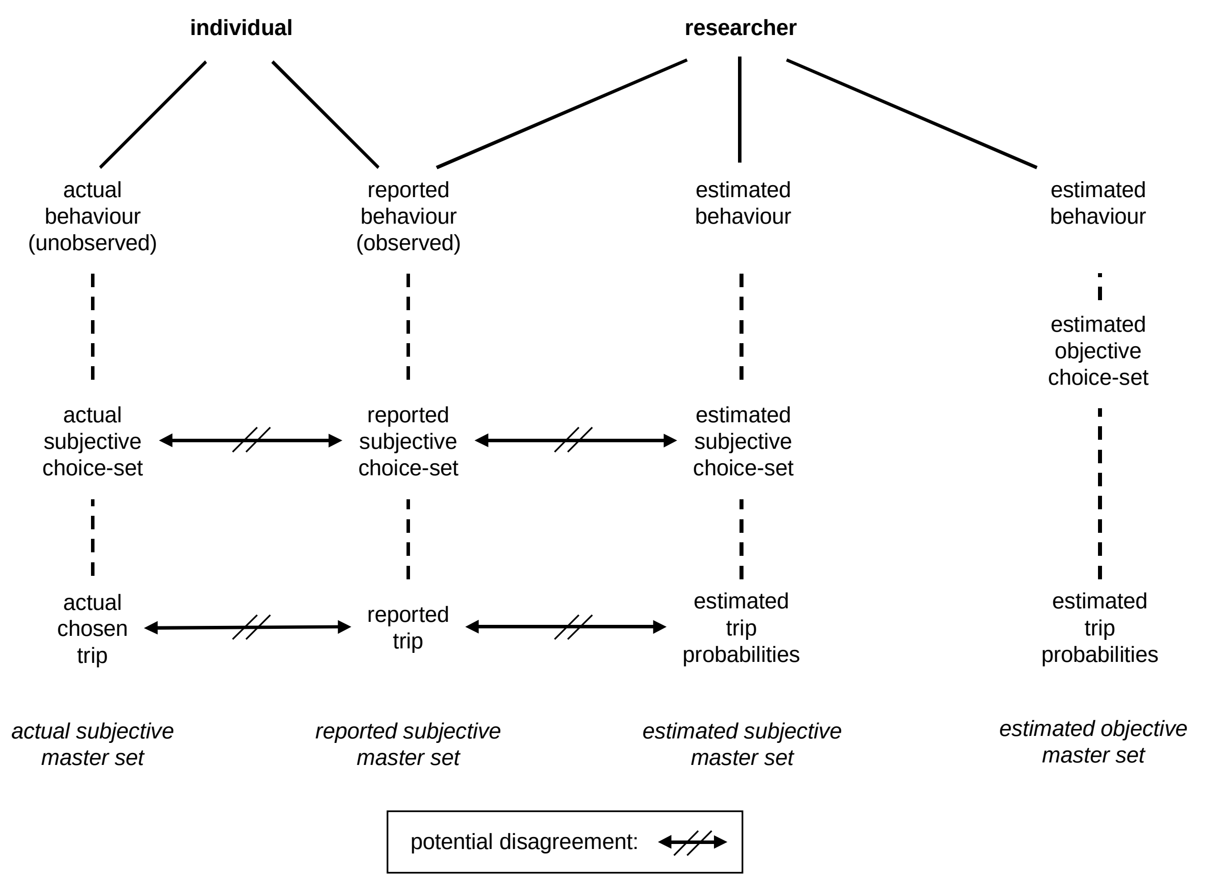
Figure 2 Relationships among existing, logical, available, feasible, known, preferred and chosen trip alternatives from the researcher's perspective



To determine the estimated subjective choice set and the estimated consideration set information about the traveller's knowledge of alternatives should be accounted for. Part of this may be based on objective criteria, for example trip frequency and years of travel experience for a specific OD-relation. Another part is based on general travel experiences and specific events and is therefore difficult to incorporate. Finally, depending on the adopted estimation technique, probabilities can be calculated that an alternative is chosen. In the case of group of travellers a similar terminology is used: estimated objective master set, estimated subjective master set, and estimated consideration master set.

Using this terminology for choice sets it is possible to show which sets might be comparable, although it will be obvious that disagreement may occur between actual behaviour, reported behaviour and estimated behaviour (see Figure 3).

Figure 3 Relationship between actual, observed an estimated behaviour



3. Multi-modal trip survey and estimating objective choice sets

3.1 Survey set-up

In 2001 a large survey was conducted among Dutch train travellers. This survey is part of a data collection program at the Delft University of Technology focusing on mode and route choice for inter-urban trips. Comparable surveys were conducted for the other main transport modes, i.e. car and inter-urban bus, in Dutch inter-urban trip making (see Hoogendoorn-Lanser, 2004a). The main purpose of these surveys is to achieve a better understanding of multi-modal travelling in general and of multi-modal route choice in particular. One of the objectives is to estimate route choice models for multi-modal travelling, enabling better estimates of the effect of improvements of the multi-modal transport system and gaining more insight into the key characteristics of a multi-modal trip (Uges, 2002).

The train survey focused on inter-urban trips (10-30 km and 30-100 km) with both access and egress in urban areas. During an in-depth telephonic interview the (door-to-door) trip was described in detail while subsequently the subjective choice set and the consideration set were established. In the interview, the train trip (main transport mode) and the access to / egress from the boarding and the alighting railway stations were explicitly distinguished. More specifically, the following potential choice alternatives were addressed:

- travel modes for access to the reported boarding railway station (line-bound transport modes, such as bus and tram, base-bound transport modes, like car and bike, and non line-bound transport modes, such as taxi);
- travel modes for egress from the reported alighting railway station (see access for transport modes);
- train sequences from the boarding to alighting railway station (differing in transfer railway stations and train types);
- boarding and alighting railway stations (with different means of access / egress);
- main transport modes (train, car, and regional bus).

In addition, personal attributes, such as gender, age, income, travel allowances, car / bike ownership and origin / destination activities were asked for. This holds equally for trip attributes, like luggage, travel companions, public transport seasonal tickets, car / bike availability, time pressure and arrival and departure times.

After having completed the interviews, the trip itself as well as the reported trip alternatives were reconstructed. The completed data contains *mode-specific* travel time components and costs of inter-urban train trips and access / egress within the combined urban car, bike and urban public transport network. Furthermore, information on transfers, such as frequencies of the subsequent transport services, walking times at transfer points and actual waiting times were collected.

3.2 Consideration sets and subjective choice sets

The questionnaire was specifically designed to reveal both the actual subjective choice set and the actual consideration set. Questioning a traveller about trip alternatives may result in two types of alternatives, the alternatives that are *known* (subjective choice set) and the alternatives that are *considered in the choice process* (consideration set). However, the barrier between consideration set and the subjective choice set is ambiguous. One way to characterise this barrier is by identifying so-called *top-of-mind* alternatives that are alternatives that the respondent could mention directly. Those top-of-mind alternatives are actually considered in the choice process. The alternatives the traveller comes up with *after a moment of thought*, are the alternatives that are included in the observed subjective choice set, but not in the observed consideration set. However, it was found that this approach in combination with a telephonic interview provided insufficient information to make a clear distinction. The alternatives stated in the interviews are most likely to be part of the actual subjective choice set. Therefore this research focuses only on the reported subjective choice set (RSCS). In the case of face-to-face interviews, however, it proved to be possible to determine the actual consideration set.

3.3 Estimated objective choice set

Theoretically, the traveller chooses from his actual consideration set (see section 2). However, for the collected data the actual consideration set is unknown and there is no certainty whether or not the actual subjective choice set is complete. To ease the task of data completion and to gain insight in the available multi-modal alternatives – consisting of both private as well as public transport modes – a procedure was developed to generate estimated objective choice sets (EOSC). Those sets will also be used to estimate combined route/mode choice models. Furthermore, the comparison of the reported subjective choice set with the estimated objective choice set might provide interesting insights into travel behaviour and the characteristics of the various choice-sets. A recent account of the generation of objective choice sets for route choice in car networks is given in (Ramming, 2002).

The estimated objective choice set is generated for each traveller, based on his or her specific origin and destination, departure time, and vehicle availability. The newly developed multi-modal choice set generation approach (Hoogendoorn-Lanser, 2004b) is an extension of Friedrich's algorithm (1999), is applicable to mixed private-public mode networks. The approach is a run-based, selective enumeration (branch-and-bound) method. All feasible alternatives within space-time window are enumerated. First, a set of train alternatives is generated for each OD-pair, using detailed timetables and a time window around the original departure time. The set of train alternatives includes different boarding and alighting railway stations as well as different train services. Secondly, access modes to and from the boarding and alighting railway stations are generated. For private modes generic rules are used with respect to maximum acceptable distances (based on observations from mobility surveys, (e.g. Van Nes and Van Goeverden, 2000), while for public transport again timetable information is used. Afterwards, the separately generated train, access and egress alternatives are concatenated to full door-to-door trips, thereby accounting for traveller's vehicle availability and assuring logical routes in space and time. The objective of the estimation procedure is to reveal all available and reasonable multi-modal alternatives in space and in time, including all reported alternatives.

In some cases, however, it proved to be necessary to make exceptions on the generic rules in order to match individual travel behaviour: for instance very long access distances on foot or by bike (Table 1 shows percentages of chosen and known trips with characteristics that do not satisfy the generic rules) or counter-intuitive combinations of modes or transport services such as public transport alternatives for access and egress that are much longer than the shortest possible public transport alternative. For example, a metro-metro access in Rotterdam, which takes almost three times as long as the available tram alternative, but is chosen by certain respondents. This can probably be explained from the traveller's mental map of the transportation system.

Table 1 Percentages of the chosen alternative (CA) and the known alternatives with characteristics that do not satisfy the generic rules.

Violation of the generic rules	**10/90-percentiles of acceptable distance ranges**	**CA %**	**RSCS %**
Walk distance outside allowed range	home-end: [0km,2km] activity-end: [0km,3km]	1.6	3.2
Cycling distance outside allowed range	home-end: [0.8km,4km] activity-end: [0.9km,5km]	5.1	9.0
Car distance outside allowed range	home-end: [1.5km,10km] activity-end: [0.7km,12km]	0.0	0..0
Route-factor compared to minimal travel time ≥ 1.5	n.a.	8.9	15.4
Route-factor compared to minimal number of transfers ≥ 2	n.a.	8.1	13.1

3.4 Characteristics of the reported alternatives

The dataset contains reported subjective choice sets for 511 individuals travelling between larger cities in The Netherlands (Leiden, The Hague, Rotterdam and Dordrecht). Table 2 shows some characteristics of these cities. All of the considered trips are home-bound trips (70% and 30% of the trips are outbound-trips and return-trips, respectively). The number of female respondents is slightly higher than the number of male respondents (58% versus 42%).

The main trip purposes are commuting (43%), study (29%), social visits (10%) and shopping (7%). 44% of the respondents is under 25 years old, 87% of the respondents is under 50 years old.

Table 2 Transport characteristics of the main cities in the corridor

	Leiden	**The Hague**	**Rotterdam**	**Dordrecht**
Available PT-modes	City bus, Regional bus	City bus, Regional bus, Tram	City bus, Regional bus, Tram, Metro	City bus, Regional bus
Number of Intercity railway stations	1	2	2	1
Number of non-Intercity railway stations	2	7	9	2

The average travel time for the door-to-door trip is 48, 49 and 59 minutes for the chosen alternative, the reported subjective alternatives and the estimated objective alternatives respectively. A typical multi-modal trip contains 1.3, 1.4 and 2.1 transfer between modes for the above-mentioned types of alternatives. The number of reported subjective alternatives (not including the chosen alternative) varies between 1 and 6 – the average value being 1.9 – alternatives. The characteristics for the estimated objective choice sets are obviously higher: a maximum of 376 (overlapping lines are counted only once) available, reasonable alternatives, and an average of 63 alternatives. The description of the various sets is split in a part related to the modes that are used and a part relating to travel time characteristics.

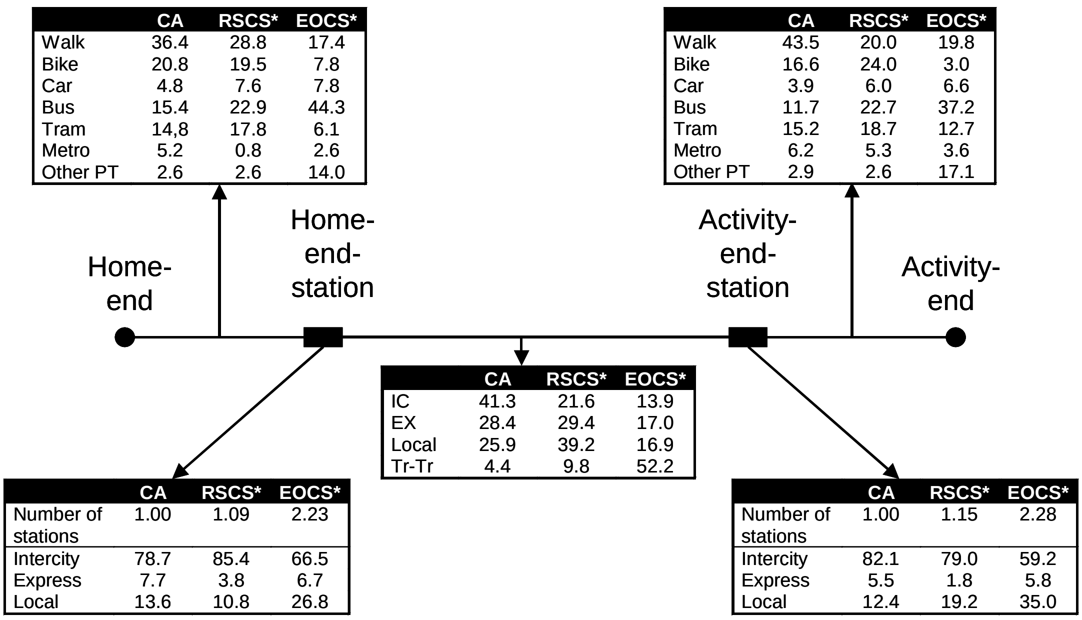
3.4.1 Mode composition of the alternative sets

Figure 4 shows the modal split for each trip leg and the characteristics of the home-end and activity-end railway stations for three types of choice sets:

- chosen alternative
- reported subjective choice set excluding the chosen alternative
- estimated objective choice set excluding the reported subjective choice set

A typical characteristic is that the chosen alternative has a relatively high share of private modes (walk, bicycle, and car) at both the home-end and the activity-end: 62% and 64% respectively. Furthermore, there is a strong preference for boarding and alighting at railway stations served by Intercity train services, although not necessarily an Intercity train service is used (41%). Compared to the chosen alternative the reported subjective choice sets mostly includes public transport alternatives: the percentages (home-end: 38% versus 44% and activity-end: 36% versus 49%) for public transport modes (bus, tram, metro) are higher. Interestingly, the average number of railway stations does not increase very much (maximum values 1.09 and 1.16 respectively). Apparently, travellers are reluctant to consider alternative boarding or alighting railway stations. In the case of the estimated objective choice sets the number of available public transport alternatives that are included increases substantially. A typical example is a share of 52.2% for the train-train alternatives, while it is only 4.4% for the chosen alternatives.

Figure 4 Modal split (in percentages) for home-end leg, home-end station, train leg, activity-end station, activity-end leg for the chosen alternative (CA), the other alternatives in the RSCS, and for the other alternatives in the EOCS respectively



Home-end leg:

	CA	RSCS*	EOCS*
Walk	36.4	28.8	17.4
Bike	20.8	19.5	7.8
Car	4.8	7.6	7.8
Bus	15.4	22.9	44.3
Tram	14,8	17.8	6.1
Metro	5.2	0.8	2.6
Other PT	2.6	2.6	14.0

Activity-end leg:

	CA	RSCS*	EOCS*
Walk	43.5	20.0	19.8
Bike	16.6	24.0	3.0
Car	3.9	6.0	6.6
Bus	11.7	22.7	37.2
Tram	15.2	18.7	12.7
Metro	6.2	5.3	3.6
Other PT	2.9	2.6	17.1

Train leg:

	CA	RSCS*	EOCS*
IC	41.3	21.6	13.9
EX	28.4	29.4	17.0
Local	25.9	39.2	16.9
Tr-Tr	4.4	9.8	52.2

Home-end station:

	CA	RSCS*	EOCS*
Number of stations	1.00	1.09	2.23
Intercity	78.7	85.4	66.5
Express	7.7	3.8	6.7
Local	13.6	10.8	26.8

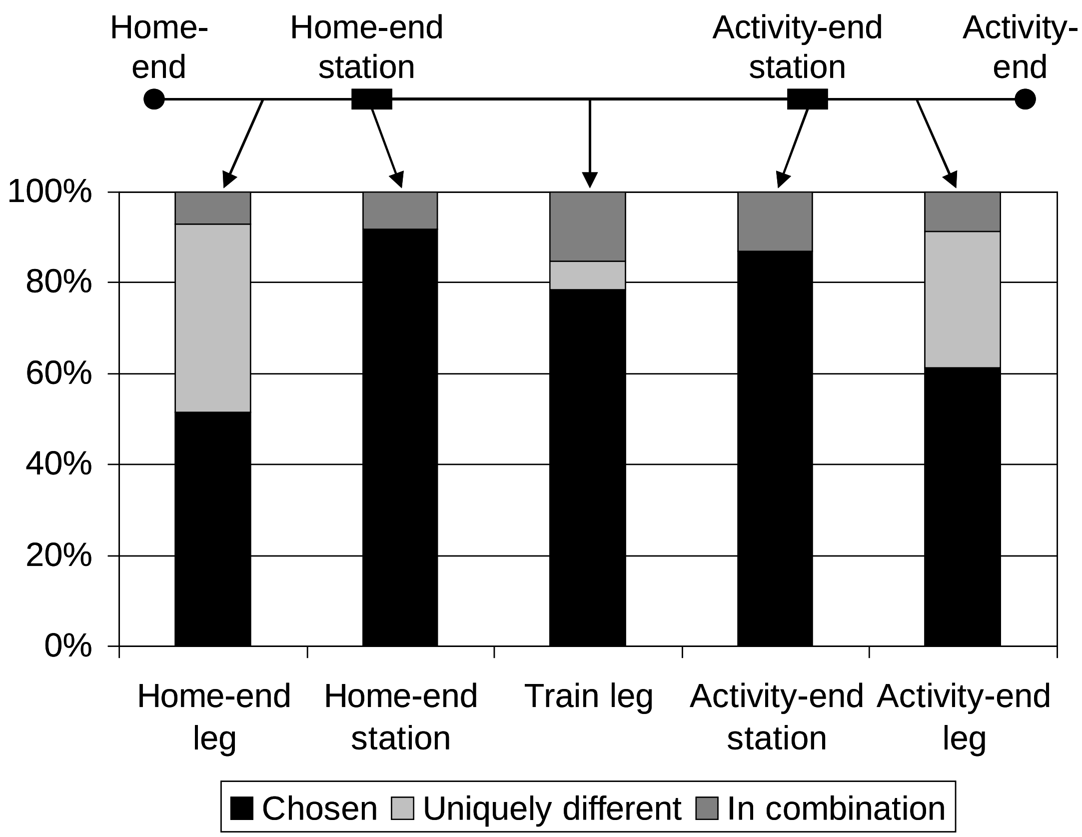
Activity-end station:

	CA	RSCS*	EOCS*
Number of stations	1.00	1.15	2.28
Intercity	82.1	79.0	59.2
Express	5.5	1.8	5.8
Local	12.4	19.2	35.0

* RSCS* is RSCS excluding CA, and EOCS* is EOCS excluding RSCS (N=511)

The strong focus on the boarding and alighting station can also be seen in Figure 5, which shows the variation in the reported subjective choice set. More than 90% of the alternatives in the reported subjective choice set have the same home-end station as the chosen alternative, while for the activity-end station the percentage is slightly lower. The largest variety in alternatives can be found for the home-end mode and the activity-end mode. Interestingly, there is a large percentage of alternatives that varies with respect to only home-end mode (41.5%) or only activity-end mode (30.0%). Given the small percentages for each trip component that vary in combination with other components, it might be concluded that the variation in the trip components is limited. However, with respect to the trip composition the variety is larger: about 25% of the alternatives of the reported subjective choice set vary with more than a single trip component. Typical examples are: only activity-end leg identical (3.4%) or only home-end leg identical (5.1%).

Figure 5 Variation in the reported subjective choice set for each trip component (N=511)



3.4.2 Travel times in the alternative sets

From the previous section it can be concluded that there is a substantial difference in the modal composition of the alternative sets. Question is whether these differences can also be found for travel times. Table 3 shows the travel times for each mode for the home-end and the activity-end leg. Again, a distinction is made between the chosen alternative (CA), other alternatives in the reported subjective choice set, and other alternatives in the estimated objective choice set.

This table shows two interesting things. First, the differences per component between the three sets are relatively small, which applies to the average values as well as the standard deviations. Apparently, the differences between alternatives cannot be explained by travel time only, thus supporting the need to focus on explanations from a behavioural perspective. Second, for private modes there is slight tendency that the components' travel times are higher if new alternatives are considered, while for public transport services the in-vehicle time (IVT) is lower. The first phenomenon seems plausible, but the second appears counter-intuitive. However, since the related walk time is higher, this might indicate a strong preference for using stops that are located close to the origin and destination. Or, seen from another perspective: travellers are reluctant to walking.

Table 3 Average travel times (in minutes) of home-end and activity-end legs (incl. standard deviation)

	Home-end leg			**Activity-end leg**		
	CA (min)	**RSCS* (min)**	**EOCS* (min)**	**CA (min)**	**RSCS* (min)**	**EOCS* (min)**
Walk	8.9 (5.7)	10.8 (6.7)	11.6 (5.7)	9.3 (5.9)	11.1 (7.5)	13.3 (7.0)
Bike IVT	8.6 (5.1)	9.5 (6.7)	8.4 (3.8)	8.5 (4.7)	7.5 (4.7)	9.4 (4.4)
Car IVT	7.6 (3.2)	6.5 (4.5)	9.3 (4.1)	7.2 (4.3)	7.9 (3.8)	6.9 (3.8)
Bus IVT	11.5 (6.5)	8.9 (6.8)	7.1 (5.9)	12.0 (6.3)	8.6 (5.1)	6.2 (5.3)
Bus walk time	3.0 (1.9)	2.8 (1.7)	3.9 (2.3)	3.1 (1.9)	3.4 (2.9)	3.9 (2.3)
Tram IVT	10.1 (6.9)	8.9 (7.2)	7.5 (6.2)	10.3 (6.9)	9.4 (5.6)	7.3 (6.0)
Tram walk time	3.7 (2.5)	4.7 (3.3)	3.9 (2.5)	0.9 (3.8)	4.1 (2.3)	3.5 (1.9)
Metro IVT	6.5 (4.9)	3.1 (2.2)	4.9 (4.6)	5.3 (4.1)	4.3 (2.0)	4.8 (4.5)
Metro walk time	4.9 (3.0)	2.7 (1.7)	6.1 (3.4)	4.8 (2.2)	4.9 (2.1)	5.7 (3.1)

* RSCS* is RSCS excluding CA, and EOCS* is EOCS excluding RSCS

3.4.3 Conclusion

The results of the survey and the comparison of the different choice sets show that multi-modal travelling is indeed a complex topic. While in general a large number of alternatives is available for a traveller, he or she only considers a subset in choosing his alternative. In this selection we can notice a preference for using railway stations served by high quality train services and an inclination for using private modes to access to or to egress from these railway stations. The alternatives that are reported by the travellers are mainly characterised by being public transport alternatives for access and egress to and from the railway stations. However, it should be noted that alternative routes for private modes, such as cycling or car, were not considered in the survey. As such the variety in public transport alternatives might be overestimated. On the other hand, public transport alternatives are in many cases clearly different alternatives if different vehicle types and service types are considered. Finally, it can be noted that with respect to private modes as access or egress modes a tendency has been found that travellers opt for shorter travel times, although the differences remain relatively small. For public transport services in access and egress, the opposite appears to be true, that is, if we look only at in-vehicle time. If walking to and from the stop is included, travellers tend to choose for stops located close by the origin or destination.

4. Estimated subjective choice sets

The previous section focused on the survey of multi-modal alternatives and stated alternatives, and the generation of an estimated objective choice set. If we want to analyse the effect of various measures in the transport system on multi-modal travelling, however, a different approach is required. In that case no individual data on route choice and the related sets is available. Generating objective choice sets seems not appropriate because of the number of possible alternatives involved. Furthermore, it would require detailed timetable data for each alternative. Therefore, an alternative approach is more suitable which tries to estimate a subjective choice set. Such an estimated subjective master set should be substantially smaller than the objective master set and should ideally contain the reported subjective choice sets. Of course, since forecasting models are based on a more aggregate description of travel behaviour, it is obvious that there will be difference between individual travel behaviour and modelled travel behaviour. These differences might provide interesting insights into individuals' travel behaviour. In this section we will present a method for generating an estimated subjective master set and compare its results with the reported subjective choice set. For the comparison additional constraints are used to account for the traveller's vehicle availability, resulting in estimated subjective choice sets. Furthermore, in order to determine the benefits of this approach a comparison will be made between the estimated sets: estimated subjective choice set and estimated objective choice set.

4.1 Estimation method

Literature shows a large variety of techniques for generating routes (for a recent account see Ramming, 2002). Typical approaches are the K-shortest path algorithm (Van Der Zijpp and Fiorenzo-Catalano, 2002) based on link elimination or link penalties (De La Barra *et al.*, 1993), simulation methods (Sheffi and Powell, 1982), and a labelling approach (Ben-Akiva *et al.*, 1984). The method used for generating the estimated objective choice set attempts to generate all realistic alternatives. For this study a combination of the labelling method and the simulation method is used in combination with a supernetwork approach (Carlier *et al.*, 2003). The supernetwork consists of the networks of all modes, i.e. walking, cycling, car driver, car passenger, local and interlocal public transport services, and of ‘boarding’ and ‘alighting’ links between each network and the walk-network. The latter links enable travellers to switch modes during a trip. The public transport service network is represented using lines and frequencies. No use is made of timetable data. For different groups of travellers the most attractive path is determined in a multi-modal supernetwork using generalised costs and shortest path algorithm. The generalised cost function synthesises the most important trip attributes and their weights as known from earlier studies (Waard, 1998). This approach reflects on hypothesis that the composition of individual choice sets is strongly determined by individual preferences for trip attributes. The link attributes are randomised using Monte-Carlo techniques and are weighted according to the preferences of the specific traveller groups. The traveller groups vary with respect to expected travel behaviour, for instance based on trip purpose, and vehicle availability at the home-end and the activity-end of the trip. The estimated subjective master set is defined as the union of all alternative sets for all traveller groups.

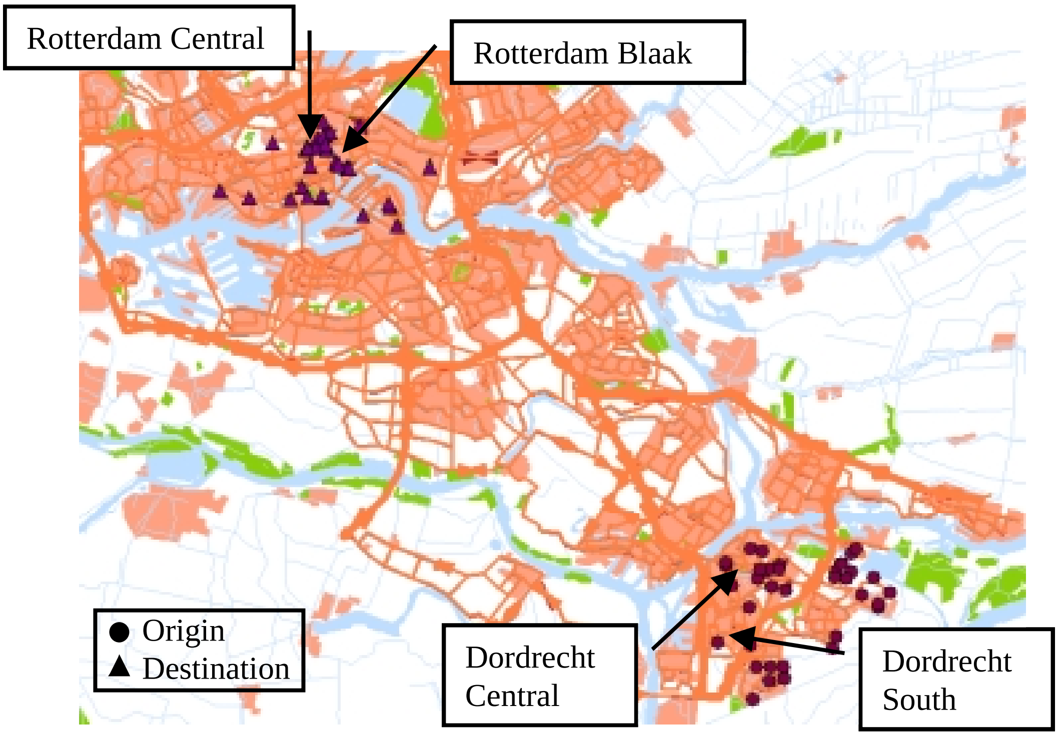
4.2 Characteristics of the estimated subjective choice set

4.2.1 Dataset characteristics

For practical reasons, the analysis of the estimated subjective choice set is limited to a set of 37 OD-pairs in the corridor Dordrecht (home-end) and Rotterdam (activity-end) during the morning peak hour (7.00 to 9.00). Figure 6 shows the location of the origins and destinations of these trips. The estimated subjective master set is generated using 20 traveller groups (4 trip purposes and 5 vehicle availability and vehicle preference categories) and 40 randomisations of the network attributes. In order to compare the estimated subjective master set with the reported subjective choice set, which refer to individual situations, only those alternatives of the estimated subjective master set are selected that meet the individual's vehicle availability, resulting in the estimated subjective choice set (ESCS).

For these 37 OD-pairs the average number of alternatives per trip is 10 (minimum 4, maximum 21). Thus the size of the estimated subjective choice set is substantially smaller than that of the estimated objective choice set (see section 3.3). The size of the related reported subjective choice set is relatively small: less than 3 alternatives per OD-pair. Consequently the estimated subjective choice set is still larger than the reported set.

Figure 6 Overview of the corridor Dordrecht-Rotterdam and the selected trip origins and destinations



4.2.2 Modal composition

Since the set of 37 OD-pairs is a distinct subset of the total set included in the survey, the modal composition of the alternatives is different than shown in Figure 4. The characteristics of the different legs are shown in Table 4. The use of private modes at the home-end is higher (68%), while public transport services are limited to bus, the only public transport mode available in Dordrecht. At the activity-end the role of public transport services is very large at the cost of the private modes especially bicycle (0.7%). This is mainly due to the high quality of public transport services offered in Rotterdam. For the train leg the distribution of service types more evenly spread than for all trips in the survey, which is due to the limited differences in service types for this corridor.

Table 4 Modal shares (in percentages) for the trip components in the estimated subjective choice set (N=37)

Access / Egress mode	**Home-end leg (%)**	**Activity-end leg (%)**	**Train service type**	**Train leg (%)**
Walk	30.0	32.1	IC	33.9
Bike	33.1	0.7	EX	18.8
Car	3.9	0.0	Local	24.2
Bus	33.1	13.6	Combinations	23.0
Tram	n.a.	22.9		
Metro	n.a.	19.3		
Combinations of public transport	n.a.	11.4		

4.2.3 Set comparison

The key question in this section is how well the estimated subjective choice set matches the reported subjective choice set. For comparing two sets, e.g. A and B, we define the set coverage as the percentage of alternatives in set A that are also elements of set B. We distinguish three levels of comparison, each having a higher level of detail:

- station level: home-end station and activity-end station combination;
- leg level: home-end mode, train service types, activity-end mode;
- trip level: unique combination of home-end mode, home-end station, train service type, activity-end station, and activity-end mode.

The estimated subjective choice set is compared with three choice sets:

- chosen alternative, which should be part of estimated subjective choice set;
- reported subjective choice set, which also should be part of estimated subjective choice set;
- estimated objective choice set, of which estimated subjective choice set should be a part of.

Table 5 shows the set coverage results for these three comparisons. At the first level, home-end and activity-end station, the set coverage is very high for all three sets: 92 up to 95%. At the second level, individual legs, the set coverage is still high: more than 85% of the reported legs are part of the estimated subjective choice set. Interestingly, the set coverage for the train leg while comparing estimated subjective choice set with the estimated objective choice set is relatively low (78.5%), which might be due to the fact that no timetable information is used. Apparently, the algorithm for estimating the subjective choice set generates too many train alternatives. At the trip level, the set coverage is clearly lower: less than 60% for all three comparisons. This implies that the composition of the alternatives deserves more attention, especially since the set coverage for the trip components is quite high.

Table 5 Set coverage results (in percentages) for the estimated subjective choice sets (ESCS)

N=37	**Chosen is in estimated set** $CA \subseteq ESCS$ **(%)**	**reported is in estimated set** $RSCS \subseteq ESCS$ **(%)**	**estimated is in objective set** $ESCS \subseteq EOCS$ **(%)**
Home-end and activity-end railway stations	94.6	91.9	92.7
Home-end leg	86.5	85.2	87.6
Train leg	89.2	86.5	78.5
Activity-end leg	89.2	88.3	87.0
Complete alternative	59.5	59.9	58.5

If we look closer at the comparison at the trip level of the reported subjective choice set and the estimated subjective choice set, there may be various reasons why the set coverage is relatively low. On the one hand it might be due to assumptions in modelling the transport system, and on the other hand it might be caused by atypical individual behaviour. A third reason might be that a more detailed description of travel behaviour with respect to trip composition is needed.

Figure 7 Comparison of the reported subjective choice set and the estimated subjective choice set at the alternative level (N=37)

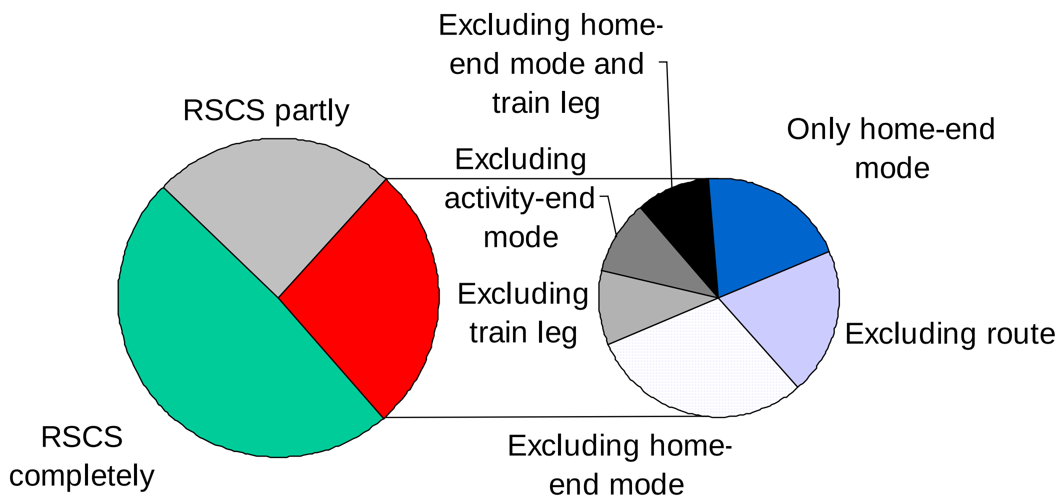


Figure 7 shows the comparison of the reported subjective choice set and the estimated subjective choice set for the 37 OD-pairs. For 18 OD-pairs the set coverage is 100%. For 9 OD-pairs the reported subjective choice set is partly covered ranging between 80% and 20%. For 10 OD-pairs the set coverage is zero. If we look closer at these 10 cases we first note that those reported subjective choice sets all consist of one alternative that is the chosen alternative. Furthermore, we can see the following characteristics.

- In three cases, the home-end mode has not been generated. In two cases this might be due to the network description in which parking cost at the home-end station are included. The third traveller uses car while the access distance is very short.
- In two cases, all components are generated, but not the reported alternatives. In both cases the reported alternatives have a longer travel time: activity-end mode walking instead of tram or Express train instead of Intercity train. However, the differences are relatively small.
- In two other cases, only the home-end mode has been generated. The destination of these OD-pairs is located to a local train station Rotterdam Blaak while the travellers prefer to travel further to alight at Rotterdam Central and to travel 'backwards' to their destination, either by walking or by using metro. This might be due to the lower frequency by which the local station train Rotterdam Blaak is served.

- In the other three cases, there are different explanations. The activity-end mode metro-metro (including a transfer) is not generated. Using tram or accepting a longer walk distance are generated as more favourable alternatives. It seems that travellers have a high appreciation for using metro and that metro-metro transfers a very acceptable. In another case there is a so-called timetable issue: .the combination of bus and train is used because of the short transfer time at the home-end station, while the generated alternatives have larger transfer times in reality. The third case, the traveller chooses to use the local train even though the Intercity train would bring him faster to his activity-end station. Apparently, there are some unaccounted benefits in using the local train service, such as the seat availability.

This analysis of cases were the reported subjective choice set was not part of the estimated subjective choice set shows that the main reason can be found in the network description and the estimation algorithm. Only in a few cases, atypical individual travel behaviour explains why the reported alternatives could not be generated. A possible improvement in the algorithm could be to incorporate stochasticity for the weights that are used to model travellers' preferences (see for instance Nielsen, 1996).

4.2.4 Conclusions

The procedure to generate estimated subjective master sets presented in this section is shown to give good results if trip components are considered. At the level of the complete alternative, however, the performance appears to be less. Furthermore, although the number of alternatives generated is much lower than that for the estimated objective master set, the number of alternatives is still three times larger than that of the reported subjective choice set. It can be concluded that more knowledge is required with respect to the composition of the route alternatives, in order to generate less but more relevant alternatives.

5. Conclusions

Multi-modal travelling involves complex alternatives consisting of different legs and thus complex travel behaviour choosing transport services, modes, and boarding and alighting railway stations. This paper analysed various types of multi-modal route sets that were observed, generated for route choice estimation purposes, and generated for forecasting purposes. The analysis of these choice sets leads to interesting conclusions:

- There are many alternatives that are more or less equal in travel time. Since the traveller only considers a small set for making a trip, there must be specific preferences, e.g. in terms of weights, that determine the considered set and of course the chosen alternative. Detailed insight into travel behaviour is essential for understanding multi-modal route choice.

- It proved to be possible to generate most of the trip components that make up an alternative. However, generating complete alternatives showed to be more difficult. More knowledge is required on the factors determining the composition of multi-modal routes.

With respect to travel behaviour the following conclusions can be stated:

- Travellers tend to prefer to board and to alight at railway stations served by high quality train services, although this does not imply that these services are used.
- Travellers prefer using private modes for access and egress to and from railway stations. Public transport is considered to be an interesting alternative.
- In case of using public transport as access and egress mode, travellers tend to choose for stops located close to the origin or destination.

With respect to generating choice sets two conclusions can be stated:

- It proved to be possible to generate estimated objective choice sets using a branch-and-bound procedure using generic rules as bounds. Only for a limited set of individuals exceptions with respect to the generic rules were needed to account for atypical travel behaviour. The estimated objective choice sets are very large: one set even having 376 alternatives.
- The algorithm presented for generating estimated subjective master sets proved to be good at generating the trip components of a multi-modal trip. The number of alternatives that is generated is still relatively large, while the performance with respect to generating reported alternatives needs to be improved. Options for improvement are the way the network is modelled, e.g. timed transfers in low frequency networks, and introducing stochasticity in modelling traveller preferences.

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